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YOUNGREENTECO
Young Green Entrepreneurship Ecosystem

SEFGEN 2026

PROCEEDINGS BOOK

INTERNATIONAL CONFERENCE ON

Sustainable Entrepreneurship for Future Generations

Innovation, Inclusion and Green Transformation

26–28 October 2026

Selçuk University · Konya, Türkiye

Hybrid conference · In person & online

Editor
Dr. Ali GANİYUSUFOĞLU

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PROJECT PARTNERS

Organised within the Erasmus+ KA220-YOU project YOUNGREENTECO · 2023-2-TR01-KA220-YOU-000185426

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SEFGEN 2026

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İLGİLİ MAKAMA

2023-2-TR01-KA220-YOU-000185426 numaralı Young Green Entrepreneurship Ecosystem isimli Erasmus+ KA220 projesi kapsamında 26-28 Ekim 2026 tarihleri arasında üniversitemizde gerçekleştirilecek olan "International Conference on Sustainable Entrepreneurship for Future Generations: Innovation, Inclusion and Green Transformation" konferansı için düzenleme kurulunda akademisyen temsilcisi olarak Yönetim ve Organizasyon Bölüm Başkanı Dr. Öğr. Üyesi Ali GANİYUSUFOĞLU görevlendirilmiştir.

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CONFERENCE PROGRAMME

Day 1 · Monday, 26 October 2026

Türkiye Time (GMT+3) · 10 minutes per paper

No	Time	Paper title	Author(s)
	09:30–10:00	**Opening Ceremony (in person)**	
IN-PERSON SESSION I	**10:00–11:00**	**Circular Economy, Green Logistics and Regional Sustainability**	Session Chair: Prof. Dr. Esra Kabaklarlı · Selçuk University – Araştırma Dekanlığı Conference Hall
IP1.1	10:00–10:10	Exploring Circular Blue Economy Practices: Comparative Case Studies of Malta, Türkiye, Italy, and Denmark	Esra Kabaklarlı, Alexia Massa Gallucci, Leila Cristina W. Muchanga-Hvelplund, Leonardo Piccinetti, Margaret Ridge, Gustavo Pérez González
IP1.2	10:10–10:20	Artificial Intelligence-Enabled Green Logistics Ventures: A Conceptual Framework for Sustainable Business Models and Carbon Reduction	Gökhan Akandere
IP1.3	10:20–10:30	Operational Risks in Green Logistics: Challenges and Implications for Sustainable Entrepreneurship and Green Innovation	Mina Faraji Marjanlou, Gökhan Akandere
IP1.4	10:30–10:40	From Industrial Waste to Sustainable Entrepreneurship: A Student Cooperative Model for Youth Empowerment and Circular Economy	Onur Özevin
IP1.5	10:40–10:50	Measuring Provincial Sustainability in Türkiye: A Composite Index and Cluster Analysis of 81 Provinces	Metin Allahverdi
IP1.6	10:50–11:00	Green Entrepreneurship from an Agricultural Economics Perspective: A Review of Circular Business Models Based on Agricultural Waste	Ali Ganiyusufoğlu
IN-PERSON SESSION II	**11:00–12:20**	**Inclusion, Gender, Green Policy and Finance**	Session Chair: Prof. Dr. Esra Kabaklarlı · Selçuk University – Araştırma Dekanlığı Conference Hall
IP2.1	11:00–11:10	Values, Fairness Perceptions, and Attitudes toward Carbon Taxation: A Literature Review with Implications for Green Entrepreneurship	Emel Mirza
IP2.2	11:10–11:20	Social Capital and Entrepreneurial Potential in Migrant Communities: A Pilot Study on Syrian and Sudanese Migrants in Konya, Türkiye	Tchaminou Abdourahmane
IP2.3	11:20–11:30	How Do Climate Policies Affect Women's Economic Empowerment? An Analysis from a Feminist Climate Justice Perspective	Perihan Hazel Kaya, Ebru Perçin
IP2.4	11:30–11:40	Women's Participation in Firm Ownership and Green Management Practices: Evidence from the 2024 World Bank Enterprise Survey in Türkiye	Ayşe Yavuz
IP2.5	11:40–11:50	Do Instant Payments Substitute for Retail Payment System Transactions in Türkiye? An Analysis of Time-Varying Dynamics	İbrahim Yavuz
IP2.6	11:50–12:00	Fast Lives, Easy Money, Green Choices? A Behavioral Perspective on Generation Z and Sustainable Entrepreneurship	Ayşen Edirneligil
IP2.7	12:00–12:10	Young Farmers as Green Entrepreneurs: Drivers, Barriers and Support Mechanisms in Farm Businesses	Ali Ganiyusufoğlu
IP2.8	12:10–12:20	Green Export Development in Pakistan: Determinants, Challenges and Policy Implications	Muhammed Suliman, Özlem Akgün
	12:20–12:30	**Discussion & Q&A**	
ONLINE SESSION 1	**14:00–15:10**	**Green Entrepreneurship and Sustainable Business Models**	Session Chair: Dr. Emel Mirza · Zoom
S1.1	14:00–14:10	Green Entrepreneurship as a Driver of Sustainable Economic Development	Shivani Negi, Ritesh Dwivedi
S1.2	14:10–14:20	Positioning for Green Credibility: A Framework for Sustainable Entrepreneurship in Emerging Markets	Blendi Shima, Erjona Deshati
S1.3	14:20–14:30	From Waste to Value: How European Circular Start-ups Transform Environmental Challenges into Business Opportunities	Junada Sulillari
S1.4	14:30–14:40	Beyond Business Models: Teaching Systems Thinking for Sustainable Entrepreneurship	Jeaninne Horowitz Gassol
S1.5	14:40–14:50	Resource Mobilisation for Green Ventures in South Africa	Boris Urban, Mahad Moti
S1.6	14:50–15:00	Smallholder Farmers' Entrepreneurial Competencies and Cassava Value-addition Activities	Abigail Adeyonu, Femi Afolayan, Adekemi Obisesan, Ibukun Ojo, Kayode Obaniyi
S1.7	15:00–15:10	Environmental Ethics Integration in Entrepreneurship Education: Assessing Educator, Pedagogical and Institutional Readiness in Nigeria	Isaac Oluwajoba Abereijo, Funmilayo Juliana Afolabi
ONLINE SESSION 2	**15:10–16:20**	**Green Finance, FinTech and Impact Investment**	Session Chair: Dr. Emel Mirza · Zoom
S2.1	15:10–15:20	Exchange Rate Volatility and Sustainable Entrepreneurship in Nigeria: Evidence from Economic Indicator	Tomilola Oloye, Tajudeen Egbetunde
S2.2	15:20–15:30	Impact of Green Finance on Ecological Footprints and Industrial Growth: Moderating Role of Governance	Muhammad Aksar, Sheher Bano, Arshad Javed
S2.3	15:30–15:40	Building Green Finance Competency through Sustainability-Oriented Education: The Mediating Role of Curriculum Exposure and Moderating Effects of Academic Background	Abdullahil Mamun, Shahanara Basher, Nazamul Hoque, Harun Bal, Mohammad Nazim Uddin
S2.4	15:40–15:50	Digital Islamic Finance and Small-Business Inclusion: A Conceptual Framework for Indonesia's Micro, Small and Medium Enterprises (MSMEs)	Irvan Hermala
S2.5	15:50–16:00	Investor Benefits from Green Finance and Impact Investment in Sustainable Firms: Insights from an Emerging Economy	Ritesh Patel
S2.6	16:00–16:10	FinTech-Enabled Green Finance and Impact Investment for Sustainable Ventures: An Interpretative Phenomenological Analysis of Malaysian FinTech Founders and a Proposed Closed-Loop Financing Architecture	Masrina Nadia Mohd Salleh, Shaliza Alwi, Juhairi Noor Faezah, Nurul Izzatty Ismail
S2.7	16:10–16:20	Greenwashing and the Stock Market Reactions to Mergers and Acquisitions Announcements	Shao-chi Chang, You-Zhen Jian

CONFERENCE PROGRAMME

Day 2 · Tuesday, 27 October 2026

Türkiye Time (GMT+3) · 10 minutes per paper

No	Time	Paper title	Author(s)
ONLINE SESSION 3	**10:00–11:00**	**Digital Transformation, Ecosystems and Policy for Green Ventures** Session Chair: Dr. Hatice Sezgin · Zoom	
S3.1	10:00–10:10	Entrepreneurial Readiness, Psychological Orientation, and Technology Adoption: Evidence from Indonesian GEM Data	Gandhi Pawitan, Nijimbere Alain Desire, Adinda Oktaviani Rachdian
S3.2	10:10–10:20	Digital Readiness for Green Ventures in South Africa	Boris Urban, Mahad Moti
S3.3	10:20–10:30	From Digital Possibilities to Green Ventures: A Dynamic Capabilities Framework for Digital–Green Transformation in Jordanian SMEs	Audi Al-Qaralleh, Ai Ping Teoh
S3.4	10:30–10:40	Digital Transformation and Innovation in the Sustainable Enterprise: An Integrative Review of Information Systems Research and a Multilevel Research Agenda	Negar Kabir
S3.5	10:40–10:50	Digital Transformation and Green Entrepreneurship: The Role of Innovation and Institutional Support	Saleh Freijat
S3.6	10:50–11:00	Y-GREEN: A Multi-Level Framework for Inclusive Green Entrepreneurial Ecosystems through Digital Inclusion Orchestration	Jomon Jose M, Jyothis Rachel Mathews
ONLINE SESSION 4	**11:00–12:00**	**Artificial Intelligence and Data-Driven Entrepreneurship for Sustainability** Session Chair: Dr. Hatice Sezgin · Zoom	
S4.1	11:00–11:10	An Explainable AI Framework for Screening Greenwashing Risk in Corporate Environmental Claims	Emine Nur Nacar
S4.2	11:10–11:20	Artificial Intelligence for Sustainable Public Parks: A Data-Driven Framework for Enhancing User Experience, Social Quality of Life and Urban Sustainability	Aya Elgobashi
S4.3	11:20–11:30	Financing Green Transformation: AI-Driven Statistical Machine-Learning Methods for Assessing the Green Bond Premium as a Lever for Inclusive Sustainable Entrepreneurship	Fatih Chellai
S4.4	11:30–11:40	Machine Learning for Classifying Green Venture Outcomes: A Small-Sample Pilot Study in Sustainable Entrepreneurship	Rajesh Kumar, Narasimha Rao Vajjhala, Ervin Ramollari, Komal Ramchandani
S4.5	11:40–11:50	AI for Whom? Reconceptualising Circular Entrepreneurship through an Inclusive AI Ecosystem Perspective	Jamiu Adetola Odugbesan, Sahar Aghazadeh, Oluwafemi Dele Anifowose
S4.6	11:50–12:00	AI-Enabled Future Skills for Sustainable Entrepreneurship: A Competency-Based Framework for University Students	Alina Kiran
ONLINE SESSION 5	**14:00–15:00**	**Youth Entrepreneurship, Employability and Future Skills** Session Chair: Dr. Hatice Sezgin · Zoom	
S5.1	14:00–14:10	Educating Students for the Bioeconomy: A Pathway to Sustainable Innovation	Swasti Srivastava
S5.2	14:10–14:20	Promoting Green Skills in Future Distribution and Logistics Managers through Gamification	Maria-Eugenia Ruiz-Molina, Antonio Marín-García, Frank Giesa
S5.3	14:20–14:30	EMPower – A Multi-Activity Programme for Technology-Based Entrepreneurship and Employability Skills	Frederico Pereira, Ana Alves, Telmo Santos
S5.4	14:30–14:40	Cultivating Future Entrepreneurs in Tourism and Hospitality: Educational Pathways, Employability Skills, and Sustainable Venture Development	Georgios Giotis
S5.5	14:40–14:50	Reengineering Entrepreneurship Education in GCC Higher Education: The ESG–Digital Nexus and Strategic Leadership Transformation	Raed Awashreh
S5.6	14:50–15:00	Youth Entrepreneurship, Green Skills, and Sustainable Employability: An Integrated Framework for the Green Transition	Zubaria Parvez, Kazim Syed
ONLINE SESSION 6	**15:00–16:00**	**Women, Inclusion and Equal Opportunities in Green Entrepreneurship** Session Chair: Dr. Hatice Sezgin · Zoom	
S6.1	15:00–15:10	Family Support, Gendered Expectations and Women's Entrepreneurial Agency: Evidence from Pakistan	Tooba Asif
S6.2	15:10–15:20	Entrepreneurship as a Coping Strategy among Families of Children with Autism: A Systematic Review with Implications for Inclusive Development in Africa	Suzana Sylivester, Josue Mbonigaba, Adili Zella
S6.3	15:20–15:30	Mentorship Models for Women Entrepreneurs in Türkiye: Comparison of Cases	Esra Bal Külahi, Tanju Özdeniz
S6.4	15:30–15:40	Women's Leadership Contribution to Carbon Reduction in Entrepreneurial Firms	Hai Long
S6.5	15:40–15:50	Community-Led Integration and Entrepreneurship among Ukrainian Refugees in Romania	Meszaros Edina Lilla
S6.6	15:50–16:00	Every Click Leaves a Trace: Digital Footprint Awareness, Curriculum Integration and Sustainable Digital Education in the Pre-University Schools	Silvia Sumedrea, Cătălin Ioan Maican
S6.7	16:00–16:10	Image-Based Hive Monitoring Systems for Sustainable Beekeeping	Musa Doğan, Emre Arslan

CONFERENCE PROGRAMME

Day 3 · Wednesday, 28 October 2026

Türkiye Time (GMT+3) · 10 minutes per paper

No	Time	Paper title	Author(s)
ONLINE SESSION 7	**10:00–11:00**	**Climate Action, Circular Economy and Local Sustainability** Session Chair: Dr. Hatice Sezgin · Zoom	
S7.1	10:00–10:10	Sustainability Strategies and Internationalization of SMEs: Literature Review, Managerial Implications, and Academic Perspectives	Oscar Csibi
S7.2	10:10–10:20	Exploring the Drivers of Ecological Footprint in OECD Countries: Effects and Transmission Channels	Amira Ghorbel, Marwa Sahnoun
S7.3	10:20–10:30	The Impact of Artificial Intelligence on Ecological Footprint: A Spatial Analysis	Burcu Türkcan, Çağla Bucak
S7.4	10:30–10:40	Green Economy and Climate Resilience: The Role of Financial Technology (FinTech) in Advancing Climate Action (SDG 13) Towards a Sustainable Future	Muhammad Kashif, Shama Urooj
S7.5	10:40–10:50	An Analysis of the European Agri-Food Sector from a Sustainability Perspective. Food Safety or a Healthy Environment? Can We Choose?	Alina Haller
S7.6	10:50–11:00	Bambara Groundnut (Vigna subterranea (L.) Verdc) as a Sustainable Plant Protein Source for Nutrition, Food Innovation and Market Opportunities in Türkiye — A Mini Review	Christopher Kalima Phiri, Celaleddin Barutçular
ONLINE SESSION 8	**11:00–12:10**	**Smart Technologies, Green Innovation and Climate Solutions** Session Chair: Dr. Hatice Sezgin · Zoom	
S8.1	11:00–11:10	Green Innovation in Cleaning Oily Water	Oleksii Malakhov, Oleksandr Palagin, Andrii Rublov
S8.2	11:10–11:20	Climate Technology for Reduction of Exhaust Gases Emission	Oleksii Malakhov, Igor Kozyryev, Andrii Bondarenko, Vitalii Nikolskyi
S8.3	11:20–11:30	AI-Enabled Smart Technologies and Green Innovation for Data-Driven Climate Mitigation and Low-Carbon Energy Management	Abdul Haq, Syed Zeeshan Usman, Saba Yasmin
S8.4	11:30–11:40	Green Digitalization, Urban Smartness, and Institutional Quality: Determinants of the Load Capacity Factor in G20 Economies	Marwa Sahnoun, Amira Ghorbel
S8.5	11:40–11:50	Comparison of Spatial Interpolation and Hybrid Machine Learning Methods for Imputing Missing Temperature Data Using ERA5-Land Climate Data	Yunus Tektaş, Nizar Polat
S8.6	11:50–12:00	Green Human Resource Management and Sustainability in the Hospitality Industry: An Empirical Study of Hotels in Udaipur, Rajasthan	Sarada Chatterjee, Devang Kumar Agarwal
S8.7	12:00–12:10	Responsible Healthcare Procurement: A Structured Literature Review and Evidence Synthesis	Melda Kevser Akgün

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Full Papers

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FULL PAPER · IP1.1 · IN-PERSON SESSION I

Exploring Circular Blue Economy Practices: Comparative Case Studies of Malta, Türkiye, Italy, and Denmark

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ABSTRACT

The circular blue economy has emerged as a strategic approach for promoting sustainable economic development through the efficient and responsible use of marine and coastal resources. By integrating circular economy principles into ocean-based activities, it seeks to balance blue economic growth with environmental protection and the conservation of marine ecosystems. The blue economy includes a wide range of traditional and emerging sectors, such as fisheries and aquaculture, coastal and marine tourism, offshore renewable energy, maritime transport, shipbuilding and repair, marine biotechnology, and the sustainable utilisation of marine resources.

This study aims to examine good practices and policy initiatives that support the transition towards a circular blue economy in Europe. A comparative case study approach is adopted, focusing on Malta, Türkiye, Italy, and Denmark. These countries were selected because they represent diverse maritime regions and blue economy profiles, including the Mediterranean Basin, the Aegean and Black Sea regions, and the North Sea. This diversity enables the identification of different governance models, sectoral priorities, and innovation practices.

The methodology is based on qualitative case study analysis of national strategies, policy documents, and international project initiatives related to circular blue economy development. Particular attention is given to fisheries, seafood value chains, and the circular utilisation of marine resources. The analysis explores how countries promote resource efficiency, waste reduction, value-added production, sustainable consumption, and innovation within marine sectors.

The findings highlight successful experiences and transferable practices that contribute to the development of more sustainable marine economies. International projects, policy frameworks, and stakeholder collaborations demonstrate the potential for improving circularity across seafood and marine value chains. The study contributes to the growing literature on circular blue economy transitions and is directly relevant to conference themes addressing sustainability, circular economy, green transformation, and innovative development pathways.

Keywords: Circular Blue Economy; Seafood Consumption; Sustainability

1. Introduction

Over the last decade, the blue economy has become a central development strategy for coastal states and international organisations, promising the sustainable use of the oceans alongside economic growth (Silver et al., 2015; Heidkamp et al., 2023). The concept nevertheless remains contested. Definitions range from the sustainable use of ocean resources for growth, livelihoods and ecosystem health to all economic activities related to oceans, seas and coasts, and different actors use the term to advance different agendas (Silver et al., 2015; Voyer et al., 2018; Heidkamp et al., 2023). Critical scholars argue that blue growth can work as a "blue fix" that opens new space for capital accumulation in the ocean while claiming to serve social and ecological

goals (Brent et al., 2020), and that an expanding ocean economy carries risks of dispossession, environmental degradation and unequal distribution of benefits (Bennett et al., 2021).

The circular economy has been proposed as one way to align ocean-based activities with environmental limits by keeping materials in use, valorising by-products and reducing waste (Ghisellini et al., 2016; Geissdoerfer et al., 2017). In the European Union this connection is explicit: the sustainable blue economy agenda calls for circular approaches in fisheries, aquaculture and other maritime sectors (European Commission, 2021). Yet evidence on how circular blue economy practices are implemented on the ground is uneven. Case evidence is concentrated in a few countries and sectors, and comparative national studies are rare (see Section 3).

This paper responds to that gap by comparing circular blue economy practices in four countries, Malta, Türkiye, Italy and Denmark, with a focus on fisheries, seafood value chains, seafood consumption and the circular use of marine resources. It asks three questions: how national and regional frameworks shape the circular blue economy, which practices have been implemented, and which lessons are transferable between contexts. The four countries differ in size, governance structure and relationship to the EU, which allows the study to examine how the same circular principles take different forms. The paper contributes a common case-study structure that can be extended to other countries and a set of transferable practices for policymakers and producers.

2. Conceptual Framework

2.1 The blue economy and its contested meanings

Silver et al. (2015) show that, at the Rio+20 conference, the blue economy was used by intergovernmental organisations, small island developing states and conservation organisations in different ways, from ocean natural capital to new opportunities for extractive industries. Voyer et al. (2018) argue that some of these interpretations are irreconcilable, so that any definition privileges a particular lens. Keen et al. (2018), drawing on Pacific ocean governance, offer a practical definition that balances economic, environmental and social objectives.

Two strands of critical work are particularly relevant here. The first concerns justice: a sustainable blue economy requires inclusive decision-making and a fair distribution of benefits and harms (Bennett et al., 2021; Noort et al., 2026). Heidkamp et al. (2023) translate this into a method, arguing for a quintuple helix of government, academia, business and civil society, situated in its environment and working through transdisciplinary action research. The second concerns the political economy of blue growth. Brent et al. (2020) argue that blue growth combines three "fixes", for conservation, protein and energy, that frame ocean expansion as sustainable without resolving its underlying contradictions. Their protein fix, the expansion of capital-intensive aquaculture that depends on wild fish for feed, is directly relevant to this paper's focus on seafood value chains.

2.2 The circular economy

The circular economy is usually defined through reduce, reuse and recycle principles and the closing of material loops (Ghisellini et al., 2016; Kirchherr et al., 2017). Kirchherr et al. (2017) analysed 114 definitions and found that the concept is frequently reduced to recycling, with limited attention to sustainable development and social outcomes. Geissdoerfer et al. (2017) distinguish circularity from the broader goal of sustainability, while Korhonen et al. (2018) and Murray et al. (2017) point to its limits, including system boundaries, rebound effects and a weak social dimension. These critiques matter for marine systems, where recovering a material is not the same as creating value or reducing pressure on ecosystems.

2.3 The circular blue economy and EU policy frameworks

Applied to the ocean, the circular economy covers three overlapping areas: the stepwise valorisation of fisheries and aquaculture by-products, the reduction of resource use in aquaculture and the recovery of marine litter. By-products such as heads, frames, viscera and shells can be turned into feed, oils, fertilisers and other products (Stevens et al., 2018). In aquaculture, feed is the main environmental hotspot, which makes feed efficiency and alternative feeds central circular interventions (Zoli et al., 2023; Cozzolino et al., 2025). The EU addresses marine litter through the Marine Strategy Framework Directive, which lists litter as a descriptor of good environmental status (Galgani et al., 2013). At policy level, the EU's approach to a sustainable blue economy links the maritime sectors to the European Green Deal and calls for circular solutions in fisheries and aquaculture (European Commission, 2021).

Across this literature, governance emerges as the main condition for implementation. Studies of blue economy governance link successful transitions to adaptive, cross-sector arrangements and warn that fragmented arrangements lead to implementation failures and justice risks (Noort et al., 2026; Pace & Pinto, 2026). Measurement is a second weakness: tools such as life cycle assessment and multi-criteria evaluation exist, but they are rarely combined with social and governance indicators (Chiucchi et al., 2025). This paper therefore assesses each case through its governance framework, its practices and its lessons rather than through a single performance metric.

3. Methodology

The study uses a qualitative comparative case study design. Each case was prepared by an author with country or regional expertise, following a common sub-structure: the blue economy profile of the country, national strategies and policy framework, international projects and initiatives, good practices in fisheries, seafood value chains and circular use of marine resources, and lessons learned. The common structure allows the cases to be compared while leaving room for country-specific emphasis. The Italian case, for example, is analysed through one region, Emilia-Romagna, because fisheries, aquaculture and waste management are largely implemented at regional level in Italy.

Three types of data were used. First, national and regional strategies, legislation, statistical reports and project documents were reviewed for each country. Second, a structured literature review was carried out, covering mainly peer-reviewed studies published between 2018 and 2025 together with foundational work on circularity, blue economy governance and marine litter. Third, for Türkiye, a seafood consumption campaign was documented with a common campaign data template that records the campaign’s objectives, audiences, messages, implementation and evaluation.

The four countries were selected because they represent different blue economy contexts. Malta is a small island state with a strong maritime orientation; Italy is a large Mediterranean Member State with regionalised implementation; Denmark is a Northern European Member State with mature waste management systems; and Türkiye is an EU candidate country bordering four seas, with a rapidly expanding aquaculture sector.

4. Findings

The four country case studies are presented below using the same sub-structure.

4.1 Case Study: Malta

Blue economy profile

Malta is the smallest EU Member State. With only 316 km² of land and a continental shelf of some 75,779 km² (European Commission, n.d.-b), the sea is its main economic space. As in the other island Member States, the

blue economy makes a larger contribution to national gross value added (GVA) and employment than the EU average (European Commission, 2025).

In 2023 the established blue economy sectors generated about €1 billion in GVA (5.4% of national GVA) and employed 26,400 people (8.9% of national employment) (European Commission, n.d.-a). Both values fell by about two thirds in 2020. GVA has since recovered, but employment remains about 6,500 jobs below its 2019 peak.

Coastal tourism is the dominant sector, with half of blue economy GVA and 64% of its jobs. Malta received 4,022,310 inbound tourists in 2025, up 12.9% on 2024, who spent €3.9 billion (Malta Business Weekly, 2026). Cruise tourism added 870,560 passengers on 387 liner calls (National Statistics Office [NSO], 2026). This concentration makes the blue economy highly exposed to demand shocks, as 2020 showed, and places heavy pressure on coastal ecosystems, water and waste systems.

Port activities are the second pillar (18% of GVA). Malta Freeport at Marsaxlokk is a Mediterranean transhipment hub, handling about 4.6 million tonnes of cargo and 85% of local imports. The Grand Harbour handled about 2.6 million tonnes in 2023, and the Malta–Gozo link through Mġarr carried nearly 6.6 million passengers (European Commission, n.d.-a). Malta operates the largest ship register in Europe and the sixth largest worldwide, with over 10,000 registrations by early 2025, and leads globally on superyachts (Marine Insight, 2025). Ship registration, maritime finance and legal services are only partly captured in EU blue economy GVA, so the figures above understate the maritime cluster's weight.

Marine living resources contribute 13% of GVA and 16% of employment. Aquaculture dominates this segment: it sold 20,000 tonnes worth €192.7 million in 2024, mostly farmed bluefin tuna exported to Japan (NSO, 2025; Blue Life Hub, 2025). Capture fisheries are small-scale and ageing, but culturally and socially important.

Desalination supplies almost two thirds of tap water (MaltaToday, 2023), and floating offshore wind and solar are being planned under the national offshore renewable energy policy (Ministry for the Environment, Energy and Enterprise, 2023). Together these make seawater a strategic resource beyond the traditional sectors.

Tourism, ports and desalination are where resource efficiency, waste and marine litter pressures concentrate. They are therefore the main areas where circularity gains can be made.

National strategies and policy framework

Malta has no stand-alone blue economy strategy. Its blue and circular economy objectives are spread across overarching development strategies, waste and circular economy plans, and environmental and sectoral instruments that largely implement EU frameworks.

Overarching strategic frameworks. Malta's Sustainable Development Strategy for 2050 is the main long-term framework and makes a climate-neutral green and blue economy its first goal. It links the blue economy to sustainable fisheries, aquaculture and a circular economy (Government of Malta, 2024). The draft *Malta Vision 2050* covers aquaculture, offshore renewable energy, shipping, coastal defence and seafood processing. It links investment in blue and green economies to renewable energy, circular waste management and biodiversity conservation. It also sets a target of 7% annual growth for the maritime sector, a 2035 contribution of €0.8–1.3 billion, and a third Freeport terminal. Its pillar on "Smart Land and Sea Usage" stresses the need for forward-looking planning of Malta's limited maritime space (Office of the Prime Minister, 2025).

Sectoral policies support the transition to a circular economy. The *Long-Term Waste Management Plan 2021–2030* and the *Single-Use Plastics Strategy* are Malta's main circular economy instruments. Both prioritise waste prevention and the reduction of plastics and marine litter. The waste management plan also introduces

mandatory waste separation and plans about €500 million of investment in four new plants to reduce landfilling (Environment and Resources Authority [ERA], 2021).

The management of marine living resources is guided by the *Multiannual National Plan for Sustainable Aquaculture 2022–2030*, which promotes species diversification, integrated multi-trophic aquaculture and algae-based feeds (Department of Fisheries and Aquaculture, 2023), and by the draft *National Fisheries Strategy 2026–2036*, which sets objectives for the next decade through 86 measures on sustainability, generational renewal, infrastructure and skills (Government of Malta, 2026).

On the marine side, the Strategic Plan for Environment and Development is the maritime spatial plan (European Commission, n.d.-b). Eighteen marine Natura 2000 sites cover over 4,100 km² (ERA, n.d.). Malta Enterprise's Blue Med scheme (€4 million) supports ocean-technology start-ups (Sovereign Group, 2023).

International projects and initiatives

Malta develops R&I solutions for the circular blue economy mainly through EU-funded transnational projects. These projects give its small research and business base access to partners, pilot facilities and know-how not available locally. The Sustainable Blue Economy Partnership, a Horizon Europe co-funded partnership in which Xjenza Malta participates as national funder, supports collaborative research projects such as VASEACAD (2025–2028), which develops solutions to valorise fish waste into value-added products. It is coordinated by the Hellenic Centre for Marine Research and brings together partners from Ireland, Norway, Spain, Cyprus, Türkiye and Malta. The project turns seafood side streams, discards and unwanted catches into bioactive protein hydrolysates, fish oil and novel aquafeeds. It focuses on the small, fragmented side streams typical of the Mediterranean and Black Sea (VASEACAD, n.d.). Other EU funding frameworks promote mobility and training to build partners' capabilities to find alternative ways of valorising waste biomass, as in the SARGEX project (2026–2029). SARGEX is a Horizon Europe Marie Skłodowska-Curie Staff Exchanges project coordinated by the Universitat Autònoma de Barcelona. It links partners in Spain, Italy, Belgium, Malta and Ireland with three Cuban partners. It turns stranded *Sargassum* into agricultural bioinputs, biochar and biogas (SARGEX, n.d.). COST Actions support research and innovation networks on specific topics. CA25125 (WastedValue), for example, is a network of 25 countries, including Malta, Italy and Türkiye. It explores green ways to extract proteins, peptides, pigments and other compounds from biological and marine waste, invasive species and beach wrack (COST Association, n.d.).

Good practices in fisheries, seafood value chains and circular use of marine resources

Malta's flagship practice is the processing of bluefin tuna by-products. Heads, viscera and bones make up about 55% of harvested biomass. Until 2021 they were discharged at sea. In 2022 the main tuna farms set up a joint company, Aquaculture Resources Limited, and opened a €12 million rendering plant at Ħal Far. The plant now processes about 6,000 tonnes of by-products a year into roughly 450 tonnes of fishmeal and 550 tonnes of fish oil, mainly for pet food and aquafeed (MaltaToday, 2022).

A life cycle study ranks this route above composting, incineration or landfill, which is particularly constrained on a small island. It identifies drying as the main source of environmental impact (Cusimano et al., 2025). Research in the PROFIUS project, involving the Maltese firm AquaBioTech Group, tracked the side streams from harvest to freezer (ECO Magazine, 2023). It confirmed their potential for higher-value uses, which VASEACAD is now developing further.

Further along the chain, the Department of Fisheries and Aquaculture's EU-funded campaign "Explore the Variety, Eat Sustainable Fish" promotes under-consumed local species such as bullet tuna and horse mackerel. Creating demand for these fish reduces pressure on overfished stocks and the risk that they are discarded (European Commission, 2026b).

Malta has also started to build demand among children. The *Fish Fridays* pilot was launched on 24 April 2026 in four primary schools in Marsaxlokk, Ħal Għaxaq, Msida and San Ġwann. Over four weeks, pupils receive free fish-based meals, subject to parental consent, and take part in educational sessions on balanced diets and the nutritional value of fish, led by nutritionists and culinary professionals (Malta Food Agency, 2026). The initiative is run by the Parliamentary Secretariat for Fisheries, Aquaculture and Animal Rights together with the Ministry for Education and the Malta Food Agency. The government justifies it by the low level of fish consumption among children, of whom only about 6% eat fish regularly, and links it to wider aims: raising awareness of underused species and supporting local fisheries (MaltaDaily, 2026). The pilot is intended to test how locally sourced food can be integrated into school meals before the scheme is extended to other schools (Malta Food Agency, 2026). Together with the "Explore the Variety" campaign, it gives Malta a publicly funded, school-based approach to seafood consumption, in contrast to the industry-led campaign documented for Türkiye (Section 4.2).



Figure 1. Launch of the Fish Fridays pilot in Maltese primary schools. Source: Malta Food Agency (2026).

Other practices cover the rest of the marine system. The traditional *lampuki* fishery uses fish aggregating devices (*kannizzati*) made of palm fronds, supported by the free distribution of fronds to fishers (MaltaToday, 2025). The Environment and Resources Authority's beach-cleaning procedures recommend leaving *Posidonia* seagrass wrack on beaches whenever possible (ERA, 2020). Ghost-net removal and single-use plastics measures address the end-of-life stage.

Lessons learned and transferable practices

The Malta case shows that a small island state can achieve real circularity in marine value chains, mostly through industry-led and project-based initiatives rather than a dedicated blue economy strategy.

Collective action makes valorisation viable at small scale. A joint venture of competing farms makes processing viable where side streams are small and seasonal; this cooperative model could transfer to the Aegean, the Black Sea and southern Italy. Investing in better cold-chain handling, spoilage control and energy-efficient drying of fish waste, as studied in PROFIUS and VASEACAD with Nordic research partners, is also needed to obtain the higher-value products that reach food, nutraceutical and cosmetic markets.

Demand-side measures complement processing: campaigns for under-consumed local species are low-cost and easy to replicate in any country.

SME-led participation in EU projects, supported by national co-funding, gives access to expertise and pilot facilities that the island lacks. However, the lack of policy integration remains the main barrier to scaling up the circular solutions developed.

The Maltese model has limits to transferability. It relies on a concentrated, export-oriented tuna sector with seasonal harvests, so countries with more dispersed fisheries may need mobile or regional processing solutions instead.

4.2 Case Study: Türkiye

Türkiye differs from the other three cases in two respects. It is not an EU Member State, although it takes part in EU research and cooperation programmes, and it borders four seas: the Black Sea, the Sea of Marmara, the Aegean and the Mediterranean. It is also the least documented of the four cases. The structured literature retrieval carried out for this study (Section 3) did not identify any peer-reviewed study that assesses Türkiye's circular blue economy practices directly. This case study therefore combines national data compiled for the common campaign data template, critical political-economy work on Turkish aquaculture and comparative evidence from the wider literature, and it treats the evidence gap itself as a finding.

Blue economy profile

Seafood consumption in Türkiye is low by international standards. Available estimates indicate an average of about 7–8 kg per person per year, below the world average; consumption is seasonal and dominated by fresh fish (Dohmen, n.d.). The main species consumed are anchovy (*hamsi*), sea bream, sea bass, rainbow trout, bonito, sardine and tuna. Low consumption also limits omega-3 intake, which makes seafood consumption a nutrition issue as well as an economic one.

On the production side, the sector has shifted from capture fisheries towards aquaculture. Brent et al. (2020) use Türkiye as one of their examples of the "protein fix", in which large-scale aquaculture is presented as the answer to declining wild stocks. Drawing on Ertör and Ortega-Cerdà (2019, as cited in Brent et al., 2020), they show that regulatory changes favoured concentration: applications for fish farm investments below 250 tonnes were rejected, and the large amount of capital needed to enter the sector pushed small-scale farms out. The growth of intensive marine aquaculture also increased the sector's dependence on wild pelagic fish. The share of anchovy landings used for direct human consumption fell from about 90% in the 1950s to less than half in the first half of the 2010s, and part of the Turkish industrial fleet moved towards Mauritanian waters to secure raw material for the sector (Brent et al., 2020). For a circular blue economy, this means that the central question in Türkiye is not only waste but the feed loop: whether wild fish are used as food or as an input to feed.

National strategies and policy framework

On the evidence available, Türkiye's policy framework for the circular blue economy is spread across separate sectoral instruments. National dietary guidance recommends eating fish once or twice a week (Republic of Türkiye Ministry of Health, n.d.), and aquaculture development is shaped by licensing rules such as the size threshold described above. However, the evidence base for this study contains no peer-reviewed analysis of a national strategy that links circular economy objectives with fisheries, aquaculture and seafood consumption. The closest governance-related contribution is the Build Back Circular framework of Çetin and Kirchherr (2025), developed for post-disaster reconstruction, which calls for collaboration between government, municipalities, academia and civil society. Although it is not a blue economy study, its multi-actor logic matches what the governance literature identifies as the main enabler of circular blue economy implementation: inclusive, adaptive and cross-sector governance (Noort et al., 2026; Pace & Pinto, 2026). As an EU candidate country, Türkiye can also use the EU's approach to a sustainable blue economy (European Commission, 2021) as a reference point for aligning its national instruments.

International projects and initiatives

Türkiye's participation in the blue economy research agenda takes place mainly through European networks. In the Black Sea basin, multi-actor forums have been proposed as a way to bring public authorities, industry, researchers and civil society together around a sustainable blue economy (Akinsete et al., 2025), and they offer a natural platform for Türkiye's northern coast. Türkiye is also a COST member country and takes part in COST Actions related to the blue economy, including RethinkBlue (CA22122) and WastedValue (CA25125), which explores the recovery of proteins, pigments and other compounds from marine waste and invasive species. Turkish partners also participate in VASEACAD, a Sustainable Blue Economy Partnership project that turns seafood side streams and unwanted catches from the Mediterranean and Black Sea into protein hydrolysates, fish oil and aquafeeds (VASEACAD, n.d.). These networks are mainly knowledge-oriented. They connect researchers and stakeholders, but they have not yet produced documented Türkiye-based circular pilots of the kind described for Italy (Section 4.3) and Malta (Section 4.1).

Good practices in fisheries, seafood value chains and circular use of marine resources

Promoting consumption through convenience. The most visible seafood initiative identified for Türkiye is industry-led. The "Bi' Ton Protein, Bi' Ton Omega-3" campaign of Dardanel Önentaş Gıda Sanayi A.Ş., launched in 2024 and still ongoing, promotes canned tuna and other ready-to-eat seafood as a convenient daily source of protein and omega-3 fatty acids. It targets working adults, families with children, students and physically active consumers through television, social media, recipe videos with a well-known chef and retail promotions, and its sustainability messages refer to traceable sourcing and responsible tuna procurement (Dardanel Önentaş Gıda Sanayi A.Ş., n.d.). The campaign addresses real barriers, since busy lifestyles, price sensitivity and a preference for fresh fish are among the reasons for low consumption. Its limits are equally clear. It is privately funded and product-specific; it has no school-based component, no public evaluation of its effect on awareness or consumption is available, and its sustainability messages are not linked to independent certification in the information available.



Figure 2. Visual of the "Bi' Ton Protein, Bi' Ton Omega-3" campaign. Source: Dardanel Önentaş Gıda Sanayi A.Ş. (n.d.).

By-products as an untapped resource. Türkiye's main farmed species, sea bass, sea bream and rainbow trout, are the same species for which circular interventions have been measured in Italy. A life cycle assessment of Italian rainbow trout farming identified feed and energy as the main hotspots, and insect-based feed produced the largest reduction in impacts, including about 14% lower global warming potential (Cozzolino et al., 2025). Processing residues such as heads, frames and viscera can be cascaded into feed, oil and other higher-value products (Stevens et al., 2018). The evidence base does not document such practices in Türkiye, but the overlap in species means that these results are directly relevant to Turkish producers.

Lessons learned and transferable practices

Four lessons emerge. First, the evidence gap is a policy problem in itself. Without published monitoring of by-products, feed inputs and recovered waste, Türkiye's circular performance cannot be compared with that of the other cases, and good practices that may exist at firm level remain invisible. A common indicator set that combines environmental, economic and social dimensions, of the kind called for in the literature (Chiucchi et al., 2025), would be a first step.

Second, circularity in Türkiye has to start from the feed loop. The shift of anchovy from plates to feed shows how the protein fix can reduce the food value of wild fish (Brent et al., 2020). Alternative feeds and better use of processing residues would address this more directly than end-of-pipe recycling. Third, the concentration of aquaculture raises a question of justice. When small farms are pushed out, the benefits of blue growth are unevenly shared (Bennett et al., 2021), so circular measures should be designed to include small producers, for example through cooperative-level collection of by-products.

Fourth, two practices from the other cases are transferable. Italy's FLAG model shows how local intermediaries can turn EU programmes into producer-led pilots (Section 4.3), and Malta's joint rendering plant for bluefin tuna by-products (Section 4.1) shows how competing producers can make by-product processing viable at small scale. On the consumption side, private campaigns such as Dardanel's could be complemented by public, evaluated and school-based programmes that link nutrition messages with sustainability and with local species such as anchovy.

4.3 Case Study: Italy – the Emilia-Romagna coast

Italy is one of the four Member States that together generate more than half of the EU blue economy's gross value added and employment (European Commission, 2025). Because Italian maritime policy is set nationally but fisheries, aquaculture and waste management are largely implemented by the regions, this case study reads the national framework through one coastal region: Emilia-Romagna, on the northern Adriatic. The region was chosen because it combines a large coastal tourism economy, intensive shellfish farming and the first regional circular economy law in Italy, and because its lagoons have become the front line of the Atlantic blue crab (*Callinectes sapidus*) invasion.

Blue economy profile

At national level, the 2025 report of the National Observatory on the Sea Economy counts 232,841 enterprises and 1,089,710 people employed in the sea economy. Its direct value added is €76.6 billion; including the activity it generates in other sectors (a multiplier of 1.8), it activates €216.7 billion, equal to 11.3% of national GDP (Unioncamere, 2025).

Emilia-Romagna's 24 coastal municipalities host 14,175 sea-economy enterprises and 76,227 workers, 3.5% of regional employment. The sector produces about €14.9 billion of value added, 8.6% of the regional economy, with a multiplier of 2.0, above the national average (Camera di Commercio di Frosinone Latina, 2025). The profile is strongly concentrated: the province of Rimini alone accounts for 32.1% of the value added and 40.4% of the employment, followed by Ravenna, the region's commercial port, with 18.6% and 20.9% (Camera di Commercio di Frosinone Latina, 2025). Coastal tourism therefore dominates the economic picture, while port logistics and industrial activity cluster around Ravenna.

The fisheries and aquaculture chain is small in value but large in volume. In 2025 it comprised 2,597 enterprises, 4,415 employees and 574 fishing vessels, generating €33.7 million in value added. Emilia-Romagna holds 5.1% of the Italian fishing fleet but landed 12.4% of the national catch in 2024, ranking third among Italian regions; yet the average first-sale price was about €3/kg against a national average of €5.5/kg. Aquaculture, operating under 118 concessions, produced about 13.9 million kg of mussels, 5 million kg of clams and 43,800 kg of oysters in 2025 (Regione Emilia-Romagna, 2026). The regional seafood market is nevertheless import-dependent:

exports of €127 million against imports of €934.7 million left a trade deficit of €807.7 million in 2025 (Regione Emilia-Romagna, 2026). High volumes, low unit prices and a structural deficit define the problem that circular approaches have to address in this territory.

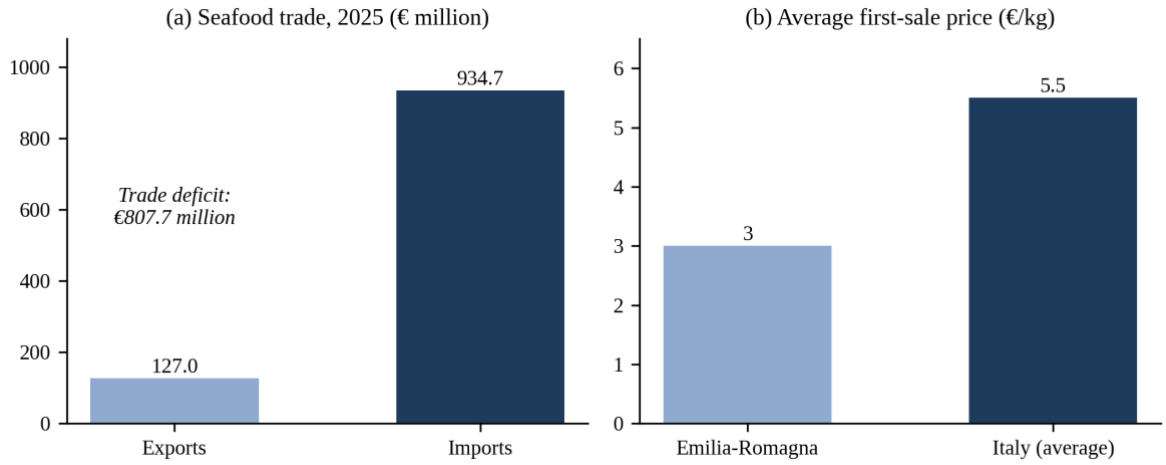


Figure 3. Seafood trade and first-sale prices in Emilia-Romagna. Source: Authors' elaboration based on Regione Emilia-Romagna (2026).

National strategies and policy framework

Italy's maritime governance was reorganised with the creation of the Interministerial Committee for Maritime Policies (Comitato interministeriale per le politiche del mare, CIPOM), which adopted the first Sea Plan (Piano del mare) for 2023–2025 on 31 July 2023 (Comitato interministeriale per le politiche del mare [CIPOM], 2023). The second edition, the Piano del mare 2026–2028, was approved by CIPOM on 18 February 2026 and published in the Official Gazette on 30 June 2026. It is organised around sixteen lines of action, including ecological transition, marine ecosystems and a dedicated line on fisheries and aquaculture (CIPOM, 2026).

Circularity is framed by a separate instrument, the National Strategy for the Circular Economy (Strategia nazionale per l'economia circolare), adopted by Ministerial Decree No. 259 of 24 June 2022 as Reform 1.1 of the National Recovery and Resilience Plan. It sets measures to 2035 on end-of-waste criteria, extended producer responsibility, secondary raw material markets and industrial symbiosis (Ministero della Transizione Ecologica, 2022). The instrument most directly relevant to fishers is the "SalvaMare" law (Law No. 60 of 17 May 2022), which regulates the recovery of waste collected by fishing nets at sea, in lagoons and in rivers ("rifiuti accidentalmente pescati") and explicitly links marine litter recovery to the promotion of the circular economy (Legge 17 maggio 2022, n. 60, 2022).

At regional level, Emilia-Romagna was the first Italian region to legislate on the circular economy, with Regional Law No. 16 of 5 October 2015. The law follows the EU waste hierarchy and has been implemented through a permanent coordination table on by-products (Coordinamento permanente per i sottoprodotti), a network of reuse centres and the #PlasticFreER strategy (Regione Emilia-Romagna, n.d.-a; Legge regionale 5 ottobre 2015, n. 16, 2015). The region's fisheries investments are channelled through the European Maritime, Fisheries and Aquaculture Fund (EMFAF/FEAMPA), with about €40 million programmed for 2021–2027 plus €5 million for climate-related emergencies such as the blue crab, anoxia and mucilage (Regione Emilia-Romagna, 2026).

International projects and initiatives

Emilia-Romagna participates in Adriatic cooperation mainly through the Interreg Italy–Croatia programme. In ARGOS (2020–2022), a strategic project led by the Friuli Venezia Giulia Region with a total budget of €5.7 million, Emilia-Romagna worked with Italian and Croatian partners towards a common regulatory framework

for fisheries and aquaculture, integrated databases and training for blue skills (Regione Emilia-Romagna, n.d.-b). PRIZEFISH, led by the University of Bologna's Interdepartmental Centre for Environmental Sciences Research (CIRSA) with 13 partners, addressed traceability, quality certification and ecosystem-based management of Adriatic products, including northern Adriatic clam stocks (Regione Emilia-Romagna, n.d.-c). At local level, the Fisheries Local Action Group of the Emilia-Romagna coast (FLAG Costa dell'Emilia-Romagna), funded under EMFF/EMFAF community-led local development, is the broker that turns these programmes into operational pilots with producer cooperatives.

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Closing the loop on mussel-farming plastics. Longline mussel farming uses large quantities of polypropylene socks (reste) that are frequently lost at sea or disposed of as mixed waste. Under a FLAG initiative led by the Cooperativa M.A.R.E. of Cattolica with the regional mussel farmers' consortium (Consorzio Mitilicoltori dell'Emilia-Romagna), the Municipality of Rimini and the multi-utility HERA, a prototype machine was developed to separate polypropylene from organic residue so that the plastic can be recycled. The project also produced simplified procedures and on-board operating guidelines for handling farm waste in port (FLAG Costa dell'Emilia-Romagna, n.d.). Its main contribution is institutional rather than technical: it created a working agreement between producers and the waste operator, which is the step most circular pilots lack.

Turning an invasive species into a feedstock. The blue crab has damaged clam farming in the Po Delta lagoons, including the Sacca di Goro, and it is one of the emergencies covered by the regional EMFAF climate reserve (Regione Emilia-Romagna, 2026). The CRAB project (Circular Re-use of Alien Blue-crab), financed by the Emilia-Romagna ERDF 2021–2027 programme under its social innovation action, brings together the Torpedo cooperative, the Cestha scientific institute in Marina di Ravenna, the Cifla innovation centre, the Clust-ER Agrifood cluster and local fishing cooperatives. Undersized or damaged crabs that cannot be sold are dehydrated and sterilised without water or chemical additives; 100 kg of fresh crab yields 30–35 kg of flour with about 65% protein, which can be used as animal or aquaculture feed or as fishing bait (Ravenna&Dintorni, 2025).

Participatory sector planning. In September 2026 the Region opened the "Stati generali" of fisheries and aquaculture, a three-stage consultation in Goro, Cesenatico and Rimini on climate adaptation, invasive species, profitability and post-2027 EU funding (Regione Emilia-Romagna, 2026). Holding the dialogue in the producing communities, rather than in the regional capital, is itself a governance practice worth noting.

Lessons learned and transferable practices

Four lessons emerge. First, a regional circular economy law with a standing by-products table gives fishers and farmers a legal route to treat residues as resources; without it, pilots such as mussel-sock recycling stall on waste classification. Second, FLAGs are the intermediary between EU programmes and small cooperatives; transferring the Emilia-Romagna model requires investing in these local brokers, not only in technology. Third, the SalvaMare law gives fishers a national legal basis to land the litter they catch, but its effect depends on port-level agreements with waste operators of the type tested in Cattolica and Rimini.

Fourth, and less comfortable, circularity in Emilia-Romagna has so far been mostly about waste, not value. The region lands a large share of Italy's catch at low prices and imports most of the seafood it consumes. Recycling mussel socks and processing blue crab reduce harm, but they do not change the €807.7 million trade deficit or the €3/kg price gap. There is also a risk in valorising an invasive species: if blue crab flour becomes profitable, it may create an incentive to maintain a harvestable stock rather than to contain it. The transferable practice is therefore the combination of a legal framework, local brokerage and producer-led pilots; the open question for other countries is how to direct circular measures towards value capture in the seafood chain, for example

through processing, certification and traceability of the kind PRIZEFISH explored, rather than only towards end-of-pipe recovery.

4.4 Case Study: Denmark

Blue economy profile

Denmark possesses an advanced maritime infrastructure heavily shaped by its geography, which features over 7,300 km of coastline and an exclusive economic zone spanning approximately 105,000 km². The Danish blue economy is a pillar of national macroeconomic stability, generating approximately €18.6 billion in GVA, accounting for roughly 5.6% of the overall national economy, and employing more than 126,800 people (European Commission, 2026a).

The country's maritime sector is structurally anchored by global shipping operations and high-tech aquaculture. **Maritime transport is the primary economic driver**, accounting for nearly 60% of the total blue GVA. Denmark maintains its status as an international leader in commercial shipping operations, managing one of the world's most modern merchant fleets. Danish-operated vessels control a significant share of global container logistics, driving a continuous domestic demand for low-emission propulsion technologies and green port infrastructure. Figure 4 illustrates a number of structural characteristics of Denmark's blue economy.

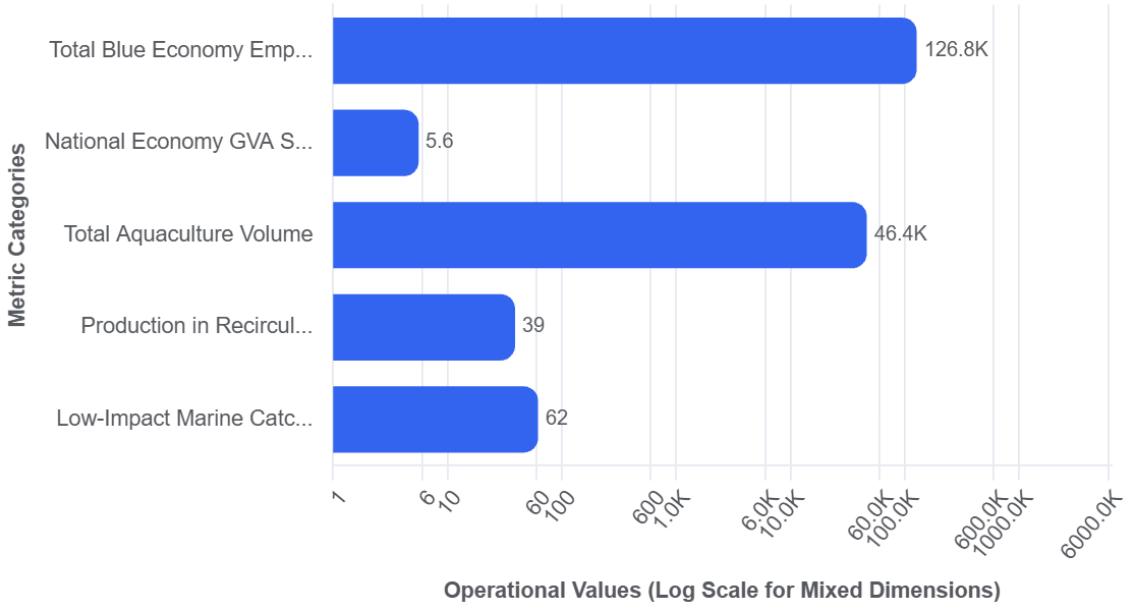


Figure 4. Selected indicators of Denmark's blue economy (logarithmic scale). Source: Compiled from European Commission (2026a), EUMOFA (2025) and Eurofish (2026).

Alongside shipping, the domestic aquaculture sector has evolved into a technology-intensive industry shaped by efforts to reduce environmental pressure on the Baltic and North Seas. In 2024, Denmark's total annual aquaculture production reached 46,405 tonnes in volume, valued at approximately €195 million. Production is divided into land-based freshwater systems and coastal sea cages. Rainbow trout remains the dominant species, but production methodologies are rapidly changing (Eurofish, 2026; European Market Observatory for Fisheries and Aquaculture Products [EUMOFA], 2025).

Driven by rigorous domestic environmental rules, 39% of all Danish aquaculture production is now conducted inside closed recirculating aquaculture systems (RAS), predominantly on land. These facilities significantly reduce water footprints and allow most nutrient outputs to be captured. Meanwhile, traditional commercial fisheries land roughly 496,000 tonnes of wild biomass annually, with 62% of landings dedicated to industrial

uses like high-grade fishmeal and bio-oils, building a direct bridge to downstream circular refinery processes (EUMOFA, 2025).

National strategies and policy framework

Denmark's strategic approach to the circular blue economy operates within an integrated regulatory ecosystem designed to synchronise marine industrial operations with environmental preservation. Rather than relying on an isolated maritime policy, the state embeds blue circularity within broader climate and resource frameworks.

- **Action Plan for Circular Economy (2020–2032):** This national plan sets out 129 initiatives, with an explicit focus on biomass, plastics, and industrial residual waste. In the marine context, the plan sets sorting, collection and processing requirements for coastal industrial operations intended to reduce the loss of polymer-based waste to the sea (Ministry of Environment of Denmark, 2021).
- **Climate Partnership for Blue Denmark:** One of the voluntary public–private climate partnerships set up by the Danish government, it was chaired by the CEO of A.P. Møller–Mærsk, with Danish Shipping as secretariat and fisheries organisations among the participants. Its 2020 report set out recommendations to the government and the ambition that the Danish fleet, from ferries and fishing vessels to ocean-going ships, can become CO_2-neutral (Climate Partnership for Blue Denmark, 2020).
- **The Danish Marine Strategy (Havstrategi II):** Implementing the EU Marine Strategy Framework Directive, the strategy sets environmental targets for good environmental status in Danish waters, including for marine litter, and its programme of measures for 2023–2027 sets out the national initiatives to reach them (Ministry of Environment of Denmark, 2024). It provides the regulatory baseline within which aquaculture facilities and commercial fleets operate.

International projects and initiatives

Denmark participates in transnational networks that support industrial circularity, drawing on EU co-funding through Horizon Europe and Interreg programmes.

The Blue Circular Economy (BCE) project (2018–2022), funded by the Interreg Northern Periphery and Arctic programme, involved the Arctic Technology Centre of the Technical University of Denmark (DTU) alongside partners from Norway, Ireland and the United Kingdom (Keep.eu, 2023). It helped small and medium-sized enterprises turn waste fishing gear into recycled products by building transnational clusters and circular business models (European Commission, 2020).

Danish ports also take part in Circular Ports (2025–2028), an Interreg Baltic Sea Region project led by Port of Hamburg Marketing that supports the EU Strategy for the Baltic Sea Region. The project maps material flows in port environments, prepares pilot actions and develops circular business models, and it has documented circular economy solutions at the Port of Aalborg (Circular Ports, n.d.).

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Danish actors have developed practical solutions that turn marine waste streams into commercial inputs.

- **Upcycling of end-of-life fishing gear:** Plastix A/S, based in Lemvig, collects discarded fishing nets, trawls and ropes and recycles them through mechanical and thermal processes into HDPE, PP and PA6 recyclates that replace virgin plastics in new products. A life cycle assessment found that these recyclates have a markedly lower carbon footprint than the virgin plastics they replace (Storm, 2017).
- **By-product biorefining and cascading:** Processing by-products such as skins, viscera and frames can be cascaded into higher-value products, including oils, collagen and protein hydrolysates for food, feed and fertiliser uses (Stevens et al., 2018). With a large share of Danish landings already used for fishmeal and fish oil (EUMOFA, 2025), the Danish processing industry provides a base for such cascading.

- **Industrial symbiosis:** The Kalundborg Symbiosis is an internationally recognised example of cross-sector resource exchange. It developed gradually from 1959 among a power plant, an oil refinery, a plasterboard factory, a biotechnology plant and the municipality. Its link to the blue economy dates from 1989, when the power plant began to use waste heat from its cooling water to farm trout and turbot, while other exchanges turned biological sludge, fly ash and gypsum into inputs for agriculture and industry (Grann, 1997).

Lessons learned and transferable practices

Denmark's transition towards a circular blue economy offers clear, practical insights for maritime nations aiming to scale up sustainable coastal operations.

First, **technological innovation must be backed by clear economic incentives** to ensure long-term commercial viability. The Danish case suggests that developing high-value recycling technologies is not enough if virgin plastics and raw materials remain cheaper than recycled alternatives. Economic instruments, such as green taxation and public procurement criteria that favour ecolabelled and circular materials, are needed to create a reliable market for recovered marine resources.

Second, **cross-sectoral clustering is essential** to overcome supply chain limitations. Individual small and medium-sized enterprises (SMEs) in the fishing and aquaculture sectors often lack the infrastructure to independently collect, transport, and process waste materials. The Danish experience indicates that grouping local businesses, academic institutions, and regional ports into collaborative networks allows SMEs to aggregate waste volumes, lower logistical costs, and access high-value regional supply chains.

Third, a further lesson concerns the **importance of local circular targets**. National strategies can stall when they are too abstract for local implementation; area-specific plans developed with municipalities, local businesses and ports help translate national circular economy goals into practice.

4.5 Comparative Overview

Table 1 summarises the four cases along five dimensions, drawing on Sections 4.1 to 4.4.

Table 1. Comparative overview of the four cases

Dimension	Malta	Türkiye	Italy	Denmark
Scale of analysis	National (small island state)	National	National framework read through the Emilia-Romagna region	National
Framework for circularity	No stand-alone blue economy strategy; Sustainable Development Strategy 2050, Long-Term Waste Management Plan 2021–2030, aquaculture plan 2022–2030	No integrated circular blue economy strategy documented; dietary guidance and aquaculture licensing	Sea Plan 2023–2025 and 2026–2028; National Circular Economy Strategy (2022); SalvaMare law; regional circular economy law (2015)	Action Plan for Circular Economy 2020–2032; Climate Partnership for Blue Denmark; Danish Marine Strategy
Documented circular practices	Joint rendering plant for bluefin tuna by-products; public campaign for under-consumed local species; school-based Fish Fridays pilot	Few documented; industry-led seafood consumption campaign	Mussel-sock recycling; blue crab flour; fishing-for-litter	Recycling of end-of-life fishing gear; by-product biorefining; Kalundborg industrial symbiosis
Main channel of implementation	Industry joint venture and EU-funded projects	Private sector and research networks	Regional law, FLAG and producer-led pilots	Integrated national framework and industrial clusters
Main challenge	Limited policy integration; reliance on a concentrated, export-oriented tuna sector	Feed dependence on wild fish; sector concentration; evidence gap	Circularity focused on waste rather than value; seafood trade deficit	Cost of recycled versus virgin materials; translating national targets to local level

5. Discussion and Conclusion

The four cases show that the same circular principles take very different institutional forms. Denmark embeds circularity in integrated national frameworks and industrial clusters such as Kalundborg. Italy combines a national framework with a regional circular economy law and local intermediaries such as the FLAG. Malta has no stand-alone blue economy strategy, yet it has achieved one of the most concrete results in the sample through an industry joint venture and EU-funded projects. Türkiye shows the least integrated configuration, with rapid aquaculture growth and few documented circular practices.

Across the cases with documented results, circular practice advances where actors are organised collectively: Malta's joint rendering company, Danish clusters linking SMEs, ports and research institutions, and Emilia-Romagna's FLAG-brokered agreement between mussel farmers, the municipality and the waste operator. This is consistent with the literature identifying cross-sector governance as the main enabler of the circular blue economy (Noort et al., 2026; Pace & Pinto, 2026) and with the quintuple helix proposed by Heidkamp et al. (2023). The absence of a dedicated strategy is therefore not decisive in itself, as Malta shows, whereas the absence of collective arrangements may be, as Türkiye suggests.

The cases also confirm that circularity tends to be reduced to waste management (Kirchherr et al., 2017; Korhonen et al., 2018). In Italy, circular measures have so far addressed waste rather than value; in Türkiye, the key loop to close is feed, given the diversion of wild fish from human consumption (Brent et al., 2020). Malta and Denmark show the next step, cascading by-products into fishmeal, oils and higher-value ingredients, but this depends on instruments that make recovered materials competitive with virgin ones and on multi-criteria evaluation, since the environmentally preferable option is not always the most profitable (Crîstiu et al., 2024; Chiucchi et al., 2025). Circular measures can also create winners and losers, so small-scale producers must share in their benefits (Bennett et al., 2021).

Several recommendations follow. Circular objectives should be integrated into maritime and fisheries strategies, most urgently in Türkiye. Investment should support collective arrangements that allow small producers to aggregate side streams and share facilities. For the main Mediterranean farmed species, the priority should be the feed loop and the cascading use of processing residues (Stevens et al., 2018; Zoli et al., 2023; Cozzolino et al., 2025). Green taxation and green public procurement can create markets for recovered materials, and seafood consumption campaigns should link nutrition with sustainability, building on models such as Malta's Fish Fridays pilot. Türkiye could also learn from Italy's SalvaMare law, which allows fishers to land the litter caught in their nets free of charge, without being treated as unauthorised waste carriers, with the costs shared nationally through the waste tariff (Legge 17 maggio 2022, n. 60, 2022). A similar rule would give Turkish fishers a simple, legal way to bring this litter ashore instead of returning it to the sea.

In conclusion, the circular blue economy is advancing mainly through sector-specific practices, while national frameworks linking them remain uneven. The transferable element is not a single technology but a combination of collective arrangements, supporting legal and economic instruments, and a shift from waste recovery towards value capture in the seafood chain.

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FULL PAPER · IP1.2 · IN-PERSON SESSION I

Artificial Intelligence-Enabled Green Logistics Ventures: A Conceptual Framework for Sustainable Business Models and Carbon Reduction

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ABSTRACT

Aim: The increasing environmental footprint of logistics activities has intensified the need for business models that combine operational efficiency with measurable environmental value creation. At the same time, artificial intelligence (AI) is reshaping logistics through route optimisation, demand forecasting, capacity planning, predictive analytics, and automated decision-making. This study aims to examine how AI-enabled capabilities can support green logistics ventures in reducing carbon emissions while strengthening the economic viability and scalability of sustainable business models. It further seeks to develop an integrated conceptual framework connecting AI capabilities, green logistics practices, sustainable value creation, and entrepreneurial competitiveness.

Methodology/Approach: The study adopts a conceptual research design based on a structured review of the literature and document analysis. Academic studies addressing artificial intelligence, green logistics, sustainable entrepreneurship, digital transformation, and low-carbon business models are synthesised alongside relevant policy and institutional documents. The analysis focuses on five AI-enabled logistics capabilities: route optimisation, demand forecasting, vehicle and load capacity optimisation, energy-efficiency management, and environmental impact measurement. These capabilities are evaluated in relation to their potential economic and environmental contributions to green ventures.

Expected Contribution: The study is expected to demonstrate that AI can contribute to green logistics entrepreneurship not merely as an operational efficiency tool but as a strategic capability supporting sustainable value creation. The proposed framework explains how data-driven logistics decisions may simultaneously reduce resource consumption, improve asset utilisation, lower emissions, and enhance the competitiveness of sustainability-oriented ventures. It also identifies possible implementation challenges related to data quality, investment requirements, digital capabilities, and responsible AI use.

Relevance to the Conference Theme: The study directly addresses SEFGEN 2026 themes of Green Entrepreneurship and Sustainable Business Models, Digital Transformation for Green Ventures, Smart Technologies and Green Innovation, and Artificial Intelligence and Data-Driven Entrepreneurship for Sustainability. By integrating entrepreneurship, logistics, digitalisation, and environmental sustainability, the study contributes to discussions on how emerging technologies can enable more resilient and low-carbon ventures for future generations.

Keywords: Artificial Intelligence, Green Logistics, Sustainable Entrepreneurship, Sustainable Business Models, Carbon Reduction

1. Introduction

Logistics is one of the foundations of economic activity. It connects producers with markets, enables specialisation and trade, and determines whether goods reach customers at the right time, in the right quantity and at an acceptable cost. Yet the same activities that create this economic value also generate a substantial environmental burden. According to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, direct greenhouse gas emissions from the transport sector reached 8.7 GtCO2-eq in 2019 and accounted for 23% of global energy-related CO2 emissions (Jaramillo et al., 2022). Freight transport is a central part of this picture, and its weight is likely to grow: the International Transport Forum projects that global freight

demand will roughly double by 2050 under current policy ambitions, while total transport CO2 emissions are expected to fall only slightly over the same period (International Transport Forum [ITF], 2023). In other words, the logistics sector is expected to move far more goods in a world that requires far fewer emissions.

Inefficiency is a large part of the problem. In the European Union, for example, about 20% of all road freight vehicle-kilometres in 2020 were driven by empty vehicles (Eurostat, 2021). Partially loaded vehicles, poorly planned routes, excess inventory movements, energy-intensive warehouses and avoidable packaging add further environmental costs that do not translate into customer value. Green logistics research has long shown that many of these inefficiencies are, at least in principle, reducible through better planning and coordination (Dekker et al., 2012; McKinnon et al., 2015). What has changed in recent years is the availability of data and analytical tools that can make such planning faster, more precise and more adaptive.

Artificial intelligence (AI) is at the centre of this change. Machine learning, optimisation algorithms and predictive analytics are increasingly used in logistics and supply chain management for routing, forecasting, capacity planning, maintenance and automated decision-making (Toorajipour et al., 2021; Wang et al., 2016). At the same time, AI has been discussed as a potential lever for climate change mitigation more broadly, with applications ranging from energy systems to transport (Kaack et al., 2022; Rolnick et al., 2022; Vinuesa et al., 2020). However, the relationship between AI and sustainability is not straightforward. AI systems consume energy, require investment and data, and may produce rebound effects in which efficiency gains increase total activity rather than reducing environmental impact (International Energy Agency [IEA], 2025; Kaack et al., 2022).

These developments are particularly relevant for entrepreneurship. Green entrepreneurial ventures, which seek to create economic value while reducing environmental harm, are expected to play an important role in the transition to a low-carbon economy (Dean & McMullen, 2007; Schaltegger & Wagner, 2011). In logistics, such ventures may offer electric last-mile delivery, digital freight matching, shared warehousing, low-carbon transport services or emissions reporting solutions. Unlike large incumbents, they usually operate with limited capital, assets and staff. For them, AI may be attractive not only because it improves efficiency but because it can make a sustainable business model economically viable and scalable. Nevertheless, it remains unclear under which conditions AI actually contributes to both environmental and economic value in such ventures.

The existing literature offers only partial answers. Studies on AI in logistics tend to focus on efficiency and technological performance; green logistics research concentrates on environmental outcomes and operational measures; and sustainable entrepreneurship research examines value creation and business models, often without a detailed account of the technologies involved (Schaltegger et al., 2016; Toorajipour et al., 2021). As a result, there is limited integrated explanation of how AI capabilities become green logistics practices, how these practices create sustainable value, and how this value ultimately strengthens the competitiveness of green ventures.

This study addresses this gap. Its aim is to develop an integrated conceptual framework explaining how AI-enabled logistics capabilities can support carbon reduction and sustainable business model development in green ventures. The study is guided by the following research question: *How can AI-enabled capabilities contribute to both environmental sustainability and competitive value creation in green logistics ventures?*

To answer this question, the study adopts a conceptual research design based on a structured literature review and document analysis. It examines five AI-enabled logistics capabilities, namely route optimisation, demand forecasting, vehicle and load capacity optimisation, energy-efficiency management, and environmental impact measurement, and evaluates their potential environmental and economic contributions. Building on this analysis, the study proposes a four-stage framework linking AI-enabled capabilities, green logistics practices,

sustainable value creation and green venture competitiveness, and formulates research propositions for future empirical testing. The study also discusses the conditions under which AI may fail to deliver sustainability benefits.

The remainder of the paper is structured as follows. Section 2 reviews the conceptual background. Section 3 explains the methodology. Section 4 analyses the five AI-enabled capabilities. Section 5 presents the proposed conceptual framework and propositions. Section 6 discusses implementation challenges and boundary conditions. Section 7 outlines theoretical, managerial and policy implications, and Section 8 concludes with limitations and directions for future research.

2. Conceptual Background

2.1. Green Logistics and the Carbon Challenge

Green logistics refers to efforts to measure and reduce the environmental impact of logistics activities, including freight transport, warehousing, materials handling, packaging and reverse flows (McKinnon et al., 2015). The concept extends traditional logistics objectives, which focus on cost and service, by adding environmental objectives such as lower emissions, lower energy use and lower waste (Dekker et al., 2012; Sbihi & Eglese, 2007). In the related field of green supply chain management, environmental thinking is integrated across the supply chain, from product design and sourcing to delivery and end-of-life management (Srivastava, 2007).

Operations research has made important contributions to this field. Dekker et al. (2012) show how decisions on network design, transport mode, vehicle choice, routing and inventory can be reformulated to account for environmental objectives. In road freight, research on the green vehicle routing problem and the pollution-routing problem has demonstrated that fuel consumption and emissions depend not only on distance but also on load, speed and vehicle characteristics, and that routing decisions can be optimised accordingly (Bektaş & Laporte, 2011; Demir et al., 2014; Lin et al., 2014). Studies on vehicle utilisation have shown that reducing empty running and improving load factors are among the most effective measures for decarbonising road freight (McKinnon & Ge, 2006).

A persistent difficulty, however, is measurement. Logistics emissions are spread across many actors, modes and subcontractors, which makes them difficult to quantify consistently. Recent standardisation efforts address this problem. The Global Logistics Emissions Council (GLEC) Framework provides a methodology for calculating and reporting logistics emissions across the transport chain (Smart Freight Centre, 2023), and ISO 14083:2023 establishes an international standard for quantifying and reporting greenhouse gas emissions arising from transport chain operations (International Organization for Standardization [ISO], 2023). These developments are important because they turn emissions from an abstract externality into a measurable performance indicator that customers, investors and regulators can compare. Policy frameworks such as the European Green Deal, which calls for a 90% reduction in transport emissions by 2050, further increase the pressure on logistics firms to provide reliable evidence of their environmental performance (European Commission, 2019).

2.2. Artificial Intelligence in Logistics and Supply Chain Management

AI can be broadly understood as the ability of computer systems to perform tasks that normally require human intelligence, such as learning from data, recognising patterns, making predictions and supporting decisions. In logistics and supply chain management, AI is applied through techniques such as machine learning, neural networks, metaheuristic optimisation and agent-based systems (Riahi et al., 2021; Toorajipour et al., 2021). Earlier work on big data analytics already showed that data-driven approaches can improve forecasting, inventory management, transport planning and supply chain coordination (Wang et al., 2016). Machine learning

methods have been shown to improve demand forecasting accuracy in supply chains compared to traditional techniques in certain settings (Carbonneau et al., 2008).

From a management perspective, AI is increasingly conceptualised not as a single technology but as an organisational capability. Mikalef and Gupta (2021) define AI capability as a firm's ability to select, orchestrate and leverage its AI-specific resources, which include data, technology, human skills and organisational routines. This view is useful because it implies that the value of AI depends less on the algorithm itself than on how it is embedded in decision processes. Empirical research on big data and predictive analytics supports this argument: Dubey et al. (2019) find that big data and predictive analytics capabilities can contribute to social and environmental sustainability in manufacturing supply chains, but that their effect depends on organisational conditions.

At the same time, the literature on AI and climate change warns against assuming that AI is inherently sustainable. Kaack et al. (2022) distinguish between the direct effects of AI, such as the energy used for computation, the application effects of AI systems, and wider system-level effects, including rebound effects and changes in consumption patterns. The International Energy Agency estimates that data centres consumed about 415 TWh of electricity in 2024, around 1.5% of global electricity consumption, and that this figure may more than double to around 945 TWh by 2030 (IEA, 2025). The same report notes that the widespread adoption of existing AI applications could reduce emissions considerably, but that rebound effects may undercut some of these benefits and that AI is "not a silver bullet" (IEA, 2025). These observations suggest that the sustainability contribution of AI must be demonstrated rather than assumed.

2.3. Sustainable Entrepreneurship and Sustainable Business Models

Sustainable entrepreneurship refers to the discovery, creation and exploitation of opportunities that generate economic gains while also creating environmental and social value (Cohen & Winn, 2007; Shepherd & Patzelt, 2011). Dean and McMullen (2007) argue that environmental degradation can be understood as a result of market failures, and that entrepreneurs can reduce such degradation by exploiting the opportunities these failures create. Schaltegger and Wagner (2011) emphasise that sustainable entrepreneurs aim to achieve sustainability effects at the market level, not only within their own organisations. Hall et al. (2010) note that while entrepreneurship is frequently presented as a solution to environmental problems, the mechanisms through which ventures actually achieve such outcomes remain insufficiently understood.

The business model concept helps to clarify these mechanisms. A business model describes how a firm creates, delivers and captures value (Teece, 2010). Sustainable business models extend this logic by including environmental and social value in the value proposition and by considering a wider set of stakeholders (Bocken et al., 2014; Schaltegger et al., 2016). Bocken et al. (2014) identify archetypes such as maximising material and energy efficiency, creating value from waste, and delivering functionality rather than ownership. Many green logistics ventures can be associated with these archetypes. For instance, digital freight platforms that reduce empty running maximise asset efficiency, and shared warehousing models deliver capacity as a service.

Digital technologies are increasingly recognised as enablers of such business models. Nambisan (2017) argues that digital technologies change the nature of entrepreneurial opportunities, processes and outcomes. George et al. (2021) show that digital innovations can help entrepreneurs address climate change and sustainable development challenges by reducing transaction costs, improving transparency and enabling new forms of value creation. Kayikci (2018) highlights that digitisation in logistics can produce economic, environmental and social sustainability effects, but that these effects vary across technologies and applications. Together, these studies suggest that AI may be particularly relevant for green ventures, provided it is connected to a viable business model.

2.4. Theoretical Lens: Resources, Capabilities and Sustainable Advantage

This study draws on the resource-based view and its extensions. The resource-based view holds that firms achieve sustained competitive advantage by controlling resources that are valuable, rare, difficult to imitate and non-substitutable (Barney, 1991). The natural-resource-based view adds that capabilities related to pollution prevention, product stewardship and sustainable development can become sources of competitive advantage as environmental constraints tighten (Hart, 1995; Hart & Dowell, 2011). Porter and van der Linde (1995) similarly argue that environmental improvements can enhance competitiveness when they are achieved through innovation and resource productivity.

The dynamic capabilities perspective explains how firms sense opportunities, seize them and reconfigure their resources in changing environments (Teece et al., 1997; Teece, 2007). AI can be understood within this perspective as a capability that improves sensing (for example, through demand forecasting and emissions measurement), seizing (for example, through optimised routing and capacity decisions) and reconfiguring (for example, through continuous learning from operational data). For green ventures, this perspective suggests that AI is strategically valuable when it becomes part of the routines through which the venture creates environmental and economic value, rather than when it is adopted as a stand-alone tool.

2.5. Research Gap

The literature reviewed above reveals three largely separate streams. Research on AI in logistics focuses primarily on efficiency and technological performance (Riahi et al., 2021; Toorajipour et al., 2021). Green logistics research focuses on environmental outcomes and the operational measures that deliver them (Dekker et al., 2012; McKinnon et al., 2015). Sustainable entrepreneurship and sustainable business model research focuses on value creation and the logic of ventures (Bocken et al., 2014; Shepherd & Patzelt, 2011). Although each stream provides valuable insights, they are rarely brought together. Consequently, there is limited integrated explanation of how AI capabilities become green logistics practices, how these practices create sustainable value, and how this value ultimately strengthens venture competitiveness. The present study seeks to address this gap by developing a framework that connects these stages explicitly.

3. Methodology

3.1. Research Design

The study adopts a conceptual research design. Conceptual research does not rely on new empirical data; instead, it builds on existing theories, studies and documents to develop new explanations, frameworks or propositions (Jaakkola, 2020). Jaakkola (2020) distinguishes four approaches to conceptual articles: theory synthesis, theory adaptation, typology and model building. The present study follows a model-building approach because it aims to explain the relationships between AI-enabled capabilities, green logistics practices, sustainable value creation and venture competitiveness. The framework development process also follows the logic proposed by Jabareen (2009), in which concepts are identified from multidisciplinary sources, deconstructed, integrated and synthesised into a coherent framework.

3.2. Structured Literature Review and Document Analysis

The conceptual analysis is based on a structured review of the literature combined with document analysis. Structured literature reviews increase transparency by defining the scope, sources and selection logic of the review in advance (Snyder, 2019; Tranfield et al., 2003). The review covered five literature streams: artificial intelligence, green logistics, sustainable entrepreneurship, digital transformation and low-carbon business models. Peer-reviewed journal articles, books and book chapters were prioritised. Search terms combined technological concepts (for example, "artificial intelligence", "machine learning", "predictive analytics", "big

data analytics") with sustainability and logistics concepts (for example, "green logistics", "carbon emissions", "vehicle routing", "sustainable entrepreneurship", "sustainable business model").

In addition, policy and institutional documents were analysed to capture the regulatory and measurement context. Document analysis is a systematic procedure for reviewing and evaluating printed and electronic documents in order to elicit meaning and develop understanding (Bowen, 2009). The documents included assessment reports, sector outlooks, statistical releases, emissions accounting standards and policy communications from organisations such as the IPCC, the International Transport Forum, the International Energy Agency, Eurostat, ISO, the Smart Freight Centre and the European Commission.

3.3. Thematic Synthesis

The selected sources were analysed through thematic synthesis. Following the logic of thematic analysis (Braun & Clarke, 2006), the material was read repeatedly, initial codes were generated, and codes were grouped into broader themes. The coding focused on three questions: (1) which AI-enabled capabilities are discussed in relation to logistics; (2) through which operational mechanisms these capabilities affect resource use and emissions; and (3) how these effects are linked to economic value and competitiveness. Five capability themes emerged as recurring across the literature: route optimisation, demand forecasting, vehicle and load capacity optimisation, energy-efficiency management, and environmental impact measurement. A further theme captured implementation challenges and boundary conditions.

Importantly, the study focuses on recurring mechanisms rather than on any single AI technology or algorithm. This choice reflects the rapid evolution of AI techniques and the aim of developing a framework that remains relevant as specific technologies change. Table 1 summarises the research design.

Table 1. Summary of the research design

Element	Description
Research design	Conceptual, model-building approach (Jaakkola, 2020); framework development following Jabareen (2009)
Sources	Peer-reviewed journal articles, books and book chapters; policy and institutional documents (IPCC, ITF, IEA, Eurostat, ISO, Smart Freight Centre, European Commission)
Literature streams	Artificial intelligence; green logistics; sustainable entrepreneurship; digital transformation; low-carbon business models
Example search terms	"artificial intelligence", "machine learning", "predictive analytics", "big data analytics" combined with "green logistics", "carbon emissions", "vehicle routing", "sustainable entrepreneurship", "sustainable business model"
Analysis	Structured literature review (Snyder, 2019; Tranfield et al., 2003); document analysis (Bowen, 2009); thematic synthesis (Braun & Clarke, 2006)
Coding questions	(1) Which AI-enabled capabilities are discussed? (2) Through which operational mechanisms do they affect resource use and emissions? (3) How are these effects linked to economic value and competitiveness?
Outputs	Five AI-enabled capability themes; implementation challenges; four-stage conceptual framework; five research propositions

Source: Author's own elaboration.

4. AI-Enabled Capabilities for Green Logistics Ventures

This section examines the five AI-enabled capabilities identified in the thematic synthesis. For each capability, the operational mechanism, the potential environmental contribution and the potential economic contribution are discussed. Table 2 summarises the analysis.

4.1. Route Optimisation

Routing decisions determine how far vehicles travel, at what speeds, with what loads and at what times. Traditional routing approaches minimise distance or cost, but research on green vehicle routing has shown that

fuel consumption and emissions depend on a combination of distance, load, speed, road gradient and vehicle type (Bektaş & Laporte, 2011; Demir et al., 2014). The pollution-routing problem, for instance, explicitly incorporates emissions and fuel consumption into routing decisions and shows that minimising distance does not necessarily minimise emissions (Bektaş & Laporte, 2011). Lin et al. (2014) review a broad range of green vehicle routing models and identify the inclusion of real-time information and time-dependent travel conditions as an important direction for research.

AI extends these approaches in two ways. First, machine learning models can predict travel times, congestion patterns and delivery durations more accurately by learning from historical and real-time data. Second, optimisation algorithms can process a large number of constraints simultaneously, including traffic, delivery windows, distance, vehicle characteristics and customer requirements, and can re-optimise routes dynamically as conditions change (Toorajipour et al., 2021). For green ventures, the potential outcomes include fewer vehicle-kilometres, lower fuel or energy use, shorter delivery times, lower emissions and lower operating costs. For ventures using electric vehicles, AI-supported routing can also take battery range and charging infrastructure into account, which may be decisive for the operational feasibility of electric fleets.

Route optimisation therefore illustrates a central argument of this study: sustainability and competitiveness can reinforce each other. A reduction in kilometres travelled simultaneously lowers emissions and costs, and more reliable delivery times improve service quality. However, these benefits depend on data quality and on whether route-level efficiency gains are translated into lower total emissions rather than additional trips.

4.2. Demand Forecasting

Demand forecasting is the basis of logistics planning. Inaccurate forecasts lead to excess inventory, emergency shipments, partial loads and avoidable movements of goods, all of which increase costs and emissions. Machine learning techniques can capture non-linear patterns, seasonality and the influence of external variables, and have been shown to improve forecasting performance in supply chain settings compared to some traditional methods (Carbonneau et al., 2008). Big data analytics further allows firms to integrate data from point-of-sale systems, weather, events and customer behaviour into forecasts (Wang et al., 2016).

For green logistics ventures, better forecasts support better planning, lower inventory movements and reduced uncertainty. They allow transport capacity to be planned in advance, shipments to be consolidated and urgent, low-load deliveries to be avoided. Environmentally, this reduces unnecessary transport and storage. Economically, it reduces inventory holding costs, lowers the need for expensive express transport and supports more stable capacity utilisation. For young firms with limited working capital, these effects may be particularly important.

4.3. Vehicle and Load Capacity Optimisation

Capacity utilisation is one of the most important determinants of logistics emissions per unit of goods moved. As noted earlier, about one-fifth of road freight vehicle-kilometres in the EU were driven empty in 2020 (Eurostat, 2021), and loaded vehicles are frequently not filled to capacity. McKinnon and Ge (2006) show that reducing empty running depends on factors such as backhaul opportunities, information availability, scheduling constraints and the compatibility of loads and vehicles.

AI can address several of these factors. Matching algorithms on digital freight platforms can connect available capacity with shipment demand, thereby reducing empty trips. Load-planning algorithms can optimise the placement of goods within vehicles and containers, considering weight, volume and delivery sequence. Fleet-level optimisation can determine the appropriate number and type of vehicles for each period. The resulting outcomes include higher vehicle utilisation, fewer empty trips and better asset productivity. For green ventures, which typically operate with scarce resources, these capabilities are central: a business model based on electric

vehicles, for instance, is more viable if each vehicle is used intensively. Capacity optimisation may also form the core value proposition of a venture, as in platform-based models that sell improved utilisation to shippers and carriers.

4.4. Energy-Efficiency Management

Energy use in logistics occurs not only in vehicles but also in warehouses, distribution centres, cold chains and handling equipment. AI-supported energy management systems can monitor energy consumption in real time, detect inefficiencies and support optimisation, for example by adjusting lighting, heating, cooling and refrigeration to actual demand, scheduling energy-intensive operations at times when renewable electricity is available, or coordinating the charging of electric vehicle fleets (Rolnick et al., 2022). Predictive maintenance, which uses sensor data and analytics to anticipate equipment failures, can further reduce energy waste and unplanned downtime (Lee et al., 2014).

For green ventures, energy-efficiency management offers environmental benefits in the form of lower energy-related emissions and economic benefits in the form of lower energy costs and longer asset life. In ventures operating electric fleets, intelligent charging management can also reduce peak electricity costs and support the integration of renewable energy. These effects, however, depend on the availability of sensors, metering and data infrastructure, which may require upfront investment.

4.5. Environmental Impact Measurement

The fifth capability concerns the measurement of environmental performance itself. Without reliable measurement, it is difficult to know whether operational changes actually reduce emissions, to communicate environmental performance credibly to customers and investors, or to comply with reporting requirements. Standards such as the GLEC Framework and ISO 14083:2023 provide common methods for quantifying and reporting transport chain emissions (ISO, 2023; Smart Freight Centre, 2023). However, applying these methods requires granular data on shipments, distances, vehicles, loads and energy sources, which are often scattered across systems and partners.

AI can support this process by automating data collection and cleaning, estimating missing values, allocating emissions to individual shipments and customers, and identifying the main drivers of emissions. In doing so, it improves carbon visibility and enables firms to track sustainability performance over time. For green ventures, this capability has particular strategic value. A venture whose value proposition is based on low-carbon logistics must be able to demonstrate its environmental performance in a credible and comparable way. Measurement therefore not only supports internal management but also becomes part of the value proposition. In short, environmental performance cannot be managed effectively without reliable measurement.

Table 2. AI-enabled capabilities and their potential contributions to green logistics ventures

Capability	Operational mechanism	Environmental contribution	Economic contribution	Key data requirements
Route optimisation	Dynamic routing considering traffic, delivery windows, distance, vehicle characteristics and customer requirements	Fewer vehicle-kilometres; lower fuel/energy use and emissions	Lower operating costs; shorter and more reliable delivery times	Order, location, traffic and vehicle data
Demand forecasting	Machine learning-based prediction of demand patterns and volumes	Fewer unnecessary transport and inventory movements	Lower inventory and express transport costs; better planning	Historical sales/orders; external variables (e.g., seasonality, events)
Vehicle and load capacity optimisation	Freight matching, load planning and fleet sizing	Fewer empty trips; lower emissions per unit transported	Higher vehicle utilisation and asset productivity	Shipment dimensions and weights; available capacity; schedules

Capability	Operational mechanism	Environmental contribution	Economic contribution	Key data requirements
Energy-efficiency management	Real-time monitoring, anomaly detection, predictive maintenance and charging coordination	Lower energy-related emissions; better integration of renewable energy	Lower energy costs; longer asset life; less downtime	Sensor and metering data; equipment and charging data
Environmental impact measurement	Automated emissions calculation, allocation and reporting in line with GLEC/ISO 14083	Improved carbon visibility; verification of reductions	Credible differentiation; compliance; stakeholder trust	Shipment-level activity data; energy sources; emission factors

Source: Author's own elaboration based on the reviewed literature (e.g., Bektaş & Laporte, 2011; Carbonneau et al., 2008; ISO, 2023; McKinnon & Ge, 2006; Toorajipour et al., 2021).

4.6. Synthesis: From Operational Tools to Strategic Capability

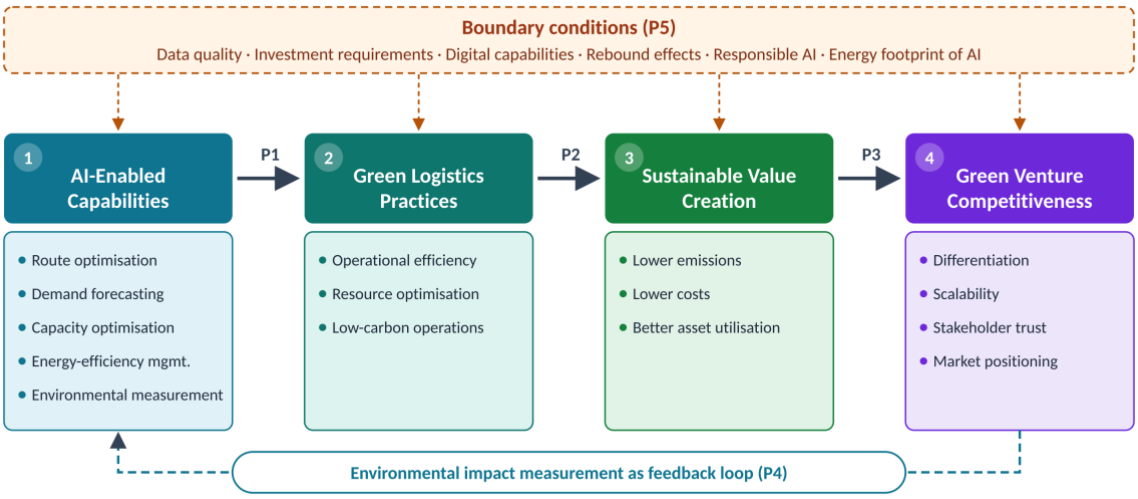
Taken together, the five capabilities show a common pattern. Each capability affects resource use through a specific operational mechanism: fewer kilometres, fewer unnecessary movements, higher utilisation, lower energy waste or better information. Each of these mechanisms has both an environmental dimension, such as lower emissions or lower resource consumption, and an economic dimension, such as lower costs or better asset productivity. This dual effect is what makes AI potentially valuable for green ventures, whose business models depend on creating both types of value at the same time.

The capabilities are also interdependent. Better demand forecasts improve the inputs for route and capacity planning; route and capacity optimisation affect energy consumption; and environmental measurement provides the feedback needed to evaluate and improve all other capabilities. This interdependence suggests that AI is most valuable when it is treated as an integrated capability embedded in the venture's operations and business model, rather than as a collection of isolated tools. This insight forms the basis of the conceptual framework presented in the next section.

5. Proposed Conceptual Framework

Building on the analysis above, this study proposes a four-stage conceptual framework explaining how AI-enabled capabilities contribute to the competitiveness of green logistics ventures (Figure 1). The framework is based on the central argument that AI creates strategic value not by itself, but when it translates into greener logistics practices and measurable sustainable outcomes.

Figure 1. Proposed conceptual framework of AI-enabled green logistics ventures



Note: P1–P5 refer to the research propositions developed in Sections 5.2–5.5. *Source:* Author's own elaboration.

5.1. Stage 1: AI-Enabled Capabilities

The first stage consists of the five AI-enabled capabilities discussed in Section 4: route optimisation, demand forecasting, capacity optimisation, energy-efficiency management and environmental impact measurement. Following Mikalef and Gupta (2021), these capabilities are understood as combinations of data, technology, human skills and organisational routines, rather than as software alone. A venture may develop such capabilities internally, access them through partners and platforms, or combine both.

5.2. Stage 2: Green Logistics Practices

Capabilities do not create value automatically. They must be translated into practices, that is, into changes in how logistics operations are actually carried out. In the framework, green logistics practices include greater operational efficiency, resource optimisation and low-carbon operations. Examples are consolidated shipments, optimised routes that are actually followed by drivers, higher load factors, demand-based energy use and the systematic use of emissions data in operational decisions. This stage reflects the dynamic capabilities argument that value arises from the deployment and reconfiguration of resources (Teece, 2007).

Proposition 1: AI-enabled capabilities are positively associated with the adoption and intensity of green logistics practices in green ventures.

5.3. Stage 3: Sustainable Value Creation

Green logistics practices lead to sustainable value creation. In the framework, this value has an environmental and an economic component: lower emissions, lower costs and better asset utilisation. The key feature of this stage is that environmental and economic value are created together rather than being traded off against each other. This reflects the argument of Porter and van der Linde (1995) that environmental improvement achieved through resource productivity can strengthen economic performance, as well as the sustainable business model logic of creating value for multiple stakeholders (Bocken et al., 2014; Schaltegger et al., 2016).

Proposition 2: Green logistics practices enabled by AI are positively associated with sustainable value creation, reflected simultaneously in lower emissions, lower operating costs and higher asset utilisation.

5.4. Stage 4: Green Venture Competitiveness

Finally, sustainable value creation strengthens green venture competitiveness. Competitiveness is reflected in differentiation, scalability, stakeholder trust and market positioning. Differentiation arises when a venture can offer verifiably lower-carbon services. Scalability arises when AI allows the venture to serve more customers without a proportional increase in assets, staff or emissions. Stakeholder trust arises when environmental claims are supported by transparent measurement. Market positioning improves as customers, investors and regulators increasingly require evidence of environmental performance (European Commission, 2019; ISO, 2023). These mechanisms are consistent with the natural-resource-based view, which links environmental capabilities to competitive advantage (Hart, 1995; Hart & Dowell, 2011).

Proposition 3: Sustainable value creation is positively associated with green venture competitiveness through differentiation, scalability, stakeholder trust and market positioning.

5.5. The Role of Measurement and Boundary Conditions

Two further elements complete the framework. First, environmental impact measurement plays a dual role. It is one of the five capabilities, but it also provides the feedback loop that connects all stages: it verifies whether practices actually reduce emissions, makes sustainable value visible to stakeholders and thereby enables competitive differentiation. Second, the relationships in the framework are subject to boundary conditions, including data quality, investment requirements, digital capabilities, rebound effects, responsible AI use and

the energy footprint of AI infrastructure. These conditions, discussed in Section 6, may weaken or even reverse the expected effects.

Proposition 4: Environmental impact measurement strengthens the relationships between green logistics practices, sustainable value creation and venture competitiveness.

Proposition 5: The positive effects of AI-enabled capabilities on sustainable value creation are weaker when data quality is low, digital capabilities are limited, rebound effects are strong, or the energy footprint of AI infrastructure is high.

5.6. Illustrative Application of the Framework

To illustrate how the framework may be applied, consider a hypothetical start-up offering electric last-mile delivery services to retailers in a large city. The example is not based on empirical data; it is intended only to show how the stages of the framework relate to each other in a concrete setting.

At the capability stage, the venture uses demand forecasts based on its clients' order histories, seasonal patterns and local events to plan the number of vehicles and drivers required each day. A routing system assigns orders to vehicles while considering delivery windows, traffic, vehicle range and charging opportunities. Load planning ensures that each vehicle departs as fully loaded as feasible, and an energy management system schedules overnight charging when electricity is cheaper. An emissions accounting module calculates the emissions of each delivery according to a recognised methodology such as the GLEC Framework.

At the practice stage, these capabilities change daily operations: deliveries are consolidated into fewer and better-filled tours, vehicles avoid congested routes, charging is coordinated with operations, and drivers follow routes that reflect both service and energy considerations. At the value stage, the venture may observe fewer vehicle-kilometres per parcel, lower energy costs, higher utilisation of its relatively expensive electric vans and lower emissions per delivery compared with conventional delivery options. At the competitiveness stage, the venture can offer retailers verified, shipment-level emissions data that they can use in their own reporting, differentiate itself from competitors that cannot provide such data, and expand to new districts without increasing its fleet in proportion to the number of parcels delivered.

The example also shows where the boundary conditions apply. If the venture's forecasts are based on poor-quality data, vehicles may be underused. If lower delivery prices lead retailers to offer more frequent, smaller deliveries, total vehicle-kilometres may rise despite higher efficiency per tour. And if emissions data are estimated with low accuracy, the venture's differentiation may be challenged by customers or regulators. In each case, measurement determines whether the expected pathway is actually realised.

5.7. Summary of the Framework

In summary, the framework suggests that the strategic value of AI for green logistics ventures lies not in the technology itself but in what it changes in practice. Each arrow in the framework represents a relationship that can be tested in future empirical research.

6. Implementation Challenges and Boundary Conditions

The framework above describes a potential pathway. Whether this pathway is realised depends on several conditions. These conditions are particularly relevant for young and small ventures, which often face resource constraints and liabilities of newness that larger incumbents can more easily absorb. This section discusses six challenges identified in the review and summarised in Table 3. They emphasise a central message of this study: AI is not automatically green, and technology adoption alone does not guarantee sustainability.

Data quality. AI systems depend on the quality, completeness and timeliness of data. In logistics, relevant data are often fragmented across shippers, carriers, subcontractors and systems, and may be incomplete or inconsistent. Poor data can produce inaccurate forecasts, unrealistic routes and misleading emissions estimates. For emissions measurement in particular, inaccurate data may lead to under- or over-reporting, undermining credibility. Small ventures may lack the volume of historical data needed to train reliable models, although they may benefit from platform-based or shared data solutions.

Investment requirements. Developing AI capabilities requires investment in software, sensors, data infrastructure and skilled personnel. For green ventures with limited capital, these costs may be significant, and the returns may materialise only over time. Cloud-based services and software-as-a-service models can reduce entry barriers, but they also create dependencies on external providers. The economic case for AI therefore depends on the scale of operations and the business model of the venture.

Digital capabilities. As the capability perspective suggests, AI creates value only when it is embedded in organisational routines and supported by human skills (Mikalef & Gupta, 2021). Ventures need employees who can interpret AI outputs, integrate them into decisions and identify errors. Drivers, warehouse staff and planners must also accept and follow AI-supported recommendations. Without these capabilities, AI tools may remain unused or be used ineffectively.

Rebound effects. Efficiency improvements may lead to increases in total activity that offset part or all of the expected environmental gains, a phenomenon known as the rebound effect (Greening et al., 2000). In logistics, lower costs per delivery may encourage more frequent deliveries, smaller shipment sizes or faster delivery promises, which may increase total vehicle-kilometres. Kaack et al. (2022) and the IEA (2025) explicitly warn that such system-level effects can undercut the climate benefits of AI applications. Consequently, sustainability should be assessed at the level of total emissions rather than efficiency per unit alone.

Responsible AI. AI systems raise questions of transparency, accountability, fairness and privacy (Floridi et al., 2018; Jobin et al., 2019). In logistics, these questions may concern the monitoring of drivers, the allocation of work, the use of customer data and the explainability of automated decisions. Ventures that position themselves as sustainable may face particular expectations to use AI responsibly, as social sustainability is also part of their value proposition.

Energy footprint of AI infrastructure. Finally, AI itself consumes energy. Training and running models require computing resources, and the electricity consumption of data centres is expected to grow substantially (IEA, 2025; Strubell et al., 2019). For many logistics applications, the computational footprint may be smaller than the potential operational savings; however, the net environmental effect should be assessed empirically and on a case-by-case basis. Ventures can reduce it by selecting efficient models, using cloud providers powered by renewable electricity and avoiding unnecessary computation.

Table 3. Implementation challenges and boundary conditions

Challenge	Description	Possible mitigation for green ventures
Data quality	Fragmented, incomplete or inconsistent logistics data reduce model accuracy and the credibility of emissions estimates	Data governance routines; shared data platforms; standardised data formats
Investment requirements	Costs of software, sensors, data infrastructure and skilled staff; delayed returns	Cloud and software-as-a-service solutions; phased implementation; partnerships
Digital capabilities	Lack of skills to interpret, integrate and act on AI outputs; low user acceptance	Training; involvement of drivers and planners; human oversight of decisions
Rebound effects	Efficiency gains may increase total activity and offset environmental benefits (Greening et al., 2000)	Monitoring total emissions, not only efficiency per unit; sustainable service design
Responsible AI	Concerns regarding transparency, accountability, fairness and privacy (Floridi et al., 2018; Jobin et al., 2019)	Explainable models; clear data policies; fair treatment of workers

Challenge	Description	Possible mitigation for green ventures
Energy footprint of AI	Electricity use of computing and data centres (IEA, 2025; Strubell et al., 2019)	Efficient models; renewable-powered cloud services; avoiding unnecessary computation

Source: Author's own elaboration.

These challenges suggest that the sustainability contribution of AI must be demonstrated through measured outcomes. In this respect, the environmental measurement capability discussed in Section 4.5 is not only a source of value but also a safeguard against unfounded sustainability claims.

7. Discussion and Implications

7.1. Theoretical Implications

The study contributes to the literature in three ways. First, it integrates three research streams that have largely developed separately: AI in logistics, green logistics and sustainable entrepreneurship. By linking AI-enabled capabilities to green logistics practices, sustainable value creation and venture competitiveness, the framework offers an explanation of the mechanisms through which technology may contribute to sustainable entrepreneurial outcomes. This responds to the observation of Hall et al. (2010) that the mechanisms linking entrepreneurship and sustainable development remain insufficiently understood.

Second, the study extends the capability-based view of AI (Mikalef & Gupta, 2021) to the context of green ventures. It suggests that the value of AI in this context depends on its translation into practices and on the simultaneous creation of environmental and economic value. In doing so, it connects the AI capability literature with the natural-resource-based view (Hart, 1995) and with sustainable business model research (Bocken et al., 2014).

Third, the study highlights measurement as a central and somewhat neglected element of the AI-sustainability relationship. Environmental impact measurement is conceptualised both as a capability and as a feedback mechanism that verifies and communicates sustainable value. This perspective links emerging emissions accounting standards (ISO, 2023; Smart Freight Centre, 2023) to entrepreneurship and strategy research.

7.2. Managerial Implications

For entrepreneurs and managers of green logistics ventures, the framework offers several practical insights. First, AI investment should be directed towards areas where environmental and economic value coincide, such as reducing empty running, consolidating shipments and improving route efficiency. Second, AI should be implemented as part of operational routines and business models, not as an isolated technology project; this requires attention to data, skills and employee acceptance. Third, ventures should invest early in reliable emissions measurement, because credible evidence of environmental performance is likely to become an increasingly important source of differentiation and stakeholder trust. Fourth, managers should monitor total emissions and not only efficiency per unit, in order to detect rebound effects.

7.3. Policy Implications

For policymakers and support organisations, the study suggests that support for green ventures should address not only access to technology but also the conditions that allow technology to create value. These include access to shared data infrastructures, support for digital skills, affordable access to AI tools for small firms, and harmonised emissions measurement standards. Policies that promote transparent and comparable emissions reporting can strengthen the link between environmental performance and competitiveness, thereby rewarding ventures that achieve genuine reductions. In this respect, the adoption of common standards such as ISO 14083:2023 in public procurement and sustainability reporting could reduce the cost of measurement

for small firms and make their environmental performance visible to customers. At the same time, policymakers should consider the system-level effects of AI-enabled efficiency, such as rebound effects in urban delivery, and assess transport policies in terms of total emissions rather than efficiency indicators alone. Finally, entrepreneurship support programmes, incubators and universities can play a role by combining training in data and AI skills with training in sustainability measurement, so that new ventures develop both types of capability from the outset.

8. Conclusion, Limitations and Future Research

This study examined how AI-enabled capabilities can support green logistics ventures in reducing carbon emissions while strengthening the economic viability and scalability of sustainable business models. Based on a structured literature review and document analysis, it identified five AI-enabled capabilities, namely route optimisation, demand forecasting, capacity optimisation, energy-efficiency management and environmental impact measurement, and analysed their potential environmental and economic contributions. It then proposed a four-stage conceptual framework linking AI-enabled capabilities, green logistics practices, sustainable value creation and green venture competitiveness, and formulated five propositions for future research.

The central conclusion is that AI becomes strategically meaningful for green ventures when it improves logistics practices, creates measurable environmental and economic value, and strengthens venture competitiveness. In other words, AI should be understood as a capability, sustainability as measurable value, and competitiveness as the outcome. At the same time, AI is not automatically green: its benefits depend on data quality, investment, digital capabilities and responsible use, and may be offset by rebound effects and the energy footprint of AI infrastructure.

The study has several limitations. First, as a conceptual study, it does not provide empirical evidence for the proposed relationships. Second, the review focused primarily on English-language academic literature and on selected international policy documents; regional differences in regulation, infrastructure and market conditions may affect the applicability of the framework. Third, the study concentrated on road freight and related warehousing activities, and other modes such as maritime, rail and air transport may involve different mechanisms. Fourth, AI technologies are evolving rapidly, and new applications, such as generative AI in logistics planning, may introduce capabilities not covered in this framework.

These limitations open several avenues for future research. Most importantly, the proposed relationships should be tested empirically using data from logistics start-ups and sustainability-oriented firms. Survey-based studies could measure AI capabilities, green logistics practices, sustainable value and competitiveness and test the propositions through structural equation modelling. Case studies could explore how ventures translate AI capabilities into practices and how they deal with the challenges identified in this study. Longitudinal studies could examine whether efficiency gains lead to lasting emission reductions or are offset by rebound effects. Comparative studies across countries, including emerging economies such as Türkiye, could investigate how institutional conditions shape the relationship between AI and sustainable entrepreneurship. Such research would help to clarify when and how AI can enable more resilient and low-carbon ventures for future generations.

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FULL PAPER · IP1.5 · IN-PERSON SESSION I

Measuring Provincial Sustainability in Türkiye: A Composite Index and Cluster Analysis of 81 Provinces

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ABSTRACT

The transition toward a greener and more sustainable economy requires assessing sustainability challenges not only at the national level but also across local contexts. In Türkiye, substantial disparities exist among provinces in terms of economic conditions, social outcomes, and environmental service provision. This study assesses the relative sustainability performance of Türkiye's 81 provinces using 2024 economic, social, and environmental indicators, classifies provinces according to their multidimensional profiles, and examines the sensitivity of the results to alternative measurement choices.

The study adopts a multidimensional approach that incorporates economic, social, and environmental sustainability indicators. Seventeen indicators were selected based on conceptual relevance, the availability of reliable and comparable provincial-level data, and previous sustainability assessment studies. The analysis used verified 2024 official statistics covering all 81 provinces.

The indicators were normalized using direction-adjusted Min-Max scaling and aggregated into equally weighted economic, social, and environmental dimension scores and an overall composite index. To enhance transparency and reproducibility, the entire calculation process was documented in Excel, covering raw data, normalization, weighting, dimension scores, and the final index. In the second stage, hierarchical clustering and K-means clustering were used to classify provinces according to their economic, social, and environmental dimension scores. Candidate solutions with two to eight clusters were compared using the Silhouette, Calinski-Harabasz, and Davies-Bouldin criteria.

The two-cluster solution provided the strongest overall cluster validity, separating 24 and 57 provinces, respectively. The clusters differed in the same direction across all three dimensions, indicating a general performance-level distinction rather than sharply contrasting sustainability profiles. Alternative index specifications remained highly correlated with the baseline ranking (Spearman's ρ = 0.983-0.998), whereas cluster memberships showed greater sensitivity to weighting, indicator selection, and clustering specifications.

The study contributes by integrating provincial ranking, multidimensional clustering, and sensitivity analysis within a single reproducible assessment framework. The findings show that overall rankings are relatively robust to alternative measurement specifications, whereas cluster memberships are more sensitive to methodological and indicator choices. Accordingly, provincial sustainability assessments should be interpreted by considering composite scores, dimension-specific performance, and methodological sensitivity together. The results should also be read in light of the study's cross-sectional design and limited environmental indicator coverage.

Keywords: Provincial sustainability; Composite index; Türkiye; Cluster analysis; Robustness analysis

1. Introduction

This study was conducted to measure the relative sustainability performance of Türkiye's 81 provinces in 2024 using economic, social, and environmental indicators, to classify provinces according to their dimension profiles, and to assess the sensitivity of the results to alternative measurement choices. The research focuses on three questions: How do provinces differ in their overall index and dimension scores? What groups of provinces emerge when economic, social, and environmental characteristics are considered jointly? To what

extent are provincial rankings and cluster memberships preserved under alternative weighting, normalization, and indicator-selection choices? These questions are examined through an integrated measurement framework that evaluates provincial sustainability in terms of both relative position and multidimensional similarity.

Assessing sustainability at the local level requires the joint consideration of economic opportunities, social conditions, and environmental services. A province's production and employment capacity may not be at the same level as its education and health conditions or its access to water and wastewater services. Therefore, assessments based on a single economic indicator or an overall ranking may not adequately reveal the areas in need of intervention. Using comparable indicators at the provincial level can make these differences visible and provide a more concrete evidence base for discussing local policy priorities.

Studies measuring sustainability at the provincial level in Türkiye have established an important basis for comparison by employing different indicator sets and methods. Saraç and Alptekin (2017) examined the 2009-2013 period using 51 indicators across economic, social, and environmental dimensions and ranked provinces using entropy weighting and grey relational analysis. Özmen and Yirmibeşoğlu (2023) evaluated the sustainability performance of 81 provinces using a fuzzy logic model based on 27 indicators and grouped provinces by performance. These studies demonstrate that the same multidimensional concept can be addressed through different measurement frameworks.

The starting point of the present study is not merely to produce another provincial ranking, but to examine the overall ranking, dimension profiles, and the sensitivity of these results to methodological choices within the same assessment framework. Two provinces with similar overall index scores may differ in economic, social, and environmental characteristics. Likewise, provinces at different positions in the ranking may share similar characteristics in some dimensions. For this reason, the relative position represented by the total score and the similarity structure revealed by dimension scores are treated as separate research questions. In addition, alternative weighting, normalization, aggregation, and indicator-coverage scenarios are used to assess the extent to which provincial rankings and cluster memberships depend on methodological choices.

The conceptual basis of the study is that sustainability requires the joint assessment of economic, social, and environmental dimensions. Within this framework, economic superiority is not assumed in advance to imply superiority in the other dimensions. Cluster analysis makes it possible to examine whether general level differences in which dimensions rise together or differentiated profiles across dimensions emerge. The conceptual and methodological contribution of the study lies in evaluating the multidimensional structure of sustainability in provincial comparisons through the distinction among the overall index, dimension profiles, and methodological sensitivity. The study provides a descriptive and comparative measurement framework and does not make causal inferences about the direction of relationships or the mechanisms connecting the dimensions.

The methodological choices are linked to these research questions. The composite index summarizes provinces' relative positions by combining indicators measured in different units on a common scale. However, interpretation of the index requires transparency regarding indicator selection and aggregation choices. The Handbook on Constructing Composite Indicators prepared by the OECD, the European Union, and the European Commission Joint Research Centre provides a basis for evaluating measurement frameworks and techniques in such comparisons (OECD/European Union/EC-JRC, 2008). In the present study, direction-adjusted Min-Max normalization, equal weighting of the three dimensions, and equal weighting of indicators within each dimension were selected to make the calculations transparent and traceable. Equal weighting does not imply that all indicators are empirically equally influential; rather, it provides a baseline model against which alternative specifications can be compared.

Cluster analysis was used to examine multidimensional similarities that the overall index alone cannot show. Alternative cluster solutions based on economic, social, and environmental dimension scores were compared, and the sensitivity of the results to methodological choices was assessed through alternative weighting, transformation, and indicator-coverage scenarios. Technical implementation and selection criteria are described in the Method section.

The applied contribution of the study is a reproducible assessment framework in which the overall ranking, dimension scores, cluster memberships, and robustness results can be jointly traced using verified official data from the same reference year. Provincial and dimension scores may support comparative assessments by local governments and regional planning bodies, while cluster profiles may contribute to discussions of shared needs and the exchange of experience among provinces with similar characteristics. However, because the environmental dimension is limited to service infrastructure and forest cover, the results should not be interpreted as a comprehensive carbon-footprint or circular-economy assessment. Within the available data scope, the framework identifies relative differences among provinces and provides a measurement basis that can be expanded with broader environmental indicator sets and multi-year data.

2. Literature Review

2.1. Measuring Local Sustainability

Local sustainability research relies on indicator frameworks that jointly assess economic opportunities, social conditions, and environmental characteristics. A central issue in this approach is which dimensions should represent sustainability and how these dimensions should be transformed into comparable measures. Michalina et al. (2021) reviewed 50 urban sustainability indicator frameworks and examined the themes used under economic, social, environmental, and institutional dimensions. The authors noted that differences in scope and indicator choices across existing frameworks can generate inconsistencies in sustainability measurement. Thus, different results from indices addressing the same concept may also stem from differences in measurement frameworks.

Indicator selection requires a joint consideration of conceptual relevance and data availability. Michalina et al. (2021) emphasize that cities differ in data sources, population size, and development context and that indicator selection should follow a transparent and justified process. This observation is also important for provincial applications in Türkiye. The fact that an indicator is relevant to sustainability does not mean that comparable data based on the same definition and period are available for all provinces. In the present study, the indicator set was therefore restricted to verified 2024 data in order to meet the requirement of comparability.

2.2. Provincial-Level Sustainability Research in Türkiye

Provincial sustainability comparisons in Türkiye have been addressed using different weighting and multi-criteria assessment methods. Gazibey, Keser, and Gökmen (2014) evaluated Türkiye's 81 provinces within economic, social, and environmental sustainability dimensions using the TOPSIS method. The study employed 52 indicators derived from relevant sustainability indices and ranked the provinces through a multi-criteria decision-making approach. Kocaeli, İstanbul, and Ankara occupied the first three positions in the resulting urban sustainability index. The study is an early and comprehensive example of provincial sustainability research in Türkiye because it integrates economic, social, and environmental indicators into a single provincial assessment framework and provides a comparative ranking for all 81 provinces through TOPSIS. Saraç and Alptekin (2017) used 51 indicators across economic, social, and environmental dimensions to calculate provincial rankings for 2009-2013. Indicator weights were determined using the entropy method, and rankings were obtained through grey relational analysis. İstanbul ranked first and Ankara second in all years, while Kocaeli, Antalya, and İzmir

were among the higher-ranking provinces. The study is important for conducting provincial comparisons over multiple years and determining indicator weights according to the information content of the data.

Kara (2019) evaluated 81 provinces using 15 criteria across economic, social, and environmental dimensions. The study applied a rating-based Analytic Hierarchy Process, with weights based on expert assessments. Eskişehir ranked first, followed by Çanakkale, Bursa, and İzmir. The source years of the indicators extended from 2007 to 2010; therefore, the publication year of the article should be distinguished from the period represented by the data. The study illustrates how expert preferences and indicator coverage can affect provincial sustainability rankings. Another example of provincial-level composite performance measurement is provided by Yiğiteli and Şanlı (2020). Although the study did not construct a sustainability index directly, it developed four provincial human development indices for 2009-2018 based on the UNDP methodology. The findings showed progress in human development over the period, while disparities in education, income, and gender remained important across provinces. Ankara, İstanbul, and Kocaeli ranked high in the Human Development Index, whereas Van, Şanlıurfa, and Ağrı ranked low. Although conceptually distinct from sustainability indices, the study provides a complementary example by showing how a multidimensional index developed at the national level can be adapted to the provincial level and applied in a longitudinal setting.

Özmen and Yirmibeşoğlu (2023) combined 27 indicators under economic, social, and ecological components using a fuzzy logic model based on 2022 data. The study evaluated all 81 provinces and presented the results in five groups based on 20-percentile intervals. Erzurum, Karaman, Kahramanmaraş, Osmaniye, Sivas, and İstanbul were reported among the provinces with high sustainability performance. This grouping was based on the distribution of scores and does not have the same meaning as a clustering solution based on multidimensional distances. The study introduced a rule-based measurement approach to provincial sustainability assessment.

Addressing the applied dimension of local sustainability, Boz and Cay (2024) examined national policy documents and smart-city practices in selected Turkish cities. The study reported that some cities with smaller populations than İstanbul and Ankara showed greater enthusiasm and more successful implementation in smart-city services. This finding suggests that local service capacity cannot be evaluated solely on the basis of population size. Nevertheless, the findings of this document- and practice-based research should not be interpreted as a sustainability index ranking covering all provinces.

The main characteristics of the selected Turkish studies are compared in Table 1.

Table 1. Selected Studies on Local Sustainability in Türkiye

Study	Scope	Approach	Relevance to the present study
Gazibey, Keser, and Gökmen (2014)	81 provinces; 52 indicators	TOPSIS	Comprehensive provincial ranking across economic, social, and environmental dimensions and multi-criteria assessment
Saraç and Alptekin (2017)	81 provinces; 2009-2013; 51 indicators	Entropy and grey relational analysis	Multi-year provincial ranking and data-driven weighting
Kara (2019)	81 provinces; 15 criteria	AHP rating approach and expert weights	Effect of indicator and expert preferences on rankings
Yiğiteli and Şanlı (2020)	81 provinces; 2009-2018	UNDP-based provincial human development indices	Adaptation of a multidimensional national index to the provincial and temporal context
Özmen and Yirmibeşoğlu (2023)	81 provinces; 2022; 27 indicators	Fuzzy logic and percentile grouping	Alternative aggregation approach and performance groups
Boz and Cay (2024)	Selected cities and national policy documents	Document and local-practice review	Assessment of local services and smart-city policies

Note. The table is based on the original publications cited above. In each study, the publication year is not necessarily the same as the data year.

Taken together, the Turkish literature shows that multidimensional provincial performance has been measured using different conceptual frameworks and methods. Gazibey, Keser, and Gökmen (2014), Saraç and Alptekin (2017), Kara (2019), and Özmen and Yirmibeşoğlu (2023) directly assessed sustainability performance through economic, social, and environmental indicators using different multi-criteria or aggregation methods. Yiğiteli and Şanlı (2020), by contrast, applied human development indicators at the provincial level and in a multi-year framework within a narrower but related conceptual scope. Indicator coverage, weighting, and aggregation methods vary substantially across this literature, and provincial positions consequently differ among studies. While a large share of previous research focuses on final index scores or rankings, joint assessment of multidimensional provincial similarities and the sensitivity of both ranking and classification results to alternative measurement choices remains more limited. Previous studies therefore provide a strong comparative basis for the present research but should not be treated as successive measurements on a common scale because of differences in data periods and methods.

2.3. Composite Indices and the Effects of Methodological Choices

Composite indices facilitate comparisons by summarizing a large number of indicators. However, the resulting summary score depends on normalization, weighting, and aggregation choices. OECD/European Union/EC-JRC (2008) recommends that the conceptual framework, indicators, and methodological choices be evaluated jointly when constructing composite indices. The handbook treats the examination of alternative models and robustness analyses as part of result interpretation. This approach helps prevent a single ranking from being presented as a definitive and method-independent result.

Equal weights and data-driven weights rely on different rationales. Diakoulaki et al. (1995) developed the CRITIC method as a weighting approach that considers both the degree of differentiation across criteria and the conflict among them. The method combines indicator standard deviations with their correlation structure. This feature makes CRITIC suitable as an alternative for assessing the sensitivity of equal-weighted results. Nevertheless, statistical information content alone does not determine the theoretical or policy importance of an indicator for sustainability.

Aggregation choice also affects the meaning of the index. Arithmetic aggregation allows a low score in one dimension to be compensated by a high score in another. Geometric aggregation reduces, but does not completely eliminate, this possibility of compensation for low-scoring dimensions. Thus, assigning equal weights to dimensions and allowing compensation among dimensions are separate choices (OECD/European Union/EC-JRC, 2008). In the present study, reporting dimension scores and a geometric alternative alongside the arithmetic index is intended to examine differences that may be obscured by the overall score.

2.4. Joint Assessment of Ranking and Profile Classification

Ranking indicates the relative position of provinces in terms of the total score, whereas clustering investigates similarities across multiple characteristics. OECD/European Union/EC-JRC (2008) describes clustering as a descriptive tool that can be used in composite-indicator studies to group similar units and present results while preserving dimension-level information. This distinction makes it possible to investigate whether provinces with similar overall index positions have different dimension profiles.

The main methodological need emerging from the literature is to evaluate provincial rankings together with dimension profiles and the sensitivity of results to measurement choices rather than reporting the overall ranking alone. The present study addresses this need by combining an index calculated from verified official 2024 data, clustering based on three dimension scores, and alternative measurement scenarios. The originality of the research does not rest on claiming the first provincial sustainability index in Türkiye, but on

complementing previous index and ranking studies through a traceable application that jointly examines provincial ranking, multidimensional similarity, and sensitivity to alternative measurement choices within the same analytical framework.

3. Method

3.1. Research Design and Data Sources

This research is a cross-sectional and comparative application evaluating the relative sustainability performance of Türkiye's 81 provinces in 2024. A composite index was constructed from economic, social, and environmental indicators, and provinces were clustered according to similarities in their scores on these three dimensions. The index was used to determine provinces' relative positions, whereas clustering was used to identify groups of provinces with similar characteristics.

Indicator selection was based on conceptual relevance to sustainability, verifiability from official sources, availability for all 81 provinces, and consistency with the same reference year. These choices follow the OECD/European Union/EC-JRC (2008) guidance that the conceptual framework, data, and methodological choices should be justified jointly in composite-indicator construction.

Data were compiled from official publications of the Turkish Statistical Institute (TURKSTAT), the Ministry of Health, the Information and Communication Technologies Authority (ICTA), the Ministry of Trade, the Turkish Patent and Trademark Office (TÜRKPATENT), and the General Directorate of Forestry (GDF). The reference year and publication date of each data item were recorded separately. Source addresses, table and page information, publication versions, and revision markers were retained in the data file.

The final dataset consists of 17 indicators: six economic, six social, and five environmental indicators. All observations refer to 2024, and no missing-value imputation was performed. Life expectancy, PM10, and the share of renewable electricity generation were excluded from the main analysis because verified and comparable data for the same reference year could not be obtained for all 81 provinces.

3.2. Indicators and Data Preparation

The indicators used in the analysis are presented in Table 2. For positive-direction indicators, higher values correspond to higher index scores; for negative-direction indicators, lower values correspond to higher index scores.

Table 2. Indicators Used in the Index

Dimension	Code	Indicator	Unit	Direction	Source
Economic	E1	GDP per capita	Nominal TRY/person	+	TURKSTAT, 2024b
Economic	E2	Employment rate	%	+	TURKSTAT, 2024c
Economic	E3	Unemployment rate	%	–	TURKSTAT, 2024c
Economic	E4	Exports per capita by province of activity	USD/person	+	Ministry of Trade, 2024
Economic	E5	Domestic patent application intensity	Applications/100,000 people	+	TÜRKPATENT, 2024
Economic	E6	Fixed broadband subscription intensity	Subscriptions/100 people	+	ICTA, 2025
Social	S2	Average completed years of schooling, population aged 25+	Years	+	TURKSTAT, 2024f
Social	S3	Expected years of schooling, ISCED 1-8	Years	+	TURKSTAT, 2024d
Social	S4	Infant mortality rate	‰	–	TURKSTAT, 2025
Social	S5	Physician density	Physicians/100,000 people	+	Ministry of Health, 2025
Social	S6	Hospital bed density	Beds/10,000 people	+	Ministry of Health, 2025

Dimension	Code	Indicator	Unit	Direction	Source
Social	S7	Absolute gap between male and female average completed years of schooling	Years	–	TURKSTAT, 2024f
Environmental	C1	Share of municipal population served by wastewater treatment	%	+	TURKSTAT, 2024e
Environmental	C2	Share of municipal population served by sewerage services	%	+	TURKSTAT, 2024e
Environmental	C3	Share of municipal population served by drinking-water treatment	%	+	TURKSTAT, 2024e
Environmental	C4	Share of collected municipal waste sent to treatment facilities	%	+	TURKSTAT, 2024a
Environmental	C5	Forest area as a share of provincial area	%	+	GDF, 2024

Note. All indicators refer to 2024. Indicator codes are retained for consistency with the data file.

For population-normalized indicators, the 2024 Address-Based Population Registration System population was used. Export, domestic patent application, and fixed broadband subscription indicators were calculated by dividing the relevant totals by provincial population. Exports were assigned according to the province of activity; patent applications were not treated as grants, and broadband subscriptions were not treated as individual internet-use rates.

Physician density was calculated using the total number of specialist, general practitioner, and resident physicians. The gender gap in education was calculated as the absolute difference between male and female average completed years of schooling. Average completed years of schooling and expected years of schooling were retained separately because they represent different educational characteristics. Revision information for the 2024 infant mortality values was recorded.

The denominators of the water and wastewater indicators are municipal populations. The waste indicator represents the ratio of tonnage sent to treatment facilities to total collected waste. Because it includes different treatment methods, including sanitary landfilling, it is not labelled as a recycling rate. The forest-area share was calculated from total forest area and provincial area reported in the same GDF table.

During data preparation, provincial names and codes were matched, and consistency of units, years, denominators, and coverage was checked. Pearson and Spearman correlations and the variance inflation factor were used to examine the possibility that indicators contained overlapping information. Pairs with an absolute correlation of at least 0.80 were reviewed separately, but this threshold was not applied as an automatic exclusion rule. Potential outliers were flagged using the 1.5 interquartile-range rule; no observations were removed and no outlier transformation was applied in the main analysis.

3.3. Construction of the Index

Indicators were transformed to the 0-1 range using Min-Max normalization while accounting for their contribution directions. Normalization bounds were calculated from all 81 provinces, and negative-direction indicators were reversed so that higher values represented higher relative performance for every indicator. Normalization and aggregation choices followed OECD/European Union/EC-JRC (2008).

In the baseline model, the economic, social, and environmental dimensions each received a weight of one third. Indicators within each dimension were combined using equal weights, and dimension scores were expressed on a 0-100 scale. The overall index was calculated as the arithmetic mean of the three dimension scores. Under this structure, each economic and social indicator accounts for approximately 5.56% of the total index, while each environmental indicator accounts for approximately 6.67%. The total contributions of the three dimensions are equal.

Arithmetic aggregation was chosen to make indicator contributions transparent, calculations reproducible, and the baseline model easy to interpret. Because this choice permits compensation across dimensions, the overall index was evaluated together with dimension scores. Provinces were ranked using unrounded index values, and tied scores received the same rank. Scores were interpreted as relative positions among the provinces examined, not as percentages of sustainability targets achieved.

3.4. Cluster Analysis

The main clustering analysis was conducted on the economic, social, and environmental dimension scores. To balance the effect of different distributions on distance calculations, the dimensions were transformed to z-scores using the sample standard deviation.

Hierarchical analysis used Euclidean distance and Ward's method. Ward's method selects mergers that minimize the increase in within-cluster variability (Ward, 1963). K-means solutions were then evaluated for cluster counts from two to eight. For each cluster count, 100 repetitions were conducted using k-means++ initialization, and an additional single-run solution initialized with the centroids from the Ward solution was calculated. The solution with the lower within-cluster sum of squares was retained. Calculations used the Lloyd algorithm and a random seed of 2024.

The number of clusters was determined using the Silhouette, Calinski-Harabasz, and Davies-Bouldin criteria. Higher Calinski-Harabasz values and lower Davies-Bouldin values were preferred (Caliński & Harabasz, 1974; Davies & Bouldin, 1979). Higher Silhouette values indicate stronger within-cluster cohesion and between-cluster separation (Rousseeuw, 1987). The metrics were calculated according to their original definitions.

Candidate solutions were ranked in the preferred direction for each of the three criteria, and the solution with the lowest mean rank was selected. Tied metric values received average ranks. A study-specific adequacy rule required the smallest cluster to contain at least five provinces. In the event of a tie in mean ranks, the solution with the higher Silhouette value and then the smaller number of clusters was preferred.

Cluster codes were assigned by ordering cluster centroids from low to high on the economic dimension. Cluster profiles were described using dimension means and provincial memberships.

3.5. Robustness and Stability Checks

The sensitivity of the results to measurement choices was examined using six alternative scenarios.

Table 3. Robustness Scenarios

Scenario	Implementation
CRITIC weights	Recalculation of within-dimension indicator weights according to variability and correlation structure
Geometric aggregation	Calculation of the overall index as the geometric mean of the three dimension scores
Logarithmic transformation	Log transformation of export and patent indicators followed by renewed normalization
Rank normalization	Transformation of indicator values to a 0-1 scale based on provincial ranks
Exclusion of fixed broadband	Recalculation of the economic dimension after excluding E6
Exclusion of forest-area share	Recalculation of the environmental dimension after excluding C6

CRITIC weights were calculated separately within each dimension using the standard-deviation and inter-indicator-correlation method proposed by Diakoulaki et al. (1995). The total weights of the three dimensions were kept at one third each. In the logarithmic scenario, one was added to export and patent values before taking natural logarithms. In rank normalization, tied observations received average ranks. In indicator-exclusion scenarios, the weights of the remaining indicators within the relevant dimension were re-equalized.

Alternative rankings were compared with the baseline ranking using Spearman correlation, mean and maximum absolute rank differences, and overlap among the top ten provinces. In scenarios that changed dimension scores, K-means was rerun while keeping the selected number of clusters fixed. Membership agreement was evaluated using the adjusted Rand index (ARI) (Hubert & Arabie, 1985). Because geometric aggregation does not change dimension scores, identical memberships under this scenario were not treated as an independent stability finding.

Initialization sensitivity was examined using 30 different random seeds and 10 K-means repetitions for each seed. Ward and K-means memberships were also compared using ARI. In addition, an alternative clustering was conducted using standardized values of all 17 indicators; to balance the total variance contribution of the dimensions, each indicator was divided by the square root of the number of indicators in its dimension.

3.6. Evaluation of Results and Reproducibility

Clusters were compared using the number of provinces and the mean dimension and overall-index scores. Differences in the distribution of overall index scores across clusters were examined descriptively using the Kruskal-Wallis test. However, because the clusters were derived from the same dimension scores that constitute the index, this result was not interpreted as independent evidence of external validity or validation.

Analyses were conducted using Python 3.12.14, NumPy 2.3.5, SciPy 1.17.0, and scikit-learn 1.8.0. Raw data, indicator calculations, normalization, weights, index values, and alternative-scenario results were provided in the Excel file, and clustering code was retained separately. If the data change, the Python analysis must be rerun to recalculate cluster memberships.

The cross-sectional design does not allow assessment of temporal change or causal relationships. The environmental dimension is limited to service infrastructure and forest cover. Confidence intervals for labour-force estimates were retained in the source file, but sampling uncertainty was not propagated separately into index scores.

4. Results

4.1. Data Coverage and Distribution of Scores

Based on the provincial sustainability index calculated from 2024 data for all 81 provinces, İstanbul, Kocaeli, and Ankara occupied the top three positions. Cluster analysis based on the economic, social, and environmental dimension scores selected a two-cluster solution containing 24 and 57 provinces. Because cluster means differed in the same direction across all three dimensions, the primary separation reflected a general performance-level distinction rather than contrasting dimension profiles.

The analysis included six economic, six social, and five environmental indicators, for a total of 17 indicators. All indicators refer to 2024, and no missing-value imputation was performed. Life expectancy, PM10, and the share of renewable electricity generation were not included in the main index because they did not meet the requirement of verified provincial coverage for the same year. Equal weights were assigned to the three dimensions and to indicators within each dimension. The scores below are relative values on a 0-100 scale based on direction-adjusted Min-Max transformations.

Table 4. Descriptive Statistics of Dimension and Index Scores

Variable	Mean	Median	SD	Minimum	Maximum
Economic	39.46	41.41	14.57	4.87	85.22
Social	48.80	50.95	15.11	6.66	87.19
Environmental	62.12	63.01	15.12	29.28	93.59
Overall index	50.13	51.78	13.15	17.70	79.32

Note. n = 81. SD denotes the sample standard deviation. Source: Authors' calculations based on official 2024 provincial data.

The mean overall index score was 50.13, the median was 51.78, and the standard deviation was 13.15. The difference between the highest and lowest provincial scores was 61.63 points. Mean scores for the economic, social, and environmental dimensions were 39.46, 48.80, and 62.12, respectively. Because the dimensions were normalized separately using different indicator sets, the higher mean environmental score does not imply that environmental sustainability targets were achieved to a greater extent than economic or social targets.

In the data-quality review, the 1.5 interquartile-range rule flagged 51 indicator values across 34 provinces. These values were not treated as errors and were retained in the main analysis. The highest within-dimension variance inflation factor was 4.56. The strong negative relationship between fixed broadband and the gender gap in education (Pearson r = −0.838) was not used as an automatic exclusion criterion because the indicators represent conceptually distinct characteristics.

4.2. Provincial Rankings and Dimension Profiles

The overall index ranking was evaluated as a composite representation of provinces' relative performance across the economic, social, and environmental dimensions. Because the total index score alone does not reveal how provinces differ across dimensions, the ranking results were considered together with dimension scores. Table 5 therefore presents the ten highest-ranking provinces together with their economic, social, and environmental scores.

Table 5. Top Ten Provinces in the Overall Index and Their Dimension Scores

Rank	Province	Economic	Social	Environmental	Index
1	İstanbul	71.54	75.22	91.21	79.32
2	Kocaeli	85.22	57.97	89.10	77.43
3	Ankara	68.72	87.19	74.36	76.75
4	İzmir	53.34	70.40	86.59	70.11
5	Eskişehir	55.63	72.65	79.90	69.39
6	Yalova	49.48	59.77	91.14	66.80
7	Isparta	45.36	73.11	79.03	65.83
8	Bolu	53.40	69.48	72.84	65.24
9	Edirne	46.74	70.83	72.71	63.43
10	Bursa	54.96	55.05	79.57	63.19

Note. Rankings were derived from unrounded index scores. Source: Authors' calculations based on official 2024 provincial data.

İstanbul ranked first with 79.32 points, followed by Kocaeli with 77.43 and Ankara with 76.75. İstanbul's economic, social, and environmental scores were 71.54, 75.22, and 91.21, respectively. Kocaeli ranked first among all provinces in the economic dimension with 85.22 points but recorded a social score of 57.97. Ankara ranked first in the social dimension with 87.19 points. These differences show that provinces with similar overall-index positions do not necessarily have the same dimensional structure and that a total score may partially conceal variation across dimensions.

İzmir and Eskişehir ranked fourth and fifth in the overall index. The presence of Yalova, Isparta, Bolu, and Edirne among the top ten indicates that the highest positions are not limited to the largest metropolitan provinces. Karabük recorded the highest environmental score (93.59), followed by İstanbul (91.21) and Yalova (91.14). In the social dimension, Ankara and İstanbul were followed by Isparta (73.11).

The lowest positions in the overall index were occupied by Muş (17.70; 81st), Ağrı (18.97; 80th), Şanlıurfa (21.77; 79th), Şırnak (25.92; 78th), and Mardin (27.29; 77th). These rankings apply to the selected indicators

and the 2024 comparison of 81 provinces. Index scores do not measure the percentage achievement of a sustainability target or provinces' progress over time.

The scope of the environmental results is limited to municipal water and wastewater services, the share of waste sent to treatment facilities, and forest cover. Because the waste indicator includes different treatment methods, including sanitary landfilling, it cannot be labelled as a recycling rate. The forest-area share also reflects natural endowment. Consequently, a high environmental dimension score in this study indicates a relative position in terms of municipal environmental services and forest cover and should not be interpreted as evidence of low carbon emissions, a low material footprint, or overall success in climate policy.

4.3. Determination of the Number of Clusters and Provincial Groups

Economic, social, and environmental dimension scores were standardized and solutions from two to eight clusters were compared. For K-means, the two-cluster solution simultaneously produced the highest Silhouette and Calinski-Harabasz values and the lowest Davies-Bouldin value (Table 6). The requirement that the smallest cluster contain at least five provinces did not alter the selection of the two-cluster solution.

Table 6. Comparison of K-means Solutions by Number of Clusters

k	Silhouette ↑	Calinski-Harabasz ↑	Davies-Bouldin ↓	Smallest cluster
2	0.433	78.00	0.840	24
3	0.320	73.10	1.028	16
4	0.297	63.07	1.107	9
5	0.288	57.05	1.063	5
6	0.254	52.74	1.112	5
7	0.274	51.88	1.027	3
8	0.284	50.75	1.012	3

Note. Arrows indicate the preferred direction. The k = 7 and k = 8 solutions did not meet the minimum cluster-size requirement.

Table 7. Mean Scores of the Two-Cluster Solution

Cluster	No. of provinces	Economic	Social	Environmental	Index
K1	24	24.01	31.15	46.95	34.04
K2	57	45.97	56.24	68.50	56.90

Source. K-means results based on the three dimension scores. Cluster codes are analytical group labels.

K1 contains 24 provinces (29.63%), whereas K2 contains 57 provinces (70.37%). The mean score of K2 is 21.96 points higher in the economic dimension, 25.09 points higher in the social dimension, and 21.56 points higher in the environmental dimension. The difference in mean overall index scores is 22.87 points. The common-direction separation across all three dimensions shows that the main distinction in the selected solution concerns general performance level rather than contrasting profiles across dimensions. In other words, no separate cluster emerged that was relatively strong economically but relatively weak environmentally, or vice versa.

K1 consists of Adıyaman, Ağrı, Bingöl, Bitlis, Diyarbakır, Gümüşhane, Hakkari, Hatay, Kars, Kahramanmaraş, Mardin, Muş, Nevşehir, Niğde, Siirt, Şanlıurfa, Van, Yozgat, Aksaray, Batman, Şırnak, Ardahan, Iğdır, and Osmaniye. The remaining 57 provinces belong to K2. Although provinces in eastern and southeastern Türkiye predominate in K1, the inclusion of Nevşehir, Niğde, Aksaray, and Yozgat indicates that the resulting classification does not directly coincide with conventional geographic-region boundaries.

Across K-means repetitions using 30 different initialization seeds, the adjusted Rand index (ARI) was 1.000. By contrast, the ARI between Ward and K-means memberships was 0.574, while the ARI relative to the alternative 17-indicator solution with balanced total variance contributions across dimensions was 0.755. These results

show that the K-means solution is stable with respect to random initialization, but the same provincial memberships are not preserved when the clustering method or input set changes.

4.4. Findings from the Robustness Analysis

The baseline ranking was compared with CRITIC weighting, geometric aggregation, logarithmic transformation of the export and patent indicators, rank normalization, and two indicator-exclusion scenarios. Spearman correlations with the baseline ranking ranged from 0.983 to 0.998 across alternative scenarios, indicating that the overall ranking structure was largely preserved. Nevertheless, this high overall agreement does not mean that individual provincial ranks or cluster memberships remained unchanged.

Table 8. Comparison of Alternative Scenarios with the Baseline Results

Scenario	Spearman ρ	Mean absolute rank difference	Maximum rank difference	Top-10 overlap	Cluster ARI
CRITIC	0.997	1.04	8	9/10	0.763
Geometric aggregation	0.995	1.80	10	10/10	—
Log exports and patents	0.998	1.09	6	9/10	0.950
Rank normalization	0.988	2.75	9	8/10	0.950
E6 broadband excluded	0.997	1.11	6	10/10	0.901
C6 forest excluded	0.983	3.14	17	9/10	0.850

Note. Rank differences are expressed in rank positions. Cluster ARI compares memberships recalculated from alternative dimension scores with the baseline solution while holding k = 2 fixed. Because geometric aggregation does not change the clustering inputs, identical memberships in this scenario were not reported as an independent robustness finding.

Under CRITIC weights, the rank correlation was 0.997, the mean absolute rank difference was 1.04, and nine of the top ten provinces overlapped with the baseline top ten. However, the ARI for cluster memberships declined to 0.763. Thus, despite the limited effect of CRITIC weighting on the overall ranking, the lower cluster agreement indicates that ranking stability and classification stability are not the same property. Under geometric aggregation, all ten baseline top-ten provinces were retained, the rank correlation was 0.995, and the maximum rank difference was ten positions.

When ln(1 + x) transformations were applied to exports and patents and when the fixed broadband indicator was excluded, mean absolute rank differences were 1.09 and 1.11, respectively. Under rank normalization, this value increased to 2.75 and overlap with the baseline top ten declined to eight provinces. These findings show that the baseline ranking is largely preserved under alternative transformations, although exact positions—particularly around the top-ten threshold—remain method-dependent.

Excluding the forest-area share produced the largest ranking changes among the scenarios examined. The mean absolute rank difference was 3.14 positions, the maximum difference was 17 positions, and the cluster ARI was 0.850. Muğla declined from 25th place in the baseline index to 42nd place under this scenario. This change illustrates the influence of forest cover on the environmental score and overall position of some provinces.

For the difference in overall index scores between clusters, the Kruskal-Wallis statistic was $H = 50.05$ with $p < 0.001$. However, because the clusters were derived from the same dimension scores used to construct the index, this result is interpreted as an exploratory indicator of separation rather than an independent test of external validity. Likewise, high correlations between the index and its dimension scores include a component-whole relationship.

5. Discussion

The main finding of this research is that the dominant clustering pattern among provinces, given the indicators examined, reflects a general performance-level distinction in which economic, social, and environmental scores

differ together rather than sharply contrasting sustainability profiles across dimensions. In the two-cluster solution, all three dimensions separated in the same direction; no clear provincial typologies emerged that were strong in one dimension and weak in another. This pattern suggests that economic opportunities, social conditions, and environmental service infrastructure may be associated with a common development base. The present analysis, however, does not determine the direction or causes of the relationships among these dimensions.

One possible explanation for this common differentiation lies in the capacities represented by the indicators. Income generation, employment, digital infrastructure, education and health resources, and municipal services capture different aspects of local resources and service-provision capacity. Although the co-movement of economic capacity with education, health, and municipal services offers a plausible interpretation, the present design does not test the mechanism underlying this relationship. In particular, the dominance of service-infrastructure indicators in the environmental dimension may have contributed to the similar direction of differentiation across the three dimensions.

The fact that İstanbul, Kocaeli, and Ankara occupy the top three positions in the overall index shows a notable similarity with previous provincial-level studies. Using 52 indicators and TOPSIS, Gazibey, Keser, and Gökmen (2014) ranked Kocaeli, İstanbul, and Ankara as the top three provinces; the same three provinces occupy the first three positions in the present study, in the order İstanbul, Kocaeli, and Ankara. İstanbul and Ankara also remained among the leading provinces throughout the analysis of Saraç and Alptekin (2017). These commonalities show that some provinces repeatedly appear in relatively high positions despite differences in data periods, indicator sets, and aggregation methods. However, because the studies do not use a common measurement framework, similarities in rankings should not be interpreted as direct evidence of temporal performance continuity. The provincial Human Development Index results of Yiğiteli and Şanlı (2020), in which Ankara, İstanbul, and Kocaeli also ranked highly, provide a complementary comparison from a conceptually different framework.

The inclusion of Kahramanmaraş and Osmaniye among the high-performing provinces in the fuzzy-logic model of Özmen and Yirmibeşoğlu (2023), whereas both belong to the lower-mean cluster in the present application, illustrates the importance of the measurement framework. A fuzzy rule base and arithmetic aggregation represent the same broad concept using different evaluative logics. The data year and indicator set also differ. Consequently, this divergence does not demonstrate that sustainability in these provinces changed in a particular direction. The observation by Michalina et al. (2021) that differences among indicator frameworks can affect measurement results supports cautious interpretation of such comparisons.

The study also demonstrates the importance of reading overall rankings together with dimension profiles. Kocaeli's strength in the economic dimension and Ankara's strength in the social dimension show that provinces with similar overall-index positions may have different characteristics. General-index proximity therefore does not imply the same dimensional structure. While the overall index summarizes the comparison, dimension scores indicate which areas require more detailed examination. For local decision-making, the underlying indicators and service conditions should also be evaluated.

The meaning of the environmental scores is particularly important in this respect. The environmental indicators used in the study largely represent water, wastewater, and waste-management services together with forest cover. A high environmental dimension score may therefore indicate a relative advantage in municipal environmental services and forest endowment within the indicator set used, but it does not support the conclusion that a province's total environmental pressure is low. Because carbon emissions, air quality, energy structure, and material use are not included, possible divergences between economic capacity and environmental pressure may not be sufficiently visible in the current classification.

The larger ranking changes produced by excluding forest-area share indicate that natural endowment plays a substantial role in the position of some provinces. Muğla's decline under this scenario demonstrates that the environmental score incorporates not only service provision but also geographic and ecological characteristics. Although forest area is an important natural-endowment indicator, it should not be directly equated with current local-government environmental-management performance because it also reflects geographic and ecological conditions. Future applications could improve policy interpretation by presenting natural endowment, environmental pressure, and environmental-management indicators separately.

Robustness analyses show that the overall provincial ranking is largely preserved under alternative measurement choices, whereas cluster memberships are more sensitive. This finding demonstrates that ranking stability and classification stability are distinct properties and that cluster results should not be interpreted as fixed provincial categories. A small change in a province's score may alter membership when the province lies close to a cluster boundary. Thus, a high rank correlation does not imply that all provinces remain in the same profile. The limited agreement between Ward and K-means also argues against treating clusters as immutable provincial categories.

The fact that K-means produced the same solution across different initializations demonstrates computational stability with respect to initialization. This stability, however, does not by itself establish the correctness of indicator coverage or methodological choices. Likewise, the difference in index scores across clusters cannot be treated as independent validation because the clusters are constructed from the same dimensions that constitute the index. The OECD/European Union/EC-JRC (2008) emphasis on examining alternative measurement choices supports transparent reporting of these distinctions.

The main methodological contribution of the study is the joint examination of overall ranking, multidimensional similarity, and methodological sensitivity using verified provincial data from the same reference year. This approach separates the summary information provided by a single composite score from variation associated with dimensions and methodological choices, allowing more cautious interpretation of results. In applied terms, the index can be used as a preliminary tool for examining local needs and comparing provinces with similar characteristics. Cluster membership alone, however, is not sufficient for investment or resource-allocation decisions.

The main limitations concern the single-year cross-sectional design, the indicator coverage—particularly in the environmental dimension—and the dependence of the composite index on normalization and aggregation choices. Although all 81 provinces are covered, the use of 2024 data alone prevents inference about sustainability trends or changes in provincial rankings over time. Min-Max normalization is sensitive to sample bounds and outliers, while arithmetic aggregation permits compensation across dimensions. Health-resource indicators may reflect the role of regional referral centres, and municipal-service indicators may use coverage populations that differ from total provincial population. Sampling uncertainty in labour-force estimates was not propagated into the index scores.

Future research could examine the persistence of provincial positions using comparable annual series. Expanding environmental indicator coverage and evaluating cluster profiles against independent variables not included in the index would strengthen interpretation. Future work should prioritize not merely increasing the number of indicators but conceptually separating environmental pressure, natural endowment, and environmental-management indicators while maintaining comparability across provinces and years.

6. Conclusion

This study demonstrates substantial differences in the 2024 sustainability performance of Türkiye's 81 provinces, both in terms of the overall index and across the economic, social, and environmental dimensions.

İstanbul, Kocaeli, and Ankara ranked first, second, and third in the overall index. The selected two-cluster solution, meanwhile, produced two provincial groups in which economic, social, and environmental scores differed in the same direction. At the same time, some provinces with similar overall-index positions displayed different dimension scores.

High correlations between the baseline ranking and alternative scenarios show that the overall ranking structure is largely preserved under the measurement choices examined. By contrast, the greater sensitivity of cluster memberships to weighting, indicator coverage, and clustering inputs indicates that classifications should be interpreted as method-dependent descriptive groupings rather than immutable provincial categories.

The central message of the research is that provincial sustainability differences should not be interpreted through a single ranking alone, but through the joint consideration of the overall index, dimension scores, and the sensitivity of results to methodological choices. The proposed framework provides a traceable and reproducible basis for identifying provincial-level differences and comparatively discussing local policy priorities. The results are limited to the 17 indicators used and the 2024 reference year. Future applications can provide a more comprehensive and dynamic assessment of provincial sustainability by broadening environmental indicator coverage and adding comparable years to the analysis.

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FULL PAPER · IP1.6 · IN-PERSON SESSION I

Green Entrepreneurship from an Agricultural Economics Perspective: A Review of Circular Business Models Based on Agricultural Waste

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ABSTRACT

Agriculture generates large volumes of crop residues, livestock manure and agro-industrial by-products. These flows are often burned, landfilled or left unmanaged. From an economic viewpoint, this outcome reflects missing markets, unpriced externalities and high transaction costs. This paper argues that green entrepreneurship can close this gap by turning agricultural waste into tradable inputs. The study conducts an integrative review of peer-reviewed literature on the circular economy, sustainable entrepreneurship and agricultural waste valorisation. It links these streams through three agricultural economics concepts, namely externalities, transaction costs and value chain coordination. The review discusses six circular business model types. These are biogas plants, upcycling ventures, environmental biorefineries, agricultural cooperatives, agroparks and support structures. Each type creates and captures value in a different way. Their success depends on stable feedstock supply, flexible logistics, price competitiveness, partnerships and supportive regulation. The review shows that the main constraint is not technology. It is the economic organisation of dispersed, seasonal and low-value biomass. The paper proposes a conceptual framework in which the green entrepreneur acts as a market maker. The entrepreneur aggregates supply, reduces uncertainty, reveals the value of residues and builds trust among farmers, processors and buyers. Four research propositions are derived from this framework. The findings offer guidance for researchers, agribusiness managers and policy makers. Policies should move from waste disposal rules toward instruments that build markets for secondary agricultural resources.

Keywords: green entrepreneurship; circular economy; agricultural waste; circular business models; agricultural economics; circular bioeconomy

1. Introduction

Agriculture sits at the centre of the sustainability debate. It feeds a growing population. It also uses land, water and energy on a large scale. A less visible issue is the waste it leaves behind. Crop residues, animal manure, pruning wood and agro-industrial by-products accumulate every season (Duque-Acevedo et al., 2020). Much of this biomass is burned in open fields, landfilled or left to decompose. These practices pollute air, soil and water. They also release greenhouse gases (Koul et al., 2022).

Yet agricultural waste is not worthless. It contains energy, nutrients, fibres and bioactive compounds. It can become biogas, compost, animal feed, bioplastics or building materials (Barros et al., 2020; Mirabella et al., 2014). The circular economy offers a frame for this shift. It aims to keep materials in use and to regenerate natural systems (Geissdoerfer et al., 2017; Kirchherr et al., 2017). In agriculture, it calls for closing nutrient loops and for the cascading use of biomass (Velasco-Muñoz et al., 2021).

This creates a puzzle. If agricultural waste holds value, why does so much of it remain unused? Technical answers explain only part of the story. Many conversion technologies are already mature. The deeper reason is economic. Waste is a by-product without a market price. Its environmental costs are borne by society rather than by the producer. Collecting it from many small farms is costly. Potential buyers and sellers rarely know each other. In short, the market for agricultural waste is either missing or thin.

Green entrepreneurship addresses exactly this kind of gap. Entrepreneurs discover and exploit opportunities that arise from market imperfections (Cohen & Winn, 2007; Dean & McMullen, 2007). In agriculture, such opportunities lie in turning unpriced residues into valuable inputs. Circular business models are the vehicles through which these opportunities are realised (Bocken et al., 2016; Lewandowski, 2016). However, the literature on these topics remains fragmented. Studies on agricultural waste focus mostly on technology and environmental impact. Studies on entrepreneurship rarely address the specific features of agriculture (Fitz-Koch et al., 2018). Studies on circular business models seldom use economic theory to explain why some models succeed and others fail.

This paper aims to bridge these streams. It reviews circular business models based on agricultural waste through the lens of agricultural economics. Three questions guide the review. Which business model types turn agricultural waste into value? Which economic factors shape their success or failure? What role does the green entrepreneur play in this process? The paper makes two contributions. First, it explains the valorisation gap with established economic concepts. Second, it proposes a framework that positions the entrepreneur as a market maker for secondary agricultural resources.

The paper is organised as follows. Section 2 builds the conceptual lens. Section 3 describes the review method. Section 4 presents the business model types. Section 5 examines the economic drivers and barriers. Section 6 integrates the findings into a framework and derives research propositions. Section 7 concludes.

2. Conceptual Background

2.1. Agricultural Waste as an Economic Problem

Agricultural economics offers three concepts that help explain the valorisation gap. The first is the externality. When a farmer burns straw, the smoke harms others. The farmer does not pay for this harm. As a result, disposal looks cheaper than it really is. The private incentive to search for a better use remains weak.

The second concept is the transaction cost. Every exchange requires search, negotiation, monitoring and enforcement (Williamson, 1985). Agricultural waste raises these costs. Supply is dispersed across many small farms. It is seasonal and bulky. Its quality varies with crop, weather and handling. Buyers face uncertainty about volume and composition. Sellers face uncertainty about payment and continuity. When these costs exceed the value of the material, no trade takes place.

The third concept is value chain coordination. Agricultural markets are organised around the main product. Grain, milk or olive oil have clear prices and grades. Residues do not. No actor is responsible for linking the farm gate to potential users of by-products. Coordination failures therefore persist even when the total gains from trade are positive.

Together, these concepts show that the waste problem is partly a problem of market design. This view shifts attention from technology to organisation. It also points to the actor who can reorganise exchange, namely the entrepreneur.

2.2. Green Entrepreneurship and Market Imperfections

Entrepreneurship research defines opportunities as situations in which new goods or services can be sold at more than their cost of production (Shane & Venkataraman, 2000). Sustainable and green entrepreneurship extend this idea. They focus on opportunities that also reduce environmental harm (Hall et al., 2010; Schaltegger & Wagner, 2011). Dean and McMullen (2007) argue that environmental degradation results from market failure. The same failures that cause harm also create room for profit. Cohen and Winn (2007) identify four imperfections behind such opportunities. These are inefficient firms, externalities, flawed pricing

mechanisms and information asymmetries. York and Venkataraman (2010) add that entrepreneurs can solve environmental problems where institutions and incumbent firms fall short.

Green entrepreneurs differ from conventional ones in their motivation and resources. Many of them enter markets with explicit environmental goals (Demirel et al., 2019). In agriculture, entrepreneurship also has distinct traits. It is tied to land, family ownership, biological cycles and rural communities (Dias et al., 2019; Fitz-Koch et al., 2018). These traits matter for waste valorisation. Farmers own the feedstock but often lack the capital or skills to process it. External entrepreneurs hold the technology but depend on farmers for supply. The relationship between these two groups is therefore central to any circular solution.

2.3. Circular Business Models

A business model describes how a firm creates, delivers and captures value (Teece, 2010; Zott et al., 2011). Sustainable business models add environmental and social value to this logic (Bocken et al., 2014). Circular business models focus on closing, slowing or narrowing resource loops (Bocken et al., 2016). Lewandowski (2016) extends the business model canvas with take-back systems and adoption factors. Urbinati et al. (2017) classify circular models by the degree to which they change customer value and the supply chain. Linder and Williander (2017) stress that circular models carry high uncertainty. They depend on return flows that the firm does not fully control.

Agricultural waste fits these definitions well. It is a return flow by nature. It also links the circular economy with the bioeconomy (D'Amato et al., 2017; Stegmann et al., 2020). The circular bioeconomy emphasises the cascading use of biomass. High-value uses should come first and energy recovery should come last (Sherwood, 2020). This principle has a direct economic meaning. The same tonne of residue can yield very different margins depending on the business model that processes it.

The three streams therefore converge. Agricultural economics explains why waste remains unused. Green entrepreneurship explains who can act on this gap. Circular business models explain how value is created and captured. The next section describes how the literature was reviewed with this combined lens.

3. Methodology

This study adopts an integrative literature review. This design suits topics that span several disciplines and lack a unified theory (Snyder, 2019; Torraco, 2005). Its aim is not to count studies. Its aim is to synthesise concepts and to build a new framework.

The search covered the Web of Science and Scopus databases. Search strings combined three groups of terms. The first group covered agricultural waste, crop residues, manure, agro-industrial by-products and biomass. The second group covered the circular economy, the circular bioeconomy and valorisation. The third group covered business models, entrepreneurship and green entrepreneurship. Seminal works on entrepreneurship and business models were added through backward citation tracking.

Three inclusion criteria were applied. Studies had to be peer-reviewed and written in English. They had to address business models, entrepreneurship or the economic conditions of waste valorisation. Priority was given to journals ranked in the first quartile of their field. Purely technical studies on conversion processes were used only for context. The selected studies were then coded along three dimensions, namely value creation, value capture and economic conditions. The coding followed the conceptual lens set out in Section 2. This step ensured that the findings could be interpreted in economic terms.

The review is qualitative and interpretive. It therefore does not claim statistical representativeness. Its strength lies in linking separate bodies of knowledge. The results are presented in the next two sections. Section 4 maps the business model types, and Section 5 explains their economic logic.

4. Circular Business Models Based on Agricultural Waste

4.1. Valorisation Pathways

Agricultural waste can follow several valorisation pathways. The literature groups them by the value of the final product (Barros et al., 2020; Duque-Acevedo et al., 2020; Koul et al., 2022). Low-value pathways include direct energy recovery through combustion. Medium-value pathways include anaerobic digestion, composting and animal feed. High-value pathways include the extraction of bioactive compounds and the production of biomaterials and bio-based chemicals (Mirabella et al., 2014; Mohan et al., 2016). Each pathway requires a different scale, level of capital and set of skills. These differences shape the business models that emerge around them.

4.2. A Typology of Business Models

Donner et al. (2020) offer the first typology of circular business models in the agricultural domain. Based on 39 cases, they identify six types. This review uses their typology as a starting point. It then interprets each type through the economic lens developed in Section 2. Table 1 summarises the results.

Table 1. Circular business model types based on agricultural waste and their economic logic

Model type	Typical feedstock and output	Value creation logic	Main economic constraint
Biogas plant	Manure and crop residues converted into energy and digestate	Energy sales and avoided disposal costs	Dependence on energy prices, tariffs and feedstock logistics
Upcycling venture	Specific by-products such as husks, peels and pomace converted into food, cosmetic or material products	Niche products with high unit margins	Small scale, consumer acceptance and market access
Environmental biorefinery	Mixed biomass converted into multiple bio-based products	Cascading use and a diversified product portfolio	High capital cost and technology risk
Agricultural cooperative	Residues of member farms processed in shared facilities	Pooled supply and shared costs	Collective decision-making and governance
Agropark	Co-located farms and processors exchanging material flows	Industrial symbiosis and shared infrastructure	Spatial planning and long-term coordination
Support structure	Networks, platforms and advisory services	Lower search and information costs	Viable revenue model and reliance on public funds

Source. Adapted from Donner et al. (2020, 2021) and interpreted through the conceptual lens of this study.

Biogas plants are the most common model. Farmers or small firms digest manure and crop residues to produce energy. Value comes from energy sales and avoided disposal costs. Digestate can also replace part of the mineral fertiliser used on farms. The model internalises a negative externality. However, it depends heavily on energy prices and public support. It also sits low in the cascade of biomass use (Sherwood, 2020).

Upcycling ventures take a specific by-product and turn it into a niche product. Examples include flour made from fruit pomace or packaging made from husks. These ventures are often start-ups led by green entrepreneurs (Demirel et al., 2019). They capture high margins per unit. Yet they struggle with small volumes, consumer acceptance and access to retail channels.

Environmental biorefineries process mixed biomass into several products. They follow the cascade principle most closely (Mohan et al., 2016; Stegmann et al., 2020). Their product portfolio spreads market risk. However, they require large investments and a stable flow of feedstock. They also face technology risk in early stages of development.

Agricultural cooperatives pool residues from member farms. They reduce the transaction costs of dispersed supply. They also build trust, since farmers share ownership and control. Their weakness lies in collective decision-making. Members may disagree on investments and on the sharing of profits.

Agroparks bring farms and processors to the same location. The output of one firm becomes the input of another. Transport costs fall and material flows become more stable. This model mirrors industrial symbiosis. It requires careful spatial planning and a long-term commitment from all partners.

Support structures do not process biomass themselves. They connect actors through platforms, networks or advisory services. They act directly on information asymmetries and search costs. Their main challenge is a viable revenue model, since many of them rely on public funding.

4.3. Cross-Cutting Patterns

Three patterns emerge across these types. First, value creation moves along a continuum. It runs from cost avoidance at the low end to new product creation at the high end. Second, all types depend on partnerships (Donner et al., 2020). No single actor controls feedstock, technology and markets at the same time. Third, each type addresses a different market imperfection. Biogas plants internalise externalities. Cooperatives and agroparks reduce transaction costs. Support structures reduce information asymmetries. Upcycling ventures and biorefineries correct flawed pricing by revealing the hidden value of residues.

These patterns show that the choice of a business model is an economic choice. It depends on which imperfection is most binding in a given context. The next section examines the specific factors that make these models succeed or fail.

5. Economic Drivers and Barriers

The literature identifies many factors that shape circular business models in agriculture. Donner et al. (2021) group them into five categories. These are technical and logistical, economic and financial, organisational and spatial, institutional and legal, and environmental, social and cultural factors. This section reorganises these factors around the economic lens of the paper. It focuses on supply, demand and institutions in turn.

5.1. Supply-Side Factors

Feedstock is the starting point of every model. In agriculture, feedstock has three difficult traits. It is seasonal, dispersed and variable in quality. Seasonality forces firms to store biomass or to leave capacity idle for part of the year. Dispersion raises collection and transport costs. Low bulk density makes long-distance transport uneconomic. Quality variation complicates processing and product standards (Duque-Acevedo et al., 2020).

These traits translate into high transaction costs. Firms must contract with many small suppliers. They must monitor quality and secure volumes over time. Farmers, in turn, fear dependence on a single buyer. Donner et al. (2021) find that flexible logistics and stable supply agreements are critical success factors. Cooperatives and agroparks perform well in this respect because they internalise part of these transactions.

A further issue concerns opportunity cost. Residues are not always free. Straw may serve as animal bedding or soil cover. Manure may already fertilise fields. Once a market emerges, these alternative uses acquire a price. Entrepreneurs must therefore offer farmers more than the value of current uses. This raises feedstock costs as markets mature.

5.2. Demand-Side Factors

On the demand side, price competitiveness is the main barrier. Bio-based products often compete with fossil-based substitutes. These substitutes benefit from scale and from unpriced carbon emissions. Kirchherr et al.

(2018) report that low virgin material prices are among the most cited market barriers to the circular economy. Without carbon pricing or green procurement, many waste-based products remain too expensive.

Consumer acceptance adds a second layer. Products derived from waste may face doubts about safety and quality. Clear standards and labels can reduce this uncertainty. Upcycling ventures often turn the waste origin into a marketing story. This strategy works in niche segments but is hard to scale.

Market thinness is a third issue. Few buyers exist for new secondary materials. Prices are volatile and lack transparency. This raises risk for both sides of the exchange. Support structures and digital platforms can help by revealing prices and matching partners.

5.3. Institutional Factors

Institutions shape both costs and incentives. Waste regulations play a dual role. They can push farmers away from burning or landfilling. Yet a strict waste status can also block the trade of by-products. When a residue is legally classified as waste, its transport and use require heavy permits. Clear rules on by-products and end-of-waste status therefore lower entry barriers (Salvador et al., 2022).

Financial institutions matter as well. Circular ventures in agriculture are often small and capital-intensive. Banks tend to perceive them as risky. Small and medium-sized enterprises report access to finance as a major barrier (Rizos et al., 2016). Subsidies for energy recovery have helped biogas plants grow. However, they may also lock biomass into low-value uses. This outcome conflicts with the cascade principle.

Cultural and social factors complete the picture. Farmers tend to be risk-averse and rely on trust-based networks. Kirchherr et al. (2018) show that cultural barriers, such as hesitant company culture and low consumer interest, often outweigh technical ones. Local stakeholder involvement and public acceptance thus emerge as success factors (Donner et al., 2021; Salvador et al., 2022).

5.4. Synthesis

The factors above point to one conclusion. The main constraint on agricultural waste valorisation is not technology. It is the economic organisation of dispersed, seasonal and low-value biomass. Supply is costly to aggregate. Demand is thin and sensitive to price. Institutions often treat residues as liabilities rather than resources. The question then becomes who can reorganise this system. The next section argues that the green entrepreneur is a key candidate.

6. Discussion

6.1. The Green Entrepreneur as Market Maker

The review suggests a specific role for the green entrepreneur in agriculture. This role goes beyond running a processing plant. The entrepreneur acts as a market maker for secondary agricultural resources. A market maker creates the conditions under which exchange becomes possible. In this context, the entrepreneur performs four functions.

The first function is aggregation. The entrepreneur pools small and scattered volumes into a reliable supply. This creates economies of scale that single farms cannot reach. The second function is uncertainty reduction. Through contracts, quality standards and stable prices, the entrepreneur lowers risk for farmers and buyers. The third function is value revelation. By developing new products, the entrepreneur shows that residues have a price. This corrects the flawed pricing described by Cohen and Winn (2007). The fourth function is trust building. The entrepreneur connects actors who would not otherwise interact. Farmers, processors, municipalities and researchers thus join a shared network.

These functions map onto the market imperfections discussed in Section 2. Aggregation and uncertainty reduction lower transaction costs. Value revelation corrects pricing failures. Trust building eases coordination failures. Externalities remain the one area where entrepreneurs need policy support. Without a price on pollution, private returns stay below social returns (Dean & McMullen, 2007). Table 2 presents the resulting framework.

Table 2. Framework linking market imperfections, entrepreneurial functions and business model types

Market imperfection	Manifestation in agricultural waste	Entrepreneurial function	Best-suited model types
Unpriced externalities	Open burning and uncontrolled manure storage	Internalisation with policy support	Biogas plant, environmental biorefinery
High transaction costs	Dispersed, seasonal and bulky supply	Aggregation and contracting	Agricultural cooperative, agropark
Information asymmetry	Unknown volumes, quality and partners	Uncertainty reduction and matching	Support structure
Flawed pricing	Residues valued at or near zero	Value revelation through new products	Upcycling venture, environmental biorefinery
Coordination failure	No actor links the farm gate with by-product users	Trust building and network orchestration	Agropark, cooperative, support structure

Source. Developed by the author based on the reviewed literature.

6.2. Research Propositions

Four propositions follow from this framework. They are intended to guide future empirical work.

Proposition 1. *The higher the transaction costs of feedstock collection in a region, the more likely collective models such as cooperatives and agroparks are to outperform independent ventures.*

Proposition 2. *Business models that move biomass to higher steps of the value cascade generate higher margins but face greater market and technology risk.*

Proposition 3. *The presence of intermediary support structures reduces information asymmetries and increases the rate of new venture creation based on agricultural waste.*

Proposition 4. *Policies that price environmental externalities and clarify the legal status of by-products increase the viability of circular business models more than technology subsidies alone.*

6.3. Implications for Policy and Practice

The framework also carries practical implications. For policy makers, the main message is a shift in focus. Waste policy has long aimed at safe disposal. A circular agriculture needs policies that build markets. These include clear by-product rules, carbon pricing, green public procurement and support for intermediaries. Energy subsidies should be designed with the cascade principle in mind. Otherwise, they may divert biomass away from higher-value uses.

For farmers and agribusiness managers, the findings stress partnerships. No actor can close the loop alone. Farmers can join cooperatives or sign long-term supply contracts. This turns residues into a second source of income. Processors can locate close to farms to cut logistics costs.

For entrepreneurs, the key lesson concerns the choice of business model. The right model depends on the binding constraint in a given region. Where supply is scattered, aggregation comes first. Where markets are thin, matching and product development come first. Regional context therefore matters as much as technology (Salvador et al., 2022).

These implications close the line of argument. The paper began with a puzzle about unused agricultural waste. It explained this puzzle with economic concepts. It then identified the entrepreneur as the actor who can help resolve it. The final section summarises the contributions and outlines future research.

7. Conclusion

This paper reviewed circular business models based on agricultural waste from an agricultural economics perspective. It started from a simple question. Why does valuable biomass remain unused? The answer lies largely in market failures. Externalities, transaction costs, information gaps and flawed pricing keep agricultural waste outside markets.

The review discussed six business model types. Each type addresses a different market imperfection. All of them depend on partnerships and supportive institutions. The paper then proposed a framework in which the green entrepreneur acts as a market maker. Through aggregation, uncertainty reduction, value revelation and trust building, the entrepreneur turns waste into tradable resources.

The study contributes to the literature in two ways. It brings economic theory into the debate on circular business models in agriculture. It also extends green entrepreneurship research to the specific context of agricultural by-products.

The study has limitations. As an integrative review, it relies on interpretation rather than statistical synthesis. Much of the case evidence comes from European settings. Conditions in developing and emerging economies may differ. Future research should test the propositions with empirical data. Comparative case studies across regions would be valuable. Quantitative studies could measure the effect of transaction costs on the choice of business model. Research on farmer behaviour and contract design would further enrich the framework. Such work would help move agriculture from a linear model of production and disposal toward a truly circular system.

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FULL PAPER · IP2.1 · IN-PERSON SESSION II

Values, Fairness Perceptions, and Attitudes toward Carbon Taxation: A Literature Review with Implications for Green Entrepreneurship

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ABSTRACT

Carbon pricing changes the opportunity structure in which green ventures emerge, but its durability depends on public acceptance. This paper reviews how basic human values and perceived fairness shape attitudes toward carbon taxation, and explains why the answer matters for green entrepreneurship ecosystems. Türkiye has launched an emissions trading pilot and faces the EU Carbon Border Adjustment Mechanism, so questions of acceptance and policy design are now practical.

The paper is a narrative, theory-building review. It draws on environmental psychology, public economics, and sustainable entrepreneurship research. It uses Stern's classification of causal factors, Schwartz's theory of basic values, and value–belief–norm theory as organising frameworks. It synthesises evidence on four groups of determinants: values, fairness perceptions, climate concern and perceived costs, and trust.

The reviewed studies point to four patterns. First, self-transcendent values tend to be associated with greater acceptance of environmental taxes, but mostly indirectly, through beliefs and personal norms. Evidence on self-enhancement is thinner. Second, fairness perceptions matter, and they depend on revenue use, perceived benefits, and cost distribution as well as on who bears the tax. Third, climate concern is not sufficient: perceived costs, political orientation, and trust condition its effect. Fourth, direct evidence from Türkiye is scarce, and the interaction between values and fairness has rarely been tested.

The paper offers five propositions and a research agenda. Its contribution is to connect two literatures that rarely meet: public acceptance of carbon pricing and the institutional conditions for green entrepreneurship. It also outlines design implications, such as revenue earmarking and value-congruent communication, for policymakers, universities, technoparks, and chambers that support green entrepreneurs.

Keywords: carbon tax; Schwartz values; perceived fairness; green entrepreneurship; Türkiye

1. Introduction

Carbon pricing is moving from the margins to the centre of Türkiye's climate and industrial policy. The country's first Climate Law, adopted in July 2025, created the legal basis for a national emissions trading system (International Carbon Action Partnership, 2025). The pilot phase of that system began in 2026, the same year in which the European Union's Carbon Border Adjustment Mechanism entered its definitive phase and began to confront Turkish exporters, who have little experience with carbon pricing, with carbon costs (Anadolu Agency, 2026). Carbon pricing is no longer an abstract option for Turkish firms, entrepreneurs, and households.

Türkiye has so far chosen emissions trading rather than an explicit carbon tax. This paper therefore treats the literature on carbon tax acceptance as evidence on how citizens respond to price-based climate policy in general. That evidence is a guide to what any future price-based instrument may face. The distinction matters, and we return to it in the limitations.

Carbon taxes are widely seen as a cost-effective way to steer an economy toward lower emissions, yet they remain underused. Carattini et al. (2018) identify public opposition as “one of the main obstacles to carbon taxes”. Two research traditions try to explain it. Environmental psychology stresses personal values, beliefs, and

norms (Stern et al., 1999; Steg et al., 2005). Public economics stresses distributional fairness, perceived benefits, and the use of revenues (Baranzini & Carattini, 2017; Sommer et al., 2022). The two traditions are usually read separately. This paper reads them together.

The review addresses four questions. (RQ1) What does the literature say about how basic values, especially Schwartz's higher-order values, relate to attitudes toward carbon and other environmental taxes? (RQ2) How do fairness perceptions shape those attitudes? (RQ3) How do climate concern, perceived costs, ideology, and trust condition the effects of values and fairness? (RQ4) Why does the answer matter for green entrepreneurship, and what does it imply for Türkiye?

The paper is organised as follows. Section 2 presents the conceptual framework. Section 3 describes the review approach. Section 4 synthesises the evidence. Section 5 offers propositions, implications, limitations, and a research agenda.

2. Conceptual Framework

2.1 Why acceptance of carbon pricing matters for green entrepreneurship

Green, or sustainable, entrepreneurship is not simply entrepreneurship with a green label. Shepherd and Patzelt (2011) define it by its focus on the "preservation of nature, life support, and community" in the pursuit of opportunities, with gains understood to include non-economic gains. The practical question for any such venture is how sustainability can be made to pay. The environmental-economics answer starts with market failure. Dean and McMullen (2007) argue that "environmentally relevant market failures represent opportunities" for entrepreneurs, because the failures that cause degradation also leave room for profitable correction. Cohen and Winn (2007) take a compatible view. They identify inefficient firms, externalities, flawed pricing mechanisms, and imperfect information as imperfections that sustainable entrepreneurs can turn into opportunities.

Carbon pricing addresses one of the largest of these failures directly, namely unpriced greenhouse gas emissions. Evidence suggests that firms respond to such price signals by redirecting innovation. Using firm-level patent data from 80 countries, Aghion et al. (2016) show that automotive firms innovate more in clean technologies when tax-inclusive fuel prices are higher, and that innovation displays "path dependence in the type of innovation". Early and sustained price signals therefore matter because they help set the technological trajectory. Price signals also work on the demand side. In an incentive-compatible online supermarket experiment, Panzone et al. (2021) found that carbon taxation strongly reduced the carbon footprint of food baskets. Lower-carbon products gain a relative price advantage, which is the kind of demand shift on which green start-ups depend. Analytical supply-chain models likewise study how carbon tax design shapes firms' green technology investment (Chen et al., 2025).

Two cautions apply. First, the Porter hypothesis, the claim that well-designed regulation can enhance competitiveness, has attracted conflicting evidence, and Ambec et al. (2013) stress that it is often misunderstood. Carbon pricing does not automatically produce green ventures. Design and credibility matter. Second, credibility depends on politics. If citizens reject a price-based instrument, governments may delay, dilute, or reverse it, and the resulting policy uncertainty weakens the signal on which green ventures rely. This second step is our own reasoning, not a finding from the cited studies. It is consistent with the observation that carbon taxes remain underused despite their advantages (Carattini et al., 2018), and with cases such as the voting on Washington State's Initiative 732 (Reed et al., 2019).

Entrepreneurs are not passive recipients of policy. Schaltegger and Wagner (2011) extend the typology of sustainable entrepreneurship to include institutional entrepreneurship, that is, entrepreneurial action aimed

at changing market contexts. Hockerts and Wüstenhagen (2010) theorise complementary roles for emerging new entrants and incumbent firms. Carbon pricing changes the position of both groups, so the political economy of its acceptance is relevant to them.

The values that drive policy support also appear in the entrepreneurship literature. Kuckertz and Wagner (2010) found that individual sustainability orientation is positively related to entrepreneurial intention among German students and alumni, although the effect fades with business experience. Santos et al. (2021) report that humane-oriented values (conservation and self-transcendence) lead to self-employment through entrepreneurial intentions. In a student sample from Pakistan, Yasir et al. (2021) found that altruistic, biospheric, hedonic, and egoistic values all had indirect effects on sustainable entrepreneurial intentions. These studies rely on specific, mostly student samples and should not be generalised. They do suggest that a population holding self-transcendent values is both a likelier supporter of carbon pricing and a likelier source of sustainable founders and early customers.

Türkiye has no carbon tax, and the small domestic literature is mostly conceptual or descriptive rather than empirical. Balı and Yaylı (2019) argue that existing environmental taxes (e.g., the special consumption tax) are fiscal rather than steering instruments, and they propose a carbon tax with rates differentiated by fuel carbon content, temporary sectoral exemptions, a revenue-neutral design, and earmarking of revenues for environmental purposes under credible monitoring; they also warn that a uniform global tax could create distributional inequities. Özdemir and Köse (2024) note that Türkiye has not adopted carbon pricing, that policy work concentrates on an emissions trading system (ETS) motivated by the EU's carbon border adjustment mechanism (CBAM), and that the only visible tax-side step was an administrative unit created within the revenue administration. They argue a carbon tax deserves more attention because it is administratively easier and generates revenue. Related Turkish contributions they review (Şahin & Çiftçi, 2021; Artun, 2024; Sapmaz, 2023) likewise recommend a carbon tax, and Sapmaz warns about public reaction and the importance of revenue use. A recent thesis (Günay, 2025) describes the pilot ETS timetable and the Climate Law proposal, which also provides for a CBAM-type instrument, again without a carbon tax. Hence, apart from Gevrek and Uyduranoglu (2015), the psychological determinants of carbon pricing acceptance in Türkiye remain largely untested.

The Turkish context adds an institutional dimension. Eroglu and Rashid (2022) surveyed Turkish start-up founders and found that perceived support had a significant positive effect on sustainable entrepreneurial orientation, whereas perceived barriers had no effect. At the policy level, the Climate Law earmarks up to 10% of emissions trading revenues for just-transition measures supporting vulnerable groups and sectors (ICAP, n.d.). Revenue use is therefore already a live design question in Türkiye.

2.2 Values, beliefs, and norms

Stern (2000) distinguishes four types of causal factors behind environmentally significant behaviour: attitudinal factors, contextual forces, personal capabilities, and habit or routine. Values belong to the attitudinal group, together with general environmental beliefs and concern about climate change. Contextual factors, such as dependence on a private car or the structure of the tax, are conceptually distinct from personal capabilities.

Schwartz's (1992, 2012) theory identifies ten basic values, which can be grouped into four higher-order dimensions: openness to change, self-transcendence, conservation, and self-enhancement. Self-transcendence combines universalism and benevolence. Self-enhancement combines power and achievement. Bilsky et al. (2011) show that the circular structure of these values is stable across three rounds of the European Social Survey. This supports the validity of the framework. It does not by itself say anything about policy support.

Value–belief–norm (VBN) theory holds that values shape beliefs about the environment, the consequences of environmental harm, and responsibility for it, and that these beliefs in turn activate personal norms (Stern et al., 1999). In this chain, general values are distant causes. They are expected to work mainly through more specific beliefs and norms, and so to show modest direct associations with specific policy attitudes (Steg et al., 2005).

2.3 Fairness

Fairness in the carbon tax debate has at least three faces. *Distributional fairness* concerns who bears the cost, and low-income households are the usual focus because they spend a larger share of their budgets on carbon-intensive necessities such as heating. *Revenue-use fairness* concerns who benefits from the proceeds. *Procedural fairness* concerns whether citizens trust the institutions that design and administer the tax. Perceived fairness is a judgement about these features, and it need not match the tax's actual incidence.

3. Method: Review Approach

This paper is a narrative, theory-building review. It is not a systematic review and does not claim exhaustive coverage. Sources were selected for relevance to four themes: (a) values and support for environmental taxes, (b) fairness and the acceptability of carbon taxes, (c) climate concern, perceived costs, ideology, and trust, and (d) sustainable entrepreneurship and carbon pricing. Priority was given to peer-reviewed articles, to studies that measure support for carbon or other environmental taxes directly, and to studies from contexts that illustrate institutional differences. Foundational theoretical works were included where they supply the organising frameworks. For each study we recorded the country, the sample, the policy studied, the main determinants, and the direction of the reported associations. We separate evidence on carbon taxes from evidence on other policies and from conceptually related work. Where a study addresses a neighbouring topic, such as general tax culture or green consumption, it is flagged as indirect evidence. Because most of the studies are cross-sectional surveys or stated-preference experiments, we describe associations and avoid causal language.

4. Synthesis of the Evidence

4.1 Values and attitudes toward environmental taxes

The most direct evidence comes from Sweden. Harring and Jagers (2013) analysed support for an increased carbon dioxide tax and found that values, beliefs, and norms, as well as political and interpersonal trust, all had significant effects. Harring et al. (2017) used two Swedish datasets to show that ideological orientation and personal values independently affect policy support, and that these effects differ across policy types. In a sample of Swedish undergraduates, Harring (2018) reported a positive link between self-transcendence value orientation and support for environmental policy, and found that personal norms partly mediate the effect of biospheric values. These results fit the VBN chain.

Steg et al. (2005) tested VBN theory for the acceptability of energy policies. Their framework implies that general values reach policy attitudes through intermediate beliefs and norms. Evidence on the opposite pole is thinner. Hauptman and Hlastec (2023) surveyed 199 Slovene taxpayers (69 accountants and 130 non-accountants) and reported that self-transcendence (r = .244) and self-enhancement (r = −.403) were related to ethical tax behaviour. That study concerns general tax attitudes and compliance, not carbon taxes, so it is indirect support for the expectation that self-enhancement is associated with lower acceptance. Evidence on openness to change and conservation is less clear, and we found no study in this review that tests those two dimensions against carbon tax attitudes directly.

Two caveats follow. First, much of the direct evidence comes from a high-trust Nordic setting. Second, effect sizes in this literature are generally modest, which is consistent with the mediated structure of VBN theory. Values are better seen as an orientation that makes some policy frames more persuasive than as a strong predictor of any single policy attitude.

4.2 Fairness perceptions

The regressivity concern is common, but the evidence on actual incidence is mixed. The studies reviewed by Rotaris and Danielis (2019) point in both directions, and some find that a carbon tax is not necessarily regressive. Perceived fairness nevertheless depends on more than incidence. Baranzini and Carattini (2017), using survey data from a sample of more than 300 individuals, found that lack of perceived primary and ancillary benefits is one of the main barriers to acceptability, that earmarking revenues for environmental purposes can raise support, and that calling a tax a “climate contribution” rather than a “carbon tax” changes responses. This suggests that fairness is partly a matter of perceived benefit and framing.

Carattini et al. (2018) draw on a wider body of evidence and note that voters tend to prefer subsidies and rebates to carbon taxes. They propose trial periods, tax escalators, environmental earmarking, lump-sum transfers, tax rebates, and communication strategies as design responses. Sommer et al. (2022) study the role of fairness in carbon tax support directly, which confirms that fairness has become a central theme of this literature.

The Turkish evidence is limited but consistent with this picture. In a choice experiment, Gevrek and Uyduranoglu (2015) found that Turkish respondents preferred a progressive to a regressive cost distribution. They also found that private cost reduced the probability of choosing a tax, that earmarking raised acceptability, and that respondents favoured a tax that promotes public awareness of climate change. Among the studies reviewed here, this is the only one that examines carbon tax preferences in Türkiye. It is also a stated-preference study from 2015, before the Climate Law.

One link is missing. In the studies reviewed, fairness and values are usually treated as separate sets of determinants. We found no study that tests whether fairness perceptions condition the effect of values. This is a gap, and Section 5 turns it into a proposition.

4.3 Climate concern, perceived costs, and ideology

Climate concern is a recurrent predictor of support, but it is not sufficient. In a representative Canadian sample, Rhodes et al. (2017) found that carbon taxes were the least popular type of climate policy, that concern about climate change was among the few consistent predictors of support across policy types, and that knowledge was not. Tobler et al. (2012), in a Swiss mail survey, found that perceived costs and perceived climate benefits were the strongest predictors of willingness to act and to support policy measures, and that right-wing respondents were less willing to support any type of climate mitigation measure. Concern, then, operates alongside cost perceptions and political orientation.

Related work on green consumption points the same way. Bulut et al. (2021) show that environmental concern relates to conscious green consumption among post-millennials, with greenwashing perceptions as a moderator. This study concerns consumption, not tax support, so we use it only to illustrate that concern has to be credible and trusted to translate into action.

4.4 Trust and institutional context

Trust appears in almost every strand. Harring and Jagers (2013) found that both political and interpersonal trust were significantly related to attitudes toward a carbon dioxide tax. A later study showed that institutional context conditions other determinants: people concerned about environmental issues were more willing to pay

environmental taxes in high quality-of-government countries than in low ones, and left-wing ideology was a weaker driver in low quality-of-government countries (Davidovic et al., 2020). Kitt et al. (2021) distinguished trust in competence, integrity, and value similarity in Canada, found that support was considerably lower for a carbon tax than for subsidies and most regulations, and reported that not all forms of trust were consistently related to support.

These findings suggest that the effect of values and concern depends on whether citizens believe that revenues will be collected and used as promised. Whether the same pattern holds in Türkiye is an open question, because the evidence reviewed here comes mostly from other contexts.

4.5 Summary

Table 1. Summary of reviewed evidence

Determinant	Typical direction	Illustrative sources	Main caveats
Self-transcendence	Positive	Harring & Jagers (2013); Harring (2018); Steg et al. (2005)	Mostly Nordic data; effects mediated by beliefs and norms; modest size
Self-enhancement	Negative (indirect evidence)	Hauptman & Hlastec (2023)	General tax attitudes, small sample; no direct carbon tax test found
Openness to change; conservation	Unclear	Harring et al. (2017) on values and ideology across policy types	Few direct tests; effects differ by policy type
Perceived fairness and benefits	Positive	Baranzini & Carattini (2017); Carattini et al. (2018); Sommer et al. (2022); Gevrek & Uyduranoglu (2015)	Incidence evidence is mixed; fairness is a perception shaped by framing and revenue use
Climate concern	Positive	Rhodes et al. (2017); Tobler et al. (2012)	Not sufficient; perceived costs and ideology matter
Perceived costs and benefits	Strong predictor	Tobler et al. (2012); Gevrek & Uyduranoglu (2015)	Stated preference; hypothetical taxes
Trust and institutions	Positive; conditioning	Harring & Jagers (2013); Davidovic et al. (2020); Kitt et al. (2021)	Context-specific; trust has several dimensions

Note. Directions describe the general pattern in the studies cited, not pooled effect sizes.

5. Discussion and Conclusion

5.1 An integrated framework and five propositions

Taken together, the evidence supports a layered view. Values are distal orientations. They shape beliefs and personal norms, which shape attitudes toward specific tax designs. Fairness perceptions, cost perceptions, and trust sit closer to the policy and decide whether a value-based predisposition turns into support. The following propositions state this view in a form that future studies can test.

P1. Self-transcendent values are positively associated with acceptance of carbon taxation, mainly through beliefs about climate consequences and personal norms.

P2. Self-enhancement values are negatively associated with acceptance, and the association is weaker and less consistent than that for self-transcendence.

P3. Perceived fairness, including perceived benefits, cost distribution, and revenue use, is positively associated with acceptance, partly independently of values.

P4. Perceived fairness moderates the value–acceptance relationship. Self-transcendence is expected to predict support most strongly when the tax design is consistent with concern for others and for nature, for example when revenues protect low-income households or fund climate action.

P5. Trust in institutions and perceived personal cost condition all of these relationships. Where trust is low, the positive effect of values and climate concern is expected to be weaker.

Table 2. Propositions and implied research designs

	Core claim	Possible test
P1	Self-transcendence → acceptance, via beliefs and norms	Mediation analysis with values, beliefs, personal norms, and acceptance
P2	Self-enhancement → lower acceptance	Direct test with higher-order value scores and carbon tax items
P3	Fairness → acceptance	Survey measures of distributional, revenue-use, and procedural fairness
P4	Fairness moderates the effect of values	Interaction models; vignette or conjoint experiments that vary revenue use
P5	Trust and cost perceptions condition effects	Cross-country or subgroup comparison; trust dimensions as moderators

Note. The propositions are the authors' synthesis of the reviewed literature. They are not tested in this paper.

5.2 Implications for green entrepreneurship and policy

Four implications follow, and each is an inference from the literature, not a finding. First, revenue-use design is central. Earmarking for low-income households and for green innovation, including start-up finance and just-transition measures, may raise acceptability, in line with evidence on earmarking (Baranzini & Carattini, 2017; Gevrek & Uyduranoglu, 2015). Linking the revenue to visible support for green ventures would also connect the tax to the entrepreneurial ecosystem.

Second, communication should connect pricing to concern for others and for nature, and should avoid ambiguous labels (Baranzini & Carattini, 2017). Third, universities, technoparks, municipalities, and chambers of commerce can act as intermediaries. They can explain carbon pricing to citizens and small firms and show how it creates demand for low-carbon products. Their credibility as trusted institutions may matter, given the evidence on trust.

Fourth, entrepreneurship education that engages with students' values may help to turn sustainability orientation into entrepreneurial action. The relationship between sustainability orientation and entrepreneurial intention is not constant over time, as Kuckertz and Wagner (2010) found for business experience. For ecosystem builders, the same value orientation that supports carbon pricing is a resource for recruiting sustainable founders, but it should be paired with supportive conditions. Eroglu and Rashid (2022) found that perceived support, not the absence of barriers, was what mattered for Turkish start-ups' sustainable orientation.

5.3 Limitations

Several limitations qualify this review. It is narrative, so the selection of sources may be biased toward studies that the authors could find and read. Much of the direct evidence comes from Sweden, Switzerland, Canada, and Italy, and we found only one carbon tax preference study from Türkiye, which is a decade old. Many studies use stated-preference designs with hypothetical taxes, and stated support is not voting or behaviour. Türkiye has adopted an emissions trading system rather than a carbon tax, so the transfer of results is indirect. Several sources are indirect evidence, such as general tax attitudes or green consumption. Finally, the entrepreneurship argument is an inference. The reviewed carbon tax studies sample citizens, not entrepreneurs.

5.4 Research agenda

Future research could test P1 to P5 with a survey that measures Schwartz's higher-order values, several dimensions of fairness, and trust in the same respondents. Experimental designs could vary revenue use and

labels to test P4. Surveys of founders and aspiring founders would show directly how entrepreneurs read carbon pricing signals and whether policy credibility affects investment decisions. Comparative work across countries exposed to the EU Carbon Border Adjustment Mechanism would clarify how external pressure and domestic acceptance interact.

5.5 Conclusion

Public acceptance of carbon pricing is a condition for the credibility of the price signals on which green ventures rely. The literature suggests that self-transcendent values and fairness perceptions both matter, that their effects are mostly indirect and conditional, and that trust and perceived costs decide whether predispositions turn into support. For Türkiye, where carbon pricing is arriving through emissions trading and trade pressure, the main lesson is practical. Acceptance depends on design, and design choices such as revenue use and communication can be made together with the support mechanisms for green entrepreneurs.

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FULL PAPER · IP2.2 · IN-PERSON SESSION II

Social Capital and Entrepreneurial Potential in Migrant Communities: A Pilot Study on Syrian and Sudanese Migrants in Konya, Türkiye

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ABSTRACT

This study investigates how social capital shapes entrepreneurial potential within migrant communities, using Syrian and Sudanese migrants living in Konya, Türkiye as a pilot case. The economic literature has largely framed migrants through their aggregate expenditure: by enlarging consumption demand they affect output, price levels and local market dynamics, and their contribution is therefore measured on the demand side of GDP. A parallel but separate literature links social capital – the networks, trust and shared norms embedded in community relations – to entrepreneurial intention and new venture creation. These two strands are rarely connected, and evidence on the supply-side, venture-creating capacity of migrant communities in Türkiye, particularly for sub-Saharan African groups such as Sudanese migrants, remains scarce.

A cross-sectional pilot survey was conducted with 22 Syrian and Sudanese migrants of working age residing in Konya, reached through purposive and snowball sampling supported by community associations and migrant-serving NGOs. A structured questionnaire, administered in Arabic and Turkish, measured community-based social capital alongside entrepreneurial intention, opportunity recognition, perceived entrepreneurial skills, economic integration and perceived barriers to entrepreneurship. Because of the small sample, results are reported descriptively; reliability testing, regression analysis and group comparisons are reserved for the larger study.

Respondents report high entrepreneurial intention (M = 4.09 of 5) and positive perceptions of opportunities in Konya, but lower self-assessed entrepreneurial knowledge and skills (M = 3.14), weak professional ties with Turkish entrepreneurs (M = 2.91) and limited awareness of support programs. Insufficient capital (68.2%) and difficulty accessing finance (63.6%) are the most frequently reported barriers. Community support is perceived as available (M = 3.77) but contributes little to economic life (M = 2.86), which points to the potential importance of bridging and linking ties that the pilot instrument did not yet measure. With n = 22 and a student-dominated sample, the results are exploratory. The study delivers a pilot instrument and exploratory evidence for a larger structural-equation study and reframes migrants from consumption-side economic actors into potential founders of inclusive ventures.

Keywords: social capital; migrant entrepreneurship; entrepreneurial intention; inclusive entrepreneurship; Konya

1. Introduction

Social capital represents an important resource in understanding the entrepreneurial potential and economic integration of migrant communities. Through social networks, interpersonal trust, shared norms and reciprocal relationships, migrants can access resources and opportunities that may otherwise remain difficult to obtain in their host societies. In particular, social capital can help migrants overcome structural barriers associated with limited access to financial resources, market information, institutional support and professional networks (Williams & Krasniqi, 2018). Consequently, social relationships should not be considered merely as instruments of social interaction but also as potential resources that can facilitate economic participation and entrepreneurial development.

The economic significance of social capital lies in its capacity to transform social relationships into accessible resources. Family ties, friendships, community connections and trust-based relationships can facilitate the exchange of information, the mobilization of informal financial support and the identification of potential

business opportunities. In this respect, social networks may function as mechanisms through which individuals convert their social relationships into economic resources (Sommer & Gamper, 2017). However, the entrepreneurial benefits of these relationships may vary depending on the nature, diversity and institutional reach of the networks in which individuals are embedded.

This relationship becomes particularly relevant in the context of migrant entrepreneurship, where individuals frequently operate within unfamiliar economic, legal and institutional environments. Migrants may initially rely on close relationships within their immediate social circles to obtain practical assistance and overcome everyday challenges. Nevertheless, access to broader networks involving local residents, entrepreneurs, professional organizations and public institutions may become equally important for identifying new opportunities and developing sustainable economic activities. Accordingly, the distinction between bonding and bridging social capital provides a useful framework for understanding how different forms of social relationships influence migrants' entrepreneurial prospects (McKeever et al., 2014; Abebe, 2022).

Within this broader framework, Türkiye provides a relevant context for examining the relationship between migration, social capital and entrepreneurship. Previous studies suggest that migrant communities in Türkiye develop different forms of social and economic networks to navigate the challenges of their host environment. Research on migrant entrepreneurship has particularly emphasized the importance of community relationships, trust, institutional connections and access to local economic structures (Moiz & Turkec, 2022). Furthermore, research on Afghan migrant entrepreneurs in Istanbul and Konya highlights the role of social capital in facilitating entrepreneurial processes and establishing relationships within both migrant communities and the wider host society (Afkari & Arıcıoğlu, 2023).

Konya offers a particularly interesting urban context for investigating these dynamics. The city hosts migrant populations with different national backgrounds, migration experiences and social structures. Previous research on migrant women entrepreneurs in Konya has highlighted the relevance of family support, institutional assistance and local cultural conditions in shaping entrepreneurial experiences (Karaarslan & Demirel, 2023). Similarly, Koyuncu (2020), examining Syrian entrepreneurs in Konya, draws attention to the challenges associated with bureaucratic procedures and relationships with local traders. The study also illustrates how economic interactions and the development of trust can contribute to broader processes of social acceptance. These findings suggest that entrepreneurial development depends not only on relationships within migrant communities but also on migrants' ability to establish connections beyond their immediate social environments.

Against this background, the present study focuses on Syrian and Sudanese migrants residing in Konya, Türkiye. The selection of these two migrant communities provides an opportunity to explore how different social networks, community relationships and forms of trust may influence entrepreneurial potential within the same urban and institutional environment. Rather than assuming that the two populations possess fundamentally different entrepreneurial characteristics, the study seeks to investigate their respective social capital resources and examine how these resources are associated with their perceived ability and willingness to engage in entrepreneurial activities. This comparative perspective also recognizes that migrants' social networks may extend across family relationships, community associations, other migrant groups, local businesses and institutional structures.

Furthermore, the study considers social capital as a multidimensional concept encompassing bonding, bridging and linking relationships. While bonding social capital concerns close relationships within family, friendship and migrant community networks, bridging social capital involves connections with individuals and groups beyond these immediate circles. Linking social capital, in turn, refers to relationships with formal institutions and organizations that may provide access to information, support and economic resources. The interaction

between these dimensions may shape migrants' capacity to recognize entrepreneurial opportunities, mobilize available resources and develop confidence in their entrepreneurial abilities (Putnam, 2000; Woolcock, 2001; see also Vershinina & Rodgers, 2023).

Although previous research has examined migrant entrepreneurship and the role of social capital in Türkiye, there remains a need to investigate how these relationships influence entrepreneurial potential among migrants who may not yet own or operate a business. Existing research on Afghan and Syrian entrepreneurs in Konya provides valuable insights into established entrepreneurial activities, but a broader examination of entrepreneurial intentions, perceived opportunities and resource mobilization can offer an additional perspective. Moreover, a comparative investigation involving Syrian and Sudanese migrants within the same city may contribute to a better understanding of how different configurations of social capital relate to entrepreneurial potential across migrant communities.

Accordingly, this study aims to explore the relationship between social capital and entrepreneurial potential among Syrian and Sudanese migrants in Konya, Türkiye. Using a pilot survey-based research design, it seeks to explore the relationship between migrants' social networks, interpersonal trust, institutional connections and their perceived entrepreneurial potential. By doing so, the research intends to contribute to the literature on migrant entrepreneurship by shifting attention from the characteristics of existing migrant-owned businesses towards the social resources and relational conditions that may encourage or constrain entrepreneurial participation.

2. Literature Review

Social capital has become an important concept in understanding the economic integration and entrepreneurial activities of migrant communities. Unlike financial or human capital, social capital refers to the resources that individuals can access through their social relationships, networks, trust and shared norms (Coleman, 1988; Putnam, 2000). For migrants, these relationships can be particularly important because they often face difficulties accessing formal financial resources, professional networks, market information and institutional support in their host countries. Consequently, social connections may serve as alternative channels through which migrants obtain information, identify business opportunities, mobilize resources and reduce the uncertainties associated with establishing a business.

In this context, social capital should not be understood merely as the existence of social relationships, but also as the capacity to transform these relationships into economic and entrepreneurial resources. Family members, relatives, friends, community associations and professional contacts can provide different forms of assistance, including financial support, business advice, information about local markets and access to potential customers. Therefore, the strength and diversity of migrants' social networks may influence their ability to recognize entrepreneurial opportunities and develop the confidence necessary to pursue them.

Social capital and migrant entrepreneurship

The relationship between social capital and migrant entrepreneurship has also been examined from different theoretical perspectives. Tolciu (2011), in “Migrant Entrepreneurs and Social Capital: A Revised Perspective”, challenges the assumption that migrant entrepreneurs depend exclusively on their ethnic or cultural communities. Based on 58 interviews with first- and second-generation Turkish entrepreneurs in Hamburg, the author argues that social capital can be understood as a strategic economic resource rather than simply a consequence of shared ethnic identity. This perspective is particularly relevant to the present study because it suggests that migrants' entrepreneurial decisions depend not only on relationships within their own communities but also on the economic opportunities and institutional conditions of the host society.

Similarly, Turkina and Thai (2013), in "Social Capital, Networks, Trust and Immigrant Entrepreneurship: A Cross-Country Analysis", demonstrate the importance of social networks, interpersonal trust and institutional trust in explaining differences in immigrant entrepreneurship across countries. Their findings indicate that these dimensions of social capital are significantly associated with immigrant entrepreneurial activity, particularly high-value-added entrepreneurship. This suggests that the entrepreneurial potential of migrants may depend not only on the number of social relationships they maintain but also on the degree of trust and institutional confidence embedded in those relationships.

Social networks and the entrepreneurial potential of migrants

One of the most important dimensions of social capital is the structure of social networks. In migrant communities, these networks can be examined through three complementary dimensions: bonding, bridging and linking social capital.

Bonding social capital refers to close relationships based on family ties, friendship, shared backgrounds and common migration experiences. These relationships may provide emotional support, informal financial assistance, business information and mutual trust. Bridging social capital, in contrast, refers to connections established with individuals and groups outside one's immediate migrant community, including members of the host society, local entrepreneurs and other professional networks. Linking social capital concerns relationships with institutions and individuals occupying positions of authority, such as public organizations, financial institutions, universities and business-support organizations (Putnam, 2000; Woolcock, 2001).

These distinctions are particularly important for migrant entrepreneurship because different forms of social relationships provide different resources. While close community networks can facilitate initial business activities, connections with local entrepreneurs and institutions may improve access to wider markets, formal financing, professional knowledge and business opportunities.

In the Turkish context, Afkari and Arıcıoğlu (2023) provide particularly relevant empirical evidence. Their qualitative study examines Afghan migrant entrepreneurs in Istanbul and Konya through semi-structured interviews with 15 entrepreneurs, comprising seven face-to-face and eight online interviews. Their findings indicate that Afghan entrepreneurs are predominantly motivated by necessity and that social capital plays an important role in their entrepreneurial decisions. Trust in their immediate environment, relationships within their communities and connections with local networks contribute to the establishment and development of their businesses. Furthermore, entrepreneurial activities appear to strengthen their social recognition and contribute to their acceptance by both Afghan and Turkish communities.

This research (Afkari & Arıcıoğlu, 2023) provides a particularly useful foundation for the present study because it demonstrates how social capital operates partly within the same geographical context, namely Konya (alongside Istanbul). However, its focus on Afghan entrepreneurs and qualitative research methods leaves room for further investigation into other migrant communities and the relationship between social capital and entrepreneurial potential before or beyond actual business establishment.

Another relevant contribution is provided by Karaarslan and Demirel (2023), in their chapter "Migrant Entrepreneur Women in Konya: Processes and Expectations". Based on qualitative interviews with 12 migrant women entrepreneurs from different backgrounds and economic sectors, the study highlights the importance of institutional support, spousal support and the cultural characteristics of the host city in shaping entrepreneurial experiences. It also identifies differences between migrants who intend to remain in Türkiye and continue their businesses and those who consider returning to their countries of origin. These findings demonstrate that entrepreneurial activities are influenced not only by individual motivation but also by family relationships, institutional conditions and expectations regarding the future.

Social capital, trust and economic integration in Konya

The relationship between social capital and economic integration becomes particularly visible when examining the experiences of Syrian entrepreneurs in Konya. Koyuncu (2020), in "Toplumsal Kabulde Ekonominin İmkânı: Konya'daki Suriyeli Girişimciler", investigates the entrepreneurial experiences of 72 Syrian entrepreneurs across 15 neighborhoods in Konya. The study examines their motivations for establishing businesses, their relationships with local residents and Turkish tradespeople, and the challenges they encounter in their economic activities. The findings indicate that Syrian entrepreneurs represent an economic opportunity rather than simply an economic burden. Nevertheless, bureaucratic obstacles and insufficient social capital initially limit their relationships with local businesses. Importantly, the study suggests that the development of trust-based economic relationships over time can facilitate social acceptance and integration. This finding highlights the possibility of a reciprocal relationship: social capital can facilitate economic activity, while economic interaction can also contribute to the development of new social relationships and trust between migrant and host communities.

A broader perspective is offered by Becerikli and Varol (2024), in their study "An Importance and Contribution of Social Capital on the Formation Process of Immigrant Entrepreneurship Networks". Their review of national and international literature establishes that social capital plays a significant role in the formation of migrant entrepreneurial networks. The authors particularly emphasize trust, cooperation and relationships extending beyond the country of residence. They also highlight the transnational character of migrant networks, through which connections with countries of origin may contribute to entrepreneurial activities in host societies. This perspective is relevant to Syrian and Sudanese migrants in Konya, whose social relationships may extend across local communities, migrant networks and their countries of origin.

Recent empirical evidence on social capital and entrepreneurship

More recent empirical research further supports the relationship between social capital and entrepreneurial activity. Wang, Dong and Yang (2025), in their article "Social Capital, Digital Economy and the Entrepreneurship of the New Generation of Migrant Youth", analyze data from China's 2018 China Migrants Dynamic Survey (CMDS) on internal migrants. Their findings demonstrate that social capital significantly promotes migrant youth entrepreneurship. In particular, social networks, social trust and social status have positive and statistically significant effects on entrepreneurial participation. However, social participation alone does not demonstrate a statistically significant effect in their model.

An especially important finding is that social capital has a stronger relationship with opportunity-driven entrepreneurship than with necessity-driven entrepreneurship. The authors also identify the digital economy as a factor that strengthens the entrepreneurial contribution of social capital. These findings provide recent empirical support for examining social networks and trust as important explanatory dimensions of migrant entrepreneurial potential.

In addition, Akcan (2023), in "Current Analysis of the Effects of Refugee Entrepreneurs and Workers on the Turkish Economic Development and Labor Market", examines the broader economic implications of refugee entrepreneurship and employment in Türkiye. The study discusses potential contributions to productivity, business costs and foreign competition, while also acknowledging possible labor-market challenges. Although its primary focus is economic effects rather than social capital, it helps establish the wider economic significance of refugee entrepreneurship in the Turkish context.

3. Research gap and contribution of the present study

The reviewed literature, which is largely qualitative, points to a positive relationship between social capital and migrant entrepreneurship. Nevertheless, several research gaps remain.

First, existing studies conducted in Türkiye have mainly concentrated on migrants who have already established businesses. For example, Afkari and Arıcıoğlu (2023) investigate Afghan entrepreneurs, while Koyuncu (2020) focuses on Syrian business owners in Konya. Although these studies provide valuable insights into the role of social relationships in business establishment, they do not directly examine the entrepreneurial potential of migrants who may not yet have established a business.

Second, to the authors' knowledge, previous research has generally focused on individual migrant communities rather than comparing different migrant populations within the same urban environment. This creates an opportunity to investigate whether social capital operates similarly among Syrian and Sudanese migrants living under relatively similar local economic and institutional conditions.

Third, the literature suggests that social capital consists of different dimensions, including social networks, interpersonal trust, institutional relationships and community support. However, further research is needed to understand how these dimensions relate to migrants' perceived entrepreneurial opportunities, business intentions and confidence in their entrepreneurial abilities.

Against this background, the present study seeks to contribute to the literature by exploring the relationship between social capital and entrepreneurial potential among Syrian and Sudanese migrants in Konya, Türkiye. Unlike studies focusing exclusively on existing migrant entrepreneurs, this research adopts a broader perspective by considering both individuals who have established businesses and those who possess entrepreneurial intentions or perceive opportunities for future business activities.

The comparative perspective also offers an opportunity to examine whether differences in social networks, trust, community relationships and access to institutional resources are associated with variations in entrepreneurial potential between the two migrant communities.

Expected relationship between social capital and entrepreneurial potential

Based on the reviewed literature, social capital is expected to have a positive relationship with entrepreneurial potential. Migrants who maintain stronger social networks may have greater access to business information, financial assistance, professional advice and potential business partners. Similarly, interpersonal trust may reduce uncertainty and encourage cooperation, while institutional connections may facilitate access to formal support mechanisms and business opportunities.

For the empirical investigation, the following relationships are proposed:

Social capital dimension	Expected relationship with entrepreneurial potential
Bonding social capital	Positive (+)
Bridging social capital	Positive (+)
Linking social capital	Positive (+)
Interpersonal trust	Positive (+)
Institutional trust	Positive (+)

4- **Main research hypothesis:**

H1: Social capital is positively and significantly associated with entrepreneurial potential among Syrian and Sudanese migrants in Konya.

Additional hypotheses:

- H1a: Bonding social capital is positively associated with entrepreneurial potential.
- H1b: Bridging social capital is positively associated with entrepreneurial potential.
- H1c: Linking social capital is positively associated with entrepreneurial potential.
- H1d: Interpersonal and institutional trust are positively associated with entrepreneurial potential.

These hypotheses are examined through a structured questionnaire using a five-point Likert scale. Since the research is designed as a pilot study, the primary objective also includes assessing the clarity, reliability and suitability of the measurement instruments before conducting a larger investigation.

5. Research methodology

Research design

The present study employs a quantitative, cross-sectional pilot survey design to investigate the association between social capital and entrepreneurial potential among Syrian and Sudanese migrants residing in Konya, Türkiye. The analysis focuses on the extent to which the structural, relational and cognitive dimensions of social capital—further differentiated into bonding, bridging and linking forms—are related to migrants' entrepreneurial intentions, capacity for opportunity recognition and self-assessed entrepreneurial capability.

The pilot character of the research serves a dual purpose: it permits an initial examination of the hypothesized relationships while simultaneously allowing an assessment of the suitability of the measurement instruments and the practical feasibility of the data-collection procedures. By concentrating on two distinct migrant communities located within a common urban setting, the study offers an exploratory perspective on the role of social capital in the formation of entrepreneurial potential.

Population and sampling

The target population comprises Syrian and Sudanese migrants of working age who reside in the city of Konya. Respondents are selected through a combination of purposive and snowball sampling procedures, implemented with the assistance of migrant community associations and non-governmental organizations.

Purposive sampling is employed to ensure that participants satisfy predefined eligibility criteria, while snowball sampling facilitates the identification of additional respondents via existing social networks. Although this non-probability strategy is well suited to the exploratory investigation of hard-to-reach migrant populations, it necessarily restricts the external validity of the findings beyond the specific sample obtained.

Data collection and measurement of variables

Primary data are gathered by means of a structured questionnaire administered in both Arabic and Turkish. The instrument encompasses socio-demographic characteristics, multi-dimensional measures of social capital, indicators of entrepreneurial potential, aspects of economic integration, perceived access to resources and perceived entrepreneurial barriers. Data were collected between October and November 2026 face to face and online.

Social capital constitutes the principal independent variable and is operationalized through its structural, relational and cognitive dimensions (Nahapiet & Ghoshal, 1998). These dimensions are further disaggregated into bonding capital (ties with family and co-ethnic community members), bridging capital (connections extending beyond immediate social circles) and linking capital (relations with formal institutions and organizations).

Entrepreneurial potential serves as the dependent variable and is measured by a composite of entrepreneurial intention, opportunity recognition and perceived entrepreneurial capability. Perceived access to finance and

prior business experience are introduced as additional explanatory variables, while selected socio-demographic attributes function as control variables.

Econometric model specification and data analysis

To empirically examine the relationship between social capital and entrepreneurial potential, this study employs a multiple linear regression framework. Entrepreneurial potential is specified as the dependent variable, with social capital serving as the primary explanatory variable.

The baseline econometric model is expressed as follows:

$$EP_i = \beta_0 + \beta_1 SC_i + \beta_2 PE_i + \sum_{k=1}^{K} \gamma_k CV_{ki} + \varepsilon_i \quad (1)$$

Where:

- *EPi*: Entrepreneurial potential of respondent *i*.
- *SCi*: Social capital of respondent *i*.
- *PEi*: Previous entrepreneurial or business experience of respondent *i*.
- *CVki*: A vector of control variables, including age, gender, education level, and duration of residence in Türkiye (k = 1, …, K).
- *β*0: Intercept (constant term).
- *β*1,*β*2,*γk*: Parameters to be estimated.
- ε_i: Error term.

To examine distinct forms of social capital in greater detail, an extended specification is estimated:

$$EP_i = \beta_0 + \beta_1 BS_i + \beta_2 BRS_i + \beta_3 LS_i + \beta_4 PE_i + \sum_{k=1}^{K} \gamma_k CV_{ki} + \varepsilon_i \quad (2)$$

Where:

- BS_i: Bonding social capital.
- BRS_i: Bridging social capital.
- LS_i: Linking social capital.

In this extended model, the coefficients *β*1, *β*2, and *β*3 capture the independent associations between each form of social capital and entrepreneurial potential. Statistically significant positive coefficients would provide preliminary empirical support for the corresponding research hypotheses. The coefficient β4 captures the association between previous business experience and entrepreneurial potential.

Depending on the measurement properties and reliability of the survey data, the empirical analysis will also evaluate the structural, relational, and cognitive dimensions of social capital. If sample size and construct validity permit, these dimensions will be estimated through separate specifications.

Given the exploratory nature of this pilot study, all regression estimates are interpreted as conditional associations rather than definitive causal effects.

Estimation is conducted by Ordinary Least Squares (OLS). Heteroskedasticity-robust standard errors are employed throughout.

Prior to model estimation, the following preparatory and diagnostic procedures are undertaken. Descriptive statistics—comprising frequencies, percentages, means and standard deviations—are used to characterize the sample and the distribution of the principal variables. Cronbach's alpha is performed to assess the internal consistency of multi-item scales. Subject to the adequacy of the sample size, exploratory factor analysis is performed to evaluate the underlying dimensional structure of the social-capital and entrepreneurial-potential

constructs. Pairwise correlation analysis provides preliminary evidence concerning the direction and magnitude of associations among the key variables.

Because the pilot sample (n = 22) is too small to estimate the multiple-regression models specified above, these models are reserved for the main study, and this paper reports descriptive statistics only. Comparisons between Syrian and Sudanese respondents are planned for the main study in order to identify potential differences in social-capital endowments and entrepreneurial perceptions.

In light of the cross-sectional design, the non-probability sampling procedure and the pilot nature of the investigation, the estimated coefficients are interpreted strictly as conditional associations rather than as causal effects.

Ethical considerations

Participation in the study is entirely voluntary. Prospective respondents are fully informed of the research objectives and of their rights prior to the administration of the questionnaire. Informed consent is obtained from all participants, and the confidentiality of individual responses is rigorously maintained. Data are utilized exclusively for academic purposes and are processed in accordance with applicable institutional guidelines and data-protection regulations.

6. Empirical findings

Socio-demographic profile of respondents

The pilot survey generated 22 valid responses from Syrian and Sudanese migrants residing in Konya, Türkiye. The socio-demographic profile of the respondents provides an initial overview of the sample and establishes the background for examining the relationship between social capital and entrepreneurial potential.

Regarding nationality, 13 respondents (59.1%) were Syrian, while 9 respondents (40.9%) were Sudanese. This distribution indicates that both migrant communities are represented in the pilot sample, although Syrian respondents constitute a slightly larger proportion.

In terms of age, the sample is predominantly composed of young adults. Seventeen respondents (77.3%) were aged between 18 and 24, while four (18.2%) were between 25 and 34. Only one respondent (4.5%) belonged to the 35–44 age group. This age distribution suggests that the findings primarily reflect the perceptions and experiences of younger migrants.

Regarding gender, 13 respondents (59.1%) were male and 9 (40.9%) were female. Concerning educational attainment, the responses indicate a generally educated sample.

With respect to respondents' status in Konya, 17 participants (77.3%) identified as students. The remaining respondents reported different circumstances, including employment, job seeking and other personal situations. This composition is particularly relevant when interpreting entrepreneurial potential, as students may express entrepreneurial intentions without necessarily having immediate access to the financial and professional resources required to establish a business.

Finally, the duration of residence in Konya indicates that most respondents have relatively long-term experience in the city. Eight participants (36.4%) reported residing in Konya for 7–10 years, while seven (31.8%) had lived there for 4–6 years. Four respondents (18.2%) reported more than ten years of residence, two (9.1%) between one and three years, and one (4.5%) less than one year.

Overall, the sample is characterized by a predominance of young, student respondents, with a relatively substantial period of residence in Konya. These characteristics provide important contextual information for

interpreting the subsequent findings concerning social networks, economic integration and entrepreneurial potential.

Table 1: Socio-demographic characteristics of respondents

Characteristics	Frequency	Percentage
Nationality		
Syrian	13	59.1%
Sudanese	9	40.9%
Age		
18–24	17	77.3%
25–34	4	18.2%
35–44	1	4.5%
Gender		
Male	13	59.1%
Female	9	40.9%
Current status in Konya		
Student	17	77.3%
Employed	2	9.1%
Other reported situations	3	13.6%
Duration of residence in Konya		
Less than 1 year	1	4.5%
1–3 years	2	9.1%
4–6 years	7	31.8%
7–10 years	8	36.4%
More than 10 years	4	18.2%

Source: Author's calculations based on the pilot survey (n = 22). Percentages may differ slightly from 100% due to rounding.

Descriptive analysis of the main research variables

Following the examination of the respondents' socio-demographic characteristics, descriptive statistics were calculated to assess their perceptions of social capital, entrepreneurial potential and economic integration. The questionnaire employed a five-point Likert scale, ranging from 1 (strongly disagree) to 5 (strongly agree).

Regarding social capital, respondents reported a relatively positive perception of the availability of support within their respective migrant communities. The highest mean score within this group was recorded for the availability of individuals who could provide assistance when needed (M = 3.77). However, the perceived positive economic contribution of the migrant community or its associations received a comparatively lower score (M = 2.86). This difference suggests that the availability of interpersonal support does not necessarily translate into an equally strong perception of collective economic benefits.

Concerning entrepreneurial potential, the intention to establish a business in the future received a relatively high mean score (M = 4.09). Respondents also expressed a positive perception of the possibility of establishing successful businesses in Konya (M = 4.36). Nevertheless, their self-assessed entrepreneurial knowledge and skills recorded a lower mean (M = 3.14). This preliminary pattern points to a distinction between entrepreneurial aspirations and respondents' perceived preparedness to establish a business.

In relation to economic integration, purchasing products or services from Turkish businesses received a mean score of 4.09. By contrast, professional connections with Turkish businesspeople and entrepreneurs recorded a lower mean (M = 2.91). This difference indicates that everyday economic participation may be more developed than professional networking among the respondents.

Table 2: Descriptive statistics of selected Likert-scale items

Research dimension and item	Mean	Std. deviation
Social capital		
Availability of community support (Q7)	3.77	1.15
Access to economic information through community members (Q8)	3.36	1.05
Participation in community activities (Q9)	3.23	1.11
Positive economic contribution of the community (Q10)	2.86	1.39
Access to opportunities through community relationships (Q11)	3.27	1.16
Entrepreneurial potential indicators		
Intention to establish a business (Q12)	4.09	1.27
Considering investment or business establishment in Konya (Q13)	3.18	1.26
Self-assessed entrepreneurial knowledge and skills (Q14)	3.14	1.36
Perceived entrepreneurial opportunities in Konya (Q15)	3.77	1.11
Economic integration		
Economic and commercial relationships with Turkish citizens (Q17)	3.59	0.91
Purchasing from Turkish businesses (Q18)	4.09	0.97
Professional connections with Turkish entrepreneurs (Q19)	2.91	1.27
Feeling part of Konya's economic life (Q20)	3.32	1.13
Increased participation in economic activities (Q21)	3.00	1.27

Note: Q16, which measures beliefs about the capacity of Syrians and Sudanese to establish successful businesses, is treated separately because it concerns a collective perception rather than the respondent's own entrepreneurial potential.

Source: Author's calculations based on the pilot survey (n = 22).

Barriers to Migrant Entrepreneurship

The findings indicate that financial constraints constitute the most frequently reported barriers to entrepreneurial activity among the Syrian and Sudanese respondents in Konya. Respondents could select more than one barrier, so percentages do not sum to 100%. Specifically, 68.2% of participants identified insufficient capital as a major obstacle, while 63.6% reported difficulties in accessing finance. These results suggest that limited financial resources and restricted access to external funding represent significant challenges for aspiring migrant entrepreneurs.

Beyond financial constraints, institutional and regulatory barriers also appear to be substantial. Approximately 59.1% of respondents reported insufficient knowledge of legal and regulatory procedures, while 50% indicated a lack of information about government entrepreneurship support programs. Furthermore, 40.9% identified bureaucratic (administrative) procedures as an obstacle. This pattern suggests that access to institutional information and an understanding of the business environment are important conditions for entrepreneurial engagement.

Social and professional networking represents another relevant dimension. A total of 40.9% of respondents identified insufficient business connections as a barrier. This finding is particularly relevant to the social capital perspective of the study, as entrepreneurial development may depend not only on relationships within migrant communities but also on connections with local entrepreneurs, suppliers, customers and institutional actors. In this respect, the development of bridging and linking social capital may facilitate access to resources and opportunities beyond migrants' immediate social networks.

Finally, language and cultural barriers were reported less frequently than financial and institutional constraints. While 27.3% of respondents identified insufficient knowledge of Turkish business culture, 18.2% reported inadequate Turkish language skills as an obstacle. Although these percentages are comparatively lower, they should not be interpreted as evidence that language and cultural factors are insignificant.

Table 3: Key barriers to entrepreneurship among respondents: frequency and percentage distribution

Barrier option (English)	Original wording (Turkish)	Respondents (n)	Share of respondents (%)
Insufficient capital	Sermaye yetersizliği	15	68.2
Access to finance	Finansmana erişim	14	63.6
Knowledge of legal/regulatory procedures	Hukuki/mevzuat bilgisi	13	59.1
Lack of information about government support	Devlet destekleri hakkında bilgi eksikliği	11	50
Bureaucratic procedures	Bürokratik işlemler	9	40.9
Insufficient business connections	İş bağlantılarının yetersizliği	9	40.9
Lack of market knowledge	Pazar bilgisi eksikliği	7	31.8
Insufficient knowledge of Turkish business culture	Türkiye'deki iş kültürünü yeterince bilmeme	6	27.3
Turkish language skills	Türkçe dil bilgisi	4	18.2

Source: Pilot survey, Q22 (n = 22). Respondents could select several options, so percentages do not sum to 100%.

Overall, the findings reveal that migrant entrepreneurship in the surveyed population is constrained by a combination of financial, institutional and network-related factors. Given the pilot nature and limited sample size of the study, these results should be interpreted as exploratory evidence rather than representative estimates of the wider Syrian and Sudanese migrant populations in Konya.

7. Discussion and comments

The findings of this pilot study provide preliminary insights into the relationship between social capital and entrepreneurial potential among Syrian and Sudanese migrants residing in Konya, Türkiye. Overall, the results suggest that entrepreneurial aspirations exist within the surveyed population; however, these aspirations are accompanied by financial, institutional and network-related constraints.

One of the most notable findings concerns the relatively high level of entrepreneurial intention among respondents. The mean score for the intention to establish a business in the future was 4.09 out of 5, while the perception of entrepreneurial opportunities in Konya reached 3.77. These results indicate a positive orientation towards entrepreneurship. Nevertheless, respondents' self-assessed knowledge and skills for establishing a business were comparatively lower, with a mean score of 3.14. This difference suggests a potential gap between entrepreneurial motivation and perceived entrepreneurial readiness. In other words, the willingness to become an entrepreneur does not necessarily imply that individuals possess the resources, knowledge and practical capabilities required to establish a sustainable business.

The findings also highlight the importance of community-based social networks. Respondents reported a relatively positive perception of the availability of support within their communities (mean = 3.77). However, the perceived contribution of community networks to their economic lives was lower (mean = 2.86). This distinction is particularly relevant to the social capital perspective. Although close community relationships may provide emotional support, information and a sense of belonging, their economic contribution may remain limited when they do not generate access to wider business opportunities, financial resources and institutional support.

The analysis of economic integration reinforces this observation. While purchasing products and services from Turkish businesses received a relatively high mean score (4.09), professional connections with Turkish entrepreneurs and businesspeople were considerably lower (2.91). This difference suggests that participation in the local consumer market does not automatically translate into integration into professional and entrepreneurial networks. Therefore, the development of bridging social capital, through relationships with local entrepreneurs and other economic actors, may represent an important pathway towards expanding

migrants' entrepreneurial opportunities. Similarly, linking social capital may facilitate access to public institutions, financial organizations and business support programs.

The analysis of entrepreneurial barriers provides further evidence of the structural challenges faced by respondents. Insufficient capital (68.2%) and difficulties in accessing finance (63.6%) were the most frequently reported obstacles. These were followed by insufficient knowledge of legal and regulatory procedures (59.1%) and limited information about government support programs (50%). In addition, 40.9% of respondents identified insufficient business connections as a constraint. These findings indicate that entrepreneurial challenges cannot be understood exclusively through individual motivation or skills. They are also shaped by the institutional and economic environment in which migrants attempt to establish or develop businesses.

An additional finding concerns the limited awareness of entrepreneurship support mechanisms in Türkiye. The mean score for respondents' knowledge of available support programs was only 2.23 out of 5. This result, considered alongside the high demand for entrepreneurship training and business development programs (mean = 4.32), points to a possible gap between existing support mechanisms and migrants' awareness of or access to them.

Taken together, these findings suggest that social capital should not be understood simply in terms of the number or strength of social relationships. Its potential economic value also depends on the capacity of networks to connect individuals with resources, institutions and opportunities beyond their immediate communities. Nevertheless, the present results are descriptive and exploratory. They do not establish a statistically verified causal relationship between social capital and entrepreneurial potential.

8. Recommendations for local ecosystems

The findings point to the need for a more inclusive local entrepreneurial ecosystem in Konya, in which migrant communities are recognized not only as beneficiaries of social assistance but also as potential contributors to local economic development. The following recommendations are proposed for local authorities, universities, business organizations, financial institutions and migrant-support organizations.

- Establish migrant-oriented entrepreneurship information and guidance services.

Local institutions should provide accessible information on business registration, legal requirements, taxation, work permits, financial obligations and available entrepreneurship support programs. Information should be delivered through multilingual guidance materials and practical consultation sessions, particularly in Turkish, Arabic and English where appropriate. Cooperation between municipal authorities, chambers of commerce and migrant associations could facilitate access to these services.

- Develop financial inclusion and access-to-finance mechanisms.

Given the high proportion of respondents identifying insufficient capital and limited access to finance as major barriers, local ecosystem actors should strengthen financial guidance and referral mechanisms. Partnerships with banks, microfinance organizations and relevant support institutions could help migrants understand available financing options, eligibility requirements and business financing procedures. Financial literacy training and business-plan development workshops should also be encouraged.

- Strengthen bridging social capital through structured networking.

The relatively low level of professional connections with Turkish entrepreneurs indicates the importance of creating opportunities for interaction beyond migrants' immediate communities. Local chambers of commerce, business associations, universities and entrepreneurship centers could organize networking events, business-matching activities, mentoring programs and sector-specific meetings. Such initiatives could connect migrant entrepreneurs with Turkish business owners, suppliers, customers and potential partners.

- Improve linking social capital through institutional partnerships.

Local authorities and public institutions should establish regular communication channels with migrant associations and community representatives. Designated contact points, institutional orientation sessions and referral mechanisms could help migrants navigate administrative procedures and identify relevant support programs. These arrangements would reduce information barriers and strengthen institutional trust.

- Introduce entrepreneurship training and business development programs.

Universities, entrepreneurship centers and local development organizations should offer practical training covering business planning, market research, financial management, taxation, digital marketing, e-commerce and Turkish business practices. Programs should be designed according to participants' educational backgrounds, language abilities and business experience. Mentorship and post-training follow-up would help translate acquired knowledge into practical entrepreneurial activities.

- Promote university–business–community cooperation.

Universities in Konya could play a facilitating role by bringing together migrant students, researchers, local entrepreneurs and business organizations. Entrepreneurship competitions, incubation opportunities, applied research projects and student-led business initiatives could encourage the development of new ideas and strengthen professional networks. Such cooperation would also enable local businesses to benefit from migrants' linguistic, cultural and transnational knowledge.

- Support migrant-led and transnational business initiatives.

The willingness of respondents to contribute to future commercial and economic links between Syria, Sudan and Konya (mean = 3.86) suggests an opportunity to explore transnational entrepreneurship. Local business organizations could facilitate trade information sessions, international business networking and partnerships involving migrant entrepreneurs. These initiatives may contribute to the internationalization of local businesses while supporting migrants' economic participation.

Overall, these recommendations emphasize that strengthening migrant entrepreneurship requires more than individual training or financial assistance. It requires coordinated action among local institutions and the development of an ecosystem in which financial resources, institutional support and social networks complement one another.

9. Conclusion

This pilot study examined the relationship between social capital and entrepreneurial potential among Syrian and Sudanese migrants residing in Konya, Türkiye. By focusing on community networks, economic integration, entrepreneurial aspirations and perceived barriers, the study aimed to provide preliminary evidence on the role of social relationships in shaping migrants' entrepreneurial opportunities. The descriptive findings reveal a relatively high level of entrepreneurial intention among respondents, alongside positive perceptions of business opportunities in Konya. However, this potential appears to coexist with limitations in perceived entrepreneurial knowledge and skills, access to finance and awareness of institutional support mechanisms. The results further suggest that community-based relationships provide a degree of support, but their perceived contribution to economic life remains comparatively limited. In particular, the difference between relatively frequent commercial interactions with Turkish businesses and weaker professional connections with Turkish entrepreneurs highlights the importance of developing broader economic networks.

From a social capital perspective, the findings underline the distinction between bonding relationships within migrant communities and bridging and linking connections with the wider economic and institutional environment. While bonding social capital may provide solidarity and immediate support, bridging and linking

relationships may offer additional opportunities to access markets, business knowledge, financial resources and formal institutions. The development of these complementary forms of social capital therefore deserves greater attention in policies supporting migrant entrepreneurship.

The study also contributes to the discussion of local economic development by highlighting the potential role of migrant communities in strengthening Konya's entrepreneurial ecosystem. Rather than treating migrants exclusively as recipients of integration policies, local stakeholders may recognize them as potential entrepreneurs, economic actors and contributors to international commercial networks. This perspective calls for more accessible institutional information, financial inclusion, entrepreneurship training, mentoring and structured networking opportunities.

Nevertheless, several limitations must be acknowledged. First, the study is based on a small pilot sample of 22 respondents, comprising 13 Syrians and 9 Sudanese. Consequently, the findings cannot be generalized to the wider Syrian and Sudanese populations in Konya or Türkiye. Second, the cross-sectional design provides a snapshot of respondents' perceptions and does not permit causal conclusions. Third, the questionnaire primarily captures community-based relationships and does not measure all dimensions of bridging and linking social capital sufficiently. Fourth, the sample is dominated by students (77.3%) recruited through snowball sampling, and results are not reported separately for Syrian and Sudanese respondents. Finally, entrepreneurial intention, perceived entrepreneurial capability and actual entrepreneurial behavior represent distinct concepts that should be measured separately in subsequent research.

Future research should therefore employ a larger and more diverse sample, improve the measurement of the different dimensions and forms of social capital, and examine the relationships between social networks, institutional access, financial resources and entrepreneurial outcomes through appropriate statistical methods. Comparative studies involving additional migrant communities and other cities in Türkiye could also provide a broader understanding of how local entrepreneurial ecosystems shape migrant entrepreneurship.

In conclusion, this pilot study suggests that the entrepreneurial potential of Syrian and Sudanese migrants in Konya should be understood through the interaction of individual aspirations, social networks and institutional conditions. The central challenge is not simply to encourage migrants to become entrepreneurs, but to create the economic and institutional conditions through which their aspirations and social resources can be transformed into viable and sustainable entrepreneurial opportunities.

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FULL PAPER · IP2.3 · IN-PERSON SESSION II

How Do Climate Policies Affect Women's Economic Empowerment? An Analysis from a Feminist Climate Justice Perspective

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ABSTRACT

The purpose of this study is to examine how climate policies affect women's economic empowerment from a feminist climate justice perspective.

The study examines the effects of climate change and climate policies on women's employment, income, care work, and economic decision-making processes. It assesses that these effects can exacerbate existing gender inequalities, while gender-sensitive climate policies offer important tools that can support women's economic empowerment.

In this context, the study demonstrates that climate policies must be shaped not only in line with environmental goals but also with due regard for the principles of gender equality and economic justice.

Keywords: Feminist Climate Justice, Climate Policies, Gender Equality, Women's Economic Empowerment

1. Introduction

Climate change is not merely an environmental issue consisting of physical processes such as rising temperatures, drought, or extreme weather events. The consequences of the climate crisis are closely linked to individuals' access to water, food, shelter, health care, and productive resources. The crisis also affects employment conditions, income distribution, caregiving responsibilities, and public decision-making processes. For this reason, climate policies cannot be viewed solely as technical interventions that reduce greenhouse gas emissions or facilitate adaptation to climate risks. These policies also determine how economic resources, social costs, and public responsibilities are distributed (IPCC, 2022; Turquet et al., 2023).

The impacts of climate change are not distributed equally across all segments of society. Factors such as income, class, age, disability status, ethnicity, immigration status, and place of residence influence the level of exposure to climate risks and the capacity to cope with them. Gender is also one of the key determinants of these disparities.

The concentration of women in sectors directly or indirectly affected by climate change—such as agriculture, food production, tourism, health, education, and domestic services—increases their economic vulnerability. In addition, a significant portion of the care for children, the sick, the elderly, and people with disabilities is provided by women without compensation. Inequalities in access to land ownership, credit, insurance, technology, and means of production also limit women's capacity to adapt to climate shocks (ICRW, 2020; IPCC, 2022).

Under these conditions, women's economic empowerment cannot be reduced solely to their participation in paid work or their ability to generate income. Economic empowerment must be assessed in conjunction with access to resources, control over income and assets, time use, participation in economic decisions, and the capacity to make strategic life choices (Kabeer, 1999). Therefore, when examining the impacts of climate

policies on women, factors such as care work, time poverty, property rights, financing, and representation must be taken into account alongside employment indicators.

Gender inequalities persist in Türkiye with regard to women's labor force participation, formal employment, and access to productive assets. Women tend to be concentrated particularly in informal, seasonal, and jobs with limited social security coverage. Climate-related disasters, losses in agricultural production, and rising costs of living are making these inequalities more visible. The fact that care and livelihood strategies aimed at protecting household well-being during times of disaster or economic crisis rely heavily on women's labor can limit women's opportunities for paid work and education (Külcür, 2020, 2022).

The feminist climate justice approach addresses the climate crisis in conjunction with gender, class, and other inequalities. This approach does not view women as a homogeneous social category. The positions of a woman working as an unpaid family laborer in a rural area and a woman with a secure job in an urban area are not the same when it comes to climate risks and policy opportunities. Therefore, simply increasing the numerical representation of women in climate policies is not sufficient. We must also examine which women are able to participate in decision-making processes, who benefits from climate finance, and how policies affect existing power dynamics (Djoudi et al., 2016).

The central research question of this study is: Through which distributive and institutional mechanisms do climate policies support or limit women's economic empowerment? By interpreting Kabeer's (1999) approach—which focuses on resources, agency, and gains—in conjunction with the principles of recognition, redistribution, representation, and reparation in feminist climate justice, this study offers a comparative analysis of four policy areas.

This study is a qualitative, thematic document review that examines the relationship between feminist climate justice and women's economic empowerment through secondary sources. No primary field data was collected. The review is based on reports from international organizations, Türkiye's climate policy documents, and relevant academic literature. Therefore, the findings below should be interpreted not as directly measured policy impacts, but as an analytical synthesis of the mechanisms defined in the literature.

2. Conceptual and Theoretical Framework

2.1. Feminist Climate Justice

The climate justice approach is based on the recognition that the economic activities causing the climate crisis and the harms resulting from the crisis are not distributed equally among countries, classes, and social groups. Historically, the countries and social groups that have produced the most greenhouse gas emissions are often not the same as those most severely affected by the consequences of climate change. A similar inequality is also evident at the household and community levels. Exposure to climate risks, the capacity to adapt to these risks, and the ability to compensate for resulting damages depend on factors such as income, property ownership, social protection, and political representation.

Feminist climate justice examines these inequalities through the lens of gender regimes and power relations. Rather than attributing women's vulnerability to climate change to biological differences, it focuses on structural factors such as property arrangements, the gendered division of labor, social norms, precarious employment, and exclusion from decision-making processes (Terry, 2009; Turquet et al., 2023).

The feminist climate justice framework developed by UN Women is based on four core principles: recognition, redistribution, representation, and reparations. Recognition refers to making visible in policies the ways in which women and other disadvantaged groups experience climate change. Redistribution requires a fair sharing of the costs of the climate crisis and the resources and opportunities provided by the green transition.

Representation envisions women not merely as beneficiaries of policy, but as active participants in policy design, implementation, and oversight. Reparation, meanwhile, encompasses social protection, compensation, and financing mechanisms that will mitigate the harms caused by historical and structural inequalities (Turquet et al., 2023).

The feminist institutionalism approach also demonstrates that public institutions and policies are not entirely gender-neutral. Even if official rules appear equal, institutions' informal norms, work cultures, and decision-making practices can reproduce gender inequalities (Chappell, 2006; Kenny, 2007). For this reason, gender equality must be adopted not as an afterthought to climate policies, but as a fundamental principle applied at every stage of policy design.

2.2. Ecofeminism, Feminist Political Ecology, and Materialist Ecofeminism

Ecofeminism draws a connection between the exploitation of nature and the devaluation of women's labor and lives. According to ecofeminist perspectives, patriarchal and capitalist relations of production treat both natural resources and the care labor that ensures the reproduction of life as unlimited and low-cost resources (Merchant, 1996; Mies & Shiva, 1993).

However, essentialist interpretations suggesting that women are biologically closer to nature have been criticized. Such interpretations can reinforce traditional gender roles by defining women as the natural guardians of the environment or as passive victims of the climate crisis (Terry, 2009).

Feminist political ecology explains women's relationship with the environment not so much through biological characteristics as through relationships of ownership, labor, access to resources, and decision-making. It examines who controls natural resources, who bears the burden of environmental harm, and who has a say in policy decisions (Nightingale, 2006; Rocheleau et al., 2013).

Materialist ecofeminism, on the other hand, focuses specifically on unpaid care work and social reproduction. The invisibility of the economic value of caring for children, the elderly, and the sick, as well as daily household chores, limits women's participation in paid employment and public life (Mellor, 2000). When climate change makes access to water and food more difficult or increases health and care needs, this invisible labor becomes even more burdensome, robbing women of time they could otherwise devote to themselves and placing an excessive burden of the cost of invisible care labor on women's shoulders.

2.3. Naila Kabeer's Approach to Women's Empowerment

Kabeer (1999) defines empowerment as the process by which individuals who previously had limited opportunities to make strategic life choices acquire this capacity. This process consists of three dimensions: resources, agency, and gains.

Resources include not only material assets but also education, health, skills, social networks, and institutional rights. Access to land, credit, technology, education, and social protection can be considered within this scope.

Agency refers to individuals' capacity to set goals, make decisions, negotiate existing power relations, and take action in line with their preferences.

Gains, on the other hand, refer to the concrete outcomes of the empowerment process, such as well-being, economic autonomy, social status, and equal citizenship.

Climate policies can affect these three dimensions in different ways. Women's access to climate finance and green skills programs can increase their resources. Participation in income-generating activities and having a say in economic decisions can strengthen agency. Effective representation on climate committees and in local governments can support both agency and social gains. Conversely, rising energy and food costs, an increased

burden of unpaid care work, or the tying of climate support to property ownership conditions can limit the empowerment process (UN Women, 2023).

2.4. Dimensions of Environmental Justice

Environmental justice encompasses not only the distribution of resources and environmental risks but also participation in decision-making processes and the recognition of different social groups (Schlosberg, 2007). By adding the dimension of interactive justice—which refers to fair and respectful treatment in interactions with institutions (Colquitt, 2001)—to this framework, climate policies are evaluated from a gender perspective.

Distributive justice concerns how environmental risks and the resources provided by climate policies are shared within society. The fact that women bear the costs of the climate crisis disproportionately while benefiting only to a limited extent from financing and green employment opportunities constitutes a distributive justice issue.

Procedural justice requires that environmental decisions be made through transparent and participatory processes. The insufficient representation of women on climate committees and their lack of adequate representation in local governments and policy-making processes fall under this category.

Interactional justice refers to individuals being treated with respect and free from discrimination in their interactions with institutions.

Recognition justice, on the other hand, requires that the needs, knowledge, and experiences of different social groups be made visible in public policies.

For a climate policy to be considered fair, these dimensions must be evaluated together.

3. Findings and Discussion

3.1. Employment and Income: The Opportunities and Risks of the Green Transition

Climate change affects employment and income through losses in agricultural productivity, water scarcity, extreme temperatures, shifts in tourism seasons, and harsher working conditions. The concentration of women in low-wage, seasonal, informal, or unpaid family labor roles in climate-sensitive sectors further increases the risk of economic loss (ICRW, 2020; IPCC, 2022).

Emissions reduction policies, on the other hand, are creating new jobs in areas such as renewable energy, energy efficiency, the circular economy, sustainable transportation, and green buildings. However, the emergence of green jobs does not necessarily mean that women will automatically have equal access to these positions. The male-dominated nature of technical professions, engineering, and construction may prevent women from fully benefiting from the economic opportunities of the green transition (ILO, 2024; OECD, 2025).

Therefore, women's participation in green employment should not be assessed solely based on the number of women in the workforce. Wage equality, social security, occupational health and safety, caregiving support, promotion opportunities, and protection against workplace violence and harassment must also be included in the assessment. It is crucial that vocational training and reskilling programs be designed with women's participation conditions in mind.

Women's entrepreneurship is also one of the key components of the green transition. Areas such as agroecology, sustainable food production, water conservation, waste management, and renewable energy cooperatives can create income opportunities for women. However, inequalities in access to credit, collateral, property ownership, and technology use limit this potential. Policies supporting women's entrepreneurship should not be limited to small-scale credit programs; they must also include support for market access, technical advisory services, social protection, and institutional capacity building (FAO, 2023).

When developing just transition policies, it is essential to consider not only those directly employed in the fossil fuel sectors but also communities that are economically dependent on these sectors. Women workers, small-scale producers, and caregivers who are indirectly affected by the transition should be included in social protection and skills development programs.

3.2. Unpaid Care Work, Time Poverty, and the Care Economy

There is a strong link between climate change and unpaid care work. Drought, water scarcity, rising food prices, infrastructure disruptions, heat waves, and climate-related health issues are increasing households' care needs. When public services are inadequate, these needs are often met through women's unpaid labor (Aguilar, 2023; Anjum & Aziz, 2025).

Spending more time securing access to water and food can limit women's opportunities for paid work, education, rest, and public participation. This situation is defined as time poverty. Time poverty is a form of inequality that directly affects women's economic empowerment but is not sufficiently reflected in traditional employment and income indicators (OECD, 2023).

Feminist climate justice challenges the view that care work is an unlimited household resource in the face of climate crises. Care responsibilities must be recognized, reduced, and shared more equitably among households, the state, the market, and society. Public daycare centers, elder care centers, accessible health services, and social care programs can increase women's control over their time (Addati et al., 2018).

The care sector also has the potential to create low-carbon jobs. Therefore, just transition policies should not focus solely on the energy and industrial sectors; they must also consider investments in health, education, child care, elder care, and social services as part of the green transition (UN Women, 2023).

3.3. Access to Productive Resources, Climate Finance, and Technology

Women's ability to adapt to climate change and benefit from green economic opportunities is closely linked to their access to productive resources. Inequalities in access to land and housing ownership, credit, savings, insurance, technology, and market information undermine women's economic resilience (Deininger et al., 2023; ICRW, 2020).

Requiring land ownership or official producer registration as a condition for applying to support programs may exclude women who lack title deeds or who work as unpaid family laborers from climate finance. Therefore, financing programs should not rely solely on traditional collateral systems (FAO, 2023).

Developing direct grant mechanisms for women's organizations and cooperatives, simplifying application processes, and using gender-disaggregated indicators in projects can increase the inclusivity of climate finance. However, financial support alone is not sufficient. Technical advisory services, institutional capacity-building, market linkages, and social protection should also be incorporated into support programs (UN Women, 2023).

Digital agriculture tools, early warning systems, climate information services, irrigation technologies, and renewable energy systems can increase the productivity and resilience of women producers. However, if inequalities in access to devices, the internet, digital skills, and technical training are not addressed, the use of technology may reproduce existing disparities (Huyer & Chanana, 2021).

3.4. Decision-Making, Participatory Governance, and Leadership

Women's participation in the development and implementation of climate policies is both a means and an outcome of economic empowerment. The lack of effective representation of diverse groups of women on climate councils, in local governments, within the public bureaucracy, and on international negotiation teams can result in policies that do not adequately address women's needs (Külcür, 2020; UNFCCC, 2025).

The mere numerical representation of women in decision-making mechanisms does not, in and of itself, imply that effective participation is taking place. For participation to be functional, it depends on women's ability to access information, have a say in budgetary processes, and influence the decisions made. Therefore, participatory mechanisms must not be limited to formal representation alone but must enable women to play an active role in determining policy priorities and the allocation of resources (CARE International & Stockholm Environment Institute, 2024).

The roles women play in local environmental initiatives, cooperatives, and social solidarity networks constitute a significant body of knowledge and experience for the development of climate policies. However, there are various structural barriers to transferring this knowledge, gained at the local level, into institutional decision-making processes. In this regard, it is important to develop mechanisms that ensure the regular and effective participation of women's organizations, cooperatives, care workers, rural producers, and disadvantaged social groups in the processes of preparing and implementing local climate action plans (UN Women, 2023).

3.5. The Experiences of Rural Women in Türkiye

Field studies conducted in Türkiye highlight the impacts of climate change on rural women. A study by Candan Demirkol, Türk Kentel, and Çallıer (2025), conducted with 22 women in the village of Belenbaşı, shows that water scarcity and climate variability have increased women's domestic chores and agricultural responsibilities. Although women contribute to production processes, their influence on agricultural decision-making may remain limited.

Çakaloğlu's (2025) study also reveals that climate-related disasters and economic losses can increase women's care burdens and psychological stress. Nevertheless, women are developing adaptation strategies through sustainable agriculture, local knowledge, and solidarity networks.

These findings indicate that women should not be viewed solely as vulnerable groups. Women possess knowledge and experience in the areas of local seed conservation, agroecological production, food processing, cooperative formation, and post-disaster solidarity. However, for this capacity to translate into lasting economic empowerment, regular funding, technical support, social security, and participation in decision-making processes are required.

Table 1. Inequality Mechanisms and Policy Options Derived from the Literature

Climate policy dimension	Major area of inequality	Need for transformative policy
Employment and a Just Transition	The concentration of green jobs in male-dominated sectors; inequalities in education, wages, and social security	Green skills and STEM programs, equal pay for equal work, care support, and decent work standards
The Economics of Care and Time	The increasing burden of unpaid care work during periods of water and food scarcity and natural disasters	Public daycare and care services, the redistribution of care responsibilities, and the inclusion of investments in care in the just transition
Productive resources and financing	Inequality in access to land, property titles, credit, insurance, and technology	Direct grants, alternative collateral models, joint ownership options, and technical support
Decision-making and governance	Limited representation on climate councils and in policy processes -	Institutional participation of women's organizations, gender-responsive budgeting, and measurable performance indicators

4. Discussion and Conclusion

4.1. Evaluation of the Findings

A combined analysis of these four themes suggests that the gender-based outcomes of climate policies do not depend solely on the amount of resources allocated. The requirement of a property deed to apply for a support program affects the distribution of resources; the overlap of training sessions with childcare hours limits actual access; and the lack of decision-making authority in advisory boards restricts agency. Consequently, a program that is formally open to everyone may produce different outcomes due to initial inequalities. This interpretation is an analytical inference derived from the reviewed literature; it is not a measured effect of a specific program in Türkiye.

When evaluated from Kabeer's (1999) perspective, climate policies are expected to collectively affect women's resources, agency, and gains. A policy focused solely on increasing women's employment may provide only limited empowerment if it fails to consider women's control over income, their care burden, or job security. Similarly, the mere numerical presence of women at climate conferences may not constitute genuine representation unless they are able to influence decision-making processes.

For the green transition to be gender-equitable, women must have access to technical training, financing, and employment opportunities. Furthermore, it is important that investments in the care economy be viewed as an integral part of climate policy. A transition model reliant on women's unpaid labor is incompatible with the goal of economic empowerment.

Taking the gender dimension into account in the distribution of climate finance is also a fundamental requirement. Programs based on conditions such as land titles, collateral, or official registration may prevent women from accessing support due to existing inequalities in property ownership. Financing systems must be redesigned to account for these structural disparities.

4.2. Policy Recommendations

The success of green skills programs should be measured not only by the number of participants but also by indicators such as post-training employment, wages, social security, and job retention. Designing training programs that incorporate support services and ensure accessible participation aligns with a gender-sensitive and people-centered approach to a just transition based on decent work (ILO, 2024). As a policy recommendation of this study, it is proposed that these outcome indicators be included in program evaluations.

Public care infrastructure should be integrated into climate adaptation and just transition policies. A study by UN Women addressing the relationship between climate and care work highlights that climate-related pressures can increase the burden of unpaid care work (Aguilar, 2023). The ILO (2024) also considers public investments in care services to be one of the components of a gender-sensitive just transition. Within this framework, it is recommended that investments in childcare, elder care, health, and social services be planned in coordination with climate policies.

Strengthening access to climate finance for women's cooperatives and women entrepreneurs is linked to the principles of resource redistribution and the recognition of structural inequalities (Turquet et al., 2023). An assessment of barriers related to land, collateral, and institutional capacity also supports the approach that places gender equality at the center of climate action (Deininger et al., 2023). This study recommends that direct grant opportunities be designed in conjunction with technical consulting, market access, and digital skills support.

Budget and performance indicators for climate policies should be monitored using gender-disaggregated data. The OECD's assessment of gender and climate action identifies the production of disaggregated data and the

monitoring of policy outcomes as key areas for action (OECD, 2023). The feminist climate justice framework also emphasizes accountability and the equitable distribution of resources (Turquet et al., 2023). In this regard, it is recommended that indicators on access to support, resource allocation, and participation in decision-making processes be published regularly.

The effective participation of women's organizations and diverse groups of women in national and local climate councils should be institutionally supported. The representational dimension of feminist climate justice is based not merely on attending meetings, but on the ability to influence decision-making and the distribution of resources (Turquet et al., 2023). The ILO (2024) also emphasizes women's participation in both the decision-making and implementation phases of just transition processes. Therefore, it is recommended that assessments of representation consider not only numerical participation but also the capacity to influence agenda-setting and budgetary processes.

4.3. Conclusion

The key finding of this study is that the potential impact of climate policy on women's economic empowerment cannot be explained by a single employment or financing indicator. Access to resources, control over time, and decision-making authority are interlinked: an improvement in one of these areas may prove insufficient if structural barriers in the others persist. Therefore, when assessing a just transition, it is essential to examine not only who benefits from policy instruments but also the conditions under which beneficiaries can utilize them.

Women's economic empowerment should not be viewed as a secondary social benefit of climate action. An approach that ensures the equitable distribution of resources, recognizes care work, enables women to participate effectively in decision-making processes, and takes into account the needs of different groups of women forms the foundation of feminist climate justice. An effective and equitable climate transition depends not only on reducing emissions but also on how the costs and benefits of the transition are shared within society. Since this study presents a document-based conceptual synthesis, the extent to which the proposed mechanisms function in Türkiye must be assessed in the future through a clause-by-clause comparison of policy documents and tested against field data.

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FULL PAPER · IP2.4 · IN-PERSON SESSION II

Women's Participation in Firm Ownership and Green Management Practices: Evidence from the 2024 World Bank Enterprise Survey in Türkiye

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ABSTRACT

This study examines the association between women's participation in firm ownership and the adoption of green management practices among firms operating in Türkiye. The study is motivated by the view that women's economic participation matters not only for inclusion and equal opportunity, but also for the development of sustainable and green entrepreneurship ecosystems. The analysis draws on firm-level microdata from the 2024 Türkiye wave of the World Bank Enterprise Survey (WBES). Women's participation in ownership is defined as the presence of at least one woman among a firm's owners. Green management practices are captured through two observable environmental actions: monitoring carbon dioxide (CO_2) emissions and implementing energy management measures. A composite green-management indicator is coded as one when a firm adopts at least one of these practices. Binary logistic regression models are estimated while controlling for firm size, firm age, and sectoral differences. The baseline model, based on 1,385 complete observations, shows a positive and statistically significant association between women's participation in firm ownership and the adoption of green management practices. The estimated odds ratio is 1.81 (p=0.001). The average discrete change from 0 to 1 in the binary ownership indicator indicates that, with the remaining covariates held at their observed values, the probability of observing at least one green management practice is approximately 8.4 percentage points higher among firms with women participating in ownership. Separate models also reveal positive and statistically significant associations with CO_2-emissions monitoring (OR=2.01; p=0.001) and energy-management measures (OR=1.59; p=0.015). Additional robustness analyses using WBES sampling weights, the share of female ownership, and the presence of a female top manager broadly reinforce the main finding. Because the data are cross-sectional, the results are interpreted as associations rather than causal effects. By providing firm-level evidence from Türkiye, the study contributes to the literature on women, inclusion, green entrepreneurship, and environmental management practices.

Keywords: women's participation in firm ownership, green management, green entrepreneurship, inclusion, World Bank Enterprise Survey

1. Introduction

Climate change, the efficient use of natural resources, and the growing visibility of environmental risks have made sustainability an increasingly important element of firms' strategic decision-making. Firms are now expected not only to create economic value, but also to monitor the environmental consequences of their activities, improve resource use, and develop more sustainable production and management practices. This transition is not limited to large corporations; it also concerns firms of different sizes and the broader entrepreneurial ecosystem. Green entrepreneurship likewise brings economic value creation together with environmental and social value creation, treating innovative responses to environmental challenges and the diffusion of sustainable business practices as important dimensions of entrepreneurial activity.

One issue receiving increasing attention in debates on sustainable and green entrepreneurship is women's participation in economic activity, firm ownership, and decision-making. A growing body of research argues that gender equality and environmental sustainability should not be treated as separate policy domains, and that inclusive economic structures can be pursued alongside green-transition goals. Potluri et al. (2024), for

example, conceptualize "women green entrepreneurship" as a distinct area of inquiry concerned with women's participation in environmentally oriented entrepreneurial activity and emphasize its potential to connect gender equality with climate action. The present study, however, does not examine a sample specifically composed of women green entrepreneurs or green ventures. Accordingly, rather than using the broader label of female entrepreneurship, the analysis focuses on what the World Bank Enterprise Survey directly measures: women's participation in firm ownership.

Empirical evidence suggests that women's representation in ownership or management may be related to firms' environmental practices. Atif et al. (2020) document an association between female representation on corporate boards and sustainable investment, while Burkhardt et al. (2020) show that women's representation in top management may be linked to stronger corporate environmental performance. More recent research points to a more nuanced relationship. Examining 30 Italian cities over the 2011–2021 period, Abid and Marchesani (2025) find that female entrepreneurship is positively associated with firms' adoption of green practices, although the strength of this relationship varies with public and private R&D investment.

At the same time, women's representation within firms does not appear to be associated with stronger environmental practices under all conditions. Pirazzi Maffiola et al. (2025), studying 231 privately held manufacturing firms in Italy, find positive links between female ownership and some dimensions of social sustainability, but less consistent evidence for environmental orientation. Using World Bank Enterprise Survey data from Central, Eastern, and Southeastern European countries, Haider et al. (2026) show that the relationship between female leadership or ownership and green investment may vary with firms' innovation capacity. In particular, differences between innovative and non-innovative firms suggest that the link between gender representation and environmental practices cannot be considered independently of firm resources and organizational capabilities.

Country-level research also supports further investigation of the relationship between women's economic participation and sustainability. In an analysis covering 49 countries, Fernández-Guadaño et al. (2026) report that female entrepreneurship is positively associated with both social and environmental sustainability, although the relationship is stronger for the social dimension. Taken together, the literature points to a meaningful connection between women's economic participation and sustainability, while also showing that the strength and form of this relationship can vary across countries, firms, and institutional settings. This variation creates a clear need for context-specific evidence.

Examining this relationship at the firm level is especially relevant in the case of Türkiye. Existing studies of female entrepreneurship in Türkiye have largely focused on economic empowerment, barriers to entrepreneurship, access to finance, social inclusion, or particular sectors. By contrast, broad firm-level evidence linking women's representation in ownership structures to directly observable environmental management practices—such as CO_2-emissions monitoring and energy management—remains relatively limited. This gap makes it important to examine the connection between gender representation and green management practices among firms in Türkiye.

This study seeks to contribute to that gap. Its main objective is to examine, at the firm level, the association between women's participation in firm ownership and the adoption of green management practices in Türkiye. To this end, the analysis uses microdata from the 2024 Türkiye wave of the World Bank Enterprise Survey. Green management practices are measured through firms' monitoring of CO_2 emissions and their implementation of energy management measures, while women's participation in firm ownership is defined by the presence of at least one woman among the firm's owners.

The study contributes to the literature in three ways. First, it brings together women's participation in firm ownership and environmental management practices using a broad set of firm-level microdata from Türkiye. Second, rather than relying on general sustainability perceptions or self-reported environmental attitudes, it focuses on concrete and observable business practices—CO_2 monitoring and energy management. Third, beyond estimating the baseline relationship while controlling for firm size, firm age, and sectoral differences, the analysis evaluates alternative specifications using women's ownership share, the presence of a female top manager, and WBES sampling weights. In these respects, the study offers new firm-level evidence from Türkiye on the relationship among women's representation in ownership, inclusive entrepreneurship, and green management practices.

2. Conceptual Framework

2.1. Green Entrepreneurship and Green Management Practices

The growing importance of sustainability challenges for firms has encouraged new approaches in the entrepreneurship literature that consider economic value creation together with environmental and social value creation. Sustainable entrepreneurship is among the most prominent of these approaches. Dean and McMullen (2007) argue that market failures contributing to environmental degradation can also create opportunities for entrepreneurs to generate economic value, highlighting the potential role of entrepreneurial action in reducing environmental harm. Similarly, Cohen and Winn (2007) note that market imperfections such as externalities, information asymmetries, and inefficient pricing can open new business opportunities for sustainable entrepreneurship. From this perspective, environmental problems are not viewed solely as external constraints that impose costs on firms; they can also create entrepreneurial opportunities for developing new products, processes, and business models.

Shepherd and Patzelt (2011) define sustainable entrepreneurship in terms of pursuing entrepreneurial opportunities that generate economic and non-economic gains while preserving nature, life-support systems, and social structures. This perspective suggests that sustainable entrepreneurship is not limited to new ventures offering environmentally friendly products or services. It also provides a broader framework that can encompass sustainability-oriented changes in the ongoing activities and processes of established firms.

At this point, it is important to distinguish green entrepreneurship from green management practices. Green entrepreneurship refers to the pursuit of economic opportunities arising from environmental challenges and to placing environmental value creation at the core of entrepreneurial activity. Green management practices, by contrast, refer to the managerial actions adopted by established firms to measure, monitor, or reduce their environmental impacts. Examples include monitoring CO_2 emissions, managing energy use, improving resource efficiency, and developing organizational processes aimed at environmental performance.

Accordingly, the firms included in the WBES sample used in this study are not all classified as "green ventures." The dependent variables—CO_2 monitoring and energy management—represent two observable dimensions of firms' environmental management practices. This distinction is important for interpreting the results. The analysis does not examine whether women's participation in ownership is associated with the creation of a green venture; rather, it examines whether such participation is associated with the presence of green management practices in established firms.

2.2. Women's Participation in Firm Ownership and Sustainability

Women's participation in entrepreneurship and firm ownership is an important component of debates on inclusive economic growth and equal opportunity. In recent years, however, interest has also grown in considering gender equality together with environmental sustainability. Potluri et al. (2024) bring the literatures

on female entrepreneurship and green entrepreneurship together through the concept of "women green entrepreneurship," treating women's participation in entrepreneurial activities that create environmental value as a distinct field of inquiry. They argue that women's position within green entrepreneurship should be examined in relation to both gender equality and climate action.

Yet women's participation in firm ownership and women green entrepreneurship are not the same concept. The ownership measure used in the WBES indicates whether at least one woman is among the firm's owners; it does not directly reveal whether a woman founded the firm, whether the venture was established around an environmental mission, or how much authority a female owner exercises in day-to-day strategic decisions. For this reason, the present study uses the more precise term "women's participation in firm ownership" rather than stronger labels such as "female-owned entrepreneurial firm" or "female-led green venture."

Even so, ownership structure represents an important governance domain in which strategic priorities, resource allocation, and long-term orientation can take shape. Differences in owners' experiences, priorities, and perceptions of stakeholders may be associated with differences in organizational decisions not only in economic terms, but also in social and environmental terms. This expectation should not be interpreted as implying that women are inherently or necessarily more environmentally oriented. A more cautious interpretation is that women's representation in ownership and management may constitute a governance characteristic associated with a broader range of experiences, perspectives, and stakeholder expectations being represented in firm decision-making.

This view is consistent with empirical research linking women's representation in firms to sustainability-related practices. Atif et al. (2020) associate female representation on boards with sustainable investment, while Burkhardt et al. (2020) report a positive relationship between women in top management and stronger corporate environmental performance. Although ownership, management, and board representation are conceptually distinct, these studies suggest that gender diversity in firm decision-making structures may be a meaningful factor to consider when examining environmental choices.

2.3. Women's Representation in Firms and Environmental Practices: Empirical Evidence

Empirical studies linking women's representation in ownership or management to environmental outcomes generally point to a meaningful relationship, although the findings are far from uniform. This variation suggests that the relationship may depend on country context, sector, firm characteristics, and the environmental outcome being examined.

Abid and Marchesani (2025), using data for 30 Italian cities over the 2011–2021 period, find that female entrepreneurship is positively associated with firms' green practices. They also show that public R&D investment strengthens this relationship, whereas private R&D investment may weaken it. Their findings indicate that the link between female entrepreneurship and green practices may reflect not only internal firm characteristics, but also the innovation and institutional environment in which firms operate.

Pirazzi Maffiola et al. (2025), by contrast, examine privately held manufacturing firms in Italy and show that the relationship between female ownership and sustainability orientation is not equally strong across dimensions. Female ownership is positively associated with some aspects of social sustainability, whereas the evidence is more limited for environmental orientation. This finding is important because it cautions against assuming that women's representation in ownership automatically translates into stronger environmental performance.

The WBES-based study by Haider et al. (2026) is particularly close to the present research in terms of both data source and empirical setting. Examining firms in Central, Eastern, and Southeastern Europe, the authors show that the relationship between female leadership or ownership and green investment practices may vary with

firms' innovation capacity. Women's representation in firms, therefore, does not appear to operate independently of organizational and innovation capabilities.

Offering a broader cross-country perspective, Fernández-Guadaño et al. (2026) find across 49 countries that female entrepreneurship is positively associated with both social and environmental sustainability. Although this finding supports a broader connection between women's economic participation and sustainable development, it also underlines the need to investigate firm-level mechanisms within specific national contexts.

The present study differs from this literature in three main respects. First, it focuses specifically on Türkiye and uses country-specific firm-level microdata. Second, women's representation in the firm is measured through participation in ownership as the main explanatory variable. Third, rather than relying on broad sustainability indices or general concepts of green investment, the study focuses on two directly observable environmental management practices: CO_2 monitoring and energy management. These features allow the relationship between women's representation in ownership and environmental management practices in Türkiye to be assessed through concrete firm-level measures.

2.4. Hypothesis Development

The theoretical and empirical literature reviewed above provides several reasons to expect a positive association between women's participation in firm ownership and sustainability-related practices. Women's participation in ownership may be associated with the representation of different experiences and priorities in decision-making, and this diversity may in turn be related to how firms respond to nonfinancial stakeholder expectations and environmental concerns.

At the same time, prior empirical evidence shows that the relationship is neither universal nor mechanical. Abid and Marchesani (2025) report a positive relationship, Pirazzi Maffiola et al. (2025) find more limited evidence for the environmental dimension, and Haider et al. (2026) show that the relationship may vary with innovation capacity. The present study therefore does not assume that women's participation in ownership has a direct causal effect on green practices. Instead, it tests an empirical expectation that the two are positively associated among firms in Türkiye.

On the basis of this theoretical and empirical framework, the study proposes the following hypothesis:

H1: Women's participation in firm ownership is positively associated with firms' adoption of green management practices.

The main hypothesis is tested using a composite green-management indicator based on CO_2-emissions monitoring and energy management measures. To assess whether the relationship is driven by the construction of the composite indicator, CO_2 monitoring and energy management are also analyzed separately as dependent variables.

3. Method

3.1. Data and Sample

The analysis uses firm-level microdata from the 2024 Türkiye wave of the World Bank Enterprise Survey (WBES). The WBES provides standardized information on several dimensions of firm activity, including ownership structure, management characteristics, firm size, sector, innovation, and environmental practices. This structure makes it possible to examine the relationship between women's participation in firm ownership and green management practices at the firm level.

The raw 2024 Türkiye WBES dataset contains 1,416 firms. After accounting for missing observations in the variables used in the analysis, the baseline logistic regression model is estimated on 1,385 firms. The number

of observations differs slightly in the models that treat CO_2 monitoring and energy management as separate outcomes because of missing values in the corresponding variables. Because the variables used in the analysis are largely complete, the baseline and alternative model samples do not differ substantially in size.

The main explanatory variable is women's participation in firm ownership. It is coded as 1 when at least one woman is among the firm's owners and 0 otherwise. The measure captures women's presence in the ownership structure, but it does not encompass all dimensions of female entrepreneurship, indicate whether a woman founded the firm, or directly measure her actual decision-making authority. The study therefore uses the more precise expression "women's participation in firm ownership" rather than referring to these firms as "female entrepreneurial firms."

3.2. Variable Definitions

The primary dependent variable is a green-management-practice indicator constructed from two observable environmental management practices. The first records whether the firm monitored its CO_2 emissions during the previous three years; the second records whether it implemented energy management measures over the same period. The composite green-management indicator is coded as 1 when the firm undertook at least one of these practices and 0 when neither practice was present.

To avoid incorrectly classifying missing responses as the absence of green practices, observations for which the status of one of the source variables could not be determined were not automatically coded as 0. Instead, those observations were retained as missing. In this way, the main dependent variable is constructed only from observable responses, reducing the risk of understating firms' environmental practices.

The baseline model controls for firm size, firm age, and sectoral differences. Firm size is measured as the natural logarithm of the number of full-time employees. Because employee counts vary substantially across firms, the logarithmic transformation is used to reduce the influence of extreme scale differences and to provide a more balanced specification. Firm age is likewise included as the natural logarithm of the number of years the firm has been operating. Sector controls are added because environmental regulation, energy intensity, production structure, and typical firm scale can differ considerably across industries.

Table 1 presents descriptive statistics for the main variables used in the analysis.

Table 1. Descriptive Statistics

Variable	N	Mean	Std. Dev.
At least one green practice	1,385	0.165	0.371
CO_2 monitoring	1,383	0.095	0.294
Energy management	1,383	0.140	0.347
Women's participation in ownership	1,385	0.176	0.381
ln(number of employees)	1,385	3.238	1.314
ln(firm age)	1,385	2.734	0.674

As shown in Table 1, approximately 16.5% of firms in the analysis sample report at least one of the two green management practices—CO_2 monitoring or energy management. Women participate in ownership in approximately 17.6% of the firms. These distributions provide sufficient variation in both the main explanatory variable and the dependent variable for the empirical analysis.

3.3. Econometric Model and Robustness Analyses

Because the primary dependent variable is binary, the analysis uses a binary logistic regression model. The model can be written as follows:

$$P(Green_i = 1) = F(\beta_0 + \beta_1 Female_i + \beta_2 Size_i + \beta_3 Age_i + \gamma Sector_i)$$

In the equation, $Green_i$ indicates whether firm i adopts at least one green management practice; $Female_i$ indicates whether at least one woman is among the firm's owners; $Size_i$ denotes firm size; Age_i denotes firm age; and $Sector_i$ represents sector controls.

The coefficient of primary interest is β_1. Because the data are cross-sectional, however, this coefficient is not interpreted as a causal effect. Rather, the estimates capture the conditional association between women's participation in firm ownership and the probability of observing green management practices after accounting for the other observed firm characteristics included in the model.

Because logit coefficients are not directly interpretable as changes in probability, the results are reported using both odds ratios (ORs) and average discrete changes from 0 to 1 for the binary explanatory variable. The odds ratios indicate the direction and relative magnitude of the association, whereas the average discrete change measures the mean change in predicted probability when the women-in-ownership indicator moves from 0 to 1, with the remaining covariates held at their observed values.

Several robustness and alternative-specification checks complement the baseline model. First, CO_2 monitoring and energy management are estimated separately as dependent variables to determine whether the results are driven by the construction of the composite green-management indicator. Second, the share of ownership held by women is used as an alternative explanatory variable to address the limitation of representing women's ownership participation with a simple binary indicator. Third, alternative models use the presence of a female top manager to capture the managerial dimension of women's representation in the firm. Finally, weighted estimates using WBES sampling weights are used to assess whether the main findings are sensitive to the sample weighting structure.

Together, these analyses help assess whether the main finding depends on a particular definition of the dependent variable, a single measure of women's representation, or the use of an unweighted sample.

4. Results

4.1. Descriptive Results and Group Comparisons

Clear differences in green management practices emerge between firms with and without women participating in ownership. As shown in Table 2, 25.5% of firms with women participating in ownership report at least one green management practice, compared with 14.7% of firms without women participating in ownership. The resulting difference of approximately 10.8 percentage points is statistically significant ($p<0.001$). A similar pattern appears for the two components of the green-management indicator. CO_2 monitoring is reported by 16.9% of firms with women participating in ownership, compared with 8.1% of the other firms. For energy management, the corresponding rates are 20.6% and 12.7%. These unadjusted comparisons suggest that environmental management practices are more frequently observed among firms with women participating in ownership. Because these comparisons do not account for firm size, age, or sector, multivariate models are needed to evaluate the relationship more carefully.

Table 2. Green Management Practices by Women's Participation in Firm Ownership

Indicator	Women in ownership	No women in ownership	Diff. (pp)	p
At least one green practice	25.5%	14.7%	+10.8 pp	<0.001
CO_2 monitoring	16.9%	8.1%	+8.9 pp	<0.001
Energy management	20.6%	12.7%	+8.0 pp	0.002

4.2. Logistic Regression Results

The baseline results in Table 3 show that the positive relationship between women's participation in firm ownership and the adoption of green management practices remains after controlling for firm size, firm age, and sectoral differences. The odds ratio associated with women's participation in ownership is 1.806, with a p-value of 0.001. This indicates that the odds of observing a green management practice are higher among firms with women participating in ownership than among otherwise comparable firms without such participation.

An odds ratio, however, should not be interpreted as a percentage change in probability. To provide a more intuitive interpretation, the average discrete change from 0 to 1 is therefore calculated for the binary ownership indicator. The estimated change is approximately 0.0839. Holding the remaining covariates at their observed values, firms with women participating in ownership have, on average, an approximately 8.4-percentage-point higher predicted probability of reporting at least one green management practice. Firm size is also positively and significantly associated with green management practices, whereas firm age is not statistically significant. The model is statistically significant overall, and an AUC of 0.693 indicates an acceptable level of discriminatory performance.

Table 3. Baseline Logistic Regression Model

Variable	Coef.	OR	95% CI	p
Women's participation in ownership	0.591	1.806	1.273–2.562	0.001
ln(number of employees)	0.449	1.566	1.398–1.754	<0.001
ln(firm age)	-0.069	0.933	0.741–1.174	0.554

N = 1,385; McFadden Pseudo-R^2 = 0.078; AUC = 0.693; model p < 0.001.

4.3. Component-Level Analyses

Table 4. Results for the Components of Green Management Practices

Dependent variable	OR	95% CI	p	Avg. discrete change (0→1)
At least one green practice	1.806	1.273–2.562	0.001	+8.4 pp
CO_2 monitoring	2.012	1.313–3.084	0.001	+6.4 pp
Energy management	1.592	1.095–2.313	0.015	+5.8 pp

Table 4 examines whether the main relationship remains when the two components of the composite green-management indicator are analyzed separately. Women's participation in firm ownership is positively and significantly associated with CO_2 monitoring (OR=2.012; p=0.001) and with energy management (OR=1.592; p=0.015). The average discrete changes from 0 to 1 in the binary ownership indicator are approximately 6.4 and 5.8 percentage points for the CO_2-monitoring and energy-management models, respectively. These results indicate that the baseline finding is not simply an artifact of how the composite indicator is constructed. At the same time, the larger odds ratio for CO_2 monitoring suggests that the magnitude of the association may differ across environmental practices. This difference should be interpreted in light of the fact that CO_2 monitoring and energy management involve different technical, financial, and organizational requirements.

4.4. Robustness Analyses

Table 5. Summary of Robustness Analyses

Model / Dependent variable	OR	p
Sampling-weighted models		
At least one green practice	1.875	<0.001
CO_2 monitoring	2.938	<0.001
Energy management	1.775	0.004

Model / Dependent variable	OR	p
Female ownership share – per 10 percentage points		
At least one green practice	1.059	0.048
CO_2 monitoring	1.083	0.019
Energy management	1.046	0.143
Female top manager		
At least one green practice	1.956	0.007
CO_2 monitoring	2.517	0.002
Energy management	1.436	0.188

The alternative estimates reported in Table 5 show that the main finding is largely preserved across different model and variable definitions. When WBES sampling weights are applied, women's participation in firm ownership remains positively and significantly associated with the composite green-management indicator, CO_2 monitoring, and energy management. When women's ownership share is used as the alternative explanatory variable, positive and significant associations are observed for the composite green-management indicator and CO_2 monitoring, while the energy-management model is not statistically significant. A similar pattern emerges when the presence of a female top manager is used: the association is positive and significant for overall green management and CO_2 monitoring, but not for energy management. These results support the view that the main finding is not driven by a single measurement choice, while also showing that the relationship is not equally strong across all environmental practices.

5. Discussion and Conclusion

This study examined the firm-level association between women's participation in firm ownership and the adoption of green management practices among firms in Türkiye. Using the 2024 Türkiye wave of the World Bank Enterprise Survey, the analysis evaluated green management through firms' monitoring of CO_2 emissions and implementation of energy management measures.

The central finding is a positive and statistically significant association between women's participation in firm ownership and the adoption of green management practices. After controlling for firm size, firm age, and sectoral differences, the odds of observing at least one green management practice are higher among firms with women represented in ownership. The average discrete change from 0 to 1 in the binary ownership indicator further shows that these firms have an approximately 8.4-percentage-point higher predicted probability of reporting at least one green management practice.

The results are broadly consistent with earlier studies linking women's economic and managerial representation in firms to environmental sustainability. Atif et al. (2020) find that female board representation is positively associated with sustainable investment, while Burkhardt et al. (2020) show that women's representation in top management may be associated with stronger corporate environmental performance. At the same time, the literature also shows that the relationship does not have the same direction or magnitude in every setting. Pirazzi Maffiola et al. (2025), for example, identify positive associations between female ownership and social sustainability practices but find less consistent evidence for environmental orientation. Haider et al. (2026) likewise show that the relationship between female leadership or ownership and green investment may depend on firms' innovation capacity.

In this respect, the evidence from Türkiye reinforces the need to examine the relationship between women's representation in ownership and environmental practices within specific country and firm contexts. The findings are also broadly consistent with Fernández-Guadaño et al. (2026), who report positive associations between female entrepreneurship and both environmental and social sustainability across countries.

The association is particularly pronounced for CO_2 monitoring. CO_2 monitoring and energy management are not identical practices in terms of cost, technical capacity, or organizational requirements. It should therefore not be expected that women's participation in firm ownership will be associated with every environmental practice to the same extent.

The robustness analyses largely reinforce the baseline result. The direction and statistical significance of the association are preserved when WBES sampling weights are used. Alternative models based on women's ownership share also produce positive relationships for the composite green-management indicator and CO_2 monitoring. Similarly, models using the presence of a female top manager yield positive and statistically significant results for overall green management and CO_2 monitoring.

These findings suggest that women's participation in economic life and firm ownership may be relevant not only from the standpoint of inclusion and equal opportunity, but also in relation to firms' sustainability practices. Programs designed to support women's participation in entrepreneurial ecosystems could therefore consider placing greater emphasis on environmental management, energy efficiency, emissions monitoring, and sustainable business skills alongside more conventional forms of entrepreneurial support.

The study nevertheless has several limitations. First, the WBES data are cross-sectional and therefore do not support causal inference. The results cannot be interpreted as showing that women's participation in firm ownership causes firms to adopt green management practices. Second, the green-management indicator is based on only two observable practices—CO_2 monitoring and energy management—and does not capture firms' overall environmental performance. Third, the presence of at least one woman among the firm's owners does not represent all dimensions of female entrepreneurship or women's actual influence over decision-making within the firm.

Future research could use panel or repeated cross-sectional data to examine how this relationship develops over time. More detailed indicators could also be used to capture women's ownership shares, managerial authority, and influence in decision-making. In addition, future studies could investigate whether firm size, innovation capacity, or sector characteristics moderate the relationship between women's representation in firms and green management practices.

Overall, the study documents a positive and statistically significant firm-level association between women's participation in firm ownership and observable green management practices in Türkiye. This finding provides an empirical basis for further research on the links among women's economic participation, inclusive entrepreneurship, and the green transition in the Turkish context.

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FULL PAPER · IP2.5 · IN-PERSON SESSION II

Do Instant Payments Substitute for Retail Payment System Transactions in Türkiye? An Analysis of Time-Varying Dynamics

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ABSTRACT

Using weekly transaction data, this study examines the time-varying relationship between instant payments and transactions processed through Türkiye's Retail Payment System (RPS), with particular attention to whether the two systems display a partial substitution pattern. The analysis covers the Instant and Continuous Transfer of Funds (FAST) System and the RPS, both operated by the Central Bank of the Republic of Türkiye. Transaction counts form the basis of the main model, while real transaction values are used for robustness. Because the two systems operate on different calendars, FAST is normalized by seven calendar days and RPS by the number of active transaction days before the series are transformed into weekly logarithmic changes. Stationarity is assessed with the ADF, Phillips-Perron, KPSS, and Zivot-Andrews tests. Short-run periodic movements and changes in FAST transaction limits are removed through deterministic pre-adjustment before estimation. The dynamic relationship is then analysed with a time-varying parameter vector autoregressive model, generalized forecast error variance decomposition, and generalized impulse response functions. In the transaction-count model, the average Total Connectedness Index is 25.97%, with substantial variation over time. The four- and ten-week cumulative RPS responses to a positive FAST shock are -0.201 and -0.174, respectively. The four-week response is negative throughout the sample, and the ten-week response is negative in 94.23% of periods. The real transaction-value model points in the same direction: the corresponding cumulative responses are -0.153 and -0.133, and both remain negative throughout the sample. The negative sign is also preserved across the baseline and eight alternative hyperparameter combinations and across lag lengths of 4, 8, 11, and 12. These findings do not imply that FAST fully replaces RPS transactions. Rather, they provide directional evidence consistent with partial, time-varying substitution between the two systems and show how the expansion of instant-payment infrastructure can reshape the distribution of transactions across payment channels.

Keywords: instant payments, digital payments, payment systems, dynamic connectedness, financial technology

1. Introduction

The rapid digitalisation of financial services has reshaped payment systems. Conventional electronic fund transfers are constrained by operating hours and settlement schedules, which has accelerated the development of instant-payment systems that operate around the clock and complete payments within seconds. These systems do more than shorten processing time. They can alter users' choices among payment instruments and, in turn, redistribute transactions across existing payment infrastructures (CPMI, 2016; CPMI, 2021).

In Türkiye, the Instant and Continuous Transfer of Funds (FAST) System, developed by the Central Bank of the Republic of Türkiye (CBRT), went live on 8 January 2021 (CBRT, 2021a). FAST operates 24/7 and completes payments within seconds. In its 2021 assessment, the CBRT noted that, following the launch of FAST, part of retail payment activity shifted from the Retail Payment System (RPS) to FAST (CBRT, 2021d). This development makes the interaction between the new instant-payment infrastructure and existing retail payment channels an empirical question rather than merely an institutional observation.

This study examines the dynamic relationship between FAST and the RPS in Türkiye and asks whether their transaction flows exhibit a substitution-oriented pattern. Using weekly transaction data, the analysis combines a time-varying parameter vector autoregressive (TVP-VAR) model with generalized forecast error variance decomposition and generalized impulse response functions. The contribution lies in treating the FAST-RPS relationship not as a single average association, but as a sequence of time-varying shock transmissions and responses.

2. Conceptual Framework and Literature Review

Digital transformation in payments can affect both the instruments users select and the intensity with which established payment channels are used. Research on retail payment choice shows that transaction speed, convenience, acceptance, and cost all matter. Arango et al. (2015), for example, show that merchant card acceptance and pricing incentives can move consumers away from alternatives such as cash and debit cards. Koulayev et al. (2016) distinguish between the adoption of a payment instrument and its actual use and document clear substitution across instruments. The diffusion of a new payment technology may therefore change not only aggregate payment activity but also the distribution of transactions across available channels.

Instant-payment systems are a prominent part of this transformation. CPMI (2016) distinguishes them from conventional retail payment systems because funds become available to the recipient in real or near-real time and the systems generally operate on a 24/7 basis. Subsequent developments show that fast-payment infrastructures have spread rapidly across countries, with central banks often playing a central role in their design, operation, and adoption (CPMI, 2021).

The literature also asks whether instant payments substitute for established payment instruments. Bruggink and Benevelli (2021) argue that instant payments can replace cards in some retail transactions, while stressing that the two instruments do not offer identical services or serve exactly the same use cases. Lobo and Brandt's (2021) assessment of Brazil's Pix shows how a central-bank-led instant-payment infrastructure can become a major part of the payment ecosystem within a relatively short period. For Colombia, Arango-Arango et al. (2021) find that the spread of instant payments in merchant transactions depends on factors including cost, informality, firm size, and user expectations.

Khiaonarong and Humphrey (2022b), using data for 12 advanced and emerging economies, find that instant payments significantly substitute for traditional instruments such as cash, cards, cheques, and direct debits in some countries. Their broader study of payment transformation also links declining cash use to consumer characteristics, costs, and the advantages offered by alternative payment instruments (Khiaonarong & Humphrey, 2022a). Taken together, these findings suggest that substitution is neither uniform across countries nor independent of the institutional features of the payment system.

The effects of instant-payment systems extend beyond direct substitution between payment instruments. Using a large dataset covering 95 countries, Cornelli et al. (2024) show that the introduction of retail fast-payment systems is positively associated with the adoption of financial applications, particularly payment apps. The relationship is stronger where the central bank plays an active role, settlement occurs in real time, and the system is more open to non-bank institutions. Instant-payment infrastructure can therefore be part of a broader process of financial digitalisation rather than a stand-alone payment innovation.

Türkiye's FAST System was introduced on 8 January 2021 as a 24/7 instant-payment system. The CBRT's 2021 assessment explicitly stated that part of retail payment activity shifted from the RPS to FAST after the new system became operational. That observation is consistent with a possible substitution mechanism, but it does not reveal how the direction or strength of the relationship evolved over time. This study addresses that gap by examining FAST and RPS through TVP-VAR connectedness and dynamic impulse-response analysis, providing

Türkiye-specific evidence on the interaction between instant payments and a traditional retail payment channel.

3. Data and Methodology

3.1. Data

The study uses FAST (Instant and Continuous Transfer of Funds) and Retail Payment System (RPS) data obtained from the Electronic Data Delivery System (EVDS) of the Central Bank of the Republic of Türkiye. Transaction counts are used in the main analysis and transaction values in the robustness analysis. FAST operates continuously seven days a week, whereas RPS transactions mainly occur on business days. Direct comparison of raw weekly totals would therefore confound transaction activity with differences in operating calendars. To address this issue, weekly FAST transaction counts are divided by seven, while weekly RPS counts are divided by the number of active RPS transaction days in the corresponding week.

The adjusted series are defined as follows:

$$FAST^{a}_{t} = FAST\ transaction\ count_{t} / 7$$

$$RPS^{a}_{t} = RPS\ transaction\ count_{t} / D_{t}$$

Here, D_t denotes the number of active RPS transaction days in week t. The adjustment is particularly useful around public holidays, when changes in the number of RPS operating days can otherwise generate mechanical fluctuations in weekly observations.

The active-day-adjusted series used in the main analysis are converted into weekly logarithmic changes:

$$\Delta ln(X_t) = 100 \times [ln(X_t) - ln(X_{t-1})]$$

The raw weekly transaction-count dataset contains 298 observations for the period 11 January 2021-21 September 2026. After taking weekly logarithmic changes, the estimation sample contains 297 observations.

For the robustness analysis, nominal FAST and RPS transaction values are deflated using the Consumer Price Index, General Index (2025=100). As with transaction counts, real values are normalised by seven days for FAST and by the number of active transaction days for the RPS, after which weekly logarithmic changes are calculated. The real transaction-value series contain 294 level observations and 293 observations after log differencing.

Before estimation, the stationarity properties of the series are examined with the ADF, Phillips-Perron, KPSS, and Zivot-Andrews tests. Evidence of stationarity is limited for the level series, whereas weekly logarithmic changes are generally stationary. The TVP-VAR models therefore use the weekly log-change series.

3.2. Methodology

Because the relationship between FAST and the RPS need not remain constant over time, the empirical analysis uses a Time-Varying Parameter Vector Autoregressive (TVP-VAR) model. The TVP-VAR framework allows both coefficients and error covariances to evolve, making it possible to trace changes in the dynamic interaction between the two payment systems over the sample (Koop & Korobilis, 2013; Antonakakis et al., 2020).

The bivariate TVP-VAR can be written in general form as:

$$Z_t = A_{1,t}Z_{t-1} + A_{2,t}Z_{t-2} + \ldots + A_{p,t}Z_{t-p} + \varepsilon_t$$

where $Z_t = [FAST_t, RPS_t]'$ is the vector of variables, $A_{p,t}$ denotes the time-varying coefficient matrices, and ε_t is the error term.

Preliminary analysis identifies short-run periodic movements in weekly FAST and RPS changes. Monthly, semi-monthly, and annual sine-cosine terms are therefore used in the deterministic pre-adjustment. Changes in the FAST transaction limit are also taken into account at the pre-adjustment stage to isolate mechanical movements associated with limit increases during the sample. The dates and amounts of FAST limit changes are compiled from CBRT press releases and annual reports (CBRT, 2021b, 2021c, 2022, 2023, 2024, 2026). The limit shock is defined as:

$$LIMIT_t = ln(New\ Limit_t / Old\ Limit_t)$$

Before estimating the TVP-VAR, the deterministic periodic components and FAST limit interventions are partialled out of both series using ordinary least squares (OLS). The resulting residuals are standardised and used as the inputs to the time-varying parameter VAR.

Fixed-coefficient VAR models are used for preliminary diagnostics. Information criteria, system stability, and residual autocorrelation are considered jointly, and an 11-week lag length is adopted in the final TVP-VAR specification. Controlling for the periodic components and FAST limit interventions substantially reduces residual autocorrelation.

The TVP-VAR is estimated with a recursive Kalman-filter procedure based on forgetting factors. In the baseline specification, $\kappa_1 = 0.99$ is used for coefficient updating, $\kappa_2 = 0.96$ for updating the error covariance matrix, and $\gamma = 0.10$ for the Minnesota-type initial prior (Litterman, 1986). A 10-week forecast horizon is used for forecast error variance decomposition. The first 26 weeks are treated as a learning period and excluded from the reported dynamic results. The transaction-count summaries therefore cover 260 weeks from 4 October 2021 to 21 September 2026, while the real transaction-value summaries cover 256 weeks from 4 October 2021 to 24 August 2026. No unstable update is observed in the baseline model.

Shock transmission between FAST and the RPS is measured using generalized forecast error variance decomposition based on Diebold and Yilmaz (2012). The analysis reports the Total Connectedness Index (TCI), directional connectedness from FAST to the RPS and from the RPS to FAST, and net connectedness. In the bivariate system, the TCI is expressed as:

$$TCI_t = 100 \times [\theta FAST \leftarrow RPS, t + \theta RPS \leftarrow FAST, t] / 2$$

where the θ̃ terms denote normalised generalized forecast error variance shares.

Connectedness measures quantify the magnitude and direction of shock transmission, but they do not indicate whether the effect is positive or negative. To assess the direction of the possible substitution pattern, time-varying generalized impulse response functions are therefore calculated (Pesaran & Shin, 1998). A FAST shock is defined as a one-standard-deviation positive innovation based on the contemporaneous error variance in the FAST equation. RPS responses are examined at horizons of 1, 4, and 10 weeks, together with cumulative responses over weeks 1-4 and 1-10. The ten-week cumulative response can be written as:

$$CIRF_{1-10,t} = GIRF_t(1) + GIRF_t(2) + \ldots + GIRF_t(10)$$

A negative cumulative RPS response to a positive FAST shock is interpreted as directional evidence consistent with substitution over the subsequent weeks. It is not treated as a structural causal effect or a structural substitution coefficient, but as the sign of a dynamic shock response within the TVP-VAR system.

Three complementary exercises are used to assess robustness. First, nine hyperparameter specifications are estimated, including the baseline and alternative combinations of κ_1, κ_2, and γ. Second, the main transaction-count model is re-estimated using CPI-deflated real transaction values. Third, sensitivity to lag length is examined by comparing TVP-VAR models with p = 4, 8, 11, and 12 over a common evaluation period. These

checks assess whether the sign of the main result depends on the hyperparameters, the transaction measure, or the selected lag length.

4. Findings

4.1. Preliminary Analysis and Stationarity Tests

Before the main analysis, the data structure, stationarity properties, and basic diagnostics from fixed-coefficient VAR models are examined. The active-day adjustment is particularly important because FAST operates seven days a week while the RPS follows an active-business-day calendar. In the raw RPS log-change series, 14 outlying weeks are identified; after the active-day adjustment, the number falls to zero. This indicates that much of the apparent extreme weekly volatility in the raw RPS series is calendar-driven.

Stationarity is assessed with the ADF (Dickey & Fuller, 1979, 1981), Phillips-Perron (Phillips & Perron, 1988), KPSS (Kwiatkowski et al., 1992), and Zivot-Andrews (Zivot & Andrews, 1992) tests. Evidence of stationarity is limited in logarithmic levels. For weekly logarithmic changes, however, the ADF and Phillips-Perron tests reject the unit-root null for all series. The KPSS test does not reject the stationarity null for the RPS transaction-count and real-value series, but rejects it at the 5% level for the FAST transaction-count and real-value series. Allowing for a structural break, the Zivot-Andrews test rejects the unit-root null for all change series.

Table 1. Stationarity Tests for Weekly Logarithmic Changes

Variable	ADF p	PP p	KPSS p	ZA p	ZA Break Date
FAST transaction count	0.0002	<0.001	0.0322	0.0007	25 Apr 2022
RPS transaction count	<0.001	<0.001	0.1000	0.0033	26 Aug 2024
FAST real value	<0.001	<0.001	0.0212	0.0003	30 Jan 2023
RPS real value	<0.001	<0.001	0.1000	0.0003	25 Dec 2023

Note: The null hypothesis is a unit root in the ADF and PP tests and stationarity in the KPSS test. The ZA test allows for a structural break.

Because the tests have different null hypotheses, the results are evaluated jointly rather than by simple majority. The ADF and Phillips-Perron results, together with the Zivot-Andrews test that allows for a structural break, support the use of weekly logarithmic changes in the dynamic analysis. The KPSS results for the FAST series nevertheless call for a more cautious interpretation of stationarity.

4.2. Lag Length and Preliminary Diagnostics

Fixed-coefficient VAR models are used only for preliminary diagnostics. The information criteria point to different lag lengths: AIC and FPE select 12 lags, BIC selects 4, and HQIC selects 11.

Table 2. Summary of VAR Preliminary Diagnostics

Diagnostic / Criterion	Result
Lag selected by AIC	12
Lag selected by BIC	4
Lag selected by HQIC	11
Lag selected by FPE	12
Stability of VAR(1)-VAR(12)	All models stable
Fixed VAR Portmanteau test	No specification fully passed
Dominant short-run cycles	Approximately 4.37 and 2.17 weeks
Lag selected after controls	11

All fixed VAR specifications are stable, but residual autocorrelation cannot be fully eliminated. The reference VAR(4), for example, satisfies the stability condition while the Portmanteau test still indicates residual autocorrelation. Residual normality is also rejected, and an ARCH effect is detected in the FAST equation.

Frequency analysis reveals pronounced short-run cycles of approximately 4.37 and 2.17 weeks in FAST and, particularly, 2.17 and 4.37 weeks in the RPS. Monthly, semi-monthly, and annual periodic components, together with FAST limit changes, are therefore controlled for before the TVP-VAR estimation.

After the periodic components and FAST limit shocks are included in the pre-adjustment, residual diagnostics improve materially in the 11-lag specification. The Portmanteau p-values at 24 and 36 weeks rise to 0.0716 and 0.1056, respectively, while the 16-week test remains just below the 5% threshold at 0.0494. Residual autocorrelation therefore cannot be said to have disappeared at every test horizon. The specification satisfies the stability condition, and the 11-week lag length selected by HQIC is used in the final TVP-VAR model.

4.3. Dynamic Connectedness Results

The TVP-VAR results show that the relationship between FAST and the RPS changes markedly over time. In the main transaction-count model, the average Total Connectedness Index (TCI) is 25.97%, ranging from 11.83% to 37.79% over the analysis period.

Table 3. TVP-VAR Dynamic Connectedness Results

Indicator	Transaction Count	Real Transaction Value
Average TCI (%)	25.97	15.35
FAST → RPS (%)	20.88	17.11
RPS → FAST (%)	31.06	13.59
Net FAST (%)	-10.19	3.51
Maximum spectral radius	0.938	0.919

Note: Dynamic summaries cover 4 October 2021-21 September 2026 (N=260) for the transaction-count model and 4 October 2021-24 August 2026 (N=256) for the real transaction-value model. Net connectedness is calculated from the unrounded directional connectedness measures.

In the transaction-count model, directional connectedness from the RPS to FAST averages 31.06%, compared with 20.88% from FAST to the RPS. FAST therefore has a net connectedness value of -10.19% and is, on average, a net receiver of shocks in the transaction-count model.

For real transaction values, the average TCI is 15.35%. Directional connectedness from FAST to the RPS is 17.11%, compared with 13.59% from the RPS to FAST, giving FAST a net connectedness value of 3.51%. In value terms, FAST therefore switches to a net transmitter of shocks.

Figure 1. TVP-VAR Total Connectedness Index

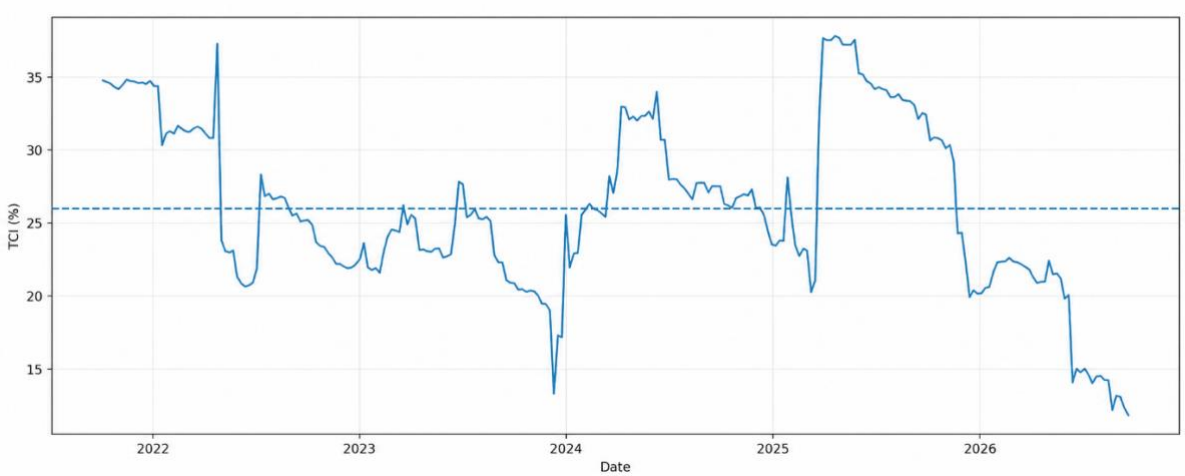
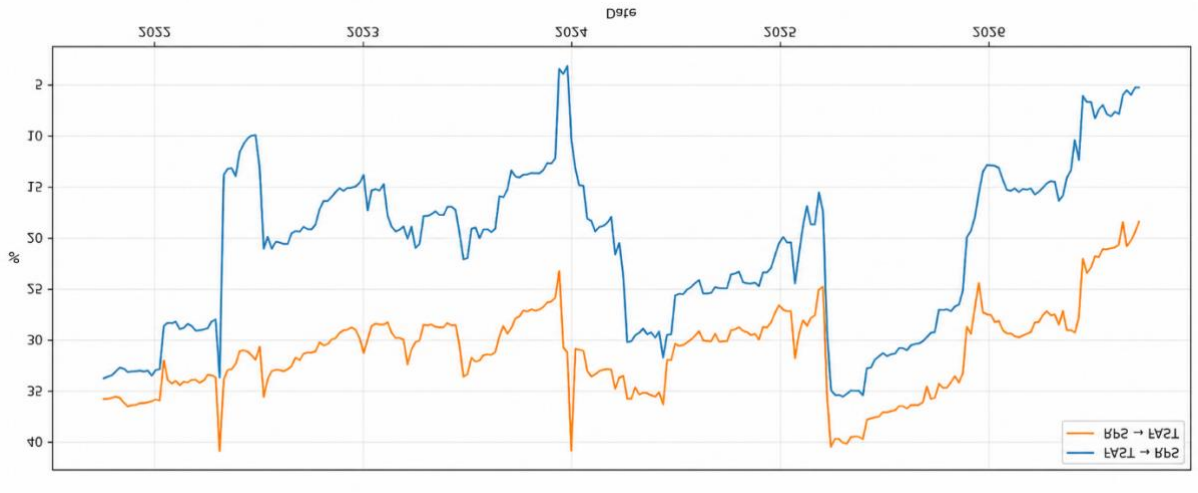


Figure 1 shows that total connectedness between FAST and the RPS is not constant over the sample. The substantial variation across periods also shows why a single full-sample average provides only a partial description of the relationship and why the time dimension matters.

Figure 2. Dynamic Directional Connectedness between FAST and the RPS



The directional connectedness series likewise show that shock transmission is neither one-way nor constant over time. The FAST-RPS relationship is therefore more informative when its time variation is considered alongside the average directional connectedness measures.

4.4. Generalized Impulse Response Results

Connectedness measures show the magnitude of shock transmission but not its sign. The response of the RPS to a positive FAST shock is therefore examined separately using generalized impulse response functions.

Table 4. Response of the RPS to a Positive FAST Shock

Indicator	Transaction Count	Real Transaction Value
1-week response	-0.242	-0.203
4-week response	-0.035	0.014
10-week response	0.017	0.041
1-4-week cumulative response	-0.201	-0.153
1-10-week cumulative response	-0.174	-0.133
Periods with negative CUM4 (%)	100.00	100.00
Periods with negative CUM10 (%)	94.23	100.00

Note: Impulse-response coefficients are expressed in standardised model units and should not be interpreted as direct percentage changes. CUM4 and CUM10 exclude the contemporaneous h=0 response and refer to cumulative responses over weeks 1-4 and 1-10 after the shock, respectively. Dynamic summary periods are the same as in Table 3.

In the transaction-count model, the average one-week RPS response to a positive FAST shock is -0.242. The four- and ten-week cumulative responses are -0.201 and -0.174, respectively. CUM4 is negative in every period of the analysis, while CUM10 is negative in 94.23% of periods.

The real transaction-value model supports the same directional result. The one-week response is -0.203, while the four- and ten-week cumulative responses are -0.153 and -0.133. In the real-value model, both cumulative responses remain negative throughout the sample.

Taken together, the results show that RPS transactions generally display a negative cumulative response to positive FAST shocks over short and medium horizons. This pattern is consistent with partial, time-varying substitution between FAST and the RPS. It does not imply that the RPS is fully displaced by FAST.

Figure 3. 1-10-Week Cumulative Response of the RPS to a FAST Shock

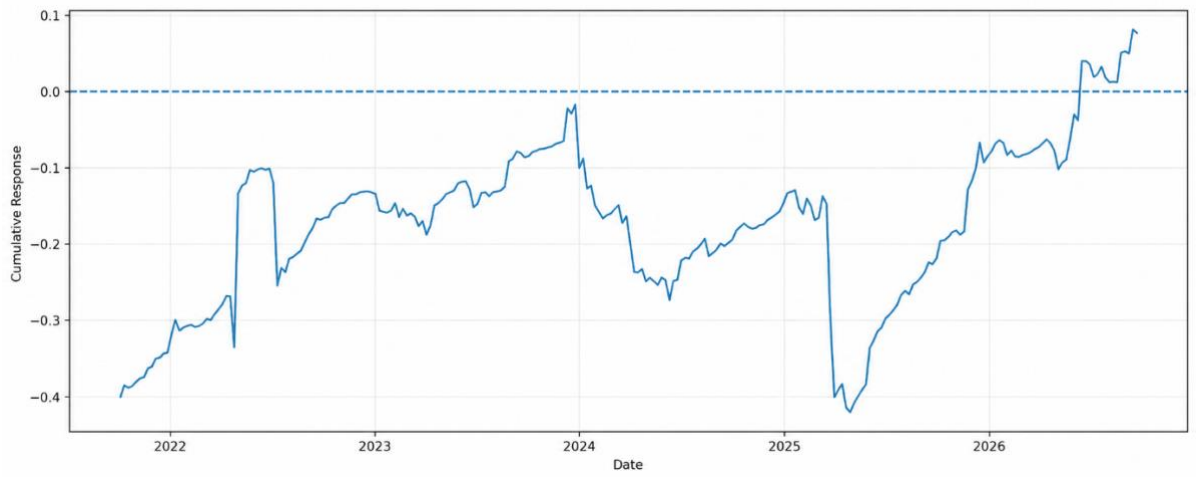


Figure 3 shows that the cumulative RPS response to positive FAST shocks remains below zero for most of the analysis period. The substitution-oriented sign is therefore not an artefact of the sample average; it is also present through most of the time dimension.

4.5. Robustness and Sensitivity Analyses

To examine whether the main findings depend on the TVP-VAR hyperparameters, nine hyperparameter combinations are estimated, including the baseline specification.

Table 5. Summary of Robustness Analyses

Indicator	Result
Specifications with negative mean CUM4	9 / 9
Specifications with negative mean CUM10	9 / 9
Minimum share of periods with negative CUM10	90.00%
Maximum share of periods with negative CUM10	100.00%
Unstable specification	0
CUM4, real transaction value	-0.153
CUM10, real transaction value	-0.133

Across all nine hyperparameter combinations, including the baseline, the mean four- and ten-week cumulative FAST-to-RPS responses remain negative. The share of periods with a negative CUM10 never falls below 90% and reaches 100% in some specifications. None of the models produces an unstable update.

The real transaction-value results also support a negative cumulative FAST-to-RPS response, indicating that the substitution-oriented sign is not specific to the transaction-count measure. CUM10 is -0.174 in the count model and -0.133 in the real-value model; the corresponding shares of negative periods are 94.23% and 100%.

An additional lag-sensitivity exercise compares the p = 4, 8, 11, and 12 models over the common evaluation period from 11 October 2021 to 21 September 2026 (N=259).

Table 6. Lag-Length Sensitivity Analysis

Lag (p)	Mean TCI (%)	CUM4	CUM10	Negative CUM4 (%)	Negative CUM10 (%)
4	25.43	-0.195	-0.187	98.46	94.59
8	26.18	-0.205	-0.209	100.00	99.23
11	25.94	-0.201	-0.173	100.00	94.21
12	25.85	-0.200	-0.174	100.00	94.21

Note: For comparability, all models are evaluated over the common period 11 October 2021-21 September 2026 (N=259). The TCI of 25.94% reported here for p=11 differs slightly from the baseline value of 25.97%, which uses 260 weeks after the learning period, solely because of the one-week difference in the evaluation window.

Mean CUM4 and CUM10 remain negative under all four lag choices. The share of periods with a negative CUM10 ranges from 94.21% to 99.23%. All specifications satisfy the stability condition, and the maximum spectral radius ranges from 0.741 to 0.938. The substitution-oriented sign of the main finding is therefore preserved across the alternative lag lengths.

More generally, the inability of the fixed-coefficient VAR diagnostics to eliminate residual autocorrelation at every test horizon suggests that a constant-parameter structure may not capture all of the dynamics in the data. Combined with the theoretical expectation that the relationship between payment systems can evolve over time, this provides a practical rationale for using a time-varying parameter approach. The main results indicate bidirectional, time-varying shock transmission between FAST and the RPS, while the cumulative RPS response to positive FAST shocks is predominantly negative. That sign is broadly preserved across alternative hyperparameters, the real transaction-value model, and different lag lengths.

5. Discussion, Conclusion, and Recommendations

This study examines the time-varying relationship between FAST and the RPS in Türkiye using weekly transaction data, TVP-VAR connectedness measures, and generalized impulse responses. In the main transaction-count model, the average Total Connectedness Index is 25.97% and varies substantially across the sample. Shock transmission from the RPS to FAST is stronger in transaction counts, whereas FAST becomes the net shock transmitter in the real transaction-value model.

The central result is the predominantly negative cumulative RPS response to positive FAST shocks. In the transaction-count model, CUM4 and CUM10 are -0.201 and -0.174, respectively; the four-week response is negative throughout the sample, and the ten-week response is negative in 94.23% of periods. The real transaction-value model supports the same conclusion: both the four- and ten-week cumulative responses are negative and remain below zero throughout the sample. The mean CUM4 and CUM10 values also remain negative under all nine hyperparameter combinations and in the p = 4, 8, 11, and 12 lag specifications, indicating that the sign is not driven by a single modelling choice.

These findings are broadly consistent with Khiaonarong and Humphrey (2022b), who show that instant payments can partially substitute for traditional payment instruments in some countries. They are also in line with Bruggink and Benevelli's (2021) argument that instant payments and established payment instruments need not be complete substitutes.

The evidence is therefore consistent with partial and time-varying substitution between FAST and RPS transactions. From a payment-system perspective, the two infrastructures should be monitored jointly, with attention to shifts across transaction types and values and to the implications of growing instant-payment use for system capacity and operational resilience.

The main limitation is the use of aggregate system-level data, which do not allow transactions to be separated by user type, purpose, or bank. The bivariate model also cannot fully isolate unobserved factors that may affect both systems at the same time, including common payment demand, pricing, bank behaviour, and regulatory developments. In addition, time-varying confidence bands are not produced for the impulse responses. Persistence of the negative sign should therefore be read as directional and descriptive robustness rather than evidence of statistical significance. The generalized impulse-response results should not be interpreted as structural causality or as a structural substitution coefficient.

Future research could separate FAST transactions into personal, commercial, and merchant payments, use bank- or user-level data, and model a broader set of payment instruments jointly. Such extensions would allow the mechanisms behind substitution across payment channels to be identified more precisely.

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FULL PAPER · IP2.6 · IN-PERSON SESSION II

Fast Lives, Easy Money, Green Choices? A Behavioral Perspective on Generation Z and Sustainable Entrepreneurship

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ABSTRACT

Generation Z is often described as the most entrepreneurial and the most environmentally concerned generation. These two dispositions, however, do not automatically lead to sustainable venture creation. Drawing on behavioral economics, this conceptual paper argues that three behavioral tensions shape whether young people's entrepreneurial energy is directed towards sustainable entrepreneurship. The first is *fast lives*, in which an accelerated pace of life, time pressure and present bias shorten planning horizons. The second is *easy money*, a socially amplified orientation towards speculative, get-rich-quick activities such as cryptocurrency and app-based trading. The third is *green choices*, strong pro-environmental values that are weakened by a persistent attitude–behavior gap. The paper combines an interdisciplinary literature review with descriptive indicators from the Global Entrepreneurship Monitor (GEM), Eurobarometer and international youth surveys, and with an original cohort analysis of the World Values Survey Wave 7 (66 countries, N = 95,178). Young adults show high early-stage entrepreneurial activity and stronger sustainability priorities than older entrepreneurs, yet fear of failure is rising and many young people enter finance through cryptocurrency and social media. In the WVS data, Gen Z is only slightly more likely than older cohorts to put the environment before economic growth (59.5% vs. 56.2%), and fewer than one in five belong to an environmental organization. In Türkiye this gap is much wider (63.3% vs. 6.1%). Building on this evidence, the paper develops a conceptual model with six propositions. Pace of life and easy-money orientation are expected to weaken sustainable entrepreneurial intention, and green values to strengthen it. Digital platforms amplify the first two tensions, while nudges and social norms, especially dynamic norms, are proposed as low-cost levers. The paper highlights time preferences and speculative financial culture as overlooked antecedents of sustainable entrepreneurship and draws implications for entrepreneurship education, financial literacy and platform design.

Keywords: Generation Z; sustainable entrepreneurship; pace of life; present bias; easy money; nudge; social norms; pro-environmental behavior

1. Introduction

The transition to a green and inclusive economy depends on technology and regulation, but also on the choices of the generation that will live longest with the consequences of today's decisions. Generation Z, broadly those born from the late 1990s onwards, is entering labour and capital markets at a time of overlapping climate, cost-of-living and technological change. Two observations about this cohort are now widely repeated. Young people are highly entrepreneurial. In the United States, adults aged 18–24 recorded the highest total early-stage entrepreneurial activity (TEA) of any age group in the most recent GEM national survey, reversing a long-standing pattern in which entrepreneurship peaked between the ages of 25 and 44 (Babson College, 2024). Young people are also deeply concerned about the environment. In a ten-country survey of 10,000 people aged 16–25, 59% said they were very or extremely worried about climate change (Hickman et al., 2021).

If both observations hold, Generation Z should be a natural driver of sustainable entrepreneurship, defined as entrepreneurial action that preserves nature and life-support systems while creating economic and non-economic gains for others (Shepherd & Patzelt, 2011). The evidence is less encouraging. Sustainable ventures

remain a small share of entrepreneurial activity in many economies (Hill et al., 2025), and fear of failure has risen worldwide (Global Entrepreneurship Monitor [GEM], 2025). The well-documented gap between environmental attitudes and behavior (Kollmuss & Agyeman, 2002) does not disappear simply because a cohort is young. At the same time, a parallel culture of "easy money", built around cryptocurrency speculation, app-based trading and influencer-promoted schemes, competes for the same entrepreneurial energy, risk appetite and savings (FINRA Investor Education Foundation & CFA Institute, 2023).

This paper asks why the entrepreneurial and environmental dispositions of Generation Z may fail to meet in sustainable entrepreneurship, and which low-cost behavioral levers could help. It takes a behavioral economics perspective, in which preferences are time-inconsistent, socially embedded and sensitive to choice architecture (Frederick et al., 2002; Thaler & Sunstein, 2008). Three research questions guide the analysis. (RQ1) How do pace of life and time preferences shape Gen Z's orientation towards long-horizon, sustainable ventures? (RQ2) How does a socially amplified easy-money culture change what young people see as entrepreneurship? (RQ3) Can nudges and social norms help close the gap between Gen Z's green values and green entrepreneurial action?

The paper makes three contributions. It brings research on time preference and pace of life into the sustainable entrepreneurship literature, where intention models have mostly emphasized attitudes, self-efficacy and sustainability orientation (Vuorio et al., 2018). It treats speculative financial culture as a competing behavioral pathway that can crowd out value-creating ventures. Finally, it combines the literature with descriptive indicators and an original generational analysis of World Values Survey data, including Türkiye, to propose a testable model with six propositions that speaks directly to the conference themes of innovation, inclusion and green transformation.

2. Method

The study uses an integrative, conceptual review rather than a systematic meta-analysis. The three literatures it connects, namely pace of life and time preference, the behavioral finance of young retail investors, and green nudging and social norms, have rarely been examined together, and the aim is to build theory rather than to pool effect sizes. Key and recent works were identified through keyword searches in multidisciplinary databases (e.g., "Generation Z" AND "sustainable entrepreneurial intention"; "pace of life"; "present bias"; "finfluencer" OR "cryptocurrency" AND young investors; "green nudge"; "social norms" AND pro-environmental behavior). These searches were supplemented by backward citation tracking of highly cited reviews and meta-analyses. The bibliographic details of all peer-reviewed sources were checked against the Crossref DOI registry.

To ground the argument empirically, the review draws on four groups of descriptive indicators. GEM national and global reports provide data on youth entrepreneurial activity, fear of failure and sustainability priorities. Eurobarometer surveys cover young Europeans' environmental engagement and climate attitudes. The World Values Survey Wave 7 (Haerpfer et al., 2024), analyzed by the author, allows cohort comparisons of environmental attitudes and action, beliefs about success and social media use. International youth surveys on investing and work complete the picture (FINRA Investor Education Foundation & CFA Institute, 2023; Deloitte, 2023, 2024). These indicators are illustrative. They are not pooled or used to test causal claims, and differences in samples, years and age definitions are noted where relevant.

The WVS analysis uses the country-pooled Wave 7 datafile (version 6.0), which covers 66 countries surveyed between 2017 and 2023. Respondents aged 18 and over with a valid year of birth (N = 95,178) were divided into three birth cohorts. These are Generation Z (born 1997 or later, n = 9,140), Millennials (1981–1996, n = 32,654) and Generation X and older (1980 or earlier, n = 53,384). Four items were examined. Q111 asks whether protecting the environment or economic growth and job creation should take priority, and we report the share

choosing the environment. Q99 records active or inactive membership of an environmental organization. Q207 measures how often social media is used as a source of information, and we report daily use. Q110 asks whether success comes from hard work or from luck and connections, and we report the share scoring 6–10 on the 1–10 scale. Membership of a charitable or humanitarian organization (Q101) was added as a prosocial benchmark. All shares are weighted with the WVS design weight (W_WEIGHT). Because the inverted release of the datafile reverses some scales, the direction of each item was checked for internal consistency. Members of environmental organizations were more likely to prioritize the environment (61.6% vs. 56.4%), and the luck item correlated positively with the view that competition is harmful (Q109, r = 0.29), as expected under the original coding.

Pooled shares partly reflect country composition, because Gen Z respondents are more numerous where fieldwork took place later. Gen Z was therefore also compared with Generation X and older *within* each of the 39 countries that have at least 100 Gen Z respondents. Results for Türkiye are reported separately. The Turkish fieldwork took place in 2018 (N = 2,414), and its 153 Gen Z respondents were aged 18–21, so these estimates should be read with caution.

3. Theoretical Background

3.1 Sustainable entrepreneurship and entrepreneurial intention

Sustainable entrepreneurship refers to the discovery and exploitation of opportunities that sustain natural and communal environments while also producing economic and social gains (Shepherd & Patzelt, 2011). Early work located these opportunities in market failures and imperfections such as externalities, public goods and information asymmetries, which entrepreneurs can address while earning a return (Cohen & Winn, 2007; Dean & McMullen, 2007; Hall et al., 2010). At the individual level, the dominant framework is the intention-based model derived from the theory of planned behavior, in which attitudes, subjective norms and perceived behavioral control predict entrepreneurial intention (Ajzen, 1991; Krueger et al., 2000; Liñán & Chen, 2009). Studies of sustainable entrepreneurial intention add sustainability orientation and environmental attitudes as antecedents (Vuorio et al., 2018).

Recent studies of Generation Z show that creativity, proactive personality, perceived behavioral control and risk perception shape young people's sustainable entrepreneurial intentions (Lopes et al., 2024). The desire for social inclusion is another important driver (Burlea-Schiopoiu & Popovici, 2024), and Gen Z students combine strong motivation to start businesses with considerable uncertainty about sustainability-oriented business models (Papp-Váry et al., 2023). What these models largely leave aside is the *temporal* and *financial-cultural* context in which intentions are formed. These are precisely the dimensions that behavioral economics brings to the fore.

3.2 A behavioral economics lens

Behavioral economics departs from the assumption of stable, exponentially discounted preferences. People often show present bias, giving disproportionate weight to immediate outcomes. As a result, they postpone investments with delayed payoffs and reverse their preferences over time (Laibson, 1997; O'Donoghue & Rabin, 1999; Frederick et al., 2002). Choices under risk depend on reference points and on probability weighting, including a tendency to overweight small chances of large gains (Kahneman & Tversky, 1979). Preferences are also social. People infer what is appropriate from what others do (descriptive norms) and from what others approve of (injunctive norms) (Cialdini et al., 1990), and prosocial or pro-environmental acts can bring a private “warm glow” (Andreoni, 1990). Finally, because decisions depend on how options are presented, changes in choice architecture such as defaults, salience, feedback and commitment devices can shift behavior without

restricting options or materially changing incentives (Thaler & Sunstein, 2008). These insights form the basis of the three tensions discussed below.

4. Three Behavioral Tensions

4.1 Fast lives, time pressure and present bias

Pace of life, the speed and density of everyday activity, differs systematically across societies. In their classic study of 31 countries, Levine and Norenzayan (1999) found faster paces in economically productive, individualistic and colder countries. Sociologists describe late modernity as a regime of "social acceleration" in which technological change, social change and the pace of daily life reinforce one another (Rosa, 2013). In such a regime, rising time pressure can erode the enjoyment of life even as material wealth grows (Garhammer, 2002). Generation Z has grown up in the most accelerated layer of this world, with constant connectivity, endless feeds and instant feedback.

This matters for sustainable entrepreneurship because sustainable ventures are, almost by definition, long-term projects. Their environmental and social returns accumulate slowly and often outside the firm, and their financial returns may lag behind those of conventional ventures. Present-biased individuals systematically under-invest in such projects (O'Donoghue & Rabin, 1999). Psychological research points the same way. A meta-analysis shows that a future-oriented time perspective is positively associated with environmental engagement (Milfont et al., 2012), which fits the role of considering future consequences when weighing immediate against distant outcomes (Strathman et al., 1994). Time affluence, the feeling of having enough time, is in turn associated with greater well-being and more ecologically responsible behavior (Kasser & Sheldon, 2009). A fast pace of life may therefore do more than reduce well-being. It may also shorten the planning horizon that sustainable ventures require.

Proposition 1 (P1): *A faster pace of life and stronger present bias are negatively associated with Gen Z's sustainable entrepreneurial intention, because they reduce the weight given to delayed environmental and social returns.*

4.2 Easy money and the redefinition of entrepreneurship

A second tension arises from the financial culture in which Generation Z has grown up. A 2022 survey of young adults in the United States, Canada, the United Kingdom and China found that cryptocurrency was the most common first investment among Gen Z investors in Canada and the UK. In the United States, 44% of Gen Z investors said their first investment was crypto, compared with 35% of Millennials and 23% of Generation X. Social media was the main source of investment information in three of the four countries, and between 41% and 60% of Gen Z investors cited fear of missing out (FOMO) as a reason for starting to invest (FINRA Investor Education Foundation & CFA Institute, 2023).

Behavioral finance helps to explain this pattern. Individual investors are drawn to attention-grabbing assets (Barber & Odean, 2008). On commission-free, gamified trading apps, herding into such stocks is followed by negative returns (Barber et al., 2022), although the aggregate holdings of these crowds do not necessarily underperform (Welch, 2022). Lottery-like assets attract investors with a propensity to gamble, who tend to be younger and less wealthy and who earn lower returns (Kumar, 2009). This is consistent with the overweighting of small probabilities of large gains (Kahneman & Tversky, 1979). Research on cryptocurrency trading points to structural and psychological similarities with gambling (Delfabbro et al., 2021) and to a link with problem gambling among regular gamblers (Mills & Nower, 2019). Financial influencers, or "finfluencers", intensify these dynamics. Many of them appear to lack investment skill, and unskilled advice can attract larger audiences (Kakhbod et al., 2023). Low financial literacy, which is particularly common among young people, further limits

their ability to judge such information (Lusardi & Mitchell, 2014), and FOMO is associated with heavier social media use (Przybylski et al., 2013).

The argument here is not that young people are irrational. Rather, an easy-money culture changes what it means to be "entrepreneurial". When entrepreneurial identity is linked to fast, individual and speculative wealth instead of to organizing resources to solve problems, risk appetite and scarce savings move away from venture creation, and even further away from sustainable venture creation. Financial insecurity reinforces this pattern. In the 2023 Deloitte survey, 46% of Gen Z respondents reported holding a second paid job alongside their main job (Deloitte, 2023), which points both to entrepreneurial activity and to limited time and resources.

Interestingly, the easy-money culture does not seem to rest on a generational belief in luck. In the WVS Wave 7 data, about one third of each cohort believes that success depends more on luck and connections than on hard work (Gen Z 33.4%, Millennials 34.7%, Generation X and older 33.3%), and Gen Z exceeds the oldest cohort on this item in only 20 of 39 countries. In Türkiye the belief is more common in every cohort, though least so among Gen Z (41.9%, compared with 46.4% and 46.8%). What sets young people's financial behavior apart is therefore more likely to lie in the channels, products and social cues through which they first meet finance than in a broad change in how they think success is achieved.

Proposition 2 (P2): *A stronger easy-money orientation is negatively associated with Gen Z's sustainable entrepreneurial intention, because it directs risk-taking and resources towards short-term speculation and defines entrepreneurial success in terms of individual wealth.*

4.3 Green choices and the attitude–behavior gap

The third tension is more hopeful. Young people report strong environmental concern. Across ten countries, 59% of 16–25-year-olds were very or extremely worried about climate change, and more than 45% said these feelings affected their daily functioning (Hickman et al., 2021). In Europe, climate change and the environment are among the issues on which young people are most active (European Commission, 2024). In cross-national survey data, younger adults were more likely than older adults to prioritize environmental protection over job creation in 12 of 20 countries (Pew Research Center, 2020). Young entrepreneurs also report stronger sustainability priorities than older ones (Babson College, 2024), and in 2024, 64% of Gen Z respondents said they would pay more for environmentally sustainable products (Deloitte, 2024).

Turning these values into sustainable ventures is demanding. GEM's first report on sustainability counts an entrepreneur as sustainable only when four conditions hold together. The entrepreneur must have "a motivation to make a difference in the world", must have "taken action to promote sustainability in their business in the past 12 months", must have "built sustainability into their long-term business strategy" and must have "prioritised sustainability over profitability or growth" (Hill et al., 2025). Each condition on its own is widely met. In 42 of 62 economies, more than 70% of new entrepreneurs consider social impacts in their strategic decisions. Yet in 29 of 62 economies, fewer than 2% of adults are new entrepreneurs who meet all four criteria (Hill et al., 2025). The distance between considering sustainability and putting it ahead of profit is, in effect, the attitude–behavior gap at the level of the firm.

Two caveats temper this picture. Cohort studies warn against assuming that every new generation is greener. Long-run survey data from the United States showed declines rather than increases in some environmental behaviors and civic orientations among earlier young cohorts (Twenge et al., 2012). In addition, environmental values often fail to become behavior because of habits, costs, weak feedback and low perceived efficacy (Kollmuss & Agyeman, 2002). Turning green values into green ventures therefore requires more than motivation. It also requires the time horizon (P1) and resources (P2) discussed above.

Proposition 3 (P3): *Pro-environmental values are positively associated with Gen Z's sustainable entrepreneurial intention, but this association is weakened by the attitude–behavior gap.*

4.4 The digital platform environment as an amplifier

Social media is the common setting of all three tensions. Platform design rewards speed and novelty and so adds to time pressure. It makes speculative success stories visible and social, which feeds FOMO, and it shapes which behaviors appear normal. The same environment can also spread green content and visible role models. It also affects the information on which green choices rest, since 49% of Europeans say it is difficult to tell reliable climate information from disinformation on social media (European Commission, 2025).

The WVS Wave 7 data show how strongly this exposure differs across generations. Of Gen Z respondents, 63.8% use social media as a daily source of information, compared with 58.1% of Millennials and 34.0% of Generation X and older. In Türkiye the corresponding shares are 82.2%, 75.1% and 53.3%. Within countries, Gen Z relies on social media more than the oldest cohort in all 39 countries where the comparison is possible.

Proposition 4 (P4): *The digital platform environment amplifies the negative associations in P1 and P2 by speeding up the pace of life and making speculative gains socially visible, while also offering channels through which green norms can spread.*

5. Behavioral Levers

5.1 Nudges and choice architecture

Nudges are changes in choice architecture that alter behavior in predictable ways without forbidding options or significantly changing economic incentives (Thaler & Sunstein, 2008). Green nudges have had large effects in specific settings. On a food-delivery app, making “no cutlery” the default and adding visible prompts raised the share of no-cutlery orders by 648% (He et al., 2023). Opt-out green electricity tariffs substantially increased the uptake of renewable energy contracts (Ebeling & Lotz, 2015). Reviews point to defaults, feedback, social comparison and salience as the most promising tools for pro-environmental behavior (Byerly et al., 2018; Schubert, 2017).

The evidence also calls for realism. A large meta-analysis estimated a small-to-medium average effect of choice-architecture interventions, with decision-structure interventions such as defaults being the most effective (Mertens et al., 2022). A re-analysis, however, found no robust overall evidence for nudging once publication bias was taken into account, while noting considerable variation across domains and types of nudge (Maier et al., 2022). Interventions scaled up by government nudge units produce much smaller effects than those reported in academic journals (DellaVigna & Linos, 2022), and combining nudges with monetary incentives appears particularly effective for pro-environmental behavior (Alt et al., 2024). Questions of transparency and autonomy also need to be addressed (Schubert, 2017).

Nudges matter for the present model in two ways. Commitment devices, defaults and tools that make future consequences visible can counter present bias and short horizons (P1). Examples include allocating a share of student or start-up grants to sustainability-oriented business development by default, pre-commitment savings features in fintech apps, and impact dashboards in incubators. Friction and salience measures on trading platforms, such as cooling-off periods, risk disclosures and the default display of long-run performance, can in turn weaken the pull of speculative easy money (P2).

Proposition 5 (P5): *Choice-architecture interventions that lengthen decision horizons and add friction to speculative choices weaken the negative associations in P1 and P2.*

5.2 Social norms

Social norms are among the strongest and best-documented levers of pro-environmental behavior. Descriptive-norm messages increased towel reuse in hotels more than standard environmental appeals (Goldstein et al., 2008), and home energy reports that compared households with their neighbors reduced energy use at scale (Allcott, 2011). Norm interventions must be designed with care, because descriptive norms can backfire among people who already behave well unless they are paired with signals of approval (Schultz et al., 2007). This matters for a cohort whose green behaviors are not yet the majority practice. *Dynamic* norms, which convey that the number of people adopting a behavior is growing, promote sustainable behavior even when that behavior is still uncommon (Sparkman & Walton, 2017).

Norms also operate at the level of entrepreneurship. Across U.S. states, environmental entrepreneurship was higher where consumer environmental norms and family-business norms were stronger (Meek et al., 2010). For Generation Z, reference groups are increasingly online and peer-based. Visible and growing communities of young green entrepreneurs could therefore act as a powerful dynamic norm. In Europe, 72% of young people say that their education taught them to care for the environment (European Commission, 2024). Schools and universities already set norms in this area, and this role could be extended from caring for the environment to environmental entrepreneurship.

Proposition 6 (P6): *Descriptive and especially dynamic social norms of sustainable entrepreneurship strengthen the translation of Gen Z's pro-environmental values into sustainable entrepreneurial intention and action, thereby narrowing the attitude–behavior gap in P3.*

6. Descriptive Evidence from Secondary Indicators and the WVS-7 Cohort Analysis

Table 1 summarizes secondary indicators for each element of the conceptual model. Because they come from different populations and years, they are used to show that the tensions are plausible, not to estimate relationships.

Table 1. Selected secondary indicators illustrating the conceptual model

Model element	Indicator	Value	Source
Entrepreneurial disposition	TEA rate, U.S. adults aged 18–24 (2023; highest of all age groups)	24%	Babson College (2024)
Entrepreneurial disposition	Intend to start a business within 3 years, U.S. adults aged 18–24 (2023)	21%	Babson College (2024)
Green choices	Entrepreneurs prioritizing sustainability, ages 18–34 vs. 35–65 (U.S., 2023)	61% vs. 47%	Babson College (2024)
Green choices	Entrepreneurs taking steps to minimize environmental impact, ages 18–34 vs. 35–65 (U.S., 2023)	66% vs. 44%	Babson College (2024)
Green choices	Young people (15–30, EU-27) active on climate change and environment (2024)	33%	European Commission (2024)
Green choices	Young people (16–25, ten countries) very or extremely worried about climate change (2021)	59%	Hickman et al. (2021)
Green choices	Gen Z willing to pay more for environmentally sustainable products (44 countries, 2024)	64%	Deloitte (2024)
Attitude–behavior gap	Economies (of 62) where fewer than 2% of adults were new entrepreneurs meeting all four GEM sustainability criteria (2021–2023)	29 of 62	Hill et al. (2025)
Fast lives / risk	Adults reluctant to start a business due to fear of failure, 51 economies (2019 → 2024)	44% → 49%	GEM (2025)
Easy money	Crypto as first investment, U.S. Gen Z vs. Millennial vs. Gen X investors (2022)	44% / 35% / 23%	FINRA Foundation & CFA Institute (2023)
Easy money	Gen Z investors citing FOMO as a reason to start investing (U.S., Canada, UK, China, 2022)	41–60%	FINRA Foundation & CFA Institute (2023)
Digital amplifier	U.S. Gen Z investors using social media to learn about investing (2022)	48%	FINRA Foundation & CFA Institute (2023)

Model element	Indicator	Value	Source
Digital amplifier	Europeans finding it hard to tell reliable climate information from disinformation on social media (2025)	49%	European Commission (2025)
Financial insecurity	Gen Z holding a second paid job in addition to their main job (44 countries, 2023)	46%	Deloitte (2023)

Note. Indicators come from different surveys, years, countries and age definitions and are reported for illustration only. GEM = Global Entrepreneurship Monitor; TEA = total early-stage entrepreneurial activity; FOMO = fear of missing out.

Three patterns emerge from these indicators. The entrepreneurial and green dispositions of young people are real. Young entrepreneurs report clearly higher sustainability, environmental and social priorities than older ones, and young Europeans are active on climate issues. The signs of an easy-money culture are just as strong, with crypto as a first investment, social media as the main source of financial information and FOMO as a common motive. Yet the conversion of these dispositions into action looks weak at the system level. Sustainable new ventures remain a small share of adult activity in many GEM economies, and fear of failure has increased.

Table 2 and Figure 2 present the author's cohort analysis of the World Values Survey Wave 7. This analysis makes it possible to examine the green-choices and digital dimensions of the model across 66 countries, including Türkiye.

Table 2. Environmental attitudes and action, beliefs about success and social media use by generation (WVS Wave 7, %)

Indicator (WVS-7 item)	Gen Z (1997+)	Millennials (1981–96)	Gen X & older (≤1980)	Gen Z > Gen X & older (countries)
All countries (66 countries, N = 95,178)				
Environment should be prioritized over economic growth (Q111)	59.5	57.4	56.2	26 of 39
Member of an environmental organization (Q99)	18.9	14.2	11.8	30 of 39
Member of a charitable/humanitarian organization (Q101)	21.5	18.0	17.4	23 of 39
Success depends on luck and connections rather than hard work (Q110, 6–10)	33.4	34.7	33.3	20 of 39
Social media used daily as an information source (Q207)	63.8	58.1	34.0	39 of 39
Türkiye (2018, N = 2,414; Gen Z n = 153)				
Environment should be prioritized over economic growth (Q111)	63.3	57.6	56.8	—
Member of an environmental organization (Q99)	6.1	5.0	5.2	—
Member of a charitable/humanitarian organization (Q101)	5.4	5.9	6.7	—
Success depends on luck and connections rather than hard work (Q110, 6–10)	41.9	46.4	46.8	—
Social media used daily as an information source (Q207)	82.2	75.1	53.3	—

Note. Author's calculations from the WVS Wave 7 country-pooled datafile, version 6.0 (Haerpfer et al., 2024). Shares are weighted (W_WEIGHT) and refer to respondents aged 18+ with valid answers. The last column gives the number of countries, among the 39 with at least 100 Gen Z respondents, in which the Gen Z share exceeds that of Generation X and older. Estimates for Gen Z in Türkiye rest on a small sample and should be read with caution.

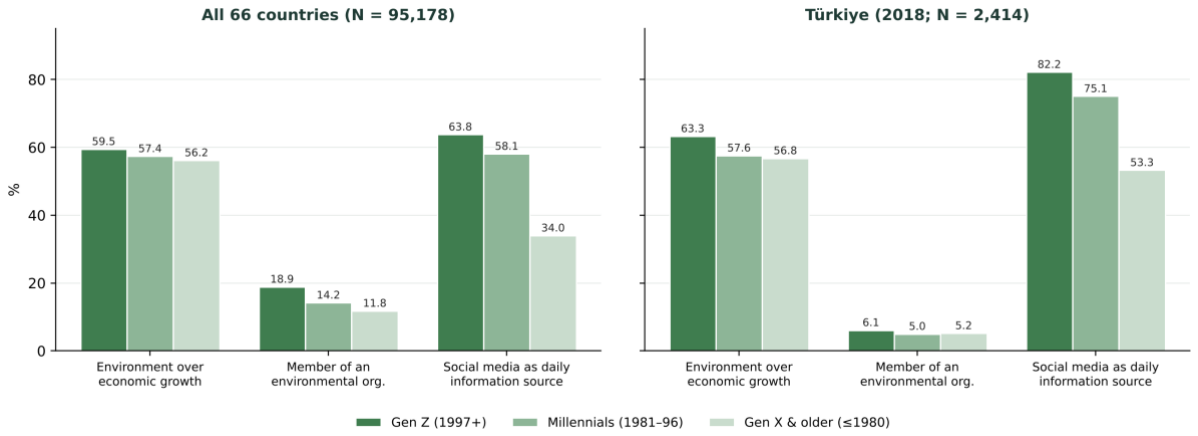


Figure 2. Environmental attitudes, environmental action and social media use by generation (WVS Wave 7, %)

Four findings stand out. First, Gen Z is greener in attitude, but only slightly. Of Gen Z respondents, 59.5% put the environment before economic growth, compared with 57.4% of Millennials and 56.2% of Generation X and older, and Gen Z is ahead of the oldest cohort in 26 of 39 countries. This is in line with cross-national evidence on age differences (Pew Research Center, 2020) and with the warning that each new generation should not be assumed to be markedly greener (Twenge et al., 2012).

Second, the gap between attitude and action is wide in every cohort. Roughly three in five respondents prioritize the environment, but fewer than one in five belong to an environmental organization (Gen Z 18.9%, Millennials 14.2%, Generation X and older 11.8%). Gen Z is the most engaged cohort and is ahead of the oldest cohort in 30 of 39 countries, yet the attitude–behavior gap proposed in P3 remains large. Membership of charitable and humanitarian organizations follows a similar pattern (21.5%, 18.0% and 17.4%, with Gen Z ahead in 23 of 39 countries).

Third, the attitude–behavior gap is particularly sharp in Türkiye. Turkish Gen Z respondents are the most pro-environmental group in the table (63.3%), yet only 6.1% belong to an environmental organization and 5.4% to a charitable one. These figures are close to those of older Turkish cohorts. Green values are present, but the organizational channels that could turn them into collective or entrepreneurial action appear thin. This strengthens the case for the norm-based and choice-architecture levers discussed in Section 5.

Fourth, social media use is the sharpest generational divide in the data, which supports the role given to the digital environment in P4. Beliefs about luck and hard work, by contrast, show no consistent generational pattern. Taken together, the WVS evidence suggests that what distinguishes Gen Z is less its values than the digital, financial and organizational environment that determines whether those values turn into action.

7. Conceptual Model and Propositions

Figure 1 brings the arguments together. Generation Z enters the model with high entrepreneurial intention, strong climate concern and considerable financial insecurity. Three behavioral tensions mediate the path from these dispositions to sustainable entrepreneurship. Fast lives (P1) and easy money (P2) weaken it, while green choices (P3) strengthen it. The digital platform environment amplifies the first two (P4). Nudges moderate the negative paths by lengthening horizons and adding friction to speculation (P5), and social norms strengthen the positive path by narrowing the attitude–behavior gap (P6). Table 3 summarizes the propositions and suggests measures for empirical testing.

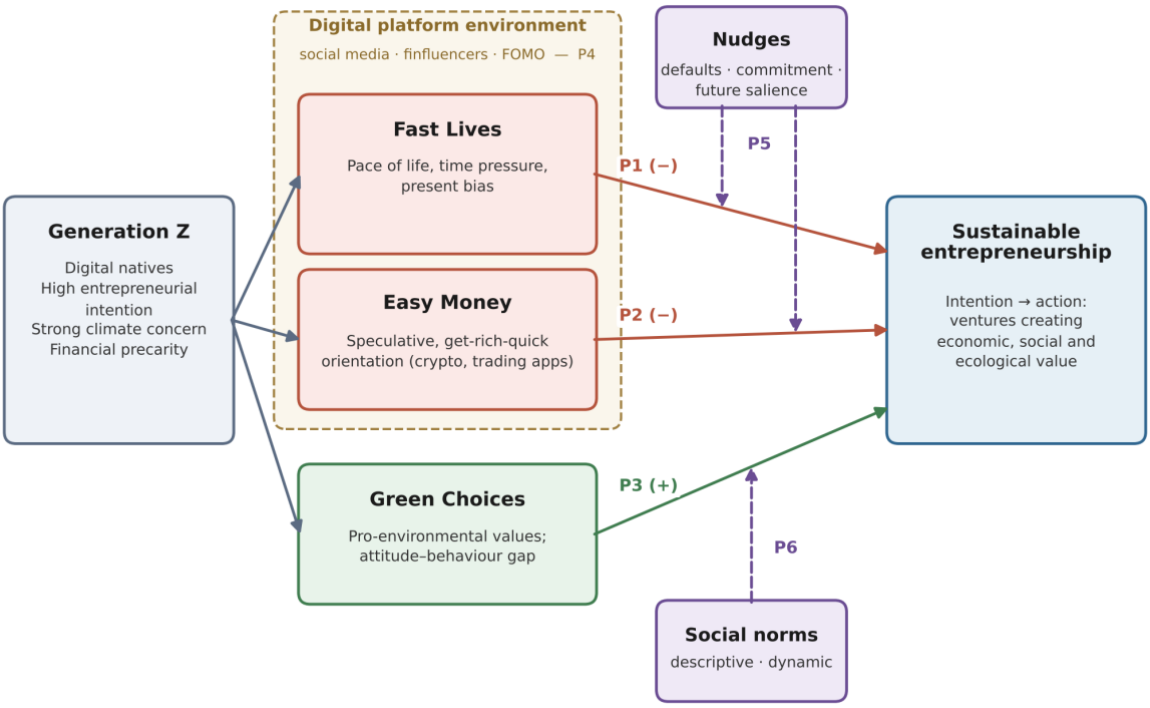


Figure 1. Behavioral tensions, amplifier and levers shaping sustainable entrepreneurship among Generation Z

Table 3. Summary of propositions and suggested measures

	Proposition	Suggested measures
P1	Faster pace of life and stronger present bias → lower sustainable entrepreneurial intention (−)	Pace-of-life and time-pressure scales; incentivized intertemporal choice (β–δ); consideration of future consequences
P2	Easy-money orientation → lower sustainable entrepreneurial intention (−)	Crypto/app-trading participation; lottery-preference items; get-rich-quick attitude scale
P3	Pro-environmental values → higher sustainable entrepreneurial intention (+), weakened by the attitude–behavior gap	Environmental values; sustainable entrepreneurial intention scale; self-reported green behavior
P4	Digital platform environment amplifies P1 and P2	Social media intensity; finfluencer exposure; FOMO scale
P5	Nudges (defaults, commitment, friction) weaken P1 and P2	Field or online experiments with default, commitment and friction treatments
P6	Descriptive and dynamic norms strengthen P3	Norm-message experiments; perceived peer norms of green entrepreneurship

8. Implications for Policy and the Entrepreneurial Ecosystem

Entrepreneurship education. Programmes for young people can include tools that lengthen time horizons, such as scenario planning, impact roadmaps and commitment contracts, so that the long-term value of sustainable ventures becomes visible. Showcasing the growing number of young green founders can turn sustainability into a dynamic norm rather than a niche choice.

Financial literacy and consumer protection. Financial education should explicitly contrast speculation with value creation and address FOMO, probability weighting and the credibility of influencers. Regulators and platforms can introduce evidence-based friction where young people first encounter investing, for example cooling-off periods, prominent information on long-run performance and default risk warnings.

Platform and incubator design. Fintech, crowdfunding and incubator platforms can make green options the default where appropriate, for instance through opt-out allocation to green savings products or impact metrics included by default in pitch templates. Such choices should be made transparently (Schubert, 2017).

Inclusion. Financial insecurity pushes young people towards both side jobs and speculative bets. Inclusive access to patient capital, micro-grants and mentoring is therefore a precondition for turning green values into ventures, and it links the green transformation agenda with the inclusion of future generations. Because the WVS evidence shows that pro-environmental values in Türkiye rarely become organized action, universities and local entrepreneurial ecosystems can play a particularly important role in creating channels through which young people can turn green ideas into ventures.

9. Limitations and Future Research

The paper is conceptual, and its secondary indicators are descriptive. They come from different samples, countries and years, some from grey literature, and they cannot establish causal relationships. The WVS analysis is cross-sectional, so cohort differences cannot be separated from age and period effects. Organizational membership is only a narrow proxy for pro-environmental behavior, and the Turkish estimates rest on a small Gen Z sample surveyed in 2018, when the oldest members of this cohort were barely 21. Future research can test the propositions with surveys that measure pace of life, present bias (for example through incentivized intertemporal choice tasks), easy-money orientation and sustainable entrepreneurial intention in the same sample. Panel data linking WVS or GEM country indicators to sustainable entrepreneurial activity over time, and field experiments that test nudges and dynamic-norm messages in entrepreneurship programmes and on fintech platforms, would also be valuable. Comparative studies of emerging economies such as Türkiye, where youth entrepreneurship, cryptocurrency adoption and climate exposure meet in distinctive ways, deserve particular attention.

10. Conclusion

Generation Z has the entrepreneurial energy and environmental concern that a green transformation needs, but behavioral forces can pull these in different directions. Fast lives shorten horizons, easy money redefines entrepreneurial success, and the attitude–behavior gap weakens the translation of green values into green action. Original evidence from 66 countries confirms that Gen Z is somewhat greener in attitude and far more immersed in social media than older cohorts, but that its green values rarely reach organized action, especially in Türkiye. By bringing time preferences, speculative financial culture, nudges and social norms into the study of sustainable entrepreneurship, this paper offers a behavioral framework and a set of testable propositions. The main message for policy is an optimistic one. Relatively low-cost changes to choice architecture, together with greater visibility of growing green norms, may help channel the entrepreneurial potential of future generations into ventures that create lasting economic, social and ecological value.

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FULL PAPER · IP2.7 · IN-PERSON SESSION II

Young Farmers as Green Entrepreneurs: Drivers, Barriers and Support Mechanisms in Farm Businesses

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ABSTRACT

European and global agriculture faces two transitions at the same time. The first is generational renewal, since the farming population is ageing and few young people enter the sector. The second is the green transition, which requires farm businesses to reduce their environmental impact and adopt new sustainable practices. Young farmers are often expected to lead both transitions. This paper asks whether and under which conditions young farmers can act as green entrepreneurs. It conducts an integrative review of peer-reviewed literature on agricultural entrepreneurship, generational renewal, farmer behaviour and sustainable farm management. The review organises the evidence into three groups, namely drivers, barriers and support mechanisms. Drivers include higher education levels, longer planning horizons, environmental and lifestyle values, diversification opportunities and digital skills. Barriers include limited access to land, capital and knowledge, delayed or unclear family succession, risk aversion and social norms within farming communities. Support mechanisms include targeted public payments, business plan based start-up aid, entrepreneurial learning networks, farm joint ventures and advisory services. The review shows that age alone does not make a farmer a green entrepreneur. Green entrepreneurship emerges when individual motivation meets access to resources and a supportive institutional setting. The paper proposes a phase-based framework that links drivers, barriers and support mechanisms to three stages, namely successor orientation, farm entry and farm development. Four research propositions are derived from this framework. The findings suggest that policies should move from uniform age-based payments toward integrated packages that combine land access, finance, learning and behavioural support.

Keywords: young farmers; green entrepreneurship; generational renewal; farm management; farmer behaviour; agricultural policy

1. Introduction

Agriculture is going through a period of deep change. Two transitions shape this change. The first is demographic. Farmers in many countries are ageing, and fewer young people take over farms or start new ones (Zagata & Sutherland, 2015). The second is environmental. Farm businesses are asked to cut emissions, protect soil and water and adopt more sustainable practices (Dessart et al., 2019). Both transitions affect the long-term viability of rural areas.

These two transitions are often linked in policy debates. Young farmers are seen as the actors who will renew the sector and make it greener. They are expected to be better educated, more open to innovation and more willing to try new business models. This expectation is attractive. Yet it rests on an assumption that is rarely tested. Zagata and Sutherland (2015) warn that the young farmer problem is often framed in simple terms. Age alone may not explain innovation or environmental behaviour (Burton, 2014).

This raises a central question. Under which conditions do young farmers become green entrepreneurs? Green entrepreneurship refers to the discovery and use of business opportunities that create both economic and environmental value (Dean & McMullen, 2007; Schaltegger & Wagner, 2011). In farm businesses, it can take many forms. Examples include organic production, agroecological practices, on-farm renewable energy, short food supply chains, agritourism and the valorisation of farm by-products.

The literature on this topic is spread across several fields. Studies on generational renewal focus on succession and entry barriers (Coopmans et al., 2021). Studies on agricultural entrepreneurship focus on skills, diversification and growth (Dias et al., 2019a; Fitz-Koch et al., 2018). Studies on farmer behaviour focus on the adoption of sustainable practices (Dessart et al., 2019; Knowler & Bradshaw, 2007). These streams rarely speak to each other. As a result, we lack an integrated view of young farmers as green entrepreneurs.

This paper addresses this gap through an integrative literature review. It pursues three objectives. First, it identifies the drivers that push young farmers toward green entrepreneurship. Second, it examines the barriers that hold them back. Third, it reviews the support mechanisms that can help them overcome these barriers. The paper then combines these elements into a phase-based framework and derives research propositions.

2. Conceptual Background

2.1. Young Farmers and Generational Renewal

The term young farmer usually refers to farm managers under the age of 40. However, young farmers are not a uniform group. Zagata and Sutherland (2015) distinguish between successors, who take over a family farm, and new entrants, who start farming without a family background. These groups face different conditions. Successors inherit land, machinery and networks. New entrants must acquire these resources from the market.

Generational renewal is more than a change of farm manager. Coopmans et al. (2021) describe it as a process with three phases. The first phase is successor identity formation, in which a young person develops the wish to farm. The second phase is the farm succession or entry process. The third phase is farm development, in which the new manager shapes the future of the business. Each phase opens different windows for change. Major events such as succession can trigger new strategic directions on the farm (Sutherland et al., 2012).

2.2. Green Entrepreneurship in Farm Businesses

Entrepreneurship is about recognising and exploiting opportunities (Shane & Venkataraman, 2000). Sustainable and green entrepreneurship add an environmental dimension to this logic (Hall et al., 2010; Schaltegger & Wagner, 2011). Some green entrepreneurs are driven by environmental values from the start. Demirel et al. (2019) describe such founders as born to be green.

Agricultural entrepreneurship has its own features. It is tied to land, biological cycles, family ownership and rural communities (Dias et al., 2019a, 2019b; Fitz-Koch et al., 2018). Farmers often become entrepreneurs through diversification, new products or new marketing channels (Vik & McElwee, 2011). Green entrepreneurship in agriculture thus combines two elements. One is a change in production practices. The other is a change in the business model through which value is created and captured (Bocken et al., 2014).

2.3. A Behavioural Lens

Whether a young farmer becomes a green entrepreneur is also a behavioural question. The theory of planned behaviour explains intentions through attitudes, social norms and perceived behavioural control (Ajzen, 1991). Entrepreneurship research uses the same theory to explain the intention to start a venture (Krueger et al., 2000). Dessart et al. (2019) apply a similar logic to sustainable farming. They group behavioural factors into dispositional, social and cognitive categories. Dispositional factors include values, risk attitudes and environmental concern. Social factors include norms and peer influence. Cognitive factors include knowledge and perceived costs and benefits.

These three lenses complement each other. The generational lens explains when change can happen. The entrepreneurial lens explains what kind of change is possible. The behavioural lens explains why some individuals act and others do not. The review in the following sections uses this combined lens.

3. Methodology

This study adopts an integrative literature review. This design is suited to topics that cross disciplinary boundaries and need conceptual synthesis (Snyder, 2019; Torraco, 2005). The aim is not to measure effect sizes. The aim is to connect separate bodies of knowledge and to build a framework.

The search covered the Web of Science and Scopus databases. Search strings combined three groups of terms. The first group referred to young farmers, new entrants, successors and generational renewal. The second group referred to entrepreneurship, diversification and business models. The third group referred to sustainability, green practices, environmental behaviour and adoption. Backward citation tracking was used to add seminal works.

Studies were included if they were peer-reviewed, written in English and focused on farm businesses. Priority was given to journals ranked in the first quartile of their field. Official policy evaluations were added where they offered evidence on support schemes. Studies that addressed only technical aspects of farming were excluded. The selected studies were coded into three categories, namely drivers, barriers and support mechanisms. Within each category, factors were further classified as economic, human capital, behavioural or institutional.

The review is qualitative and interpretive. It does not claim statistical representativeness. Its value lies in the synthesis of fragmented evidence. The next three sections present the results in the order of drivers, barriers and support mechanisms.

4. Drivers of Green Entrepreneurship Among Young Farmers

4.1. Human Capital and Planning Horizon

Human capital is the most frequently cited driver. Younger farmers tend to have higher levels of formal education than older cohorts. Education improves the ability to process information and to assess new opportunities. Pindado et al. (2018) show that human and social capital help explain which new entrants in European agriculture behave entrepreneurially. Prior experience outside farming also brings new ideas and skills into the farm.

Age also shapes the planning horizon. A young manager expects to run the farm for decades. This makes long-term investments in soil health, renewable energy or new markets more attractive. However, the evidence is not uniform. Burton (2014) finds that the effect of age on environmental behaviour is mixed across studies. Age often works through other factors, such as education, succession status and farm size. This suggests that youth is an enabling condition rather than a direct cause.

4.2. Values and Motivations

Values form a second driver. Many new generation farmers hold strong environmental and social values. Milone and Ventura (2019) observe that some young farmers rediscover peasant-like strategies. They seek autonomy, reduce dependence on external inputs and build short supply chains. These choices combine ecological goals with economic resilience.

Motivations are rarely purely economic. Vik and McElwee (2011) show that farmers diversify for a mix of financial, social and lifestyle reasons. Läpple and Van Rensburg (2011) find that early adopters of organic farming were more driven by environmental attitudes than later adopters. Young farmers who enter with a green vision may therefore act as early adopters in their communities.

4.3. Market Opportunities and Diversification

Market opportunities form a third driver. Consumer demand for organic, local and traceable food creates new niches. Diversification into processing, direct sales, agritourism or energy production can raise income and spread risk (Barbieri & Mahoney, 2009). Pindado and Sánchez (2017) find that new agricultural ventures differ from established farms in their entrepreneurial behaviour. Newer ventures tend to place more emphasis on innovation and growth. For young farmers with limited land, high-value green niches can offset the disadvantage of small scale.

4.4. Digital Skills

Digital skills form a fourth driver. Young farmers are generally more familiar with digital tools. Smart farming technologies can reduce input use and improve resource efficiency. Digital platforms can connect farmers directly with consumers. Morris et al. (2017) link diversification and entrepreneurship among farmers to technology adoption. Klerkx et al. (2019) note, however, that digital agriculture also raises questions about skills, costs and inclusion.

Taken together, these drivers suggest that young farmers have a strong potential for green entrepreneurship. Yet potential does not automatically lead to action. The next section explains why many young farmers do not realise this potential.

5. Barriers to Green Entrepreneurship Among Young Farmers

5.1. Structural Barriers

Access to land is the most serious structural barrier. Land is scarce, expensive and often held by older farmers who delay retirement. The European Court of Auditors (2017) reports that about 60 percent of young farmers in the EU face problems in buying or renting land. New entrants are hit hardest because they cannot rely on inheritance (Zagata & Sutherland, 2015).

Access to capital is the second structural barrier. Young farmers have few assets to offer as collateral. Banks therefore see them as high-risk borrowers. Green investments often require high initial costs and bring returns only after several years. About 35 percent of young farmers report difficulties in accessing credit and subsidies (European Court of Auditors, 2017). Eistrup et al. (2019) show that land and capital constraints jointly limit the strategic options of young farm managers.

Access to markets is a further structural barrier. Small and new farms have little bargaining power in conventional supply chains. Green products often need certification, which adds cost and paperwork. Without established buyers, young farmers may find it hard to earn a price premium for sustainable production. This weakens the economic case for the green transition at the farm level.

Access to knowledge is the third barrier. Green practices are often knowledge-intensive. Organic farming, agroecology and on-farm processing require new technical and managerial skills. Many young farmers lack full agricultural training. Advisory services do not always cover sustainable business models.

5.2. Family and Succession Barriers

For successors, the family farm is both a resource and a constraint. Succession is often gradual and unclear. The older generation may keep control over key decisions for many years. This limits the room of young farmers to introduce new practices. Suess-Reyes and Fuetsch (2016) show that succession-oriented strategies, innovation and sustainability are closely linked in family farms. When succession is delayed, innovation is often delayed as well. May et al. (2019) find that participation in decision-making strongly affects whether young farmers stay on the farm.

5.3. Behavioural and Social Barriers

Behavioural barriers are less visible but equally important. Many farmers are risk-averse. Green practices may involve yield losses or price uncertainty during the transition period. This makes them appear risky, especially for a young farmer with debt. Dessart et al. (2019) show that risk aversion and perceived costs reduce the adoption of sustainable practices.

Social norms also play a role. Farming communities often value productivity and tidy fields. A young farmer who adopts unconventional practices may face doubt or criticism from neighbours. May et al. (2019) find that community integration and the opinions of neighbours influence young farmers' decisions. Knowler and Bradshaw (2007) add that few factors explain adoption in all contexts. Local culture therefore matters.

These barriers interact. A young farmer without land cannot invest. A farmer without a clear succession plan cannot make long-term decisions. A farmer who fears social disapproval may not try new practices even when resources are available. The question is therefore how support mechanisms can address these barriers together. The next section turns to this question.

6. Support Mechanisms

6.1. Public Policy Instruments

Public policy is the most visible form of support. In the European Union, the Common Agricultural Policy offers two main instruments for young farmers. The first is an additional direct payment per hectare. The second is a start-up grant linked to a business plan. The European Court of Auditors (2017) finds that the direct payment is poorly targeted. It is not based on needs and represents only a small share of farm income. The business plan based start-up aid is better targeted, since it links funding to a development strategy.

The effect of payments also depends on behaviour. May et al. (2019) show that the young farmer payment influences the decision to stay in farming mainly through non-economic motivations. Pessimism about farming, family integration and community ties matter more. This finding suggests that financial support works best when combined with measures that address social and psychological factors.

6.2. Learning and Networks

Entrepreneurial learning is a second support mechanism. Seuneke et al. (2013) show that farmers develop entrepreneurial skills through learning by doing, networking and reflection. Formal training is only one part of this process. Peer networks, farmer groups and demonstration farms give young farmers access to practical knowledge. They also reduce the social risk of trying new practices, since change becomes visible and shared.

Social capital strengthens these effects. Pindado et al. (2018) show that networks help new entrants identify and exploit opportunities. Mentoring by experienced farmers can transfer tacit knowledge. Links with universities, cooperatives and local food networks can open new markets for green products.

6.3. Access to Land and Finance

Innovative arrangements can ease the land barrier. Farm joint ventures, share farming and long-term leases connect young farmers with retiring owners. Ingram and Kirwan (2011) show that such arrangements can match new entrants with retiring farmers. Their success depends on trust, clear contracts and support from intermediaries. Land banks and public land leasing schemes offer further options.

On the finance side, guarantee funds, microcredit and green loans can lower the cost of capital. Business plan requirements can also improve the quality of green investment projects. Support works best when it is matched

to the stage of the young farmer's career. This observation leads to the framework presented in the next section.

6.4. Synthesis of the Evidence

Sections 4, 5 and 6 can be read as three sides of the same picture. Table 1 brings them together across four dimensions. Each dimension contains a driver, a barrier and a matching form of support. The table shows that most barriers have a known policy response. The challenge lies less in the absence of tools and more in their coordination.

Table 1. Drivers, barriers and support mechanisms of green entrepreneurship among young farmers

Dimension	Drivers	Barriers	Support mechanisms
Economic and structural	Market demand for green products, diversification options	Limited access to land, capital and markets	Start-up aid, guarantee funds, land mobility schemes, joint ventures
Human capital	Higher education, off-farm experience, digital skills	Gaps in technical and managerial knowledge	Training, advisory services, demonstration farms
Behavioural and social	Environmental values, long planning horizon	Risk aversion, social norms, pessimism about farming	Peer networks, mentoring, risk-sharing tools
Family and institutional	Succession as a trigger for change	Delayed succession, uniform age-based payments	Succession planning, business plan based and phase-specific support

Source. Compiled by the author from the reviewed literature.

7. Discussion

7.1. A Phase-Based Framework

The review shows that drivers, barriers and support mechanisms do not act at the same time. Their relevance changes as the young farmer moves through different stages. Building on the three phases described by Coopmans et al. (2021), this paper proposes a phase-based framework. Table 2 summarises it.

Table 2. Phase-based framework of green entrepreneurship among young farmers

Phase	Key question	Main drivers	Main barriers	Targeted support
Orientation	Does the young person want to farm, and in a green way?	Environmental values, education, role models	Pessimism about farming, low social status of the profession	Education, mentoring, exposure to green business models
Entry and succession	Can the young farmer access resources and control?	Long planning horizon, succession as a trigger for change	Land scarcity, limited capital, delayed transfer of decision-making	Land mobility schemes, start-up aid with business plans, succession planning
Development	Can the farm grow along a green path?	Diversification opportunities, market demand, digital skills	Risk aversion, social norms, knowledge gaps, market access	Advisory services, peer networks, market development, risk-sharing tools

Source. Developed by the author based on Coopmans et al. (2021) and the reviewed literature.

In the orientation phase, the main question is whether a young person wants to farm and in what way. Values, education and role models shape a green entrepreneurial identity. Support should focus on education, exposure to green business models and mentoring.

In the entry phase, the main question is whether the young farmer can access resources. Land, capital and decision-making power are the binding constraints. Support should focus on land mobility, start-up finance and clear succession agreements. Succession can act as a trigger for strategic change (Sutherland et al., 2012). Policy should therefore treat this moment as a window for green transition.

The framework also helps distinguish between the two groups of young farmers. Successors usually pass the orientation phase within the family. Their main obstacle lies in the entry phase, where control over the farm is

transferred slowly. New entrants face the opposite pattern. They often bring strong green motivations and outside experience. Yet they meet the hardest resource barriers at entry, especially for land and capital (Zagata & Sutherland, 2015). Support should therefore be tailored to each group rather than defined by age alone.

In the development phase, the main question is whether the farm business can grow along a green path. Market access, risk management and continuous learning matter most. Support should focus on advisory services, networks, market development and risk-sharing tools.

The framework shows a key insight. Age is not the cause of green entrepreneurship. It is a window of opportunity. Whether this window is used depends on the match between individual motivation, access to resources and institutional support. This insight explains why uniform age-based payments have had limited effect (European Court of Auditors, 2017).

7.2. Research Propositions

Four propositions follow from the framework. They can guide future empirical work.

Proposition 1. *Young farmers with higher human capital and off-farm experience are more likely to pursue green entrepreneurial strategies, but only when they have access to land and decision-making power.*

Proposition 2. *Early and clear succession arrangements increase the likelihood that successors introduce green innovations on family farms.*

Proposition 3. *Peer networks and entrepreneurial learning reduce the perceived risk of green practices and therefore strengthen the effect of financial support.*

Proposition 4. *Phase-specific support packages that combine land access, finance, learning and behavioural measures are more effective than uniform age-based payments.*

7.3. Implications for Policy and Farm Management

The findings carry implications for policy makers. Support for young farmers should be designed as a package rather than a single payment. Land mobility measures, start-up finance, training and networks should be linked. Green criteria can be built into business plan requirements. Behavioural tools, such as peer learning and demonstration farms, can complement financial incentives.

The findings also carry implications for farm management. Family farms can plan succession earlier and share decision-making with the next generation. Young farmers can use diversification and short supply chains to compensate for limited scale. Advisory services can integrate sustainability and entrepreneurship into the same training programmes. These implications complete the line of argument of this paper. The final section summarises the contributions and limitations.

8. Conclusion

This paper reviewed the literature on young farmers as green entrepreneurs. It started from a common assumption. Young farmers are expected to lead both the generational and the green transition in agriculture. The review shows that this expectation is only partly justified.

Young farmers do have important drivers for green entrepreneurship. These include education, long planning horizons, environmental values, diversification opportunities and digital skills. However, they also face strong barriers. Limited access to land, capital and knowledge, unclear succession and behavioural constraints often block their potential. Support mechanisms can reduce these barriers, but current schemes are often too uniform.

The study makes two contributions. First, it connects the literatures on generational renewal, agricultural entrepreneurship and farmer behaviour. Second, it offers a phase-based framework that links drivers, barriers and support mechanisms to the career stages of young farmers.

The study has limitations. As an integrative review, it relies on interpretation rather than statistical synthesis. Much of the evidence comes from European contexts. Conditions in other regions may differ in land tenure, family structures and policy support. Future research should test the proposed propositions with longitudinal and comparative data. Studies could also compare successors and new entrants more systematically. Such research would help design policies that turn young farmers' potential into real green ventures.

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FULL PAPER · IP2.8 · IN-PERSON SESSION II

Green Export Development in Pakistan: Determinants, Challenges and Policy Implications

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ABSTRACT

This study reviews the existing literature on green export development in Pakistan, focusing on its determinants, challenges, and policy implications. Green exports refer to goods and services produced, processed, or delivered through environmentally sustainable practices for international markets. Using a narrative literature review approach supported by thematic synthesis, the study synthesises relevant academic literature to examine the conditions associated with sustainable export development in Pakistan. The review identifies five interrelated dimensions: green finance, green innovation, sustainable supply chains, green human capital, and government policies and institutional support. The synthesis suggests that these dimensions may complement one another in facilitating environmentally responsible production practices, technological upgrading, and adaptation to international sustainability requirements. However, the reviewed evidence remains limited regarding their direct and combined effects on green export performance in Pakistan. The study also identifies financial constraints, technological limitations, infrastructural weaknesses, institutional challenges, and shortages of sustainability-related skills as potential barriers to sustainable export development. Based on these findings, the review proposes policy priorities related to improving access to green finance, supporting green innovation, strengthening human capital, developing sustainable supply chain infrastructure, enhancing environmental governance, and promoting institutional coordination. By integrating financial, technological, organisational, supply chain, and institutional perspectives, the study provides a conceptual foundation for future empirical research and offers policy-oriented recommendations for supporting environmentally sustainable and competitive export development in Pakistan.

Keywords: Green exports, sustainable trade, export performance, green finance, sustainable supply chains, renewable energy, Pakistan

1. Introduction

Environmental considerations have become increasingly important in shaping international trade in the global economy. Importing countries are placing greater emphasis on low-carbon supply chains, environmentally friendly products, environmental standards, and sustainability certifications. At the same time, international policies and financial mechanisms are evolving to support low-carbon production and sustainable economic development. Within this changing environment, green exports have emerged as a potential means of enhancing international competitiveness while addressing environmental challenges. For developing economies such as Pakistan, the transition towards green exports presents both significant opportunities and policy challenges. Pakistan's export sector remains concentrated in a relatively limited range of products and destination markets. Such concentration may increase the country's vulnerability to external economic shocks and limit opportunities for export diversification. In addition, Iqbal (2016) examined the determinants of Pakistan's bilateral exports, highlighting the roles of economic size, geographical distance, and regional trade relationships in shaping export flows. Consequently, export diversification, technological upgrading, and the adoption of environmentally responsible production practices have become increasingly important for strengthening Pakistan's long-term export competitiveness. The existing literature highlights the importance of

sustainability-oriented business practices in improving organisational performance and competitiveness. Awan et al. (2017) found that market stakeholder pressure positively influences the adoption of green manufacturing practices, while these practices are positively associated with firms' environmental performance. The study also highlights the role of workplace safety practices in supporting social sustainability and employee well-being. Similarly, Masood et al. (2025) found that free trade agreements (FTAs) had a positive and statistically significant effect on Pakistan's textile exports, although their effects varied across trading partners and product categories. Their findings also highlight Pakistan's continued reliance on lower-value-added textile exports and the need for stronger policy support to facilitate a transition towards higher-value-added products. Although the study does not directly examine environmental sustainability, its findings provide relevant insights into the trade and industrial policy conditions associated with Pakistan's export competitiveness.

Pakistan's vulnerability to climate-related challenges, together with its dependence on textiles and agricultural commodities, further underscores the importance of transitioning towards greener production and export practices. Nevertheless, structural weaknesses continue to hinder export diversification and upgrading. Khan and Afzal (2016) found that Pakistan's export diversification had not generated the expected improvements in economic development or export growth, partly because its export structure remained concentrated in low-technology and less sophisticated products. Their findings emphasise the importance of stronger industrial policies, improved institutional capacity, and closer cooperation between public and private sector actors in supporting export competitiveness.

In this context, green exports involve the integration of environmentally responsible practices into production, management, and supply chain activities associated with international trade. Such practices aim to reconcile economic development with environmental protection. The literature also highlights the importance of organisational readiness and innovation capabilities in adopting environmentally sustainable business practices. Fahad et al. (2022) examined the adoption of green innovation practices, emphasising the role of organisational and technological factors in supporting environmentally responsible business activities. Their findings suggest that organisational capabilities may facilitate the integration of sustainability into firms' operations and strengthen their competitive position. Against this background, the present study aims to review and synthesise the existing literature on green export development in Pakistan, focusing on its determinants, challenges, and policy implications. Specifically, the review examines the opportunities and barriers associated with sustainable export practices and considers the roles of green finance, green innovation, sustainable supply chains, green human capital, and institutional support. By integrating findings from the existing literature, the study seeks to provide a more comprehensive understanding of the factors influencing green export development and to offer policy-oriented recommendations for firms, policymakers, and other stakeholders seeking to enhance Pakistan's export competitiveness while promoting environmental sustainability.

2. Literature Review

The literature on green exports and sustainable export performance highlights the growing relationship between environmental sustainability and international trade. Globalisation, technological advancements, and expanding access to international markets have intensified competition among firms, increasing the importance of strategic adaptation and sustainable business practices (Aggarwal, 2011). Within this evolving business environment, environmental considerations have become increasingly relevant to trade policies and international competitiveness. Green exports have consequently gained attention as a potential pathway towards integrating economic development with environmental sustainability (Sonnenfeld, 2014). Green exports generally refer to internationally traded goods and services associated with environmentally responsible production, processing, and management practices. Green export strategies extend beyond

individual production activities and may involve marketing, research and development, procurement, finance, human resource management, and supply chain operations. Their implementation therefore requires organisational commitment to environmental objectives and the integration of sustainability principles into business processes. Leonidou et al. (2015), based on evidence from Greek manufacturing exporters, found that environmentally friendly export business strategies were positively associated with product differentiation advantages, which in turn improved export market and financial performance. However, the study did not find significant effects through cost leadership advantages. These findings suggest that sustainability-oriented export strategies may offer opportunities for Pakistani exporters to strengthen their competitive positioning through product differentiation rather than relying solely on cost-based competition. Small and medium-sized enterprises (SMEs) also play an important role in economic development and may contribute to the adoption of sustainable business practices, although their ability to pursue such strategies depends on their resources and capabilities (Ahmedova, 2015).

At the international level, sustainable trade initiatives have increasingly focused on the environmental and socioeconomic implications of production and export activities. The United Nations Conference on Trade and Development (UNCTAD) has addressed the relationship between international trade, development, and sustainability, providing a broader institutional context for discussions of environmentally responsible export development (United Nations Conference on Trade and Development, 2020). Within this context, voluntary sustainability standards and related policy initiatives can be considered mechanisms for encouraging sustainable production practices and facilitating participation in environmentally sensitive international markets. However, their effectiveness may depend on firms' compliance capabilities, the availability of institutional support, and the costs associated with meeting international requirements. The literature also identifies financial and organisational factors that may influence the adoption of environmentally sustainable practices. Green finance and environmentally oriented policy instruments can provide incentives for firms to invest in cleaner technologies and improve their production processes. From a broader sustainability perspective, firms are increasingly expected to consider environmental performance alongside social responsibilities, including employee well-being and responsible business conduct. Shi et al. (2025) contribute to this discussion by examining the relationship between green-oriented economic mechanisms and environmental outcomes, highlighting the relevance of financial and policy conditions to sustainability-related transitions.

Changing market expectations represent another important dimension of green export development. Growing environmental awareness among consumers has increased the strategic relevance of environmentally responsible products and business practices, particularly in markets where sustainability considerations influence purchasing decisions (Aggarwal, 2011). Recent research has also examined how countries and firms can identify opportunities for developing more environmentally sustainable export structures. Pérez-Hernández et al. (2025) proposed an analytical framework integrating evolutionary economic geography and economic complexity approaches to identify potential green export opportunities. Their approach suggests that existing productive capabilities can provide a foundation for diversification into more sophisticated and environmentally sustainable export activities. Institutional capacity and infrastructure are equally relevant to the development of green exports. Emam et al. (2023), in their examination of Ecuador's National Green Export Review, found no statistically significant evidence that the policy improved the international competitiveness of the country's fish exports in the short run. Although this finding does not establish the effectiveness of green export policies in other national contexts, it highlights the need for careful evaluation of sustainability-oriented trade initiatives. In the context of Pakistan, institutional capacity, infrastructure, compliance costs, and market access should therefore be considered when designing and implementing policies to promote green exports. Overall, the reviewed literature suggests that green export development is shaped by the interaction of

organisational capabilities, environmental practices, financial resources, market opportunities, and institutional conditions. Although these studies provide insights into different dimensions of sustainable trade, their findings emerge from diverse geographical and sectoral contexts. Consequently, their implications for Pakistan require careful consideration of the country's export structure, industrial capabilities, and policy environment. Building on these perspectives, the present study synthesises the literature around five interrelated dimensions: green finance, green innovation, sustainable supply chains, green human capital, and government policies and institutional support.

3. Methodology

This study adopts a narrative literature review approach supported by thematic synthesis to examine the determinants, challenges, and policy implications of green export development in Pakistan. The review is guided by the following research questions:

RQ1: What potential determinants and policy implications of green export development in Pakistan can be identified from the existing literature?

RQ2: What barriers do Pakistani exporters face in adopting green practices and sustainable export strategies?

To address these questions, the study draws on academic literature related to green exports, sustainable trade, environmental sustainability, export competitiveness, and sustainability-oriented business practices. Relevant publications were considered in relation to their contribution to understanding the financial, technological, organisational, and institutional conditions associated with sustainable export development. Particular attention was given to research conducted in Pakistan, while studies from other developing and emerging economies were also considered where they offered relevant conceptual or comparative insights. In addition, the Pakistan Bureau of Statistics (2024) report was consulted to provide contextual information on Pakistan's external trade structure. The review considers publications from different years, including earlier studies that provide relevant contextual insights and more recent research addressing developments in sustainable business practices and export-related activities. Given the limited availability of studies directly examining green export performance in Pakistan, the review also incorporates research on related topics, including general export performance, green finance, green innovation, sustainable supply chain management, green human capital, and environmental performance. These studies are used to inform the discussion of potential determinants and challenges rather than to establish direct empirical relationships with green export performance. The literature is discussed across five interrelated thematic dimensions: green finance, green innovation, sustainable supply chains, green human capital, government policies and institutional support. These dimensions provide an analytical framework for synthesising relevant findings, identifying potential complementarities, and examining barriers and policy implications associated with Pakistan's transition towards environmentally sustainable export activities. Table 1 summarises ten studies that provide relevant empirical and contextual insights into Pakistan's export development and sustainability-related business practices. Additional academic publications are considered to support the broader theoretical and policy discussion. As a narrative review, the study does not claim to provide an exhaustive or systematic assessment of the available literature. Instead, it offers a qualitative synthesis of selected research to identify potential determinants, challenges, and policy priorities while highlighting areas requiring further empirical investigation.

4. Discussion

4.1. Overview of Pakistan's Export Structure and Implications for Green Transition

Pakistan's export competitiveness is affected by several economic and industrial constraints, including high energy costs, inflationary pressures, exchange rate fluctuations, technological limitations, and disruptions to

global supply chains. These challenges are particularly relevant to the energy-intensive textile industry, where rising production costs can weaken firms' ability to compete in international markets. Addressing such constraints requires greater investment in technological upgrading, innovation, energy efficiency, and sustainable production practices. These measures may support the development of higher-value-added products and improve the resilience of export-oriented industries. In addition, Jadoon et al. (2018) identified positive relationships between export performance and macroeconomic factors, including foreign direct investment, gross domestic product, and employment, indicating that export development is closely connected to broader economic conditions. Against this background, the transition towards greener production and export practices presents an opportunity to address some of Pakistan's structural export challenges while responding to evolving environmental requirements in international markets. The adoption of renewable energy technologies, cleaner production methods, and resource-efficient industrial processes may help export-oriented firms reduce their environmental impact and improve operational efficiency. Similarly, the development of a transparent green taxonomy could provide a clearer framework for identifying environmentally sustainable economic activities and guiding green investment. However, the potential contribution of these initiatives to export performance depends on their implementation, accessibility, and alignment with the needs of export-oriented industries. The existing literature provides further insights into the relationship between export development, financial conditions, and environmentally sustainable business practices. Mahmood and Ahmed (2017) examined factors associated with Pakistan's export performance, offering a broader economic perspective on the conditions relevant to export upgrading. From an environmental policy perspective, Shi et al. (2025) highlighted the potential relevance of green-oriented financial and policy mechanisms for supporting environmentally responsible production. Such mechanisms may encourage firms to invest in cleaner technologies, although their effectiveness is likely to depend on institutional capacity, financing conditions, and firms' ability to meet sustainability requirements. Similarly, Singh et al. (2024), examining Indian exporting SMEs, found that institutional support and green export strategies were relevant to export-related outcomes, while the relationship between green innovation and green export strategy was not statistically significant. These findings highlight the importance of considering institutional and organisational conditions when evaluating the potential contribution of sustainability-oriented strategies to export competitiveness. Integrating sustainability principles into production processes, supply chain management, investment decisions, and export strategies may help firms respond to changing international market expectations. Nevertheless, the extent to which these practices translate into improved export performance depends on complementary improvements in technological capabilities, infrastructure, financing, and institutional support. Therefore, Pakistan's transition towards green exports requires a coordinated approach that addresses both environmental sustainability and the structural constraints affecting its export competitiveness.

4.2. Green Finance

Green finance has emerged as an important mechanism for directing financial resources towards environmentally sustainable investments and supporting the transition to low-carbon economic activities (Sachs et al., 2019; Tavares et al., 2024). In developing economies such as Pakistan, access to green financing may enable export-oriented firms to invest in cleaner technologies, renewable energy, and resource-efficient production processes. However, its effectiveness depends on financing accessibility, institutional support, and firms' capacity to translate financial resources into technological and operational improvements. Recent empirical studies provide insights into the potential contributions and limitations of green finance. Nabi et al. (2025) found that green finance was associated with reductions in ecological footprints in Pakistan, although the magnitude of this relationship varied across quantiles. Examining Chinese clean energy enterprises, Gu and Tian (2023) reported that green credit policies promoted technological innovation through mechanisms

involving credit costs and financing constraints. However, Liu and Dong (2022) found that green credit policies increased strategic green innovation among heavily polluting Chinese enterprises without significantly improving substantive green innovation. Collectively, these findings suggest that green finance may support environmental sustainability and technological upgrading, but its effectiveness depends on policy design and the quality of firms' investments. Importantly, these studies do not directly establish a relationship between green finance and green export performance in Pakistan. Pakistan's transition towards sustainable export development also depends on broader organisational, institutional, and economic conditions. Amjad et al. (2025) examined the relationships among sustainable human resource management practices, green human capital, green business innovation, perceived organisational support, and sustainability-related business performance in Pakistan's textile sector. Furthermore, Haral (2023) examined the macroeconomic determinants of Pakistan's exports, including foreign direct investment, while Iqbal (2016) highlighted the roles of economic size, geographical distance, and regional trade relationships in shaping Pakistan's export flows. Malik et al. (2018) examined barriers to green finance in Pakistan, particularly in relation to financing renewable energy projects, and highlighted the importance of appropriate financial mechanisms and institutional support. Mumtaz and Smith (2019) also discussed green finance in the context of Pakistan's sustainable development priorities. Although these studies do not directly investigate green export performance, they provide relevant insights into the financial and institutional conditions that may support environmentally sustainable investments. Overall, the literature suggests that green finance may facilitate sustainable export development in Pakistan by supporting environmentally responsible investments and technological upgrading. Nevertheless, its potential contribution to export competitiveness is likely to depend on accessible financing instruments, institutional effectiveness, and complementary policies promoting innovation and environmental compliance. Further empirical research is required to determine whether these mechanisms translate into measurable improvements in Pakistan's green export performance.

4.3. Green Innovation

While green finance provides financial resources for sustainability-oriented investments, green innovation enables firms to translate these investments into environmentally responsible products, processes, and business practices. Green innovation encompasses the development and adoption of technologies and organisational practices aimed at reducing environmental impacts, including energy-efficient production systems, water conservation and reuse, waste minimisation, and environmentally sustainable product development. By improving resource efficiency and supporting compliance with environmental requirements, green innovation may contribute to firms' long-term competitiveness and sustainable export development. The growing importance of environmental standards and sustainability requirements in international markets has increased the strategic relevance of green innovation, particularly for export-oriented firms operating in environmentally sensitive sectors. Firms that lack the technological capabilities to adopt cleaner production processes may face difficulties in responding to evolving market expectations and environmental requirements. Aftab et al. (2023) and Fahad et al. (2022) provide insights into the organisational and technological factors associated with the adoption of environmentally sustainable business practices. Their findings highlight the importance of innovation capabilities, organisational readiness, and environmental management in facilitating sustainability-oriented transitions. In this context, green innovation may help Pakistani exporters strengthen their capacity to meet international sustainability expectations, although its contribution to export performance depends on firms' resources, technological capabilities, and market conditions. Beyond firm-level competitiveness, green innovation has also been examined in relation to broader economic and environmental outcomes. Ahmed et al. (2022) identified a positive relationship between green innovation and green economic growth, suggesting that environmentally oriented technological development may contribute to sustainable economic objectives. This perspective indicates that investments in cleaner technologies and resource-efficient

production processes can have implications beyond individual firms, potentially supporting wider economic and environmental improvements. More broadly, green innovation may also extend beyond production technologies to include environmentally oriented product development and marketing practices. Jafar et al. (2019), in a study of university students in Lahore, Pakistan, examined the relationships between green brand image, environmental concern, green brand awareness, and consumer brand preferences. Their findings provide consumer-level insights into green marketing in Pakistan and suggest that sustainability-related marketing practices may complement technological and product innovations, although the study did not examine export performance or the international competitiveness of Pakistani firms. For export-oriented firms, the integration of environmental considerations into product development, production processes, and market communication may therefore support a more comprehensive approach to sustainable business development. Overall, the reviewed literature suggests that green innovation represents a potentially important component of sustainable export development. Its relevance lies in improving resource efficiency, supporting adaptation to environmental requirements, and strengthening firms' capabilities to develop environmentally responsible products and processes. For Pakistan, promoting investment in green technologies, strengthening innovation capabilities, and encouraging the adoption of sustainable production practices may help address structural limitations in export-oriented industries. However, the extent to which these initiatives improve export competitiveness requires further empirical examination in the Pakistani context.

4.4. Sustainable Supply Chains

Sustainable supply chain management has become an increasingly important consideration in international trade and export competitiveness. It involves integrating economic, environmental, and social objectives into supply chain activities, including procurement, production, transportation, distribution, and supplier relationships. Sustainable supply chain practices aim to reduce environmental impacts, improve resource efficiency, promote responsible labour conditions, and support long-term economic sustainability. These practices may include carbon emission reduction, waste management, ethical sourcing, resource optimisation, and greater transparency across supply chain networks. Growing environmental awareness and evolving sustainability requirements in international markets have encouraged firms to incorporate these considerations into their operations. Consequently, sustainable supply chain management is increasingly recognised as a potential contributor to organisational resilience and competitive positioning (Khan & Halme, 2025). Seuring and Müller (2008) provide a conceptual foundation for understanding sustainable supply chain management through the integration of environmental and social considerations into conventional supply chain practices. Their perspective emphasises the importance of coordination among supply chain actors and the management of sustainability-related risks and requirements. For export-oriented firms, such coordination may be particularly relevant when responding to environmental standards, buyer expectations, and sustainability requirements across international supply chains. However, the contribution of sustainable supply chain practices to export performance depends on firms' implementation capabilities and the conditions under which they operate. In Pakistan, Ali et al. (2020) identified green warehousing, green production, and green procurement as the highest-ranked green supply chain management practices in CPEC-related construction supply chains. Complementing this perspective, Shah et al. (2025) explored the potential synergies among human resource management, finance, and sustainable supply chain management in Pakistani organisations, emphasising the relevance of cross-functional coordination for corporate sustainability initiatives. At the same time, environmentally intensive industries, particularly textiles and cement production, face challenges associated with energy consumption, resource use, waste generation, and industrial emissions. These challenges highlight the potential importance of integrating sustainable practices into procurement, production, and distribution activities. Measures such as improving energy efficiency, reducing material waste, strengthening supplier coordination, and adopting cleaner production methods may help firms address

environmental concerns while improving operational efficiency. Despite these potential benefits, the adoption of sustainable supply chain practices in Pakistan may be constrained by infrastructural limitations, institutional weaknesses, financial barriers, and organisational resistance to change. Reliable transportation systems, electricity supply, communication networks, and financial services are important for efficient supply chain operations and export activities. Rehman et al. (2020) highlight the relevance of infrastructure and related economic conditions to export development, suggesting that improvements in these areas may provide a supportive environment for more efficient and sustainable supply chain operations. Nevertheless, infrastructure development alone may be insufficient without complementary organisational capabilities and effective institutional support. Stakeholder awareness and environmental governance also influence the broader conditions under which sustainable business practices are adopted (Awan et al., 2017). Siddique et al. (2013) examined barriers to green marketing adoption in Pakistan, highlighting the roles of environmental awareness, international buyer pressure, and regulatory enforcement in shaping firms' environmental practices. Although evidence on green marketing barriers does not directly establish the adoption of sustainable supply chain practices by exporting firms, it highlights the relevance of environmental awareness, regulatory enforcement, and international buyer expectations to environmentally responsible business practices. Similarly, the effectiveness of environmental regulations and their enforcement may influence firms' incentives to adopt sustainable practices. Overall, the reviewed literature suggests that sustainable supply chain management represents a potentially important component of green export development in Pakistan. By integrating environmental and social considerations into supply chain operations, firms may strengthen their ability to respond to international sustainability requirements and improve resource efficiency. However, achieving these outcomes requires improvements in infrastructure, institutional effectiveness, organisational capabilities, and stakeholder engagement. A coordinated approach to these factors may support the transition towards more environmentally responsible and competitive export-oriented supply chains.

4.5. Green Human Capital

The effectiveness of green innovation initiatives and sustainable supply chain practices depends not only on technological and financial resources but also on the knowledge, skills, and environmental commitment of employees and managers. Green human capital encompasses employees' environmental knowledge, technical competencies, ecological awareness, and sustainability-oriented values that support environmentally responsible organisational practices. As firms increasingly adopt cleaner production technologies and sustainable business strategies, the development of green human capital has become an important consideration for organisational sustainability and competitiveness. In Pakistan, limited access to specialised environmental expertise and sustainability-related training may constrain firms' ability to adopt environmentally responsible production practices and respond to international sustainability requirements. Investments in green technologies and modern production systems may not achieve their intended outcomes without employees who possess the necessary technical and managerial capabilities to implement and maintain them. Consequently, developing green human capital should be considered a complementary priority alongside technological upgrading and sustainable supply chain development. The literature on green human resource management (GHRM) provides insights into how organisations can strengthen sustainability-related capabilities. Shahzad et al. (2025) found that green human resource management is positively associated with intellectual capital, green innovation, and sustainable organisational performance. Their findings also highlight the roles of green intellectual capital and innovation in explaining the relationship between human resource practices and sustainability outcomes. Similarly, Asghar et al. (2025) examined the relationship between green inclusive leadership and employees' green creativity, emphasising the importance of leadership practices in encouraging environmentally oriented ideas and behaviours. Together, these studies suggest that organisational policies and leadership approaches can contribute to developing the human capabilities required

for sustainability-oriented business activities. Evidence from Pakistan further highlights the relevance of organisational leadership and employee commitment to environmental sustainability. Ashraf et al. (2024), in a study conducted within Pakistan's tourism sector, examined the relationship between environmentally oriented servant leadership and employees' green behaviour. Their findings identified psychological green climate and green commitment as relevant mediating mechanisms. Although this evidence is drawn from the tourism sector rather than export-oriented manufacturing, it provides useful insights into the organisational conditions that may encourage environmentally responsible employee behaviour. Aftab and Veneziani (2024) also investigated the relationship between human resource management practices and environmental performance using data from manufacturing-sector employees. Their findings highlighted both direct and indirect relationships, including the mediating role of employees' green commitment. This evidence suggests that sustainability-oriented training, environmental awareness, and employee engagement may contribute to improving organisational environmental performance. For export-oriented firms, such practices could complement investments in cleaner technologies and sustainable production systems by strengthening employees' capacity to implement environmental initiatives. Overall, the reviewed literature indicates that green human capital may serve as an important enabling factor in Pakistan's transition towards sustainable export development. While financial resources, technological innovation, and sustainable supply chain practices provide essential foundations for environmental improvement, their effectiveness also depends on employees' competencies and organisational commitment. Strengthening environmental education, vocational training, sustainability-oriented human resource management, and green leadership practices may therefore help Pakistani firms develop the capabilities needed to respond to international sustainability requirements. However, the direct contribution of green human capital to Pakistan's export performance remains an area requiring further empirical investigation.

4.6. Government Policies and Institutional Support

The effectiveness of green finance, green innovation, sustainable supply chain management, and green human capital development is closely associated with the broader policy and institutional environment. Government policies and institutional support can create favourable conditions for firms to adopt environmentally responsible business practices and respond to sustainability requirements in international markets. In this regard, effective regulatory frameworks, financial incentives, technical assistance, and institutional coordination may play important roles in facilitating the transition towards sustainable export development. In Pakistan, financial sector policies and institutional initiatives aimed at promoting environmentally responsible banking and investment provide a relevant context for supporting sustainable development. More broadly, policy instruments aimed at supporting green export development may include financial incentives for environmentally certified firms, tax benefits for cleaner technologies, technical assistance programmes, and capacity-building initiatives. Such measures could help export-oriented firms overcome financial and technological constraints, strengthen their environmental management capabilities, and improve their ability to respond to international sustainability requirements. However, their effectiveness depends on consistent implementation, institutional capacity, and accessibility to firms, particularly small and medium-sized enterprises. The wider international literature also highlights the importance of government support for export development. Vo et al. (2023) examined the relationship between government assistance and export performance, identifying positive associations with policy instruments such as tax incentives, credit support, trade promotion programmes, and customs-related reforms. Their findings particularly emphasised the relevance of trade promotion assistance and customs procedures to export outcomes. Although this evidence concerns general export support rather than green export policies specifically, it suggests that institutional measures can influence firms' ability to participate in international markets. Nevertheless, the applicability of these findings to Pakistan's green export sector requires consideration of differences in institutional conditions

and policy implementation. Developing a more coordinated institutional framework may therefore represent an important policy priority for Pakistan. Cooperation among government agencies, financial institutions, regulatory authorities, and industry associations could support the alignment of environmental objectives with export development strategies. Within such a framework, improving access to green finance, strengthening environmental governance, supporting sustainability certification, and facilitating technological upgrading may help firms address barriers to environmentally responsible production and international market participation. Institutional initiatives that promote knowledge transfer, environmental awareness, and technical training could also complement investments in green innovation and human capital development. Overall, government policies and institutional support represent an important enabling dimension connecting the financial, technological, organisational, and human resource aspects of green export development. The potential benefits of green investments and sustainable business practices may remain limited where regulatory frameworks are unclear, institutional coordination is weak, or implementation capacity is insufficient. Strengthening institutional effectiveness and developing coherent policy measures may therefore support Pakistan's transition towards a more environmentally sustainable and competitive export sector. However, the specific effects of these measures on green export performance require further empirical assessment in the Pakistani context.

Table 1. Summary of Selected Studies and Policy Implications

Author(s)	Research Focus	Main Findings	Policy Implications
Amjad et al. (2025)	Green human capital, sustainability performance, and innovation	Green human capital and green business innovation are associated with improved sustainability-related business performance in Pakistan's textile sector.	Strengthen environmental training, support green innovation, and improve organisational capacity for sustainability compliance.
Haral (2023)	Macroeconomic determinants of Pakistan's exports	FDI and GDP were positively associated with exports, while gross capital formation showed a significant negative association.	Improve the investment environment and strengthen export-oriented productive capacity, while recognising that the study does not specifically address green exports.
Iqbal (2016)	Determinants of Pakistan's bilateral exports	Economic size and SAARC membership were positively associated with exports, while geographical distance was negatively associated with exports.	Strengthen regional trade cooperation, improve market access, and pursue export market diversification.
Ali et al. (2020)	Prioritisation of green supply chain management practices in Pakistan's CPEC-related construction sector	Green warehousing, green production, and green procurement were the three highest-ranked practices based on expert evaluations using fuzzy TOPSIS.	Prioritise feasible green warehousing, production, and procurement initiatives in construction supply chains, while considering implementation costs and environmental benefits.
Sher et al. (2019)	Barriers to the adoption of green entrepreneurial farming in Pakistan	Identified 20 critical barriers, including limited training, weak entrepreneurial and market orientation, inadequate government support, and restricted access to credit.	Strengthen farmer training and extension services, improve access to green financing, provide government incentives, and support market-oriented green agricultural practices.
Awan et al. (2017)	Stakeholder pressure and sustainable supply chain practices among Pakistani manufacturing exporters	Market stakeholder pressure positively influences green manufacturing practices, which are positively associated with environmental performance.	Strengthen buyer–supplier collaboration, provide technical assistance and training, and support exporters in adopting green manufacturing and workplace safety practices.
Rehman et al. (2020)	Infrastructure development and export performance in Pakistan	Transport, energy, communication, and financial infrastructure were positively associated with Pakistan's aggregate exports in both the short and long run.	Prioritise investment in transport, energy, communication, and financial infrastructure to improve export capacity and international competitiveness.

Author(s)	Research Focus	Main Findings	Policy Implications
Siddique et al. (2013)	Barriers to green marketing adoption among firms in Pakistan	Interviews with managers from three firms identified limited environmental awareness, weak regulatory enforcement, financial constraints, and pressure from international buyers as important influences on green marketing adoption.	Improve environmental regulation enforcement, strengthen awareness and employee training, and facilitate firms' access to environmentally friendly technologies.
Jafar et al. (2019)	Green brand image, environmental concern, green brand awareness, and consumer preferences	Green brand image and green brand awareness were positively associated with consumer brand preference, while environmental concern showed no statistically significant relationship. The study did not examine export performance.	Strengthen green branding and credible environmental communication to improve consumer awareness and preferences.
Ahmed et al. (2022)	Green innovation, green trade, clean energy, and green economic growth in South Asia	Green innovation, green trade, and cleaner energy production were positively associated with green economic growth across five South Asian economies, including Pakistan.	Support green technological innovation, expand trade in environmental goods, and promote renewable energy production to advance green economic growth.

Note: Policy implications are derived from the review synthesis and do not necessarily represent the original authors' recommendations.

4.7. Synthesis of the Review

The reviewed literature identifies five interrelated dimensions relevant to sustainable export development in Pakistan: green finance, green innovation, sustainable supply chains, green human capital, and government policies and institutional support. Although these dimensions have often been examined from different disciplinary and sectoral perspectives, their combined consideration provides an integrated understanding of the financial, technological, organisational, and institutional conditions associated with environmentally responsible export activities. Green finance may facilitate firms' access to resources required for investments in cleaner technologies, renewable energy, and resource-efficient production systems. Green innovation can complement these investments by supporting the development and adoption of environmentally responsible products, processes, and business practices. Sustainable supply chain management provides an operational perspective by integrating environmental and social considerations into procurement, production, logistics, distribution, and relationships with supply chain partners. Together, these dimensions suggest that financial resources, technological capabilities, and operational practices may reinforce one another in supporting sustainability-oriented business activities. Green human capital represents a complementary organisational dimension. Employees' environmental knowledge, technical competencies, and commitment to sustainability may influence firms' ability to implement cleaner technologies, manage environmental risks, and maintain sustainable supply chain practices. Accordingly, technological and financial investments may be more effective when accompanied by appropriate employee training, managerial capabilities, and sustainability-oriented human resource practices. Government policies and institutional support provide the broader environment within which these firm-level initiatives are developed and implemented. Regulatory frameworks, financial incentives, sustainability standards, certification systems, and trade promotion measures may influence firms' opportunities and incentives to adopt environmentally responsible practices. Institutional coordination may also facilitate access to financing, knowledge transfer, technological upgrading, and compliance with international sustainability requirements. The synthesis therefore suggests that the five dimensions should not be considered in isolation. Instead, they represent potentially complementary conditions whose effectiveness may depend on their interaction. For example, access to green finance may be insufficient without technological capabilities and skilled employees, while investments in cleaner production may face implementation difficulties in the absence of adequate infrastructure and institutional support. These relationships offer a useful conceptual perspective for understanding the challenges associated with Pakistan's transition towards greener export activities. Nevertheless, an important distinction must be maintained between the potential relationships identified through the literature and empirically established effects on

export performance. Several reviewed studies address organisational sustainability, green innovation, environmental management, or general export performance rather than green export outcomes directly. Consequently, the reviewed evidence is insufficient to establish whether, or to what extent, these five dimensions individually or jointly influence Pakistan's green export performance. Overall, this review highlights the need for an integrated approach to sustainable export development that considers financial resources, technological upgrading, sustainable supply chain practices, human capabilities, and institutional conditions together. The synthesis provides a foundation for identifying policy priorities and developing future empirical research on the relationships between sustainability-oriented practices and export competitiveness in Pakistan.

5. Conclusion

This study reviewed the existing literature to examine the determinants, challenges, and policy implications of green export development in Pakistan. The review identified five interrelated dimensions relevant to sustainable export development: green finance, green innovation, sustainable supply chains, green human capital, and government policies and institutional support. The synthesis suggests that these dimensions may complement one another in enabling firms to adopt environmentally responsible practices and respond to sustainability requirements in international markets. However, their direct and combined effects on green export performance in Pakistan remain to be empirically established. The review also draws attention to Pakistan's reliance on traditional export sectors, particularly textiles and agricultural products, emphasising the importance of integrating sustainable production practices with export diversification and technological upgrading. The literature identifies several challenges to this transition, including infrastructural limitations, restricted access to financing, technological constraints, institutional weaknesses, and shortages of sustainability-related skills. Addressing these challenges requires coordinated efforts that consider both firms' organisational capabilities and the broader policy environment. Overall, the study contributes to the literature on sustainable trade by integrating financial, technological, organisational, supply chain, and institutional perspectives into a common framework for understanding green export development in Pakistan. The synthesis suggests that a transition towards more environmentally sustainable export activities requires complementary improvements across these dimensions rather than isolated interventions. Although the review does not establish causal relationships or evaluate the effectiveness of specific policies, it provides a foundation for understanding the conditions that may support sustainable export development and for guiding subsequent empirical research. Strengthening these conditions may help Pakistan pursue environmental sustainability objectives while developing a more resilient and competitive export sector.

5.1. Theoretical Implications

This review contributes to the literature on green exports, sustainable trade, and sustainable export development by synthesising existing research relevant to Pakistan. It highlights the multidimensional nature of sustainable export development and suggests that financial, technological, organisational, environmental, and institutional factors should be considered together rather than independently when examining sustainability-oriented export activities. More specifically, the review integrates five interrelated dimensions: green finance, green innovation, sustainable supply chains, green human capital, and government policies and institutional support. These dimensions provide complementary perspectives on the conditions that may enable firms to adopt environmentally responsible practices and respond to sustainability requirements in international markets. Green finance may facilitate investment in cleaner technologies, while green innovation and sustainable supply chain management may support resource efficiency and improvements in environmental performance. Green human capital and institutional support, in turn, may strengthen the organisational capabilities and policy conditions necessary for implementing these initiatives. The principal theoretical contribution of the review lies in integrating these perspectives to provide a conceptual basis for

examining green export development in a developing economy. Rather than establishing causal relationships among the identified dimensions, this synthesis highlights their potential complementarities and provides a basis for developing and testing more specific theoretical relationships in future empirical research. In this respect, the review offers a foundation for examining how sustainability-oriented business practices and institutional conditions may be associated with export competitiveness in Pakistan and comparable emerging economies.

5.2. Policy Implications

The synthesis of the reviewed literature suggests that sustainable export development in Pakistan requires a coordinated policy approach addressing financial, technological, organisational, infrastructural, and institutional constraints. Rather than relying on isolated interventions, policymakers should consider complementary measures that support firms' capacity to adopt environmentally responsible production practices and respond to sustainability requirements in international markets. Based on the five dimensions identified in the literature, six policy priorities are proposed. First, strengthening green finance mechanisms may facilitate investment in cleaner production technologies, renewable energy, and resource-efficient manufacturing systems. Improving access to suitable financing instruments, particularly for small and medium-sized export-oriented enterprises, could help address the financial barriers associated with sustainability-related investments. Targeted financial incentives, including appropriate subsidies and tax benefits, may also reduce the initial costs of adopting environmentally responsible technologies. However, the design and effectiveness of such instruments should be evaluated in relation to firms' financing needs and implementation capacities. Second, promoting green innovation and technological upgrading should be considered an important component of export development policies. Support for research and development, cleaner production processes, environmentally responsible product innovation, and technology adoption may help firms improve resource efficiency and respond to international environmental requirements. Such initiatives could be particularly relevant to export-oriented industries seeking to strengthen their technological capabilities and move towards higher-value-added production. Third, developing green human capital represents an important priority for supporting the effective implementation of sustainability-oriented business practices. Environmental education, vocational training, and professional development programmes may strengthen employees' and managers' environmental knowledge and technical competencies. Encouraging sustainability-oriented human resource management and leadership practices could further improve firms' organisational readiness to implement cleaner technologies, environmental management systems, and sustainable supply chain initiatives. Fourth, improving infrastructure and sustainable supply chain systems may help address operational constraints faced by export-oriented firms. Investment in transportation networks, logistics facilities, reliable energy systems, digital infrastructure, and waste management and recycling facilities could support more efficient and environmentally responsible production and distribution activities. These improvements may also strengthen firms' ability to meet sustainability-related expectations within international supply chains. Fifth, strengthening environmental governance and compliance mechanisms may facilitate the adoption of responsible production practices and support access to international markets. Clear environmental regulations, effective monitoring arrangements, credible sustainability certification systems, and technical assistance for meeting international standards could help firms respond to environmental requirements. Particular attention should be given to the accessibility and implementation costs of compliance mechanisms, especially for firms with limited financial and technical resources. Finally, enhancing institutional coordination and stakeholder cooperation may improve the implementation of sustainability-oriented export policies. Greater collaboration among government agencies, financial institutions, research organisations, industry associations, international development partners, and private sector firms could facilitate knowledge sharing, technological upgrading, and the diffusion of environmentally responsible

business practices. Stronger coordination may also help align industrial development, environmental governance, and export promotion objectives. Taken together, these policy priorities suggest that Pakistan's transition towards sustainable export development may benefit from an integrated policy approach combining financial support, technological development, human capital formation, infrastructural improvements, environmental governance, and institutional cooperation. However, these recommendations are derived from a synthesis of existing literature rather than a direct evaluation of policy effectiveness. Their practical contribution to green export performance will therefore depend on implementation conditions, institutional capacity, sector-specific characteristics, and further empirical assessment.

5.3. Future Research Directions

Although this review synthesises existing research on green export development in Pakistan, several areas require further investigation. In particular, the relationships between sustainability-oriented business practices, institutional conditions, and green export performance remain insufficiently established in the Pakistani context. First, future studies could employ longitudinal data and appropriate econometric methods to examine the relationships between green finance, green innovation, sustainable supply chain management, green human capital, institutional support, and green export performance over time. Such research could provide stronger empirical evidence regarding the nature, magnitude, and temporal dynamics of these relationships. Where suitable research designs and identification strategies are available, future studies could also investigate potential causal effects. Second, further research should examine a broader range of export-oriented industries beyond the sectors most frequently discussed in the reviewed literature, particularly textiles and agriculture. Sector-specific investigations could help identify differences in technological capabilities, environmental requirements, financing constraints, and opportunities for sustainable export development. Third, comparative studies involving Pakistan and other developing or emerging economies may provide insights into how institutional frameworks, technological capabilities, and policy instruments shape green export development under different economic conditions. Such comparisons could help identify potentially transferable policy approaches while recognising differences in national and sectoral contexts. Fourth, future research could explore the potential applications of emerging digital technologies, including artificial intelligence, blockchain, and digital supply chain management systems, in supporting environmentally responsible production and export activities. Particular attention could be given to their possible roles in improving traceability, resource efficiency, environmental monitoring, and sustainability-related information management. Finally, greater attention should be devoted to the behavioural and organisational factors influencing firms' adoption of sustainable business practices. Future studies could examine the roles of leadership commitment, organisational culture, stakeholder pressure, environmental awareness, and consumer preferences in shaping sustainability strategies and export-related outcomes. Addressing these research directions could strengthen the empirical foundations of green export research and provide more context-specific evidence for policymakers, business leaders, and other stakeholders seeking to support sustainable export development in Pakistan.

5.4. Limitations of the Study

Despite its contributions, this study has several limitations that should be considered when interpreting its findings. First, the study adopts a narrative literature review approach based on selected academic publications rather than a systematic or exhaustive literature search. Although the reviewed studies provide insights into different dimensions of sustainable export development, the literature considered may not represent the full range of available research. Consequently, the findings should be interpreted as a qualitative synthesis of selected literature rather than a comprehensive assessment of all available evidence on green export development in Pakistan. Second, the existing literature directly examining green export performance in

Pakistan remains limited. Several studies included in the review focus on related topics, such as green innovation, sustainable supply chain management, green human resource management, environmental performance, and general export competitiveness. While these studies provide relevant conceptual and contextual insights, their findings do not necessarily establish direct relationships with green export performance. This limits the extent to which conclusions can be drawn regarding the specific determinants and outcomes of green exports in Pakistan. Third, the reviewed studies differ in their geographical contexts, sectoral coverage, research designs, and analytical approaches. Evidence obtained from other developing economies or from sectors not directly involved in export-oriented manufacturing may not be fully applicable to Pakistan's export industries. These differences should therefore be considered when interpreting the findings and developing policy recommendations. Finally, this study relies on secondary literature and does not undertake an independent empirical investigation. As a result, the proposed relationships among green finance, green innovation, sustainable supply chains, green human capital, institutional support, and green export performance have not been empirically tested in this review. The review therefore identifies potential complementarities and policy-relevant considerations rather than establishing causal relationships or evaluating the effectiveness of specific policy interventions. Notwithstanding these limitations, the study provides an integrated perspective on the conditions associated with sustainable export development in Pakistan. Its findings offer a foundation for future empirical investigations and more context-specific assessments of sustainability-oriented export strategies.

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FULL PAPER · S1.2 · ONLINE SESSION 1

Positioning for Green Credibility: A Framework for Sustainable Entrepreneurship in Emerging Markets

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ABSTRACT

Advice given to entrepreneurs usually encourages them to "build sustainably" or to "position the venture as green", but provides very little that a founder can actually put into practice. In order to fill this gap, this conceptual paper defines an actionable objective at the level of the founder, which is called moderate greenness, and presents a strategic framework for intentionally creating it, no matter whether the venture's core sustainability innovation is incremental or systemic. Based on optimal-distinctiveness theory and on consumer research concerning moderate incongruity - a body of research showing that products and claims which are seen as only moderately distinctive are more likely to be adopted than those seen as either too familiar or too radical - the paper develops a similar kind of reasoning for the particular way in which green products are perceived. It also draws on the sustainability-liability literature, which shows that when green features are visible, negative assumptions about performance, price, or taste are often triggered, and on the greenwashing-skepticism literature, which shows the other way around - that claims which are too broad to be believed carry a corresponding risk. The paper therefore suggests three levers that founders can control in order to adjust how "green" a venture is perceived to be: the Systemic-Attribute-Cue (SAC) lever, the Concrete-Abstract (CA) lever, and the Mainstream-Green Category (MGC) lever. Each of these levers is supported by real-world examples and is based on a clear boundary condition derived from research into how sustainability claims are construed. The framework turns a general sustainability recommendation into a clear and resource-efficient strategy for positioning, something that is especially relevant to price-sensitive, emerging economies such as Albania and the wider Western Balkans, where the risks of sustainability liability and greenwashing skepticism are likely to be most severe and where founders have the smallest margin for making costly errors in their positioning. The paper makes a direct contribution to the Green Entrepreneurship and Sustainable Business Models theme by providing entrepreneurship educators, founders, and policymakers with a practical tool for enhancing the market acceptance of green ventures in the region.

Keywords: sustainable entrepreneurship, green marketing, product positioning, greenwashing, sustainability liability, emerging markets

Introduction

A founder who has recently developed a product that is genuinely more sustainable runs into a second, less obvious difficulty: how to discuss it. Although green entrepreneurship-this being the creation of new businesses in which ecological considerations are built into the core business model rather than being treated as an extra addition (Akinsemolu, 2020; Saari & Joensuu-Salo, 2020)-is generally promoted, specific guidance on this point is very limited. Founders are advised to 'build sustainably', to 'position the venture as green', and to make sustainability 'core to the brand'. But nothing is said about what this actually means in practice, how one can tell if a product is green enough, or how a founder with limited resources should communicate this information. This omission is by no means minor. An increasing amount of consumer research indicates that visible sustainability features do not simply boost a product's chances of success in the market; under certain identifiable circumstances, they in fact have a negative effect. Luchs, Naylor, Irwin, and Raghunathan (2010) described what they called the 'sustainability liability': in product categories where consumers place importance on strength, potency, or efficacy, a green attribute leads people to assume the product is gentle,

and this assumption competes with what the customer really wants, thereby reducing their preference in comparison to a conventional alternative. Skard, Jørgensen, and Pedersen (2020) built on this finding by distinguishing between core and peripheral green attributes. More recent evidence, however, does not simply confirm the existing view but rather challenges it: Chernev, Blair, Böckenholt, and Mishra (2025), by analysing archival data together with new consumer samples, discover that the sustainability-liability effect has diminished over time and is now small in most product categories, although it is still detectable in relation to attributes connected with strength-dependent performance claims, exactly the type of category boundary that the framework in this paper is designed to help founders deal with. On the other hand, founders who overly emphasize their sustainability messaging come under a different kind of penalty: greenwashing scepticism. Nguyen, Yang, Nguyen, Johnson, and Cao (2019) found that when consumers perceive greenwashing, it reduces their intention to buy green products because of increased scepticism, and Farooq and Wicaksono (2021) show that having been exposed to greenwashing causes consumers to become distrustful of any future sustainability claim, no matter how accurate it is.

Beneath the two scenarios-where sustainability is either too slight to make a difference or so great that it is hard to believe or worthwhile-there is a practical range. The main argument of this paper is that this range can be defined accurately and intentionally engineered. Research carried out over many decades in the fields of consumer psychology and strategic management has led to a finding similar to that in the neighbouring area of product innovation, namely that products seen as only moderately novel are more readily adopted than those seen as either too familiar or too radically new (Mandler, 1982; Moreau, Markman, & Lehmann, 2001; Deephouse, 1999). The present paper puts forward a comparable argument regarding how green a venture is regarded to be, drawing on the sustainability-specific literature examined below rather than taking it over from the newness literature.

It is not simply a matter of relabelling for cosmetic purposes. The mechanisms which create a moderate-newness sweet spot-namely processing fluency, ease of categorization, and the psychological comfort derived from a moderate level of incongruity-are related to but different from those which produce a moderate-greenness sweet spot (involving attribute-based quality inference and the credibility discount associated with sustainability claims). The paper's contribution is to demonstrate in which cases these two groups of problems have a common solution architecture, what levers a founder can use to move a claim along a perceptual continuum, and in which instances the underlying psychology differs sufficiently that different levers need to be applied in the case of sustainability. This distinction is most important in emerging and transition economies, since the paper contends that in these economies the liability relating to sustainability and the scepticism towards greenwashing are likely to have a greater impact than in the affluent, environmentally concerned markets in which most of the original consumer research was carried out.

The paper is divided into three sections. In the first part, it sets out an ex-ante definition of what might be called "moderate greenness" for entrepreneurs. The second part presents a three-dimensional approach, known as the Systemic-Attribute-Cue (SAC), Concrete-Abstract (CA), and Mainstream-Green Category (MGC) framework, for shaping that perception, using examples of businesses which (intentionally or not) have already applied these levers. In the third part, the paper looks at the framework's special significance for price-sensitive emerging economies such as Albania and the broader Western Balkans, referring to recent evidence on the obstacles encountered by sustainable entrepreneurship in the region (Andjelković et al., 2025; Vučković & Čučković, 2024).

Conceptual Framework

The framework presented in this paper is based on four areas of literature, each of which, when considered on its own, deals with a separate and distinct issue; yet when taken together, they define a single feasible area. The first two sections below lay out the limits of this area: the sustainability liability determines the lower limit (since insufficient visible greenness fails to distinguish a product and even a desirable green feature can still be offset by conventional advantages), and greenwashing skepticism sets the upper limit (if the claim is too strong or too vague then it tends to be disbelieved). The third section gives a theoretical explanation for why a position somewhere between these two limits should be expected to do better than either of the extremes, and the fourth section introduces an essential complication particular to sustainability claims that a more basic approach would overlook. Finally, the fifth section argues that these dynamics are not merely a general marketing issue but constitute a more serious and high-stakes problem for founders operating in markets that are price-sensitive and constrained by institutional factors, which is also where the practical importance of the paper lies.

The Sustainability Liability

The empirical fact on which this paper is based is that sustainability is not a general advantage. Luchs et al. (2010) demonstrated through experiment that when a product category is linked with benefits relating to strength (for example, cleaning products, batteries, running shoes), a sustainability cue reduces preference by triggering an association between 'ethical' and 'gentle'. Skard et al. (2020) built on this by dividing the attributes into core ones (that is, the ingredients or materials themselves) and peripheral ones (such as packaging and branding cues), discovering that the disadvantage effect applies to both types of attributes in categories that depend on strength but becomes an advantage for core attributes in those that depend on gentleness. Granato, Fischer and van Trijp (2022) describe a similar trade-off at the level of packaging, showing that consumers compare conventional functional benefits with sustainability gains rather than seeing the two as complementary, and Mondelaars, Verbeke and Van Huylenbroeck (2009) find that even in product categories where a sustainability feature is valued, health-related quality aspects usually take precedence over environmental ones when making a purchase decision. Wei, Ang and Jancenelle (2018) provide an important qualification in this regard: consumers' willingness to pay more for green products is not solely determined by their individual disposition but can be altered by actions taken by the firm, something which supports the paper's argument that it is positioning-rather than just the product itself-that has a measurable impact on the results. The practical message for a founder is that one should not automatically aim to maximise visible greenness; the effect of visible greenness on preference depends on what the customers of the category actually buy the product for.

Greenwashing Skepticism as the Upper Bound

There is also a second and essentially independent body of literature that identifies skepticism as a risk in the opposite direction. In one of the most frequently cited studies in this area, Skarmeas and Leonidou (2013) found that doubt about corporate social responsibility assertions leads to negative word of mouth and reduced purchase intention even if the claims in question are actually true, thus demonstrating that skepticism itself constitutes a risk rather than simply being the lack of persuasion. Nguyen et al. (2019) treated greenwashing specifically as the cause of green skepticism, this skepticism in turn dampening green purchase intention even among consumers who would otherwise be in favour of sustainable products. Aji and Sutikno (2015) extended the causal pathway to include perceived consumer skepticism and green perceived risk, while Farooq and Wicaksono (2021) showed that skepticism is in part a learned reaction: previous exposure to greenwashing in a given market or industry leads to a lack of trust in later claims, even when those claims are accurate. Orazi and Chan (2018) provided a finding that is directly applicable to how a claim should be worded: when specific

and verifiable environmental claims are later contradicted by specific external information, consumers impose a heavier penalty on the brand than in the case where either the original claim or the contradiction is vague; specificity acts as a safeguard only if the claim is also true. Altogether, this body of literature sets the upper limit of the moderate-greenness area: claims that are too general, too vague or not supported by evidence trigger precisely the kind of skepticism that undermines the business case for making the claim in the first place.

Why a Moderate Position Outperforms an Extreme One

The connection between these two types of failure and the 'sweet spot' argument is based on optimal distinctiveness theory (Deephouse, 1999), the idea being that organisations and products have to satisfy two requirements at once-being similar to their category in order to be seen as legitimate and at the same time being different enough to be preferred-and this tension is, on average, resolved at moderate rather than at extreme levels of distinctiveness. However, Zhao, Bu, Li and Li (2022) applied this principle at the level of product design, demonstrating in a large longitudinal dataset on automobile design that distinctiveness in relation to a firm's own previous products has a different (negative) impact on performance than distinctiveness in relation to competitors (which has a positive effect), a point which this paper will revisit when looking at the Mainstream-Green Category lever. On the consumer psychology side, Mandler's (1982) notion of moderate incongruity states that a discrepancy between what is expected and what actually happens is either not noticed if it is too small or is unpleasant if it is too large, with interest and positive arousal being greatest in the middle range; Moreau, Markman and Lehmann (2001) find that when dealing with genuinely new products, consumers make sense of them by taking over categorisation cues from those they already know. Sood and Tellis (2005) provide a helpful pre-existing definition for identifying the type of novelty involved: the kind of newness that occurs at the level of a product's components, as opposed to its platform/technology or its surface design, is the one most consistently perceived as moderate. The category-comparison mechanism that underlies the Mainstream-Green Category lever also has its own separate basis in Chakravarti and Lynch's (1983) framework on context effects, which states that the set of items against which a judgement is made influences the judgement itself, and Noseworthy, Wang and Islam (20012) show specifically that the context in which an ambiguous new product is categorised determines which attributes consumers place the most emphasis on when forming a preference. The framework outlined below adapts this same 'locus' logic (defining moderation in terms of where the claim is anchored rather than in terms of the claim's overall magnitude) to sustainability claims.

The authors claim that an analogous 'locus' logic also applies to the concept of greenness, with one key modification. While the newness problem mainly concerns the mental effort involved in processing an unfamiliar product, the greenness problem mainly relates to credibility and how well a claim fits with the quality assumptions that are typical of a given category. A claim can be easy to process and yet still be invalid: a broad, easy-to-understand green claim such as '100% sustainable' is in fact the type of claim that greenwashing research (Aji & Sutikno, 2015) identifies as most likely to cause suspicion. The three levers mentioned below are designed to address both aspects (perceptual ease and credibility) and not just perceptual ease alone.

Concrete Versus Abstract Framing, Specifically for Sustainability

There is also a third body of literature that has a direct bearing on one of the three levers. Reczek, Trudel, and White (2018) examined whether concrete or abstract construal was better when it came to people's responses to environmentally friendly products and discovered a more complicated pattern than the simple idea that 'concrete wins' would suggest: since abstract construal is compatible with a future-oriented mindset, it can in fact lead to more positive reactions to appeals concerning sustainability, while concrete framing is most effective when it provides detailed and verifiable information that a sceptical and present-focused consumer can check. This result has to be taken into account when developing the Concrete-Abstract lever discussed

below, and the framework regards it as a boundary condition rather than as an exception to be disregarded. Further support for the concrete-claim aspect of this pattern, particularly when it comes to sceptical audiences, is provided by the corporate social responsibility literature: Joireman, Liu, and Kareklas (2014) find that when concrete, specific claims are accompanied by supporting evidence, the responses of highly sceptical consumers become similar to those of less sceptical consumers, whereas vague claims have no such effect.

Regional Context: The Western Balkans

Ultimately, the argument that the moderate-greenness problem is more severe in emerging markets is based on recent regional evidence, in contrast to the existing body of research which has long examined the constraints facing transition economies as a whole. Aidis (2005) shows that, over many decades, institutional obstacles-such as inconsistent regulation, weak enforcement of property rights, and a lack of formal financing-have hindered the operations of small and medium-sized enterprises in transition economies, a situation which the more recent regional studies discussed below confirm has not been completely overcome. Andjelković et al. (2025) interviewed managers and business owners in Albania, Bosnia and Herzegovina, North Macedonia, and Serbia and discovered that sustainable entrepreneurship in the region is affected by a number of overlapping difficulties: insufficient financial assistance, the absence or inconsistency of sustainability reporting standards, weak regulation, and limited support from higher-education institutions. Vučković and Čučković (2024) also find at the firm level evidence of a slow and uneven process of "greening" among small and medium-sized enterprises in the Western Balkans. Mustafayev and Isgandarov (2024) report similar difficulties encountered by green startups in post-transition economies in general. Furthermore, Ernst, Kahle, Dubiel, Prabhu, and Subramaniam (2015) provide an additional perspective drawn from the wider literature on innovation in emerging markets: value innovations that succeed in price-sensitive markets are generally those that have been explicitly designed to meet affordability constraints rather than being modified afterwards from products originally developed for wealthier markets, a point which this paper's framework applies to sustainability positioning in particular. However, none of this existing literature looks directly at consumer-facing positioning, and that too is a gap which this paper's framework is intended to address: while the current regional literature explains why it is difficult to develop sustainable entrepreneurship from the supply side, it does not explain how a founder who has overcome those obstacles should then present the resulting product to a customer base that is both price-sensitive and skeptical.

Method

This is a conceptual study: instead of involving the collection of primary data, its contribution lies in the advancement of theory and in synthesising existing ideas. The kind of conceptual work referred to here is itself a recognised and assessable methodology, possessing specific design principles and quality criteria (Meredith, 1993; MacInnis, 2011). According to Jaakkola's (2020) classification of the different types of designs used in conceptual articles (theory synthesis, theory adaptation, typology development, and model development), the current paper should be considered as an example of theory adaptation; that is, an established theoretical framework (the optimal-distinctiveness and moderate-incongruity theory) is applied to a new area of application (green-product perception) by determining the points at which the theory can be transferred and the places where the relevant literature in that specific domain calls for modifications. Sääksjärvi (2026) employs a similarly structured approach to theory adaptation in order to develop a lever-based framework for product newness, a perceptual variable that is related but different from the one under consideration here; the present paper adopts the same general design logic but bases its substantive content on a separate and sustainability-specific body of literature. The development of the present framework proceeds in three clear stages, in accordance with MacInnis's (2011) requirements for a conceptual contribution (the delineation of the

constructs, the explanation of the relationships between them, and the demonstration of the framework's boundary conditions).

To begin with, a systematic literature search was carried out in four thematic areas that are directly related to people's perception of green products: the literature on sustainability and liability (Luchs et al., 2010; Skard et al., 2020; Chernev et al., 2025), the literature concerning greenwashing scepticism (Nguyen et al., 2019; Aji & Sutikno, 2015; Farooq & Wicaksono, 2021), the literature on optimal distinctiveness and moderate newness which forms the basis of the source framework (Deephouse, 1999; Mandler, 1982; Moreau et al., 2001; Sood & Tellis, 2005; Bu et al., 2022), and the construal-level research that has been applied to sustainability claims (Reczek et al., 2018). The fifth area, focusing on sustainable entrepreneurship in the Western Balkans (Andjelković et al., 2025; Vučković & Čučković, 2024; Mustafayev & Isgandarov, 2024), was searched on its own in order that the paper's claim regarding its regional relevance might be supported by evidence rather than stated as an assertion. The sources in each of the pools were chosen on the basis of their theoretical relevance to the constructs being developed rather than as a result of following a systematic review procedure, which is in line with usual practice in conceptual work involving the adaptation of theory (Jaakkola, 2020).

Second, three levers that were under the control of the founders were developed by applying to the credibility and quality-inference processes identified in the sustainability-liability and greenwashing literature the logic of optimal-distinctiveness and moderate-incongruity theory (Deephouse, 1999; Mandler, 1982; Moreau et al., 2001; Sood & Tellis, 2005), with moderation being determined by the point at which a claim is anchored rather than by its total magnitude; each of these levers was then examined in the light of the construal-level literature as it has been applied specifically to sustainability claims (Reczek et al., 2018). It was discovered at this stage that the Concrete-Abstract lever needed a real modification: Reczek et al. (2018) demonstrate that abstract construal can perform better than concrete construal when it comes to future-oriented sustainability appeals, a pattern which is not present in the general product-newness literature. This finding is treated as an explicit boundary condition rather than being omitted in order to keep the argument cleaner.

Third, real and publicly available examples of positioning decisions made by existing companies (Patagonia, Seventh Generation, Method, Tesla, Beyond Meat, and Allbirds) are used to illustrate each lever. These cases act as existence proofs to show that the lever mechanisms function in actual markets, rather than serving as a validated test of the framework's predictions. It is not claimed that these companies deliberately applied the framework or did so in the way described here; the examples are analytical reconstructions of positioning decisions that are consistent with the logic of the levers. In the Findings section a hypothetical, illustrative application of the framework to a venture in the Western Balkans is presented in order to make its relevance to that region more tangible; this illustration is clearly hypothetical and does not include any primary data from a real venture. It is identified in the Discussion and Conclusion as a key priority to validate the framework's predictions against actual founder behaviour and consumer response in the region.4

Findings

The Framework: Three Strategic Levers for Engineering Moderate Greenness

The literature surveyed above shows that there is a moderate-greenness area and gives a general explanation as to why it should do better than either of the extremes. However, by itself it doesn't tell a founder what to do on a Monday morning-for example, which words to use on the packaging, which category to place a product in, or which claim to highlight in an investor presentation or on a shelf display. It is in this section that the transition from the theoretical zone to specific actions is made: it defines moderate greenness in terms that a founder can compare with their own business, and then outlines three levers that a founder can directly control,

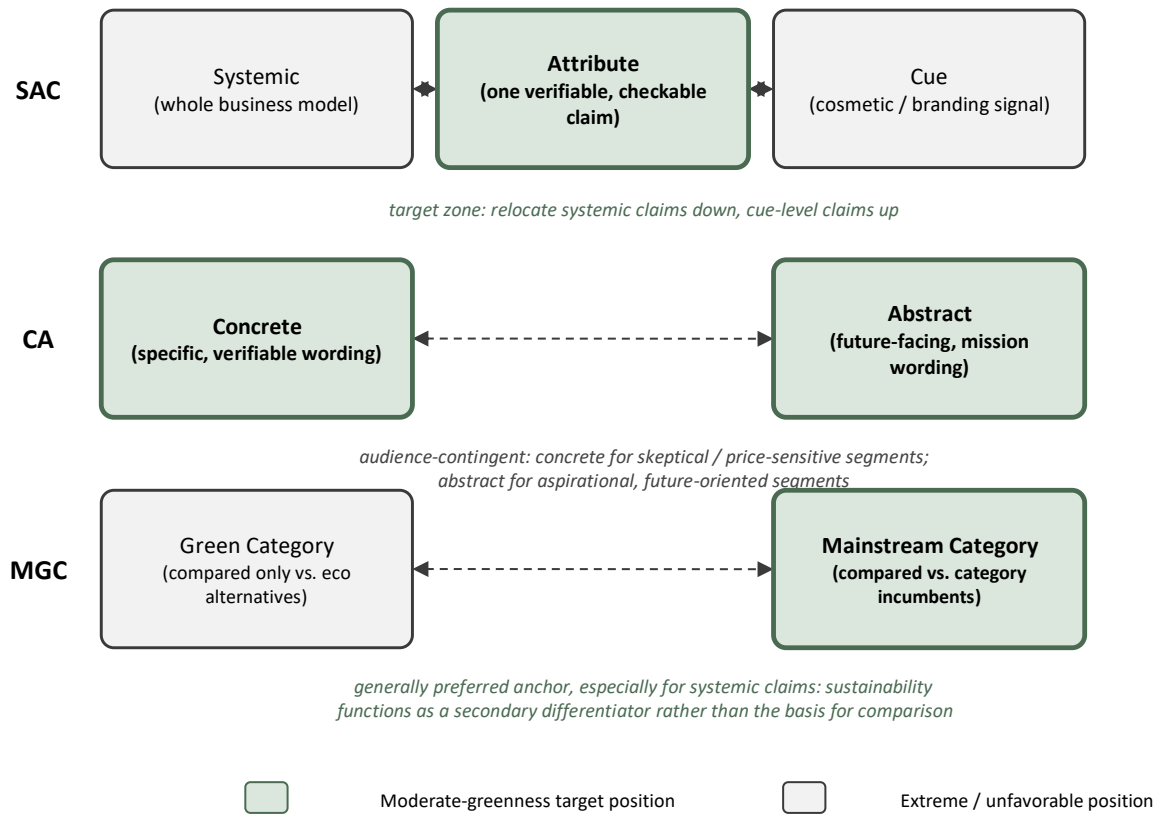
including real-world examples and a summary table (Table 1) that can be used on its own as a quick-reference tool, without needing to refer to the rest of the argument.

Defining Moderate Greenness

In the same way that Sood and Tellis (2005) argued, an ex-ante, actionable definition should identify the claim rather than having to wait and see its effects. This paper suggests that a venture is considered "moderately green" if its sustainability claim is based on one verifiable attribute that is relevant to the category, rather than being tied to the entire business model on one side or to a purely cosmetic element on the other. When a venture presents itself as completely reworking its entire supply chain in a circular way, it is making a systemic claim: such claims are difficult to verify, hard to compare, and, according to the sustainability-liability literature, are likely to lead to a broad (and often negative) assumption regarding the product's main performance. If, on the other hand, a venture changes the colour of its packaging to green or includes a leaf icon, it is making a cue-level claim: this type of claim has low credibility, is easily seen as greenwashing, and is unlikely to withstand close examination. The moderate category lies at the level of a specific and checkable attribute-such as a stated percentage of recycled material, a measured decrease in water use, or a specific substitution of a certified ingredient. Figure 1 summarizes the three levers that are developed below and indicates, in each case, the position of the moderate-greenness target along the continuum.

Figure 1. The Three-Lever Framework for Engineering Moderate Greenness

SAC = Systemic-Attribute-Cue · CA = Concrete-Abstract · MGC = Mainstream-Green Category



Lever 1: Systemic-Attribute-Cue (SAC)

The SAC repositions a sustainability claim along a continuum from systemic (that is, relating to the entire business model or technology platform), via attribute (a single specific and verifiable feature), to cue (a cosmetic or branding-related signal), using the same locus logic that was employed above to define moderate greenness.

Move from a systemic claim to one that focuses on individual attributes. A business based on a real systemic innovation--the kind of sustainable value proposition, value creation, and value capture that is described in the literature on sustainable business model innovation (Shakeel, Mardani, Chofreh, Goni, & Klemeš, 2020), for example a circular-economy supply chain or a regenerative-agriculture sourcing model--should not promote the overall system narrative in its marketing, since this kind of narrative is abstract and difficult for customers to verify, and (according to Luchs et al., 2010) is likely to cause negative quality assumptions in cases where strength is a factor. Patagonia's Worn Wear resale and repair programme is an example of this: instead of using the full extent of its supply-chain philosophy in its communication with customers, the company bases much of its sustainability messaging on one attribute at a time (such as the amount of recycled fibre in a particular garment or the number of times a jacket has been repaired), with each of these attributes being independently verifiable and capable of comparison.

Instead, move from making claims at the cue level to making claims at the attribute level. A business whose current sustainability signal is only cosmetic-for example, the colour of its packaging or a certification logo without any further details-should take the opposite course and make a specific, named attribute claim, or it will trigger the kind of skepticism toward greenwashing that Aji and Sutikno (2015) and Farooq and Wicaksono (2021) have documented. Seventh Generation's own shift over time from using general 'eco-friendly' language on its packaging to specifying on individual products the plant-derived ingredients it contains is an example of this kind of move: the claim thus becomes something that can be proven to be false, and that is exactly what gives it credibility.

Lever 2: Concrete-Abstract (CA)

The way in which the CA lever is used determines how a sustainability claim is phrased, regardless of the specific attribute it relates to. As Reczek et al. (2018) demonstrate, this lever functions differently in the case of sustainability claims than it does for ordinary product-newness claims, and therefore founders should apply it on a conditional basis rather than by means of a fixed rule.

For customers who are concerned about current prices or performance (since this is the more typical case in an emerging market that is price-sensitive), specific and concrete statements are more effective than abstract ones. A claim such as 'reduces packaging waste by 40 per cent' can be verified and is dealt with more easily than 'environmentally responsible packaging', and it does not lead to people asking 'what does that actually mean'. This is shown in the case of Method's household cleaning products, where ingredient lists and specific claims regarding biodegradability take the place of more general 'green' terminology.

When it comes to an aspirational and forward-looking positioning-something that is more effective when the company is aiming at an early-adopter group that already sees sustainability as a marker of identity-some degree of abstraction can be advantageous, as Reczek et al. (2018) found that abstract thinking is compatible with a future-oriented mindset. In its initial marketing, Tesla relied on an abstract, mission-based statement ("accelerating the world's transition to sustainable energy") aimed at its early-adopter customers, whereas in its later communications directed at the mass market-including the Model 3 and Model Y-the company adopted more concrete claims that allow for comparisons, such as cost per mile and charging range, which serves as an implicit example of the CA lever's conditional logic.

Lever 3: Mainstream-Green Category (MGC)

The lever operated by the MGC determines the comparison set that a venture selects. A product may be placed within a specific 'green' or 'eco' category, in which case it is compared only with other sustainable products and acquires the premium pricing characteristic of that category and, as noted by Luchs et al. (2010), sometimes also the expectation of lower performance, or it may be included in the mainstream category, where it

competes on normal terms (on price, taste and performance) with sustainability acting only as a secondary means of differentiation rather than as the basis of the comparison.

The fact that Beyond Meat has chosen to be labelled and placed on the shelf as a 'burger' rather than as a 'plant-based protein alternative' is the best example of this: by basing itself on the ordinary burger category, the product was able to draw upon a familiar and well-understood set of comparisons as well as the expectations regarding taste and format that a specialist 'alternative protein' label would not have provided, while at the same time allowing sustainability to act as a secondary selling point rather than the main criterion for judgment. Similarly, Allbirds' wool sneakers provide another instance of this: they are positioned within the mainstream athletic footwear category and are compared in terms of comfort and design with brands such as Nike or Adidas, rather than being placed in a specialist 'sustainable footwear' category where they would only be compared with other products that have an eco-label.

Since the SAC lever's main argument is genuinely systemic (at the high end), the MGC lever provides another way of achieving moderation by grounding the venture in the mainstream category even though its underlying model is more radical, thereby gaining legitimacy and a familiar frame of reference from the conventional category, while the SAC and CA levers carry out the task of making the specific sustainability claim credible and verifiable.

Interaction of the Three Levers

The three levers are not mutually exclusive, and since Bu et al. (2022) found that distinctiveness in relation to a firm's own previous products is different from distinctiveness in relation to its competitors, this indicates another refinement that is worth testing through empirical research in future work: a venture might be distinct within the mainstream category (using the MGC lever, by positioning itself as part of the category) while at the same time being attribute-specific and concrete (using both the SAC and CA levers) in the way that distinctiveness is conveyed. It is not necessary for a founder to use all three levers; the decision should be based on which failure mode-sustainability liability or greenwashing skepticism-is the greater immediate threat given the venture's category and target segment.

Table 1 presents the three levers together in a concise form for easy reference when looking at the subsequent applications.

Table 1

Summary of the Three Founder-Controlled Levers

Lever	What It Relocates	Low-End Position	High-End Position	Moderate-Greenness Target	Key Supporting Sources
Systemic-Attribute-Cue (SAC)	The scope of what the sustainability claim refers to	Cue (cosmetic/branding signal only)	Systemic (whole business model or platform)	Attribute: one verifiable, checkable feature	Luchs et al. (2010); Skard et al. (2020); Shakeel et al. (2020)
Concrete-Abstract (CA)	The wording of the claim	Concrete (specific, falsifiable wording)	Abstract (future-facing, mission-level wording)	Audience-contingent: concrete for skeptical/price-sensitive segments; abstract for aspirational segments	Reczek et al. (2018); Joireman et al. (2014); Orazi & Chan (2018)
Mainstream-Green Category (MGC)	The comparison set invoked by the claim	Green/eco category (compared only vs. other sustainable alternatives)	Mainstream category (compared vs. category incumbents)	Mainstream category, generally, with greenness as a secondary differentiator	Deephouse (1999); Bu et al. (2022); Noseworthy et al. (2012); Chakravarti & Lynch (1983)

Illustrative Application: A Composite Western Balkans Venture

The example given here is a hypothetical composite, not the result of any detailed study; it has been put together for illustrative purposes on the basis of the regional constraints documented by Andjelković et al. (2025) in Albania, Bosnia and Herzegovina, North Macedonia, and Serbia, and it is not claimed that it presents data from a real company. A small firm based in Tirana that manufactures household cleaning products changes from using imported petrochemical formulations to one based on plant-derived surfactants, the decision being driven in part by cost (since a local and seasonal input is involved) and in part by a real environmental concern. By presenting the venture at the systemic level as "an eco-friendly and sustainable cleaning company", it runs the risk of suffering two simultaneous failures which are predicted by the above-mentioned literature: the inference of sustainability liability that a "gentle" formulation based on plants will not clean as well as an imported chemical brand (Luchs et al., 2010), especially in a category where effectiveness depends on strength; and, since Albanian consumers have few independent ways of verifying a systemic sustainability claim made by a small local producer, there is a greater likelihood of the claim being seen as marketing rather than as reflecting actual substance (Farooq & Wicaksono, 2021).

Using the three levers alters the way the product is positioned without changing the product itself. The SAC lever shifts the claim from the systemic level-such as 'sustainable company'-to a specific attribute: 'made with a plant-based surfactant sourced from Albanian sunflower oil', a claim which a customer can check out and compare with others. For a price-sensitive, present-focused target group, the CA lever prefers the concrete version of that claim rather than an abstract one like 'environmentally conscious cleaning'. In this case, concreteness serves two purposes: it acts as a sign of credibility and also gives a reassurance about performance. The MGC lever keeps the product placed on the shelf and promoted within the mainstream household cleaning category, where it is compared with imported existing products on the basis of price and cleaning performance, the plant-based feature acting as a secondary point of distinction rather than the main reason for the purchase decision, thus avoiding the higher price and lower performance expectations that would come with an explicit 'eco cleaning' category. The outcome is a positioning that is clearly and moderately green, rather than either remaining commercially invisible or being open to suspicion: this is exactly the area that the framework is intended to identify.

Discussion and Conclusion

Relevance to Emerging, Price-Sensitive Markets

The reason why this framework is seen as particularly relevant to markets such as Albania and the wider Western Balkans is based on two interrelated conditions which are described in the regional literature. On the one hand, Andjelković et al. (2025) and Vučković and Čučković (2024) demonstrate that entrepreneurs in the Western Balkans already work under more stringent financial and institutional restrictions than do those in the markets where most of the research on sustainability liabilities and greenwashing has taken place, so that a founder has less capacity to absorb the commercial consequences of making a mistake in either direction regarding their positioning. On the other hand, price sensitivity probably intensifies the sustainability liability itself; in product categories where price is the main factor influencing purchase decisions, any suggestion that a green feature involves a trade-off with value for money (that is, a specific example of the general strength-versus-gentleness mechanism identified by Luchs et al., 2010) is likely to have a greater impact on the consumer's decision than in a market in which customers have more discretionary income to pay for a green premium.

For entrepreneurs' educators, the framework provides a practical and teachable alternative to the general advice commonly found in current curricula regarding a 'position as sustainable'. For policymakers and

supporting organisations in the region (since Andjelković et al., 2025, point out the 'absence of... clearly defined sustainability metrics' and the 'lack of support from higher education institutions' as obstacles), the SAC lever's focus on verifiable claims at the attribute level suggests a specific kind of institutional action - the introduction of standardised, low-cost attribute verification or certification schemes which would allow resource-poor founders to make credible and checkable claims without having to rely on the marketing and legal support structures that larger companies in richer markets can afford.

Contribution and Conclusions

The aim of this paper was to substitute for the piece of advice that founders are unable to put into practice - "position the venture as sustainable" - one that they can actually carry out: they should place the claim at the attribute level, phrase it in a way that suits the audience they are addressing, and select the comparison set with care. It has been shown that, just as "make the product new" has been found to be of little help to founders, so too is the original advice. Based on the sustainability-liability literature (Luchs et al., 2010; Skard et al., 2020), the greenwashing-skepticism literature (Nguyen et al., 2019; Aji & Sutikno, 2015; Farooq & Wicaksono, 2021), and the optimal-distinctiveness and moderate-incongruity literatures (Deephouse, 1999; Mandler, 1982; Moreau et al., 2001; Sood & Tellis, 2005), the paper defined an actionable goal, moderate greenness, at the attribute level rather than at the systemic or cosmetic level, and introduced three founder-controlled levers (Systemic-Attribute-Cue, Concrete-Abstract, Mainstream-Green Category) through which this can be deliberately achieved. In line with MacInnis's (2011) perspective that a conceptual contribution should be assessed according to the originality and usefulness of the relationships it proposes rather than merely on the basis of statistical validation, the paper's contribution consists in specifying testable and falsifiable relationships between the constructs which had hitherto only been mentioned in general terms. The levers are based on a psychological mechanism that is specific to sustainability claims (namely, credibility and category-specific quality inference, not just processing fluency), and the Concrete-Abstract lever in particular includes an explicit boundary condition taken from Reczek et al. (2018) that a more straightforward treatment of the construct would have overlooked.

The practical importance of the framework is greatest in markets that are price-sensitive and restricted by institutional factors such as Albania and the wider Western Balkans, since recent evidence (Andjelković et al., 2025; Vučković & Čučković, 2024) indicates that sustainable entrepreneurship in these areas already functions under severe resource limitations and therefore has very little capacity to absorb a costly error in positioning.

Limitations and Future Research

Just as happens in any instance of theoretical adaptation to develop a conceptual contribution (Jaakkola, 2020), the framework's propositions are at this stage theoretically derived rather than having been empirically tested; Meredith (1993) makes it clear that the value of this type of conceptual work consists in producing precise, testable propositions for use in later empirical research, not in taking the place of such research. Future research should empirically test the framework's predictions by carrying out experimental replications of the sustainability-liability and greenwashing-skepticism effects using stimuli that have been manipulated at the attribute., concrete., and category levels, and by conducting field research with the founders in the area, and should also examine the boundary conditions which the construal-level literature (Reczek et al., 2018) suggests are more important for sustainability claims than for ordinary novelty claims.

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FULL PAPER · S1.3 · ONLINE SESSION 1

From Waste to Value: How European Circular Start-ups Transform Environmental Challenges into Business Opportunities

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ABSTRACT

As climate change has become a global challenge attracting growing attention and efforts from stakeholders worldwide, more attention is also being dedicated to waste, a key contributor to the significant increase in carbon emissions. European stakeholders are also increasing their efforts at different levels, from business to policy. Businesses have become increasingly active in addressing the waste problem by developing innovative solutions aimed to reduce waste. Circular start-ups have also become key players through solutions that aim to reduce waste and turn this problem into a business opportunity.

This research examines the role of circular start-ups in addressing the waste problem and how they exploit it as a business opportunity, leading to reduced environmental impact as well as business and financial benefits. A key factor considered is the role of the ecosystem in which they operate in supporting the development and growth of circular start-ups. The research is primary and exploratory, with primary data collected from the founders of three selected circular start-ups operating in different European countries. The data collected are used to develop case studies, which are used to understand how start-ups develop circular solutions and balance environmental impact with business and financial benefits.

The research found that, despite the challenges, the European circular start-ups examined are able to transform the waste problem into a business opportunity by developing solutions that combine reduced environmental impact with business and financial benefits. The findings also suggest that ecosystem players are considered a key factor in supporting start-ups in developing circular solutions and growing. Future research can focus on a deeper analysis and use quantitative methods to better understand the role and relative importance of different ecosystem players in the success of these start-ups.

Keywords: start-ups, circular economy, environment, waste

1. Introduction

As the adverse effects of climate change have become more evident, this is mobilising stakeholders globally to enhance their efforts to reverse these negative effects. There are many sectors and factors that are key contributors to the high level of greenhouse gas emissions, but across these sectors, many innovative solutions have been brought to the market that contribute to reducing their level. Among this solutions, many are focused on waste, with businesses adopting circular business models that enable them turn waste into value. As these businesses contribute to reducing environmental impacts, they are also creating value in many directions, including revenue generation for the company itself.

Start-ups have also become crucial players in the transition to a circular economy by transforming waste into value (Petri et al., 2025). The solutions they offer vary because the waste as input and the path followed by each start-up differ. Some of them focus on transforming food waste, while others focus on textile waste, industrial waste, and other types of waste. Although start-ups worldwide are contributing to addressing this problem, this research focuses on the work European start-ups are doing in this direction. As the pressure of climate change increases, policymakers are also becoming more active in their initiatives and strengthening legislation to accelerate action towards achieving the Net Zero goal under the Paris Agreement. An example is

the European Commission rules under the Ecodesign for Sustainable Products Regulation, effective from 19th July 2026, which prohibit large companies from destroying unsold footwear, clothing or accessories. This measure suggests that reducing environmental impacts requires coordinated efforts among stakeholders (Hysaj, 2024), while voluntary initiatives by businesses and other stakeholders can be complemented by regulatory and enforcement mechanisms to support the achievement of environmental goals. This is reflected in circular material use rate, which for the European Union was only 12.2% in 2024 (Eurostat, n.d), highlighting the need for intensified efforts in this direction

Several factors drive circular entrepreneurship, including personal and professional factors, social and ecological values and identity, business growth, business resilience, cost reduction, and legal drivers (Dantas et al., 2022; Cullen & De Angelis, 2021; Geissdoerfer et al., 2022). However, adopting circular business models can be very challenging, particularly for start-ups, which often face challenges which can be financial, legal, market, technical, organisational, and value chain barriers (Geissdoerfer et al., 2022). Among these, limited access to finance is a key barrier (Sulillari et al., 2025), particularly for start-ups in less-developed countries where the venture capital market is underdeveloped, and access to funding from angel investors is limited (Sulillari, 2023a). These challenges can be overcome through supportive entrepreneurial ecosystems, partnerships and coordinated efforts among all the actors across the value chain (Lit et al., 2024).

Despite its importance, this topic remains underexplored, leaving a gap in the literature. This research aims to address this gap by analysing how European circular start-ups tackle the waste-related challenge and turn it into a business opportunity.

2. Literature Review

Growing interest in climate change and the waste problem is reflected in the growing body of research addressing these challenges. While much of the existing literature has examined circular economy practices and circular business models in general, less attention has been dedicated to the role of circular start-ups in addressing the waste challenge. This gap makes this research an initial step toward enriching the existing literature in this field. This section summarises key existing research on this topic and is divided into three parts. It starts with the role of circular start-ups in tackling waste-related problems, continues with the challenges circular start-ups face, and ends with the role the ecosystem plays in supporting circular start-ups in tackling the waste problem.

2.1 Circular start-ups and their role in addressing waste

Start-ups are often seen as a source of innovation and have become key contributors to solving the waste problem. This has motivated researchers to examine circular business models for start-ups. Although the waste problem holds potential for implementing circularity, most existing work has examined start-ups' circular business models in general, rather than focusing specifically on waste (Hoang and Böckel, 2024; Petri et al., 2025). The literature distinguishes five types of circular start-ups: design-based, platform-based, waste-based, nature-based and service-based (Henry et al., 2020).

Research differs regarding the aspects of circular start-ups examined. (Finner et al., 2026) focused on the way circular start-ups integrate environmental values and examined how they align value creation and ownership with circular goals. However, start-ups differ in the growth strategies they choose to follow, such as impact, commercial, institutional, cultural, and ecosystem-related strategies (Dalmarco et al., 2026). Also, circular start-ups are more inclined to implement deep circular strategies than existing firms (Henry et al., 2020).

Start-ups play an important role in the circular transition (Petri et al., 2025), but the factors that drive circular entrepreneurship may vary and include both intrinsic and extrinsic factors. Key motivations for becoming

circular economy entrepreneurs include identity, flexibility in the work environment and the opportunity to generate a good income (Dantas et al., 2022). Other drivers include financial drivers such as business growth, business resilience, cost reduction, and resource scarcity; legal drivers such as regulatory push and legal compliance; market-related drivers such as long-term customer satisfaction and changing customer demands; technical drivers such as new technological opportunities; and organisational drivers such as corporate sustainability (Geissdoerfer et al., 2022; Saarinen & Aarikka-Stenroos, 2023). Ecological and social value are also central to value creation for these entrepreneurs (Cullen & De Angelis, 2021). Circular entrepreneurs are distinguished by superior communication skills and the ability to secure financing, while their motivations, according to Liu & Gardella (2025), are mainly personal and professional.

2.2 Challenges of circular start-ups

Despite their motivation to adopt circular business models and contribute to tackling the waste problem, circular start-ups face various challenges. These challenges can be financial, legal, market, technical, organisational, and value chain barriers (Geissdoerfer et al., 2022). Financial barriers include high initial investment costs, shareholder short-term orientation, financial uncertainty, pre-existing investments, limited financial resources, and difficulties in accessing capital for sustainable investments (Prendi et al., 2024; Geissdoerfer et al., 2022; Lit et al., 2024; Petri et al., 2025; Saarinen & Aarikka-Stenroos, 2023). Legal barriers include a lack of legislative support and a weak regulatory framework (Petri et al., 2025; Geissdoerfer et al., 2022; Hysaj, 2024). Market barriers include the challenge of balancing affordability and sustainability, lack of social awareness, uncertainty in market demand, lack of standardisation, prices that do not reflect true costs, and competition with efficient linear systems (Geissdoerfer et al., 2022; Prendi et al., 2024; Lit et al., 2024; Petri et al., 2025; Hysaj, 2024)

Technical barriers include technical trade-offs, lack of access to sustainable technologies and appropriate infrastructure, limited technical and infrastructure capabilities, and technology dependence (Geissdoerfer et al., 2022; Hoang and Böckel, 2024; Lluri & Lluri, 2025; Petri et al., 2025; Hysaj, 2024). Organisational barriers include lack of leadership towards the circular economy, organisational ambidexterity, organisational transformation challenges, lack of experience with the new circular business models, difficulties in classifying circular business models, organisational resistance to the transition to a circular economy, and lack of experience and skills (Prendi et al., 2024; Geissdoerfer et al., 2022; Petri et al., 2025). Value-chain barriers include difficulties in coordinating the value network, heterogeneity of post-customer waste, operational uncertainty, immature reverse logistics systems, traceability and trust challenges, and lack of a supportive demand and supply network (Geissdoerfer et al., 2022; Prendi et al., 2024).

Other barriers include cultural barriers, limited availability of sustainable resources, lack of collaboration and partnerships with other organisations, limited resources, poor credibility, and inadequate institutional support (Hysaj, 2024; Prendi et al., 2024; Lit et al., 2024). In many cases, it can also be challenging to convince investors of the business model (Lit et al., 2024). Furthermore, low credibility can make it difficult for circular start-ups to enter and influence complex markets, while public engagement can also create challenges for adopting circular economy practices in some cases (Lluri & Lluri, 2025).

These findings highlight the challenges faced by circular start-ups and the important role of value chain collaboration, resources and knowledge in adopting circular business models. They also highlight the role of institutions in supporting start-ups in dealing with these challenges. Some authors, such as Hoang and Böckel (2024), offer a tool for circular start-ups to deal with the challenges they face during the venturing process.

2.3 The role of ecosystem on start-ups development and growth

Although circular start-ups that turn waste into a business opportunity face various challenges, many succeed. The factors that contribute to circular start-ups' success vary. Existing literature highlights the key role of cross-sector collaboration in addressing the issue of limited infrastructure when adopting circular business models (Finner et al., 2026), partnerships, communication and action-taking (Hoang and Böckel, 2024), and the importance of entrepreneurial ecosystems and coordinated efforts among all the actors across the value chain (Lit et al., 2024). Other authors highlight the crucial role of business model strategies, such as waste-to-resource initiatives, industrial symbiosis, and product life extension (Hysaj, 2024). This is supported by findings of Dalmarco et al. (2026), who found that circular start-ups tend to adopt commercial and ecosystem scalability strategies and highlighted the crucial role of access to partners, resources, and markets in geographical expansion.

According to (Lit et al., 2024), whose research focused on circular business models in plastics, companies may rely on designing a compelling circular value proposition, sensing the market trajectory and reacting accordingly, and the ability to influence and leverage the company's network to their advantage to overcome barriers. Fernandes et al. (2025), on the other hand, examined the role of national systems of entrepreneurship and the role of digital transition in the relationship between national systems of entrepreneurship and the circular economy. This is consistent with the findings of (Finner et al., 2026b), who examined circular entrepreneurial ecosystems and identified five elements of how entrepreneurial ecosystems function for start-ups, including resource endowment, collaboration, culture, regulatory framework and digital technologies. Other important factors include circular design concepts, digitalisation, and circular materials management (Hild, 2023).

A key supporting factor that is considered important for the success of circular start-ups in many studies is coordinated effort (Hysaj, 2024). Entrepreneurship, including social entrepreneurship, is seen as a key driver of the circular economy, suggesting that policies should focus on increasing synergies between social entrepreneurship and the circular economy, raising awareness and capacity-building, which can lead to enhanced stakeholder engagement (Fernandes et al., 2025; Sula, 2025). Something positive is that the interest of venture capital investors and impact investors in investing in such sustainability and climate start-ups has increased, suggesting there is more funding available for them (Sulillari, 2024; Sulillari 2023b). Moreover, Hamid et al. (2026) found that the relationship between circular economy drivers and innovation is partly mediated by competitive scanning and proactive searching for opportunities. They also found that political and cultural drivers are positively associated with sustainable innovation, while technological factors did not affect innovation. Other studies have examined the relationship between informal entrepreneurship and the circular economy (Kosta & Ianole-Calin 2026).

Overall, the literature review shows that the development and growth of circular start-ups in general, and, as a result, those offering a solution in the waste space, depend on various financial and non-financial factors, such as infrastructure, access to markets, collaboration across the value chain, partnerships, institutional support and entrepreneurial ecosystems. Other factors that can significantly affect start-ups' ability to develop and grow include cultural factors, digital technologies and the regulatory framework. These findings lay the foundation for examining how these factors affect selected start-ups' work in turning the waste-related challenge into a business opportunity.

3. Methodology of the Research

The waste problem has become a global challenge and is attracting growing attention from all stakeholders. Start-ups are increasingly contributing to solving this problem by bringing innovative solutions that aim to

reduce waste and its negative environmental effects. By contributing to waste reduction, start-ups can transform waste into a business opportunity and reap the benefits resulting from it. This is what this study examines. The research focuses on identifying ways through which start-ups can contribute in this direction. Furthermore, the analysis focuses on how it can be transformed into a business opportunity, meaning the relationship between environmental impact and business-related impact will be at the core of the research. A key factor examined is the role of the ecosystem in supporting the success of circular start-ups. The key objectives of the study are:

- To examine the role of circular start-ups in solving the waste problem.
- To investigate how the waste problem can be transformed into a business opportunity by circular start-ups.
- To understand how environmental value creation is connected to the business and financial benefits generated by circular start-ups.
- To understand the role of the ecosystem in promoting the adoption of circular practices by circular start-ups.
- To make recommendations that can support policymakers and start-up managers in making better decisions related to circular business model adoption.

The research is primary and exploratory, with primary data collected through semi-structured interviews with the founders of three selected circular start-ups operating in different European countries. The case selection was purposive, with start-ups included in the research being relevant to the research and contributing to transforming the waste-related challenge into a circular business opportunity. The data are collected through the interviews and are used to develop case studies, which are further examined as a whole to reveal differences and similarities across them. Including three case studies gives an in-depth understanding of how circular start-ups can tackle the waste problem and transform it into a business opportunity, linking environmental impact with business and financial benefits. Comparing start-ups from different countries also helps to identify the role of the ecosystem in supporting circular start-ups in their development and growth.

The case studies are analyzed using a comparative approach focused on how each start-up identifies the waste-related problem as a business opportunity, how it develops a solution, the resources and support required, and the environmental and financial benefits related to it. A key factor considered is the role of the ecosystem in which each start-up operates. This helps to identify key differences and similarities among the cases and how the ecosystem can influence the development and growth of circular start-ups.

Despite its contribution, the research faces various limitations that should be considered when interpreting the results. A key limitation relates to the chosen methodology, which is based on case studies and may influence the generalization of the results. In addition, the study includes only three case studies, meaning that not all European countries are represented. These limitations can be considered and addressed in future research.

4. Discussion of Results

As previously mentioned, this research uses case studies to analyse how European start-ups are transforming the waste problem into a business opportunity. This analysis provides insights into the paths selected start-ups have followed to bring innovative solutions to market and the factors they consider important for their development and growth.

Nada

Nada is a Luxembourg-based circular bioeconomy start-up founded in 2025, which transforms agricultural side-streams, such as fruit seeds and peels, into high-performance bioactive ingredients for the cosmetics industry.

Its technology enables the recovery of valuable compounds without conventional organic solvents. Through its solution, Nada addresses the environmental problem of agricultural food loss and waste, as well as the environmental impact associated with conventional cosmetic ingredients. It also responds to the increasing pressure on cosmetic companies to reduce their environmental impact by finding more sustainable alternatives to conventional raw materials. Market research and discussions with agricultural and cosmetic-industry stakeholders helped confirm this problem, which the company is now addressing.

The company has transformed a waste-related environmental challenge into a business opportunity, by creating value at various levels. Agricultural partners can generate additional revenue from materials previously considered waste, while cosmetic companies gain access to sustainable and traceable ingredients. The company itself generates revenue by selling these ingredients. In this way, Nada contributes to the value chain by transforming low-value agricultural side-streams into higher-value specialty ingredients.

Nada uses a green extraction platform based primarily on supercritical CO_2 to recover valuable bioactive compounds from agricultural side-streams. The company currently produces Pomega-5™, a pomegranate seed oil and is investigating additional feedstock and extraction pathways to expand the platform. The environmental value the company creates mainly relates to waste and resource valorisation and the potential reduction in the need for virgin raw materials by providing alternative sources of cosmetic ingredients. This is enabled through the company's technology, which avoids conventional organic solvents and allows CO_2 to be recycled within the process.

While addressing this environmental challenge, the company also expects to generate business and financial benefits. It is an early-stage, pre-revenue company; the financial value generated so far is primarily related to technology development, partnerships, customer validation and intellectual property rather than significant sales revenue. However, the company is validating interest from potential cosmetic customers. The founders expect to generate revenue through B2B sales of high-value cosmetic ingredients and highlight the potential for attractive margins because relatively low-value agricultural side-streams can be converted into higher-value specialty ingredients. The company also expects to develop multiple ingredients from different feedstocks, creating a diversified product pipeline rather than relying on a single ingredient.

The company's impact model is based on creating a market for upcycled ingredients, supporting cosmetic companies in reducing Scope 3 emissions, while increasing demand for agricultural side-streams that would otherwise be discarded. However, the founders also highlight that transforming waste into value is associated with important challenges. For example, agricultural side-streams may be inexpensive, but collecting, drying, transporting and processing them can create high costs and environmental impacts. Therefore, a balance is needed between the amount of biomass which can be valorised and factors such as logistics, energy consumption, extraction yield and the final market value of the ingredient.

They also highlight the key role that support from large companies, research institutes, governments, start-ups, brands, celebrities, farmers, and others has played in helping them move forward, with coordinated efforts among stakeholders remaining key to addressing the waste problem. This suggests that transitioning to circularity does not automatically guarantee environmental and financial benefits, but it also depends on the entire process and its efficiency. The founders also highlight the key role of the involvement of different stakeholders, such as large companies, research institutes, governments, and start-up accelerators, in supporting their company's development. Now, for Nada, support from these stakeholders is particularly important for accelerating technology development, feedstock access, and pilot-scale validation. This highlights the crucial role of the ecosystem in supporting circular start-ups to develop and grow.

The main barriers the company faces include technology scale-up, ensuring sufficient feedstock, customer validation, high upfront costs, and market adoption. Key factors supporting the company's development and growth include non-dilutive funding, technical infrastructure and commercial access, particularly for the early stage where the company operates. Grants and research and development support enable pilot-scale validation, while access to pilot facilities, analytical expertise and process-engineering capabilities is considered important to accelerate technology readiness level progression.

Other forms of support, including introductions to cosmetic brands, ingredient distributors and industrial partners, are also considered highly valuable because customer validation and letters of intent are critical for attracting investment. Mentorship related to scaling, intellectual property, regulatory strategy and fundraising would also be valuable. These results suggest that a supporting ecosystem is not only important for developing their circular technology but also for commercialisation and future growth. Key priorities for the company include bringing the first ingredient, Pomega-5™, from laboratory development towards commercial-scale validation, while also developing a second ingredient from pomegranate peel and investigating additional agricultural feedstocks, such as orange seeds and avocado residues. The company also plans to expand into nutraceuticals, where agricultural side-streams can similarly be converted into high-value bioactive compounds.

The founders highlight that a key factor for successfully transforming environmental challenges into sustainable business opportunities is the ability to identify market gaps and recognise that circularity is no longer simply an option but increasingly a necessity. They also highlight the importance of access to grants and participating in start-up accelerators in supporting their growth and contribution to the circular transition.

Overall, the Nada case illustrates how a circular start-up can transform agricultural waste streams into a business opportunity, and also demonstrates how the transformation of waste into value has technological, logistical, environmental and financial implications. This case also suggests that for a circular start-up to successfully transform waste into value does not depend only on the technology itself, but also on access to funding, infrastructure, feedstock, industrial partners and customers. It also highlights the key role of the entrepreneurial ecosystem in supporting the development and growth of circular start-ups in this space. These findings are consistent with the literature review, which highlights the key role of funding, entrepreneurial ecosystem, and partnerships in overcoming the challenges related to scaling circular economy solutions ((Lit et al., 2024; Hoang and Böckel, 2024; Dalmarco et al.,2026).

Bal Bg

BAL BG is an Albanian-based early-stage circular bioeconomy start-up, established in 2026, currently operating in the validation and pre-feasibility stage. The company is developing a local value chain to recover organic residues from agriculture, livestock farming, agri-food processing and, where appropriate, source-separated municipal organic waste. Its proposed technical approach includes anaerobic digestion to produce biogas or renewable energy and the management of digestate as a potential agricultural product.

The start-up addresses the environmental problem of fragmented organic-residue management, where agricultural and livestock residues are dispersed among different operators and vary seasonally. These residues can be burned, left to decompose, disposed of without recovery, or used in ways that are not systematically recorded, potentially contributing to methane emissions, local pollution and the loss of nutrients that could return to agriculture. The problem was identified through the work on the Bio Agro Booster concept, interactions with farmers and agri-food operators, desk research, and initial consultation with the Municipality of Divjakë.

BAL BGseeks to transform organic residues into inputs for a coordinated local value chain. The proposed model would connect residue generators, municipalities, technology and research partners, and potential users of energy and recovered nutrients. Potential revenue streams include waste-management or coordination services, the sale or use of biogas and renewable energy, digestate-related products, and project-development partnerships. The founder highlights that these benefits depend on scale, feedstock quality, logistics, offtake arrangements, capital costs and regulation.

The intended loop includes converting organic residues into biogas or usable energy, while nutrients retained in digestate can be managed safely and returned to local agriculture where quality requirements and regulatory conditions permit. Expected benefits include reducing uncontrolled methane emissions from decomposing organic matter, limiting open dumping or burning, displacing a portion of fossil-energy use and recovering nutrients. Properly managed digestate may also contribute organic matter and nutrients to agricultural soils. Revenue can be generated from service fees, energy or biogas sales, recovered-nutrient products, project coordination and partnerships, and avoided waste-management or energy costs for participating actors.

The founder identified potential environmental indicators, including the quantity of residues mapped, contracted and treated, methane captured or avoided, renewable energy produced, fossil energy displaced, transport distance, and quantities and quality of digestate returned to productive use. At its current stage of development, BAL BG is creating value primarily through developing and validating its business concept, preliminary technical and territorial analysis, and establishing contacts with public, private and technical actors. Its selection for early-stage financing from StartUp Albania and earlier innovation programs, including EIT Food EWA 2025, is seen as a key contributor to concept development. The company has also engaged with the Municipality of Divjakë, farmers, livestock holdings, agri-food operators, academic contacts and technical specialists. They have contributed to obtaining data and validating the proposed model.

According to the founder, the most valuable support would combine patient early-stage finance with practical implementation capacity. Relevant forms of support include working capital, blended finance, anaerobic-digestion expertise, legal and permitting guidance, reliable municipal and agricultural datasets, GIS and site-screening support, feedstock testing, pilot infrastructure, and introductions to municipalities, suppliers, offtakers, technology partners and investors. This support could facilitate the transition from concept validation towards implementation.

The company's immediate priorities include territorial and market mapping, identifying priority residue streams and operators, collecting primary data, screening potential sites, testing feedstock quality where feasible, and refining the techno-economic model. The founder identifies potential opportunities in livestock manure, concentrated agri-processing residues, local energy users, nutrient recovery, and methane-management services. The company can also explore R&D consortia and technology partnerships. A credible sequence would be to validate a pilot first. The case highlights that transforming organic residues into a viable circular business depends on reliable material-flow data, economically feasible collection and treatment processes, enabling regulation, appropriate financing, and committed partnerships across the value chain.

The company faces several barriers, including limited and fragmented local data, uncertain quantities, seasonality, collection and transport costs, insufficient source separation of municipal organic waste, and the need to build trust and contractual commitments among multiple small operators. The founder also highlights that moving towards circularity faces various challenges, such as finding an equilibrium between maximising environmental recovery and maintaining a viable logistics model. Similarly, mixed municipal organic waste could increase available volume but may introduce contamination and reduce the safety or value of the digestate. The case of BAL BG illustrates that a supportive ecosystem is key to the process of turning the waste-related problem into a business opportunity. The results of BAL BG case are also consistent with the literature

review which highlights the crucial role of partnerships, institutional support, infrastructure, and coordination of efforts among stakeholders can support circular start-ups in the waste space succeed (Hysaj, 2024; Prendi et al., 2024; Lit et al., 2024; Geissdoerfer et al., 2022).

Carbon Made

CarbonMade is an early-stage Serbian-based start-up founded in 2022. The company aims to transform agricultural biomass into biochar, which can be used as input in various industries, such as agriculture and construction. In addition to biochar production, the heat generated during the production process is used to produce clean energy. In this way, the company contributes to waste reduction by converting it into biochar while also producing clean energy, which can help reduce carbon emissions. The company currently operates in Serbia and Croatia.

The company addresses the problem of large quantities of waste generated by agricultural, forestry and industrial processes, a significant part of which remains underutilised. In many cases, large quantities of waste are burned or left to decompose, resulting in the loss of potentially valuable resources and contributing to environmental problems. CarbonMade is tackling this problem by utilising agricultural waste leftovers that would otherwise be burned or left to decompose, and converting them into commercially viable products. The problem was identified through collaboration with industry experts and partners, which helped verify the technical aspects of biochar production and identify ways the technology could be applied.

CarbonMade is also transforming the waste problem into a business opportunity by creating value for multiple actors. The company creates value for local farmers and forestry operations by purchasing waste from them. Society and the environment also benefit from reduced agricultural waste and the potential reduction of carbon emissions. The company itself expects to generate revenue from biochar and clean energy sales. Another potential benefit is reduced external energy dependence, because the clean energy produced is expected to be used for the company's needs.

The founders also highlight that CO_2 capture by plants and trees explains the potential for carbon removal through the pyrolysis process, where carbon is retained in biochar and can be stored permanently. This provides an example of how environmental benefits can be combined with business and financial benefits. The company seeks to reduce the amount of carbon released back into the atmosphere. Furthermore, the heat generated during the process is used in biochar production, reducing the need for fossil-based energy. Considering the current stage of the company, it has not generated revenue yet, but it has secured offtake agreements with various clients for its products.

The company uses its own calculations to estimate the carbon avoidance achieved through its operations. The founders indicate that they will complete a Life Cycle Assessment (LCA) in the near future to determine the exact environmental impact. Regarding the process of balancing environmental with business and financial benefits, the founders highlight the growing focus on climate change and solutions that help address global environmental challenges. However, circular start-ups can face various challenges, particularly during the early stage of the development, and when introducing innovative products in the market.

As the founders highlight, at this stage they have depended on angel investors and are in discussions with institutional investors. Among the key barriers, they emphasise the crucial role of financing, which remains a key challenge for start-ups. Access to financing would therefore help accelerate the company's development and growth. The company plans to expand throughout the Balkan region, with opportunities to enter neighbouring countries. The founders also highlight that successfully transforming the waste problem into a business opportunity requires key strategic partnerships, a qualified team, business agreements, and a clear execution roadmap.

Overall, the CarbonMade case illustrates how agricultural biomass can be transformed into biochar and energy, creating both environmental and financial benefits. The case also highlights the crucial role of financing, strategic partnerships, and market access in supporting circular start-ups' development and growth, which supports the findings of existing literature in the field (Lluri & Lluri, 2025; Lit et al., 2024; Hysaj, 2024).This can be key in bringing solutions to the market.

These three case studies helped identify some key patterns, even though they differ in their development stage and technologies. All of them identify the high potential of waste to be transformed into valuable products, even though the path each has followed differs. Each case illustrates how waste can be transformed through a circular solution from an environmental problem to a business opportunity. Every start-up holds the potential to create value in various directions, including business benefits from selling high-value ingredients (NADA), energy and recovered nutrients (NAL-BG), or biochar and clean energy (CarbonMade). At the same time, these case studies show that transforming waste into value does not only depend on technology, but also on other factors, such as access to finance, market access, reliable feedstock, technical expertise and partnerships across the value chain. These findings reinforce the findings of existing literature about the important role of collaboration, ecosystems, and resources for circular start-ups.

Besides these similarities, the three case studies also reveal differences in how circular start-ups in the waste space are developed and how they move towards commercialisation. NADA, for example, is more technology and innovation-driven, with a strong focus on research and product development, while BAL BG is more focused on coordination across the value chain and overcoming feedstock and infrastructure-related challenges. CarbonMade, on the other hand, represents a more advanced model, where biochar is combined with clean energy and the company has already secured offtake agreements. These results suggest that the differences may be a reflection of the context of the country where the start-ups operate, which can differ across different regions of Europe. However, a key insight from this analysis is that these start-ups need to balance environmental impact with economic viability, so they can create a commercially sustainable solution.

5. Conclusions

This research examined how European circular start-ups take advantage of waste-related challenges and turn them into business opportunities. It focused on better understanding the path that the founders of these start-ups follow in developing innovative solutions to bring innovative solutions in this are, what are the key challenges that face and what are the key factors that can support their development and growth. The methodology followed was based on case studies selected from different regions across Europe, which helped include differences in the context of the country where they operate.

The results showed that selected European start-ups transforming waste into value face various challenges, such as technology scale-up, ensuring sufficient feedstock, customer validation, high upfront costs, market adoption, collection and transport costs, the need to build trust and contractual commitments among multiple small operators, and access to financing. While key supporting factors identified include financing, strategic partnerships, market access, institutional support, infrastructure, access to funding, infrastructure, feedstock, industrial partner, and coordination of efforts among stakeholders. These factors can support circular start-ups in the waste space to succeed in transforming waste into value and are consistent with existing literature in the field (Lluri&Lluri, 2025; Lit et al., 2024; Hysaj, 2024; Prendi et al., 2024; Geissdoerfer et al., 2022; Hoang and Böckel, 2024; Dalmarco et al., 2026). These findings also highlight the key role of the entrepreneurial ecosystem in supporting the development and growth of circular start-ups in this space, which was one of the main objectives.

Through these findings, this research suggests that policymakers should increase their support for circular economy start-ups, through dedicated programmes that can support the development and growth of circular start-ups addressing the waste challenge. This could include increasing financial support for these start-ups and creating a more supportive entrepreneurial ecosystem in general. On the other hand, these findings can provide useful insights for those who aim to develop or run circular start-ups in this space. Despite contributing to enriching the literature in an emerging field, the research faces limitations. A key limitation relates to the research methodology, which is based on case studies. Part of the research was based on only three start-ups turning waste to value across different regions of Europe. As a result, the results interpretation should be made with caution and not generalised to all European circular start-ups operating in this space. Future research can address this limitation by analysing larger samples and potentially moving from qualitative to quantitative analysis to better understand the key barriers and supporting factors.

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FULL PAPER · S1.5 · ONLINE SESSION 1

Resource Mobilisation for Green Ventures in South Africa

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ABSTRACT

Green ventures businesses built around renewable energy, resource efficiency, circular economy models, or environmental services face all the resource constraints of conventional entrepreneurship in South Africa's emerging market, plus additional demands for specialised green technology, longer payback horizons, and nascent green finance markets. This paper asks a targeted question: can South African businesses mobilise the resources needed to create and grow green ventures? We address it by synthesizing findings from four empirical studies of resource mobilisation among South African entrepreneurs covering academic spin-offs, social enterprises, women's digital entrepreneurship and entrepreneurial finance, reading their results through the lens of the emerging green entrepreneurship and green finance literature. Across the four studies we identify recurrent resource mobilisation mechanisms: internal revenue generation, strategic alliances and partnerships, social capital (bridging and bonding networks), investment readiness, and knowledge mobilisation. Drawing on the Resource-Based View (RBV), social capital theory, and entrepreneurial finance literature, we propose an integrative conceptual model in which entrepreneurs combine internal and external resource mobilisation capabilities to fuel venture growth, and we extend this model to the green venture context. Our synthesis suggests a qualified yes: South African entrepreneurs already demonstrate the internal-revenue, network, investment-readiness, and knowledge-mobilisation capabilities that green ventures require, but green ventures also face capital-intensity and technical-know-how demands that none of the four source studies directly measured. We frame this as a conceptual and evidence-based extension rather than a direct empirical test, and we offer new research propositions to guide the future studies needed to confirm it directly. The paper contributes to theory by showing how multi-level resource mobilisation processes (individual, organizational, and network-level) can be read onto the specific resource demands of green venture creation in resource-constrained environments, and discusses implications for entrepreneurs, support organisations, and policymakers building green entrepreneurial ecosystems in African emerging markets.

Keywords: Resource Mobilisation; Green Entrepreneurship; Social Capital

Introduction

Entrepreneurs in emerging markets must rely on ingenuity and resourcefulness to overcome environmental challenges, such as limited access to formal financing, infrastructure gaps, and institutional voids (Khanna & Palepu, 2010; Mair & Martí, 2009). These conditions, often present in African economies, require entrepreneurs to excel in resource mobilisation; assembling, generating, and combining resources, both tangible and intangible, to support venture creation and growth. Traditional entrepreneurship theories from advanced economies often assume the ready availability of formal market mechanisms and capital markets, an assumption that does not hold in many African contexts (Bruton, Ahlstrom, & Obloj, 2008). Therefore, understanding how African entrepreneurs mobilise resources from various sources is key to explaining how ventures survive and scale despite resource constraints.

A growing body of research in Africa has examined resource-related factors in entrepreneurship, but these studies have tended to focus on specific domains. For example, social enterprise research has explored how revenue-generating strategies and alliances affect scalability (Urban & Bukula, 2024); research on women entrepreneurs has looked at how using digital platforms builds social capital (Urban & Moetse, 2024);

entrepreneurial finance studies have analysed venture capital and angel investor criteria (Urban & Moreno, 2022); and academic entrepreneurship research has identified organizational factors enabling university spin-offs (Urban & Seely, 2023). Each of these offers insights into different facets of resource mobilisation. However, an integrative view is needed to understand how entrepreneurs coordinate multiple resource streams and capabilities in tandem.

This paper provides such an integration by synthesizing evidence from the four studies to develop a unified framework of resource mobilisation for entrepreneurial growth in African emerging markets. We define resource mobilisation broadly to include acquiring financial resources (internal earnings and external capital), leveraging social networks (social capital, alliances), and harnessing knowledge and partnerships (e.g., academic research, industry collaborations) all of which have been identified as critical for venture success in the emerging markets context.

A pressing application of this general question concerns green ventures. South Africa's green transition spanning renewable energy, water and resource efficiency, circular-economy business models, and environmental services depend on entrepreneurs being able to translate green business ideas into funded, growing operations. Green finance in Africa is expanding but remains fragmented and difficult for smaller ventures to access, with green entrepreneurs frequently citing high upfront capital costs, limited access to patient capital, and a shortage of technical and financial literacy specific to green business models as key barriers (Lwesya, 2025). At the same time, green entrepreneurship research increasingly points to the same generic capabilities identified in mainstream entrepreneurship research resourcefulness, network-building, and investment readiness as what separates green ventures that scale from those that stall, alongside green-specific drivers such as environmental values, regulation, and access to green-labelled markets (Singh, Kumar, & Dana, 2025). This raises a direct question for the South African context: do the resource mobilisation capabilities that South African entrepreneurs already demonstrate in mainstream ventures extend to the specific resource demands of green venture creation?

This paper addresses that question with appropriate caution. None of the four studies synthesised here sampled green ventures directly; instead, they examine academic spin-offs, social enterprises, women's digital entrepreneurship and venture finance, in general South African settings. Importantly, all four studies were authored by the same author of the present paper and whom has access to the original data underpinning those studies. The synthesis is therefore grounded in the original empirical work of the paper's own author, rather than in a detached secondary reading of unrelated studies. We consequently treat the question of green venture resource mobilisation as a conceptual and evidence-based extension of the author's established findings, read through the emerging literature on green entrepreneurship and green finance in Africa, rather than as a direct empirical test. Where the extension is well supported by the underlying evidence, we say so plainly; where it remains speculative, we flag it as such and propose it as a target for future research using dedicated green-venture samples.

The research question guiding this work is: Can South African businesses mobilise the resources needed to create and grow green ventures, and if so, through which mechanisms? We answer this by first establishing, from four empirical studies, how various resource mobilisation mechanisms collectively enable South African entrepreneurs to achieve venture growth and scalability in general, and then assessing how well those mechanisms transfer to the specific resource demands of green ventures.

We proceed by reviewing relevant literature on resources and entrepreneurship in emerging markets, including the specific resource demands of green ventures, and outlining the key resource mobilisation mechanisms identified in prior research. We then describe our integrative empirical synthesis methodology. Next, we present our findings, highlighting common resource mobilisation themes, their link to entrepreneurial growth,

and what they imply for green venture creation specifically. We propose a conceptual framework and research propositions illustrating how entrepreneurs combine these resources to overcome constraints, including constraints specific to green ventures. Finally, we discuss implications for theory and practice, and outline directions for future research.

Conceptual Framework

Resources and Venture Growth

According to the Resource-Based View (RBV), access to valuable, rare, inimitable, and organisationally embedded resources is a fundamental determinant of a firm's competitive advantage and growth (Barney, 1991). Newly founded ventures, however, often lack resources and must acquire or generate them. In contexts where formal institutional support is weak, the process of resource mobilisation becomes critical (Bruton et al., 2008). We define resource mobilisation in entrepreneurship as the activities by which entrepreneurs acquire, create, and leverage the resources and capabilities financial, human, social, technological, knowledge-based needed for venture development. This broad view aligns with how entrepreneurs in emerging economies must be adept at combining a variety of resource strategies, from bootstrapping and alliances to creative re-purposing of existing assets, a phenomenon related to entrepreneurial bricolage (Baker & Nelson, 2005) and effectuation (Sarasvathy, 2001) when facing constraints.

In the African context, resource mobilisation often involves tapping into informal channels and networks. Emerging economy entrepreneurs may rely on both formal means (like raising capital from investors or government grants) and informal means (like social networks, family support, or community resources) to start and grow ventures (Mair & Martí, 2009). For example, in South Africa and other sub-Saharan countries, research shows entrepreneurs compensate for gaps in formal institutions by leveraging local communities, diaspora, and immigrant networks for funding and market access (Rivera-Santos et al., 2015; Urban & Moti, 2025).

Knowledge and Institutional Resource Mobilisation.

A dimension of resource mobilisation relevant in emerging markets is the conversion of knowledge and institutional resources into entrepreneurial ventures. This is evident in the context of academic spin-offs, where resources like research findings, university support, and intellectual property are mobilised to create new companies. A recent study on South African academic spin-offs (Urban & Seely, 2023) points to several critical organizational factors: research mobilisation (the process of translating research into opportunities), extensive external collaboration networks, an unconventional or proactive organizational orientation, and supportive university policies all had significant positive effects on the creation of spin-off ventures. This highlights that in resource-scarce environments, entrepreneurs benefit from mobilising not just financial or social capital, but also institutional support structures and knowledge-based assets, and that universities can act as important intermediaries in this process, much as intermediary organizations do in open innovation settings more broadly (Sieg, Wallin, & von Krogh, 2010).

Social Capital and Networks

Social capital - the goodwill, trust, and resources accessible through one's social networks (Bourdieu, 1986; Coleman, 1988) is often a critical asset for entrepreneurs. Social capital comes in two forms: bonding (strong ties within a close-knit group, providing support and trust) and bridging (looser ties that connect across social circles, providing access to new information or resources) (Putnam, 2000). In resource-poor environments, entrepreneurs' networks can substitute for formal support structures by offering mentorship, market linkages, and sometimes financial help (Mair & Martí, 2009). However, unless effectively mobilised, social networks alone may not yield material resources. A study of South African women entrepreneurs using digital crowdfunding

found that their involvement with online platforms significantly increased both bonding and bridging social capital, demonstrating that digital tools can expand networks beyond traditional boundaries, but neither type of social capital directly led to greater financial capital in that setting (Urban & Moetse, 2024).

Strategic Alliances and Partnerships

Beyond individual networks, entrepreneurs in emerging markets frequently form strategic alliances and partnerships formal collaborative arrangements with other organizations or companies to access resources and capabilities they lack. Alliances can provide access to distribution channels, technology, or expertise, effectively broadening a venture's resource base (Lavie, 2006). In a study on social enterprises in South Africa, strategic alliance-building (collaborating with partners like NGOs, government, or business) was hypothesized as a driver of scaling social impact (Urban & Bukula, 2024). While that particular study found no significant direct effect of alliance-building on scaling in the final regression model, alliances are widely documented as growth enablers in other contexts, especially when carefully managed to avoid mission drift (Cornforth, 2014). Partnerships remain an important piece of the resource puzzle but may operate through indirect pathways for instance, alliances could be instrumental in increasing an organization's credibility, learning, or access to beneficiaries, which in turn supports expansion. The study also found that earnings generation is a significant and positive predictor of social enterprise scaling. This finding is important considering that many social enterprises in South Africa are challenged by financial resource constraints. This study, conducted in an African emerging market context, allows social entrepreneurs to more deeply understand the relevance of earnings generation and strategic alliance-building in their scaling efforts.

Financial Resource Generation and Investment Readiness

Access to financial capital is perhaps the most obvious resource challenge. In emerging markets, entrepreneurs often lack robust banking support or venture financing, making internal revenue generation (bootstrapping or early sales) a vital survival strategy (Ebben & Johnson, 2006). The social enterprise scaling study (Urban & Bukula, 2024) underscores this: it found that earnings generation capability was a significant positive predictor of a social enterprise's scalability, implying that ventures which could generate their own income had a better chance of expanding their impact. At the same time, external financing remains important for acceleration and scaling beyond subsistence. Informal investors (like family and friends), angel investors, and venture capitalists can provide the growth capital needed, but they require entrepreneurs to exhibit certain qualities, often a combination of a competent team, a solid business model, viability, and potential for returns (Maxwell, Jeffrey, & Lévesque, 2011). An empirical assessment of South African VC and angel investment criteria (Urban & Moreno, 2022) found that VCs and angels prioritized many of the same criteria, particularly the strength of the management team and business preparedness; in fact, the only major divergence was that early-stage entrepreneurs rated team preparedness and attributes even more highly than investors did, highlighting the centrality of human capital and readiness. Being investment-ready that is, having transparent plans, validated markets, and credible management is thus a key capability for raising external funds, a pattern echoed in recent evidence on how resource mobilisation approaches shape venture performance under severe resource constraints (Adegbile, Liedong, & Wagner, 2024).

Entrepreneurial Ecosystems in Emerging Markets

The literature on entrepreneurial ecosystems underscores that thriving venture communities are characterized by robust availability of diverse resources financial capital, human capital, knowledge, support services, networks, and enabling institutions (Stam & van de Ven, 2021; Isenberg, 2010). In many African ecosystems, formal components (like venture capital funds or incubators) are few, making informal and community-based resources critical (Rivera-Santos, Holt, Littlewood, & Kolk, 2015). The capability to self-organize resource

combinations, an aspect of entrepreneurial agency in ecosystems, becomes a defining trait of successful entrepreneurs (Stam & van de Ven, 2021).

Resource Mobilisation for Green Ventures

A distinct but rapidly growing literature examines the resource demands specific to green entrepreneurship. Green finance in Africa is expanding spanning green bonds, climate funds, and impact investment but access remains highly uneven, with smaller and younger ventures reporting far greater difficulty reaching it than established firms, and with regulatory uncertainty, thin local capital markets, and a shortage of green-specialised financial expertise repeatedly cited as barriers (Lwesya, 2025). Where green ventures involve supply-chain-facing operations, South African SME research shows that adopting green supply chain management practices can improve business sustainability, but that SMEs need targeted knowledge mobilisation and, often, external partnership support to adopt these practices, since the requisite technical know-how is not always available in-house (Tsikada, Chasaya, & Ayandibu, 2025). More broadly, the green entrepreneurship landscape is shaped by the same generic resource mobilisation levers documented in mainstream entrepreneurship internal funding, networks, and investor readiness but with the addition of green-specific factors such as environmental values, supportive regulation, and demonstrable access to green-labelled markets or green finance instruments (Singh et al., 2025).

Read together, this literature implies that green ventures do not require an entirely different resource mobilisation playbook so much as a more demanding version of the same one: the same internal revenue generation, social capital, investment readiness, and knowledge mobilisation mechanisms identified in mainstream African entrepreneurship research remain necessary, but green ventures layer on additional requirements technical and environmental knowledge, access to green-specific finance instruments, and credibility with green-focused investors and partners that are not guaranteed to be present just because an entrepreneur has demonstrated general resource mobilisation capability. This is the premise on which the remainder of this paper builds: rather than assuming that South Africa's demonstrated general resource mobilisation capability translates automatically into green venture capability, we treat it as a testable diagnostic and return to the question explicitly in the Findings and Discussion.

Summary of Key Resource Mobilisation Mechanisms. Across these literatures, several recurring themes emerge:

- **Knowledge and institutional leveraging:** converting knowledge (academic research or innovative ideas) into ventures; drawing on institutional support from universities or government.
- **Internal resource generation (bootstrapping):** generating revenues, reinvesting profits, lean operations.
- **Social networks and alliances:** building strong social capital (both bonding ties for support and bridging ties for new opportunities) and formal partnerships to leverage others' resources.
- **Investment readiness and external finance:** cultivating venture quality (team, plans, credibility) to access external capital sources.

These mechanisms often intersect and collectively form an entrepreneur's resource mobilisation strategy. In the following sections, we examine how these elements were evidenced in our four focal studies and integrate them into a holistic framework.

Methodology

This paper employs an integrative empirical synthesis approach to develop a new framework grounded in existing research (Hoon, 2013; Tranfield, Denyer, & Smart, 2003). The evidence base consists of four published empirical studies (2020-2024) by Urban and co-authors focusing on entrepreneurship in South Africa that offer

diverse perspectives on resource mobilisation and growth. Boris Urban is also an author of the present paper; therefore, the four studies are not treated as distant secondary sources but as parts of his own body of scholarly work, to which he has access through the original data, findings, and study-level interpretation. By combining these four studies, the present synthesis identifies cross-cutting relationships among earnings generation, strategic alliances, social capital, investment readiness, knowledge mobilisation, and entrepreneurial growth. The four studies are:

1. Academic Spin-Offs (Urban & Seely, 2023): Identifies organizational factors (research mobilisation, collaboration, etc.) enabling academic spin-off formation.
2. Social Enterprise Scaling (Urban & Bukula, 2024): Investigates earnings generation and strategic alliances as predictors of social enterprise scalability.
3. Women Entrepreneurs and Social Capital (Urban & Moetse, 2024): Examines bridging and bonding social capital via digital crowdfunding and their relationship to financial capital access.
4. Entrepreneurial Finance (Urban & Moreno, 2022): Assesses investment criteria of venture capitalists and business angels, highlighting what makes ventures investment ready.

Each study was conducted in South Africa using quantitative methods (surveys of relevant entrepreneurial populations, statistical hypothesis testing via regression or structural equation modeling). Table 1 summarizes key features of these studies.

Table 1

Evidence Base (Four Studies) for Resource Mobilisation and Growth

Study & Context	Sample & Methodology	Key Findings (Resource Mobilisation-Related)
Urban & Bukula (2024): Social enterprise scaling	n = 158 social enterprises in South Africa; survey, regression	Earnings generation capability is a significant positive predictor of scalability, while alliance-building showed no significant direct effect on scaling. Highlights the importance of internal revenue for scaling given funding constraints.
Urban & Moetse (2024): Women entrepreneurs' digital social capital	~100 women entrepreneurs in South Africa using crowdfunding; survey, regression	Digital platform use (crowdfunding) significantly increases bonding and bridging social capital, but neither type was significantly linked to financial capital obtained. Suggests social capital alone is not enough to secure funding without additional factors.
Urban & Moreno (2022): VC and angel investment criteria	Comparison of VCs, angel investors, and entrepreneurs in South Africa; survey (rating criteria), rank analysis	VCs and angels share similar top criteria for investing; strong management team and venture preparedness ranked highest by both. Team preparedness was emphasized even more by entrepreneurs. Implies the importance of investment readiness in resource acquisition.
Urban & Seely (2023): Academic spin-offs	~120 academics in South African universities; survey, SEM	Research mobilisation, external collaboration networks, unconventionality (risk-taking), and supportive university policies each positively and significantly influenced the creation of academic spin-off ventures. Indicates leveraging knowledge and institutional support as resource mobilisation levers.

We coded each study for its theoretical framing, independent and dependent variables, context, and results, focusing on what resources or capabilities were examined and how they affected entrepreneurial outcomes. We then conducted a cross-study analysis to detect commonalities and differences.

Analytical Approach

This synthesis is qualitative in nature, using thematic cross-case analysis rather than re-pooling data quantitatively. The trustworthiness of this approach comes from relying on peer-reviewed empirical results and

connecting them with established theory. We identified resource mobilisation themes present in at least one study and looked for their presence or absence in others, as well as how each mechanism influenced outcomes. For instance, we noted that earnings generation, alliance-building, social capital, and collaboration all relate to the broader concept of leveraging networks and internal resources. By comparing the studies, we derived a unified set of resource mobilisation domains that cut across contexts.

Scope and Limitations

Our integrative method means that we do not introduce new data beyond the four studies; instead, we reinterpret existing evidence. One limitation is that each underlying study has its own context and measures, and we carefully avoid over-generalization. However, all studies share an African emerging market setting and a focus on how entrepreneurs overcome resource constraints, allowing meaningful synthesis. Our approach addresses a key gap by compiling findings that were previously siloed and using them to inform a new conceptual model. Nevertheless, this approach is not a substitute for new empirical work follow-up research should test the proposed framework directly.

Findings

The cross-study synthesis reveals several key resource mobilisation mechanisms employed by entrepreneurs in African emerging markets to drive venture growth and scalability. These mechanisms are interrelated, and successful entrepreneurs often engage in multiple resource mobilisation strategies simultaneously.

4.1 Knowledge Mobilisation and Institutional Support

The academic spin-off study (Urban & Seely, 2023) introduces a distinct but related dimension of resource mobilisation: converting knowledge and institutional resources into new ventures. Key factors that significantly influenced spin-off creation were research mobilisation (the infrastructure to identify and exploit academic research commercially) and external collaboration networks (connecting researchers with industry or government partners). Additionally, an organizational climate of unconventionality (willingness to break traditional norms and take risks) and supportive university policies also facilitated spin-offs. These findings indicate that resource mobilisation for entrepreneurial growth can involve intangible assets like knowledge and formal institutional mechanisms, not just money or personal networks. In emerging markets, universities and research institutions can play a critical role as anchor points for entrepreneurship by channelling research outputs into the economy, but only if academics and administrators possess the capability to mobilise those knowledge resources and navigate institutional processes (Kruss & Visser, 2017).

4.2 Internal Resource Generation (Bootstrapping and Earnings)

A striking finding from the social enterprise study (Urban & Bukula, 2024) is that earnings generation (EG), that is, the ability of a social enterprise to generate its own income, was a significant and positive predictor of scaling up social impact. This is especially important in South Africa, where many social enterprises operate under persistent financial resource constraints and cannot rely solely on grants, donors, or formal investment. The study therefore shows that internal revenue generation is not merely a survival tactic but a scalable resource mobilisation capability: ventures that can generate and reinvest their own earnings are better positioned to expand their reach and sustain impact. Conducted in an African emerging market context, the study also enables social entrepreneurs to understand more deeply the relevance of earnings generation and strategic alliance-building in their scaling efforts, even where alliance-building may operate indirectly rather than as a direct predictor in the final model. In this sense, bootstrapping, early monetisation, and disciplined income generation become core capabilities for growth in resource-constrained environments (Desa & Koch, 2014; Weerawardena & Mort, 2006).

4.3 Social Capital and Strategic Alliances

Social capital emerged across multiple studies as an important but complex resource. In the women entrepreneurs study (Urban & Moetse, 2024), digital engagement via crowdfunding-built bridging and bonding social capital expanding women's networks both in diversity and in depth. Bridging connections (to new, heterogeneous contacts) broaden the pool of potential partners, customers or supporters; bonding ties (to close community and family) offer trust-based support. However, these network ties by themselves did not statistically increase the financial capital raised by women entrepreneurs. This result emphasizes that social networks must be actively translated into tangible resources trust and connections must be leveraged to gather funding or knowledge. It may be that additional factors, such as business viability or investor trust, moderate the conversion of social capital into finance.

Strategic alliances are a formalized extension of social capital into contractual partnerships. In social enterprises, alliance-building was considered essential theoretically to share knowledge and resources (Cannatelli, 2017), but the Urban & Bukula (2024) study found alliance-building had no direct effect on scaling once earnings were accounted for. One interpretation is that alliances contribute indirectly: alliances may help create the conditions for revenue generation or operational efficiency, but only revenue had a direct measurable impact on scaling. Still, alliances are widely regarded as crucial for accessing external capabilities and for reaching new markets (Lavie, 2006). In sum, social capital and partnerships provide a necessary network infrastructure for resource mobilisation, even if their payoff may need complementary steps, such as converting relationships into funding or knowledge.

4.4 Investment Readiness and External Funding

Access to external finance venture capital or angel investment is often limited in Africa due to underdeveloped capital markets (Bruton et al., 2008). When available, it requires entrepreneurs to meet high standards. The venture finance study (Urban & Moreno, 2022) sheds light on what those standards are: investors value the human and strategic capital of ventures, especially the quality and preparedness of the entrepreneurial team, above all else. Essentially, both venture capitalists (VCs) and business angels are more likely to invest in entrepreneurs who demonstrate strong leadership and business planning (Maxwell et al., 2011). These attributes, sometimes called investment readiness, can be construed as a form of capability itself: the ability to present the venture as a credible vehicle for growth. Therefore, resource mobilisation via external funding is not only about having connections to investors (social capital) but also about the venture's internal capacity to satisfy investor criteria, that is, having the right team, prototype, and market validation. In emerging markets, where formal investor trust might be lower, signalling competence and reliability is particularly pivotal (Adegbile et al., 2024).

4.5 Integration: Resource Mobilisation and Growth Outcomes

The four studies are best understood as complementary parts of a single resource mobilisation process rather than as separate findings. Taken together, they suggest that venture creation and growth in South Africa depend on the entrepreneur's ability to move from knowledge mobilisation to network mobilisation, to financial mobilisation, and finally to scaling through internal revenue and partnerships. The academic spin-off study shows how university-based knowledge, research mobilisation, supportive institutional policies, and external collaboration can convert an idea into an entrepreneurial opportunity. The women's digital entrepreneurship study then shows how entrepreneurs can use digital platforms and social capital to expand bridging and bonding ties, thereby increasing visibility, legitimacy, and access to wider community and stakeholder networks. The venture finance study adds that these networks must be matched by investment readiness if entrepreneurs are to attract business angels or venture capital, because investors place strong emphasis on team quality, preparedness, and venture credibility. Finally, the social enterprise study shows that

once the venture is operating, earnings generation becomes a significant and positive predictor of scaling, while strategic alliances can support access to complementary resources, markets, knowledge, and legitimacy.

Applied to the green venture context, this integration can be illustrated through a possible pathway rather than treated as a direct empirical finding. For example, a green entrepreneurship idea may originate from university-level research developed by a female academic entrepreneur. At the first stage, the entrepreneur mobilises knowledge and institutional resources by drawing on research expertise, university support, intellectual property processes, and collaboration with external actors. At the second stage, she uses social capital and digital capital to connect the idea to community networks, potential users, partners, and supporters, thereby building legitimacy and practical insight around the green opportunity. At the third stage, these signals of credibility and preparedness may help the venture approach angel investors or other early-stage financiers for funding. At the fourth stage, once the venture begins operating, earnings generation provides an internal financial base for survival and growth, while strategic alliances with universities, communities, government agencies, suppliers, customers, or sustainability partners help the venture access complementary resources and sustain its environmental and commercial impact. The integration therefore does not claim that all green ventures will follow this exact sequence; rather, it shows how the four studies can be combined into a logical resource mobilisation pathway in which knowledge, networks, finance, earnings, and alliances interact to support green venture creation and scaling in South Africa.

4.6 Conceptual Framework Development

From the synthesis of these studies and supporting theory, we propose a conceptual framework (Figure 1) that illustrates how resource mobilisation capabilities feed into venture growth and success in African emerging markets. The framework positions resource mobilisation as the central process bridging entrepreneurial inputs and outcomes.

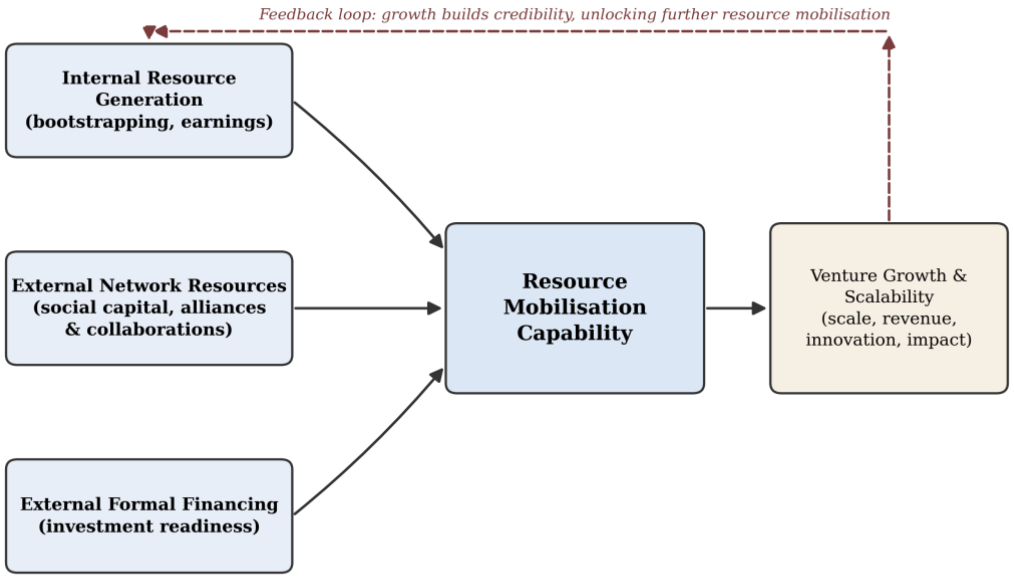


Figure 1. Conceptual framework of resource mobilisation and entrepreneurial growth. Internal generation, network resources, and formal financing jointly build resource mobilisation capability, which drives venture growth and scalability; dotted lines show the reinforcing feedback loop from growth back to further resource mobilisation.

In this model, entrepreneurs leverage resources from three broad categories: internal resource generation, the entrepreneur's capacity for bootstrapping and generating early revenues to self-fund operations; external network resource mobilisation, the ability to build and leverage social capital, alliances, and collaborations, converting networks into tangible resources such as information, funding, and partnerships; and external formal financing, the capability to attract external finance by meeting the criteria of formal investors, including robust business plans, skilled teams, and demonstrated growth potential.

These resource mobilisation capabilities are self-reinforcing and often sequential: internal resource generation can create initial traction and credibility, which can make the venture more attractive to partners or investors; social capital and alliances extend the venture's reach and can facilitate introductions to potential investors or customers; and investment readiness ensures that when opportunities for funding arise, via networks or formal pitching, the entrepreneur can secure capital for expansion.

All these, in combination, funnel into venture growth outcomes such as increased scale (serving more beneficiaries or customers), revenue growth, profit, innovation outputs, or, in the case of social ventures, increased social impact. The dashed lines in Figure 1 indicate feedback loops: achieving some growth can improve credibility and lead to more opportunities for alliances or funding, creating a virtuous cycle of resource mobilisation.

4.7 Can South African Businesses Mobilise Resources to Create Green Ventures?

Reading the above findings against the green entrepreneurship and green finance literature (Lwesya, 2025; Tsikada et al., 2025; Singh et al., 2025) lets us answer the research question directly, with appropriate caution. On the positive side, three findings transfer reasonably well to the green venture context. First, the strong role of earnings generation in social enterprise scaling indicates that South African entrepreneurs already possess the internal-revenue discipline bootstrapping, early monetisation, lean operations that green ventures need to survive the long payback horizons typical of renewable energy, resource-efficiency, and circular-economy business models before green-specific finance becomes available. Second, the finding that social capital must be actively converted into tangible resources is directly relevant to green ventures, whose bridging ties into industry associations, government green-transition programmes, and technical partners are plausibly what determine whether environmental values translate into funded projects, consistent with the emphasis on network-based knowledge mobilisation documented among South African SMEs adopting green supply chain practices (Tsikada et al., 2025). Third, the centrality of investment readiness team quality, business preparedness, credible plans transfers directly: green finance providers, like the VCs and angels studied here, are likely to weight preparedness and team credibility heavily, and a green venture that cannot demonstrate these fundamentals is unlikely to overcome the additional scepticism that new or unfamiliar green technologies attract from investors.

On the cautionary side, none of this evidence was generated on green ventures themselves: the four source studies sampled academic spin-offs, social enterprises, women's digital enterprises and general venture-finance participants, none of them selected for a green or environmental focus. We cannot rule out that green ventures face additional resource barriers not captured in any of the four studies, such as the shortage of green-specialised financial expertise and thin access to dedicated green finance instruments documented at the continental level (Lwesya, 2025), or the technical knowledge gap that South African SMEs report when attempting to adopt green supply chain practices without external support (Tsikada et al., 2025). Knowledge mobilisation is instructive here: the academic spin-off evidence shows South African universities can successfully channel specialised knowledge into new ventures when research mobilisation infrastructure and supportive policies are in place, which is encouraging for green ventures that depend on translating technical or environmental research into commercial products, but this pathway has again not been tested on green spin-offs specifically. Our answer to the research question is therefore a qualified yes: South African entrepreneurs demonstrate the general resource mobilisation capabilities internal revenue generation, network conversion, investment readiness, and knowledge mobilisation that green venture creation requires, but whether these capabilities are sufficient on their own, or need to be supplemented by green-specific finance access and technical knowledge partnerships, has not yet been demonstrated directly and remains an open empirical question.

Discussion and Conclusion

Theoretical Implications

This integrative synthesis contributes to entrepreneurship scholarship by highlighting the multi-dimensional nature of resource mobilisation in emerging markets. Whereas much of the classic entrepreneurship literature in developed contexts might isolate factors like financial capital or social networks, our framework emphasizes that in resource-constrained settings, success is typically the result of entrepreneurs orchestrating diverse resource pathways. By connecting findings across micro-level (individual capability), meso-level (enterprise strategy), and macro-level (institutional) analyses, this framework aligns with calls for more contextually grounded theory of entrepreneurship in developing economies (George, Corbishley, Khayesi, Haas, & Tihanyi, 2016; Bruton, Ahlstrom, & Li, 2010).

Our framework reinforces the relevance of the Resource-Based View (RBV) (Barney, 1991) in entrepreneurship by illustrating that both tangible and intangible resources (e.g., finances, social networks, knowledge) and the capabilities to utilise them effectively are crucial for competitive advantage and growth in startups. It also interacts with the dynamic capabilities perspective (Teece, 2007): entrepreneurs who can continuously reconfigure and supplement their resource base, for example pivoting from bootstrapping to investor financing at the right time, demonstrate dynamic capabilities that are likely to lead to better performance (Zahra, Sapienza, & Davidsson, 2006).

From the perspective of social capital theory (Putnam, 2000), our findings nuance the role of networks: bridging and bonding ties expand the range of resources, yet must be coupled with other actions, such as credible signals to investors or effective revenue strategies, to yield direct outcomes. This suggests that social capital is necessary but not sufficient for resource mobilisation; it must be activated through strategic behaviour (Anderson, Dodd, & Jack, 2010).

Additionally, our synthesis implicitly resonates with effectuation and entrepreneurial bricolage theories: entrepreneurs in these contexts often start with the means at hand (effectuation) and creatively recombine resources in novel ways (bricolage) to address immediate challenges (Baker & Nelson, 2005; Sarasvathy, 2001). For instance, the emphasis on earnings generation in social enterprises can be seen as an effectual tactic of ensuring viability with existing means, and reliance on non-financial assets like networks or knowledge can be viewed as a form of bricolage behaviour when formal resources are lacking.

By bridging various literature streams social entrepreneurship (Austin, Stevenson, & Wei-Skillern, 2006), gender and digital entrepreneurship, venture financing, and academic entrepreneurship our framework suggests that these seemingly separate domains can all be understood through a common lens of resource mobilisation. It underscores how context adversity intensifies the need for certain capabilities: for instance, internal revenue generation might not appear as critical in a Silicon Valley startup flush with venture capital, but in an African social enterprise, it emerges as a top predictor of scaling success. Similarly, meeting investor criteria might be universally important, but in a context where investors are scarce and risk-averse, entrepreneurs must work even harder to be investment ready (Bruton, Ketchen, & Ireland, 2015).

Finally, our synthesis speaks to the emerging green entrepreneurship literature by suggesting that resource mobilisation capability, rather than being domain-specific, is a portable capacity that general entrepreneurship research can usefully inform. The same internal-revenue, network-conversion, investment-readiness, and knowledge-mobilisation mechanisms identified across our four studies map onto the resource demands documented for green ventures in Africa (Lwesya, 2025; Tsikada et al., 2025; Singh et al., 2025), suggesting that theory built from mainstream African entrepreneurship research need not be reinvented from scratch for the

green venture context, but rather extended and stress-tested against green-specific constraints such as technical knowledge gaps and green finance access.

Practical Implications for Entrepreneurs and Support Organisations

Our findings have direct implications for entrepreneurs striving to grow businesses in Africa, including green ventures, and for organizations that support them:

- **Entrepreneurs should cultivate a mix of resource mobilisation skills:** It is not enough to have a great idea; entrepreneurs must also be adept at building networks, securing initial revenues, wooing investors, and leveraging knowledge and partnerships. For example, a South African entrepreneur might need to start by selling services to generate revenue, join local and online communities to build social capital, engage mentors or partners to gain know-how and credibility, and prepare a compelling business case to attract investors. Entrepreneurs should self-assess their strengths and gaps across these domains and seek training or co-founders to cover areas where they are less proficient.
- **Role of digital platforms and incubators:** The finding that digital crowdfunding increased women's bridging and bonding social capital points to the potential of online platforms, incubators, and co-working spaces as network facilitators. Support organisations can create environments where entrepreneurs meet potential co-founders, advisers, and investors, thus enhancing social capital. For female entrepreneurs, in particular, digital networks can help overcome traditional barriers to networking.
- **Focusing on early revenue:** Consistent with the idea that selling is the ultimate fundraising, entrepreneurs in emerging markets should emphasize business models that allow early revenue streams and customer validation. This not only provides cash flow but also demonstrates traction to potential investors or grant-making bodies. Basic financial management training, ensuring entrepreneurs can manage and leverage that revenue effectively, would also be invaluable.
- **Investment readiness programs, including for green finance:** Given the importance of team and preparedness to investors, acceleration programs should focus on grooming entrepreneurs to become investable. This means refining business plans, developing prototypes or pilots, building strong teams, and practicing investor pitches. Understanding what investors look for, which our evidence shows is often aligned with global patterns of favouring team quality and market potential, is key for entrepreneurs aiming to scale. For green ventures specifically, this readiness work should also cover the vocabulary and metrics that green finance providers expect verifiable environmental impact, resource-efficiency savings, or regulatory compliance since general business preparedness alone may not close the additional scepticism that unfamiliar green technologies can attract from investors (Lwesya, 2025).
- **Academic institutions as catalysts, including for green technology transfer:** Universities and research institutions in Africa should actively foster knowledge transfer and entrepreneurship. This can include training researchers in commercialization, incentivizing external partnerships, simplifying bureaucratic procedures for spin-offs, and providing seed funding or incubator support to budding academic entrepreneurs (Kruss & Visser, 2017). The spin-off study's findings demonstrate that such institutional support pays off with more new ventures; the same knowledge-mobilisation infrastructure, extended to environmental science, engineering, and agricultural research groups, is a plausible route for channelling green technical knowledge into green venture creation, and pairing it with the SME-facing technical support that green supply chain adoption research shows South African businesses often lack in-house (Tsikada et al., 2025).

Policy Implications, Including for Green Ventures

Policymakers aiming to stimulate entrepreneurship in emerging markets might focus on interventions that enhance resource flows. This could involve improving financial infrastructure, for example supporting micro-venture funds or credit facilities that match entrepreneurs with small amounts of growth capital or offering seed grants for validated community enterprises to match their self-generated revenues. Strengthening entrepreneurial ecosystem linkages is another approach: policies that encourage public-private partnerships, network-building events, and ease of collaboration between academia and industry can increase entrepreneurs' access to resources beyond their immediate circles. Government and development agencies could also invest in programs that teach resource mobilisation skills, from grant writing to crowd-pitching, and create platforms, physical or virtual, where entrepreneurs can connect with resource providers. For green ventures specifically, our synthesis points to two additional priorities: first, expanding access to dedicated green finance instruments and simplifying the regulatory pathways that green entrepreneurship research identifies as barriers to green finance access in Africa (Lwesya, 2025); and second, building technical-support programmes, such as green supply chain and resource-efficiency advisory services, that give smaller green ventures the specialised knowledge that South African SME research shows they often lack in-house (Tsikada et al., 2025).

Comparing with Developed Markets

While resource mobilisation is important everywhere, the balance tends to differ in emerging markets. Entrepreneurs in Silicon Valley, for example, might rely heavily on venture capital, whereas an entrepreneur in Lagos or Johannesburg might need to rely first on personal savings, family and friend funding, and small customer sales, then use the momentum to seek growth capital. Our framework highlights that context influences which resource levers are most critical. In African contexts, internal and network-based resources often substitute for institutional ones, whereas in developed contexts formal resources might be easier to obtain (Aldrich & Martinez, 2015). Recognizing these contextual differences is important for transferring and adapting best practices in entrepreneurship development across regions.

Propositions for Future Research. Building on our framework, we outline key propositions for future empirical research:

- **Proposition 1:** Green ventures that develop strong internal earnings-generation capabilities will be more likely to grow and sustain environmental value in resource-constrained markets. **Rationale:** Because many green ventures face long payback periods, high initial costs, and uneven access to green finance, the ability to generate early revenue reduces dependence on grants or external investors. Earnings generation allows green entrepreneurs to reinvest in technology, operations, and market development, thereby supporting both venture survival and the wider spread of green products, services, and practices.
- **Proposition 2:** Green entrepreneurs who mobilise bridging and bonding social capital through both community networks and digital platforms will be better positioned to diffuse green ideas, build legitimacy, and access resource providers. **Rationale:** Green entrepreneurship often requires behavioural change among customers, communities, suppliers, and funders. Bonding ties help create trust and local adoption, while bridging ties connect green ventures to new markets, technical experts, investors, and policy actors. Digital platforms can extend these ties beyond local boundaries, helping green solutions spread more rapidly and gain visibility.
- **Proposition 3:** Green ventures that form strategic alliances with universities, government agencies, communities, suppliers, customers, and sustainability-focused organisations will achieve stronger growth and broader environmental impact than green ventures operating in isolation. **Rationale:** Green ventures rarely possess all the technical, financial, regulatory, and market resources they need internally. Strategic

alliances allow them to access complementary knowledge, pilot sites, credibility, distribution channels, and environmental expertise. These partnerships can therefore help green ventures overcome resource scarcity, reduce adoption barriers, and scale solutions that create both commercial and ecological value.

- **Proposition 4:** Green ventures that demonstrate strong investment readiness, including capable teams, validated business models, evidence of environmental value, and credible growth plans, will be more likely to attract angel investment, venture capital, and green finance. **Rationale:** Investors in emerging markets often face uncertainty about new technologies and unfamiliar green business models. Investment readiness reduces this uncertainty by signalling competence, preparedness, and commercial viability. When green ventures can show both financial prospects and measurable environmental benefits, they are better able to unlock external capital needed for growth and wider diffusion.
- **Proposition 5:** Universities, incubators, and research institutions that actively mobilise green knowledge, intellectual property, technical expertise, and entrepreneurial support will increase the creation and growth of green ventures. **Rationale:** Many green ventures depend on specialised scientific, engineering, environmental, or sustainability knowledge that entrepreneurs may not possess alone. Institutional support can convert research into practical green solutions, provide access to laboratories and experts, and help entrepreneurs translate technical ideas into viable ventures. This strengthens the pipeline of green businesses and adds value by turning knowledge into market and societal impact.
- **Proposition 6:** Green ventures that combine internal earnings generation, social and digital capital, strategic alliances, and investment readiness will be more likely to scale than green ventures relying on any single resource mobilisation mechanism. **Rationale:** Green entrepreneurship requires the orchestration of multiple resources because environmental ventures must solve technical, financial, market, and legitimacy challenges at the same time. Internal earnings provide resilience, networks create reach and trust, alliances supply complementary capabilities, and investment readiness unlocks growth capital. The combination of these mechanisms creates a stronger pathway for green ventures to grow, spread, and add economic, social, and environmental value.
- **Proposition 7:** Green ventures that access specialised green finance and technical knowledge partnerships will face fewer barriers to growth and will be better able to deliver measurable sustainability outcomes. **Rationale:** General entrepreneurial resources are important, but green ventures also require sector-specific finance, environmental expertise, regulatory understanding, and impact measurement capabilities. Technical and green-finance partnerships help ventures overcome knowledge gaps, demonstrate environmental performance, and strengthen credibility with funders, customers, and policymakers. This supports the spread of green entrepreneurship by making green ventures more viable, trusted, and scalable.

Future studies could test these propositions with new data, possibly using multi-variable models that include both direct and indirect effects, for example testing mediation by self-efficacy or moderation by institutional context. Propositions 6 and 7 in particular should be treated as the paper's explicit invitation to close the central gap in this synthesis: none of the four source studies sampled green ventures, so every claim above about green ventures is an extension of general findings through the green entrepreneurship literature, not a direct measurement, and should be read accordingly.

Conclusion

This paper set out to answer a targeted question: can South African businesses mobilise the resources needed to create and grow green ventures? By synthesizing four rigorous studies of resource mobilisation in South African social enterprises, women's digital entrepreneurship, venture finance, and academic spin-offs, and reading their results through the emerging green entrepreneurship and green finance literature, we arrive at a

qualified yes. Resource mobilisation is the lifeblood of entrepreneurship generally, and South African entrepreneurs already demonstrate the internal-revenue generation, network-conversion, investment-readiness, and knowledge-mobilisation capabilities that green venture creation requires. Internal financial resource generation emerges as a vital foundation for surviving the long payback horizons typical of green business models. Social capital and alliances expand an entrepreneur's reach into the technical and green-finance partners that green ventures need, although they must be coupled with effective investment readiness to translate into external funding. The mobilisation of knowledge resources and institutional support, demonstrated here through academic spin-offs, offers a plausible pathway for channelling environmental and technical research into new green ventures. Together, these insights form an integrated picture of how South African entrepreneurs could, in principle, overcome the resource scarcity that green ventures face: through the same creativity, network-building, and multi-pronged resource acquisition strategies documented in mainstream entrepreneurship.

That qualification matters. None of the four source studies sampled green ventures directly, so every claim in this paper about green ventures specifically is a conceptual and evidence-based extension of general findings, not a direct measurement, and green ventures may face additional barriers green finance access, technical knowledge gaps, and investor unfamiliarity with green technologies that this synthesis could not observe. The contributions of this work are therefore both theoretical and practical, but incomplete without the direct follow-up research the paper's propositions call for. The proposed resource mobilisation framework connects previously disparate findings into a cohesive model, reinforcing the idea that an ecosystem of resources, financial, social, and knowledge-based, underpins entrepreneurial success in challenging environments, and offers a testable starting point for understanding whether that ecosystem serves green ventures as well as it appears to serve conventional ones. Practically, it suggests that entrepreneurs, their supporters, and policymakers should focus on building these capability areas simultaneously, while specifically closing the green finance and technical knowledge gaps this paper identifies, to give green ventures a fair chance at the same resource mobilisation pathways that have supported entrepreneurial growth elsewhere in South Africa.

By reinterpreting the evidence through a resource mobilisation lens, this paper paves the way for a richer understanding of entrepreneurship, including green entrepreneurship, in Africa and similar contexts. We encourage future research to empirically validate and refine the proposed framework using dedicated green-venture samples, examine how these resource mobilisation mechanisms interact, for example whether strong networks amplify the benefits of internal funding or vice versa, and explore additional resource strategies including green-specific finance instruments and technical knowledge partnerships relevant to emerging markets.

In conclusion, staying ahead of the curve in African entrepreneurship, green ventures included, is not merely about having a novel idea; it is equally about mobilising and orchestrating resources creatively and effectively in environments where doing so is both challenging and essential for growth.

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FULL PAPER · S1.6 · ONLINE SESSION 1

Smallholder Farmers' Entrepreneurial Competencies and Cassava Value-addition Activities

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ABSTRACT

Cassava is one of the crops prone to post-harvest losses in Nigeria due to farmers' limited involvement in value-addition activities. This study investigates the association between cassava farmers' entrepreneurial competencies (ECs) and their value-addition activities in Kogi State, Nigeria. A multistage sampling technique was employed to select 246 respondents, and data were collected by trained enumerators using a well-structured, pre-tested questionnaire. The data were analyzed with descriptive statistics and Cragg's double-hurdle model. The results show that only about 56% of respondents processed their raw cassava tubers into other forms, with the quantity processed accounting for 57% of the harvested quantity. The findings from the first hurdle indicate that the sex of the household head, participation in entrepreneurial training, and their involvement in cassava value-addition activities (CaVaAs) are related. Positive and significant associations exist between farmers' levels of ECs and their participation (0.3098) and the extent of participation (0.2226). While the risk-taking, persistence, collective and social indicators, and opportunity-seeking ECs domains influenced participation in CaVaAs, they also influenced the extent of involvement, except for the collective and social indicator domain. The findings remain robust after conducting robustness checks such as using the Tobit model and changing variable definitions. A case is therefore made for boosting the ECs of cassava farmers through entrepreneurial training, with a curriculum rich in the persistence, collective and social indicators and oppourtunity-seeking domains and gender sensitive.

Keywords: Entrepreneurial competencies, value-addition, cassava farmers, smallholder, Nigeria

1. Introduction

Globally, agriculture employs about 26.2% of the labour force, and in 2022, 48% of Africa's workforce (FAO, 2024). Agriculture remains the dominant employer of labour, especially in rural areas of developing countries (Davis et al., 2023). The sector employed 46% of Nigeria's workforce in 2023, mostly smallholders living in rural areas (Africa Development Bank Group, 2024). As a result, the agricultural sector's development is fundamental to Nigeria's economic growth, and cassava is one of the six priority crops identified for funding to boost production and reduce food insecurity and unemployment.

Cassava farming, with its value-addition, has a considerable contribution to Nigeria's economy in terms of employment creation (Omoluabi & Ibitoye, 2024). More than 1 million households in Nigeria are growing vitamin-fortified cassava, thereby improving nutrition and the welfare of the farm households (FAO, 2018; Afolayan et al., 2026). Seeing this, the national government introduced the "presidential initiative on cassava production and export" program to increase its production to 150 million tons per annum. For instance, the government spent close to ₦40 billion ($ 96 million) on the cassava enterprise in 2021. It was expected that the intervention would generate approximately US$5.0 billion in annual income through the export of cassava along its value chain.

Despite the benefits of cassava value-addition, and the numerous challenges affecting farmers' involvement, a vital knowledge gap exists about the effect of farmers' ECs in determining value-addition behaviour. Previous

studies on AgVa and CaVaAs have mainly focused on socioeconomic, institutional, infrastructural and environmental factors as the determinants of farmers' participation (Manning, 2015; Oyeyinka et al., 2023; Sama et al., 2023; Bosompem et al., 2024). While these factors are relevant, equally important are farmers' capability to identify oppourtunities, cope with risks, deploy resources, develop strategies, and institute market relationships that will determine whether they will be involved and the extent of involvement in value-addition activities.

Albeit little is known about how the multidimensional ECs determine farmers' value-addition activities, especially in Nigeria. Also, insufficient attention has been given to the relationship between the decision to participate and the extent of participation among participants. Addressing this gap is vital because the ECs that shape participation decisions may vary from those required to get more involved.

The high perishability nature of cassava has led to studies on the involvement of farmers in its value-addition activities and the determinants of such choice which are mainly on demographic and institutional factors (Bosompem et al., 2024; Manning, 2015; Oyeyinka, et al., 2023; Sama, et al., 2023). Notwithstanding, a gap exists in the effect of farmers' ECs on their involvement and the extent of their involvement in value-addition activities, especially in Nigeria. Previous studies have largely discussed farmers' involvement in value addition, the resources at their disposal, and their institutional access. This simply implicitly assumes that farmers owning related resources will react equally to value-addition opportunities. The approach underestimates the behavioural and competence aspects of business decision-making.

The entrepreneurial capability perception dares this notion by suggesting that discrepancies exist in farmers' ability to seize opportunities, take risks, modernise, utilise resources, and translate opportunities into productive economic activities. Therefore, ECs may provide an additional layer of insight into heterogeneity in farmers' involvement in value-addition activities, even after adjusting for conventional socioeconomic and institutional factors. As such, this study is one of the few empirical studies that relate composite ECs and their dimensions to the decision to participate, as well as the extent of participation, in CaVaAs among smallholder farmers in rural areas. Therefore, objective of this study was to analyze the effect of cassava farmers' ECs on their value-addition activities.

2. Literature review

2.1. Concept of Agricultural Value-addition

Various scholars have defined value-addition from an agricultural outlook. It is often considered synonymous with value creation. In food and agribusiness, value creation, or value-addition, is the process by which a company modifies a product's location, timing, and form to better suit market preferences (Anderson & Hanselka, 2009). Aworh (2015) believed that any action taken by a firm to enhance perishable product storage, reduce postharvest losses, increase market value, and promote profitability was considered AgVa. AgVa was also described by Paraman et al. (2015) as the conversion of raw agricultural produce into another form. Lu and Dudensing (2015) described AgVa as a collection of farming activities that allows farmers to meet consumers' demands for high-quality agricultural products, including those related to form, identity, space, time, and other attributes. The AgVa's definitions by Paraman et al. (2015) and Aworh (2015) centre on postharvest operations and procedures that increase profitability. Nonetheless, Lu and Dudensing's (2015) definition of AgVa includes both pre-harvest and post-harvest practices that can improve consumers' acceptance and profitability.

In this study, six postharvest activities in which cassava farmers were engaged and that, according to Aworh (2015) and Lu and Dudensing (2015), have the potential to boost cassava farms' productivity and profitability were considered cassava value-addition. However, for ease of measurement, emphasis is placed on the processing of cassava tubers into other forms, according to (Paraman et al, 2015). Farmers can unlock new

revenue streams, improve market competitiveness, and contribute to sustainable agricultural development by integrating value-addition activities into their operations. Enhancing value is crucial for improving the quality of life for small-scale farmers in Nigeria (Lu & Dudensing, 2015).

2.2. Concept of Entrepreneurial Competencies (ECs)

Entrepreneurship is the ability to be creative, realise innovation, and capitalise on opportunities for success amid competition. A company's competitive advantage is spawned from its distinctive set of factors. These resources include management skills, organisational processes, and knowledge (Barney, 1991). To sustain a competitive advantage, a resource must be valuable (worth something), rare (unique), inimitable (cannot be easily sold or traded), and non-substitutable (Barney, 1991). Competencies are vital to acquiring such a competitive advantage (Mitchelmore et al., 2014). Competencies refer to a behaviour in which performance is achieved.

Entrepreneurial competencies refer to the capacity to apply acquired knowledge to the venture's progress and profitability (Opolot, et al., 2018; Phelan & Sharpley, 2012). They represent the capacity to investigate, distribute, plan, and oversee the venture's resources for maximum efficiency and to seize business opportunities. According to Bird (1995), ECs are the vital potentials of a person that lead to the creation of new ventures. While some potential is natural, others are developed through education. These competencies are considerably higher in customary production activities than in modern ones (Babu, et al., 2016).

The studies of general ECs have been prioritized (Baum & Locke, 2004; Chen, et al., 1998; Oosterbeek & van Praag, Ijsselstein, 2010; Rauch & Frese, 2007; Unger, et al., 2011). Those linked with ECs among farmers have received little attention (Salau, et al., 2017; Sher, et al., 2019; Rosairo & Potts, 2016). Pindado and Sánchez (2017) opined that the pattern of competencies is particular to each area, given the culture and economic level of each region.

Detecting the ECs of smallholder farmers enables pinpointing the information they utilise to reach their financial objectives. Phelan and Sharpley (2011) identify their areas of weakness and develop training to enable them to thrive in agribusinesses (Cortés-Rodríguez, et al., 2022). In his research on competitive competencies in the agriculture industry, McElwee (2012) concluded that farmers must be educated and trained to improve their skills. This can be achieved by creating targeted policies that account for recipients' unique competencies. A specific study of small-scale farmers is necessary to assess their competencies, develop interventions, and coordinate efforts for sustainable community development.

To date, researchers have examined different domains of ECs, namely, conceptual, opportunity-seeking, learning competency, risk-taking, motivation, networking, strategic, perseverance, innovative, insight into market, ethical, etc. (Kyndt & Baert, 2015; Lee et al., 2016; Nakhata, 2018; Osagie et al., 2016; Quagrainie, 2018; Stephen et al., 2017; Suhaimi et al., 2018; Yusuff et al., 2016; Tehseen, et al., 2019). This study identified six main domains of ECs that are most appropriate for smallholders in rural areas (Adeyonu et al., 2022).

2.3. Theory and hypothesis

As posited by neoclassical economists, rational farmers aim to maximise profits given limited resources by making choices that improve the performance of their farms and agribusinesses. However, achieving this objective is influenced by the environment in which farmers operate and by their endowments (internal capabilities). In agribusiness, farmers need the capacity to recognise opportunities, assess risks, allocate resources, organise economic activities, strategise, and establish connections with suppliers of farm inputs and buyers of their produce. The internal capacity serves as the theoretical basis for relating ECs with farmers' participation in and intensity of involvement in CaVaAs.

Hence, this study is underpinned by the entrepreneurial competency theory (ECT) and the resource-based view (RBV) of the enterprise. These two theories are complementary. While ECT reveals the association between farmers' behavioural and managerial competencies and entrepreneurial involvement, the RBV explains how these abilities can constitute internal endowments that culminate in optimal entrepreneurial outcomes. The theories provide a basis for understanding the connection between internal capabilities, such as levels of ECs, and performance outcomes, such as participation and the extent of involvement in CaVaAs among smallholder farmers.

The ECT stresses that particular behavioural competencies, such as organisational management, opportunity recognition, relationship building, and strategic thinking, are critical for enterprise success. These competencies are dynamic because they can be acquired through learning and can be improved through experience over time. According to Man et al. (2002), they have a considerable impact on entrepreneurial behaviour and enterprise performance. In the context of this study, ECs can enrich farmers' capability to identify value-addition oppourtunities, deploy their risk-taking propensity, develop tactical plans, organise various factors, and connect with buyers and/or suppliers. So, framers with stronger ECs may be in a better position to overcome the managerial, organisational, and informational challenges linked with value-addition

The RBV complements this argument by postulating that an enterprise can achieve its objectives by exploiting rare, valuable, inimitable, and non-substitutable resources. From these postulates, farmers' ECs constitute valuable human capital that can be used to identify and explore oppourtunities, mobilise resources, innovate, access markets, and increase value-addition activities. But the possession of such competencies does not operate in isolation. Their effectiveness may be linked to access to complementary factors such as socioeconomic characteristics, institutional factors, infrastructural facilities and the environmental conditions. Hence, the theories indicate that farmers' ECs relate to complementary factors that shape value-addition participation.

The theories also provide a framework (Fig 1.) for differentiating between the decision to participate and the intensity of participation in CaVaAs. Some of the ECs may first dictate whether farmers identify value-addition opportunities and have the capability to undertake them. Once this hurdle has been surmounted, different EC domains may determine the extent to which they will get involved by deploying resources, organising activities, accessing markets, etc. Thus, the effect of ECs might not be the same across decisions about participation and participation intensity.

Drawing from the theoretical framework, the following hypotheses stated in the null form are suggested:

$H_0$1 = There is no significant association between composite ECs with its components and participation in CaVaAs.

$H_0$2 = The composite ECs with their components and the extent of participation in CaVaAs are not significantly related.

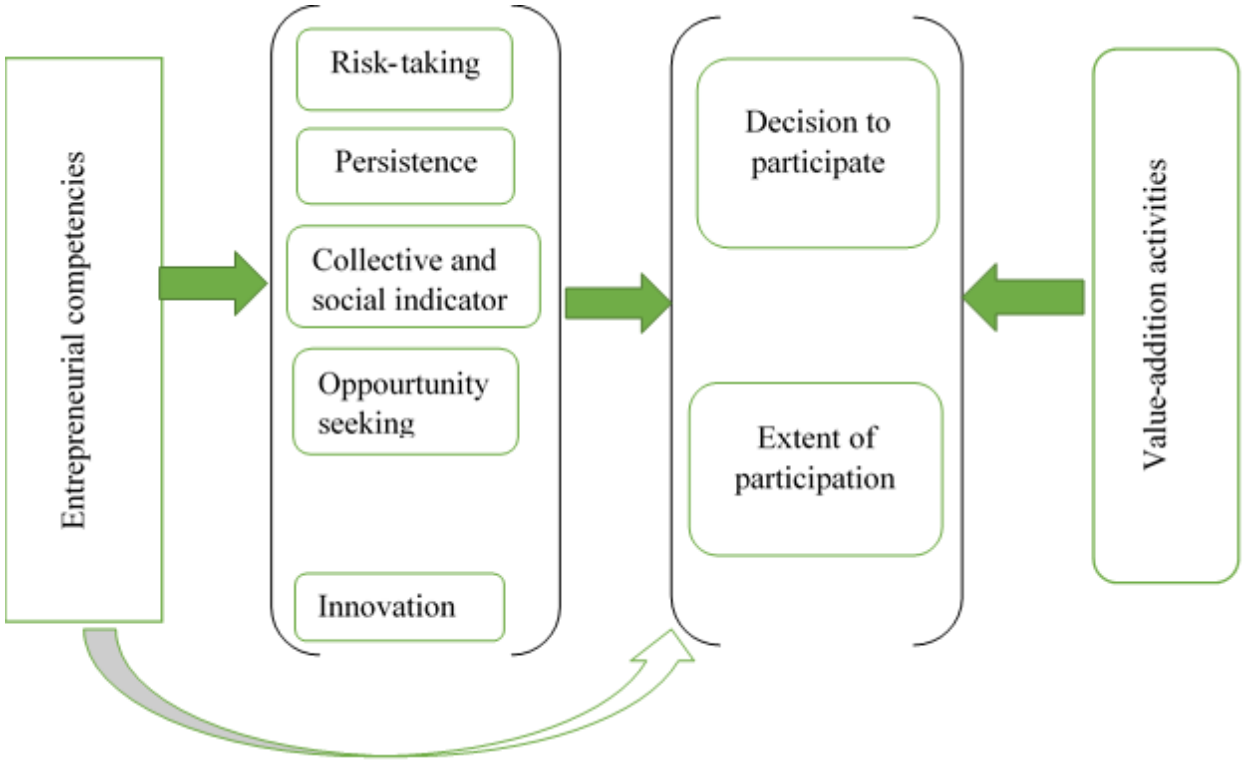


Fig. 1: Theoretical framework guiding the study

2.4 Empirical review

Prior research on farmers' participation in AgVa shows that participation is influenced by a blend of socioeconomic, farm-level, institutional, and entrepreneurial variables. Nevertheless, discrepancies occur in the magnitude and direction of the associations across contexts. This implies that farmers' participation in value-addition can only be explained by multiple categories of determinants.

The most commonly reported socioeconomic and farm characteristics, as noted by various scholars, are gender and years of farming experience. Several of the previous studies reported a higher probability of involvement among female than male farmers (Obasi & Enyia, 2016; Falola, et al., 2016; Bosompem et al., 2024). This pattern is an indication that females may be involved more in certain value-addition activities, possibly showing their customary tasks in processing and post-harvest activities.

Likewise, there has been a direct relationship between years of farming experience and participation in value addition (Donkor, et al., 2018; Musyoka, et al., 2020; Bosompem et al., 2024). This shows that knowledge, experience, and acquaintance with markets may aid farmers' involvement in value-addition activities. Nonetheless, these associations may be context-specific because gender tasks, resource possession, and agricultural value chains are production system-specific.

Access to credit, extension services, and market access are important institutional factors that play a vital role in farmers' participation in value-addition with less consistency in the evidence provided. In particular, several studies have reported a direct association between access to credit and extension services (Falola et al., 2016; Donkor et al., 2018; Obasi & Enyia, 2016). Nonetheless, a few other studies have reported an indirect association between some institutional variables and participation (Okoruwa, et al., 2020; Bosompem et al., 2024). These contrary findings are indicative that institutional factors may not necessarily be the sole determinants of farmers' participation in value-addition. How effective they are may be connected with the accessibility, affordability, quality, and nature of local market conditions and production environments.

Recent studies have also linked ECs to agricultural growth. Burhanuddin and Ramadhan (2019) and Hasanah, et al. (2024) opined that farmers' ECs are directly related with farm performance. Competencies are capable of aiding entrepreneurial behaviour as well as serving as essential internal resources that increase farmers' capability to utilize oppourtunities and mobilise external resources. Nonetheless, previous studies have tended to examine ECs as a composite construct or in relation to general measures of farm growth, with little attention to the multidimensional nature of the competencies through which ECs may influence farmers' value-addition decisions and whether the influence differ from the extent of participation decision.

To address this gap, this study investigated six dimensions of farmers' ECs and analysed their individual impact on participation in, and the extent of participation in, CaVaAs. This study advances the frontier of knowledge by demonstrating how integrating composite ECs and six of its domains with conventional socioeconomic and institutional factors may drive both the decision to participate and the extent of participation among cassava farmers in Kogi State, Nigeria. By doing this, the study advances a more sophisticated understanding of how individual-level entrepreneurial traits influence agribusiness development.

3. Methodology

3.1. Sampling Techniques

A multistage sampling procedure was employed to select the respondents. The ten LGAs that dominate cassava production were purposely selected at the first stage. The second stage involved randomly selecting three LGAs from the 10 selected LGAs. The third stage involved a random selection of 10 villages from each of the three LGAs, for a total of 30 villages. The village leaders assisted the enumerators in compiling lists of cassava-based farm households in each selected village to establish a sampling frame. The fourth and last stage of the sampling was a random selection of 30% of the cassava-based farm households from each of the chosen villages to ensure proportionality. This led to the selection of 246 farmers but only the 226 well filled questionnaire were used for this study.

3.2. Data collection instrument and validation

The questionnaire used in data collection was evaluated for the adequacy of is content by the relevant experts in our institution. It was later pretested with 35 cassava farmers outside the study area. The instrument was revised based on experts' recommendations and field feedback. The construct validity of the ECs scale was evaluated using exploratory factor analysis. Before the factor extraction, the Kaiser–Meyer–Olkin (KMO) measure of sampling adequacy, and Bartlett's test of sphericity were performed to evaluate the suitability of the data for factor analysis. The KMO value of >8 with a Bartlett's test of < 0.05 are adjudged suitable for the study model. The questionnaire was used to collect data from all the selected respondents between January-February, 2025 on the 2024 farming season using KoboCollect which was integrated with GPS. Farmers were asked to rate their EC levels on a 5-point Likert-type scale from 1 (very low) to 5 (very high).

3.3. Analytical Techniques

Descriptive and inferential statistics were employed to analyse the data using STATA 15. Descriptive statistics such as frequency, percentage, mean, and standard deviation were used to analyse farmers' value-addition activities and ECs. A double hurdle model was used to estimate the influence of ECs on farmers' CaVaAs.

3.3.1. Classification of the Entrepreneurial Competencies

The information on the ECs was collected across six domains, each with five items, except for risk-taking (RISKT), which had 4 items to capture the unique behavioural capabilities that may define farmers' participation in CaVaAs. The domains with five items are collective and social indicators (CSIs), innovation (INVT), motivation (MTVT), oppourtunity-seeking (OPSK), and persistence (PSTC). This resulted in a total of 29 items.

3.4.2. Cragg Double-Hurdle Model (CDHM)

A two-stage analytical approach was adopted in analyzing the effect of ECs on smallholder cassava farmers' participation in value-addition activities. Its adoption was premised on the fact that participation in CaVaAs is binary- the decision to participate or not to participate and the extent of participation. To estimate the factors influencing smallholder farmers' decision to participate in CaVaAs, it was assumed that the factors influencing the decision to process cassava are independent of the quantity of cassava to be processed. The two popular techniques in the literature for modelling it are the CDHM and the Heckman two-stage selection model. There is a convergence between the two models that discrete outcomes are shown by the decision to participate and the extent of participation. In this study, some farmers did not add value to their raw cassava by turning it into another product. This implies that the farmers did not process the cassava tuber from their farms in the planting season before the survey was conducted. Hence, the CDHM developed by Cragg, (1971) was employed for this study.

4.0 Findings and discussion

4.1 Distribution of Farmers by Cassava Value-addition Activities

Table 1 shows that six CaVaAs were identified in the study area. The most popular activity performed by almost 81% of the farmers was the transportation of raw cassava tubers. This was closely followed by the marketing of raw cassava tubers, which got almost 78% of the respondents engaged in it. It is to be noted that the marketing of the raw tubers was done at both the farm gate and other designated local market areas. The fact that more than 75% of farmers participate in transportation and marketing indicates that most of them do so at the CaVaAs' primary stage. Bosompem et al. (2024) reported that marketing raw cassava tubers was the most popular value-adding practice among farmers in Ghana. Unexpectedly, only a little above 50% of the farmers participated in the processing of raw cassava tubers into other forms. In contrast, less than one-third stored the processed products till a later date. Only slightly more than half of the farmers reported engaging in processing, despite its crucial role in the CAVaAs. This limited involvement suggests that value-addition is still underutilized, most likely due to financial, technical, and/or infrastructure limitations.

Table 1. Participation in Cassava Value-addition Activities

CaVaAs	Frequency (n = 232*)	Percentage
Transportation of raw cassava tuber	187	80.60
Marketing of raw cassava tuber	180	77.59
Processing of cassava tubers	130	56.03
Marketing of processed cassava tubers	99	42.67
Transportation of processed cassava tubers	78	33.62
Storage of processed cassava products	75	32.33

Note: * implies multiple responses

4.2. Extent of Value-addition to Various Products

The average quantity of the raw cassava harvested and processed into other products, is described in Fig. 2. The table shows that while the mean quantity harvested was 21.27 tons, less than 60% were processed into various products, with the highest proportion being cassava flakes (28.75%), which are primarily consumed locally. Starch, which can be used for industrial purposes and exported, is being produced in limited quantities (1.77%). While producing food items from cassava is laudable, the country can still leverage its production capacity to increase its foreign exchange base via cassava processing to starch, high-quality cassava flour, and even alcohol (Osuagwu, 2020).

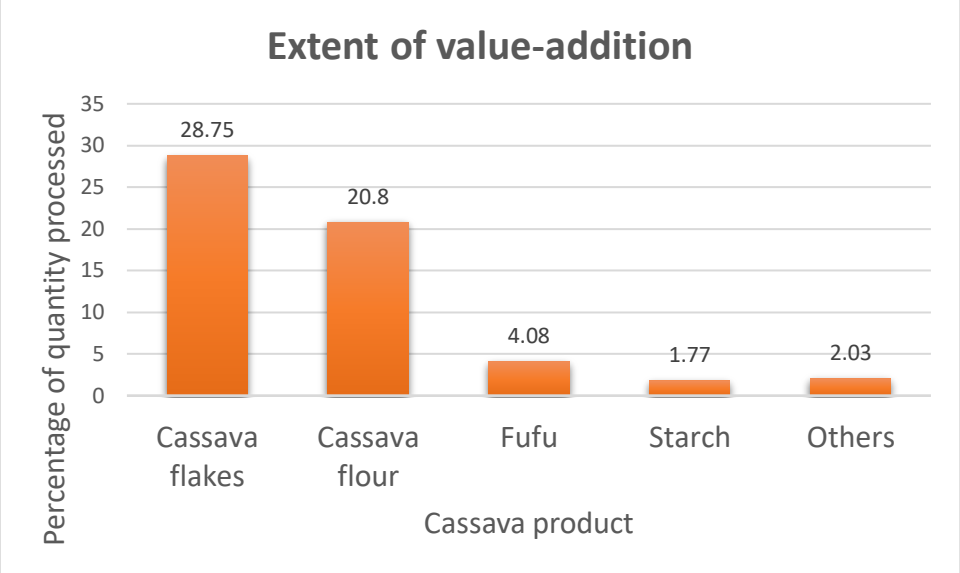


Fig. 2: Percentage of harvested cassava converted into each processed product

4.3 Farmers' Entrepreneurial Competencies

The different domains of ECs were ranked based on the mean values obtained from farmers' responses on their level of competencies in each of the domains. As shown in Table 2, the mean value of the aggregate ECs stood at 2.47. The RISKT domain, which comprises: 'confronting risky situations is my nature as an entrepreneur', 'I am not a risk-averter and always prepared to take risks at all times', among others ranked first. In other words, the RISKT domain is paramount for rural cassava farmers. Next to this is the PSTC domain which consists of: 'once I decide to do something, I do not give up until I reach the goal', I continue a difficult task even when the others have already given up', and 'the more difficult a task is, the more determined I am to finish it', etc. The third on the list is the CSIs, which captures farmers' relationships with others within and outside their communities. The innovation domain is the least of all the domains, with a mean value that is far below the composite ECs mean.

In summary, the ranking suggests that although cassava farmers may have a reasonable amount of perseverance and risk tolerance, critical skills like social networking and innovation are still lacking. All these domains define the ECs of the farmers and are expected to influence their CaVaAs (Ataei, et al., 2020).

Table 2. Farmers level of Entrepreneurial Competencies

Entrepreneurial Competencies	Mean	Rank
Aggregate	2.470	
Risk-taking	2.716	1st
Persistence	2.626	2nd
Collective and Social Indicators	2.618	3rd
Oppourtunity-seeking	2.579	4th
Motivation	2.412	5th
Innovation	1.831	6th

4.4 Association between ECs and CaVaAs

The results of the analysis of the relationship between ECs and CaVaAs are presented in Table 3. The R^2 was 0.3409, which signifies that about 34% of the variation in farmers' involvement in CAVaAs was explained by farmers' characteristics, their levels of ECs, and institutional variables. As presented, the model is a good fit given the significance of the sigma variable (P<0.05). The variables shown to influence farmers' decision to participate and the extent of participation in CaVaAs are sex and participation in entrepreneurial training. The

composite ECs of farmers and its RISKT, PSTC, CSIs, and OPSK domains were found to determine farmers' decision to participate in CaVaAs. On this premise, the null hypotheses 1 is hereby rejected. Equally, the aggregate ECs of farmers, in addition to their PSTC, OPSK, and INVT have significant effects on the extent of farmers' participation in CaVaAs. Hence, hypotheses 2 is hereby rejected.

The results show that while sex had a direct influence on the level of involvement, it had a significant but indirect influence on the decision to participate in CaVaAs. In particular, whereas male participants showed a 8% higher level of involvement than their female counterparts, the likelihood of male-headed households taking part in CaVaAs was 43.97% lower than that of female-headed households. Women are frequently more involved in postharvest activities, informal processing, and food transformation for domestic use and local markets, especially in rural settings. Since they have traditionally played these roles, households headed by females may be more inclined to participate in CaVaAs. However, males are more likely to get more involved after they get involved, probably because they have easier access to resources such as capital, labour and market networks that allow them to grow or intensify their involvement in CaVaAs. This highlights the principal discrepancies that often influence economic involvement, even in cases where women are more likely to participate in certain CaVaAs (Bosompem et al., 2024; Falola, et al., 2016; Obasi & Enyia, 2016).

The findings show that the decision to participate in CaVaAs and the level of involvement are directly and statistically significantly correlated with entrepreneurial training participation. In particular, farmers who took part in entrepreneurship training had a 42.94% higher likelihood of conducting CaVaAs than farmers who did not. Additionally, trained farmers participated to a 1.5% greater extent than their untrained colleagues. Farmers who receive entrepreneurial training can better recognize business opportunities, control risks, and participate in CaVaAs with the knowledge, abilities, and self-assurance needed. As a result, skilled farmers feel more equipped to take advantage of these opportunities and be more aware of the advantages of CaVaAs. The correlation between the level of involvement and training indicates that it not only affects participation decisions but also facilitates deeper engagement. This can entail increasing the amount of processed cassava or diversifying into packaging and branding for new niche markets (Opolot, et al., 2018).

Furthermore, the results indicate that the choice to participate in CaVaAs and the degree of such involvement are substantially and directly correlated with the aggregate ECs. Particularly, compared to respondents with very low ECs, individuals with moderate ECs were 30.98% more likely to participate in CaVaAs. Likewise, those with low ECs were 14.16% more likely to participate than those with very low ECs. Additionally, compared to their very low ECs counterparts, people with moderate ECs were 22.26% more likely to add greater value to cassava. Cassava farmers with higher EC levels are better equipped to identify opportunities for value-addition, evaluate risks, and efficiently mobilize resources to participate in CaVaAs.

Also, the results reveal an indirect relationship between the decision to participate in CaVaAs and the RISKT dimension of ECs. Actually, it was found that farmers with very low risk-taking skills were 14.64% more likely to participate in CaVaAs than those with low risk-taking skills. This finding no doubt appears counterintuitive. However, it offers a fascinating perspective on the behavioural cues of risk perception and entrepreneurial judgement. One tenable explanation is that those with very low risk-taking tendencies have already internalised their constraints and use ultra-conservative yet consistent participation tactics within the low-risk and known parts of CaVaAs.

On the other hand, even though they are aware of the possible advantages of value-addition, people with low risk-taking tendencies may have a sense of internal conflict since they are hesitant to take action because of unsolved anxieties and uncertainties. Compared to their more self-aware, risk-averse peers, they may be less involved due to this cognitive dissonance, delaying or stopping engagement entirely (Ataei et al., 2020).

The PSTC domain, participation, and the extent of participation in CaVaAs are significantly and directly associated. The results indicate that the probability that farmers with a moderately low persistence domain will participate in CaVaAs is 15.73% higher than that of those with a very low PSTC domain. In the same vein, the likelihood that farmers with low and moderate levels of PSTC domain will participate and get deeply involved are 28.51% and 13.34% respectively, higher than those with very low domain. Farmers with higher persistence are more likely to persevere through the time-consuming and sometimes uncertain nature of value-addition processes, such as processing, packaging, or marketing cassava and its byproducts (Ataei et al., 2020).

The CSIs domain significantly impacted respondents' CaVaAs in the study area. Specifically, the probability that farmers with low and moderate levels of CSIs domain are 16.13% and 12.93% respectively, higher than those with very low. Farmers with better CSIs gain more support and information from their networks on CaVaAs. This aligns with the findings of (Ataei et al., 2020). Also, the OPSK domain, the decision to add value, and the extent of CaVaAs are significantly and directly linked. The results imply that compared to the respondents with very low OPSK levels, there is a 17.20% and 17.99% higher likelihood that those with low and moderately low OPSK domains will participate in CaVaAs. However, the extent of value-addition was 15.92% higher among the farmers with moderate levels of OPSK domain in comparison with their counterparts with very low levels. Farmers' awareness of opportunities in CaVaAs led them to participate in the activities and deepen their involvement by committing more effort, time, and other resources.

Lastly, the INVT domain is significantly and directly related to farmers' CaVaAs. The analysis shows that the extent of involvement of farmers with moderate levels of INVT is 21.88% higher than that of those with very low innovation. This may be because farmers with greater innovative inclinations are more likely to identify gaps in orthodox cassava utilization and seek improvements in processing techniques that translate to increased involvement in CaVaAs (Ataei et al., 2020).

Table 5. Effect of Entrepreneurial Competencies on Respondents' Value-addition activities

Variable	Probit model (participation)		Truncated regression (extent of participation)	
	Marginal effect	Std. err.	Coefficient	Std. err.
Farmer's characteristics				
Age (years)	-0.0042	0.0094	-0.0029	0.0039
Sex	-0.4397**	0.2150	0.0820***	0.0258
Formal Education	0.4414	0.3710	-0.1548	0.1453
Entrepreneurial training	0.4294***	0.1011	0.0150**	0.0061
Entrepreneurial competencies				
Entrepreneurial competencies: Low Moderate	 0.1235 0.3098***	 0.0977 0.1001	 0.1416*** 0.2226**	 0.0289 0.0872
Risk-taking domain: Low Moderate	 -0.1464*** -0.1399	 0.0422 0.0984	 -0.1809 -0.1072	 0.1123 0.1040
Persistence domain: Low Moderate	 -0.1715 -0.1573**	 0.1132 0.0730	 -0.2851** -0.1334**	 0.1228 0.0613
Collective and social indicator: Low Moderate	 0.1613** 0.1293**	 0.0554 0.0590	 -0.1108 -0.0579	 0.1009 0.1069
Oppourtunity-seeking domain: Low Moderate	 0.1720** 0.1799**	 0.0867 0.0838	 0.1417 0.1792**	 0.1000 0.0631

Variable	Probit model (participation) Marginal effect	Std. err.	Truncated regression (extent of participation) Coefficient	Std. err.
Motivation domain:				
Low	0.1633	0.1101	0.0940	0.1263
Moderate	-0.0407	0.0991	-0.1026	0.1032
Innovation:				
Low	0.0270	0.1199	0.0432	0.1255
Moderate	-0.0063	0.1658	0.2188***	0.0704
Constant			0.2724**	0.2724
Model diagnostics				
Number of obs. 396 379				
Sigma 0.5046 0.0335				
Log-likelihood -144.1048				
Prob > Chi^2 0.0072				
Pseudo R^2 0.3409				

Note: ** and *** denote the 5% and 1% levels of significance, respectively; female, no formal education, no entrepreneurial training, and very low are the base categories for the sex, formal education, entrepreneurial training, and entrepreneurial competencies variables.

6. Conclusion and implications

The study investigated the association between aggregate ECs and their six domains: CSIs, INVT, MTVT, OPSK, PSTC, and RISKT, as well as sex, age, level of education and participation in entrepreneurial training. It theoretically examined ECs domains as behaviourial factors that determined CaVaAs. The CDHM was employed to measure the relationship between farmers' ECs as well as other factors, and their decision to participate, as well as the extent of participation in CaVaAs. The confidence in the findings was further enhanced by the robustness tests, whose key estimates remained stable across the specified substitute models. The practical and policy-relevant intuitions from the findings include designing gender-based extension services, developing agricultural entrepreneurial training curricula focused on persistence, collective and social indicators and oppourtunity-seeking competencies, as well as supporting other value chain interventions. The study contributes to the emerging field of agricultural entrepreneurship in the developing economy by incorporating farmers' behavioural competencies with the wider agricultural value chain and providing a deeper understanding of CaVaAs.

Research Limitations and Suggestions for Further Studies

First, the study relied on self-reported measures ECs. This may be subjected to perception, recall, or social-desirability bias. Hence, future studies could complement the subject measures with behaviourial assessment, objective indicators or other relevant metrics. Secondly, this study focuses only on six ECs domains, of which two are significant factors in farmers' value-addition activities (participation and extent of participation). This may restrict the inclusiveness of the discussion of farmers' value-addition conduct. Thus, future research could broaden its scope by examining additional relevant competency domains. Thirdly, the study focused on processing-based value-addition and just mentioned other value addition activities in the cassava value chain. Upcoming research could examine the relationship between ECs and other value-addition activities. Fourthly, cross-sectional data were used for this study. This constraints the ability to establish causal association between ECs and participation in value-addition as well as the intensity of participation. As such, the findings are interpreted as association and not definitive cause-effect scenario. Future research will benefit from a longitudinal survey to determine whether perceived competencies were developed before or concurrent with the value-addition activities in addition to the establishment of cause-effect relationship between the variables.

Fifthly, this study was limited to Kogi State in the country's north-central geopolitical zone. Given that the level of development across states and zones varies, future research should expand the study area to other country zones. Also, this study employed the Cragg double hurdle model to analyse the association between ECs and some other demographic and institutional variables, and participation as well as the extent of participation in CaVaAs. Other important variables like market access, quality of infrastructure, access to processing technologies, household wealth etc were omitted. All of these may also influence farmers' participation and the model's explanatory power. Fellow researchers interested in this research area could consider alternative limited-variable analytical models and incorporate some of the omitted explanatory variables to provide a more balanced interpretation of the findings.

Lastly, this study relied solely on quantitative survey data. Future research in this area could employ qualitative or mixed-methods designs to gain deeper insights into the behavioural and contextual approaches through which ECs influence value-addition activities.

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FULL PAPER · S3.1 · ONLINE SESSION 3

Entrepreneurial Readiness, Psychological Orientation, and Technology Adoption: Evidence from Indonesian GEM Data

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ABSTRACT

Digital transformation offers substantial opportunities for small and medium-sized enterprises (SMEs), yet the availability of technology alone may not explain why some entrepreneurs adopt new technologies while others do not. This study examines how perceived entrepreneurial readiness, entrepreneurial psychological orientation, and entrepreneurial motivation are associated with technology adoption and how technology adoption, in turn, is associated with participation in the digital economy among Indonesian entrepreneurs. By focusing on individual-level entrepreneurial characteristics, the study complements approaches that primarily emphasize technological access, infrastructure, and external business conditions.

The study uses individual-level data from the 2020 Global Entrepreneurship Monitor (GEM) Adult Population Survey in Indonesia. A sample of 1,054 respondents involved in entrepreneurial activities is analysed using Structural Equation Modelling (SEM). The conceptual model specifies Perceived Entrepreneurial Readiness, Entrepreneurial Psychological Orientation, and Entrepreneurial Motivation as antecedents of Technology Adoption, which is subsequently linked to Digital Economy participation.

The results reveal that Entrepreneurial Psychological Orientation is positively and significantly associated with Technology Adoption, whereas Perceived Entrepreneurial Readiness and Entrepreneurial Motivation show no statistically significant relationships. Technology Adoption is, in turn, positively and significantly associated with Digital Economy participation. These findings suggest that psychological orientation, particularly creativity and future-oriented thinking, plays an important role in understanding entrepreneurs' engagement with technology. The study contributes to discussions of digital and inclusive entrepreneurship by highlighting the human and behavioural dimensions that complement technological development. For entrepreneurship-support initiatives, the findings suggest that strengthening entrepreneurial creativity, opportunity orientation, and longer-term thinking may complement interventions focused primarily on technological access and skills. Given the cross-sectional and self-reported nature of the GEM data, the results represent associations rather than causal effects and should be interpreted within the Indonesian context.

Keywords: entrepreneurial readiness; psychological orientation; technology adoption; digital economy; Global Entrepreneurship Monitor

1. Introduction and Research Questions

Digital transformation has become increasingly important for entrepreneurship and small and medium-sized enterprise (SME) development. Technologies and technology-enabled business processes can provide entrepreneurs with opportunities to improve their operations, develop new products and services, and participate more extensively in an increasingly digital economy. However, the availability of technology does not necessarily lead to its adoption. Entrepreneurs facing similar technological opportunities may differ substantially in their willingness and ability to engage with new technologies.

Much of the discussion on SME digitalisation has focused on external conditions, including infrastructure, access to technology, financing, and digital capabilities. While these factors remain important, technology adoption is also an entrepreneurial decision. How entrepreneurs perceive their readiness to undertake entrepreneurial

activities, how they recognise and respond to opportunities, how creatively and proactively they approach business development, and why they engage in entrepreneurship may be relevant to understanding their engagement with technology. The original manuscript therefore starts from the uneven adoption of technology among Indonesian SMEs and the need to understand its individual-level determinants.

This study revisits this issue by distinguishing three individual-level antecedents: **Perceived Entrepreneurial Readiness (PER)**, **Entrepreneurial Psychological Orientation (EPO)**, and **Entrepreneurial Motivation (EM)**. Technology Adoption (TA) subsequently connects these entrepreneurial characteristics with participation in the **Digital Economy (DE)**.

Accordingly, the study addresses two research questions:

RQ1: How are perceived entrepreneurial readiness, entrepreneurial psychological orientation, and entrepreneurial motivation associated with technology adoption among Indonesian entrepreneurs?

RQ2: How is technology adoption associated with entrepreneurs' participation in the digital economy?

2. Conceptual Framework and Hypotheses

The conceptual model comprises five constructs. **Perceived Entrepreneurial Readiness** captures entrepreneurs' perceptions of entrepreneurial opportunities and capabilities, fear of failure, and perceived ease of starting a business. This replaces the *Demographic Factor* label used in the earlier model, which grouped perceived opportunity, entrepreneurial skills, fear of failure, and ease of starting a business rather than actual demographic characteristics.

Entrepreneurial Psychological Orientation represents opportunity recognition, proactive behaviour, creativity, and long-term orientation. **Entrepreneurial Motivation** captures different motivations for engaging in entrepreneurship, including making a difference, earning a living, continuing a family tradition, and building wealth or higher income. These dimensions represent different ways in which individual entrepreneurial characteristics may be associated with technology engagement.

The three constructs are specified as antecedents of **Technology Adoption**, which is subsequently associated with **Digital Economy** participation. The conceptual model therefore proposes four hypotheses:

H1: Perceived Entrepreneurial Readiness is positively associated with Technology Adoption among Indonesian entrepreneurs.

H2: Entrepreneurial Psychological Orientation is positively associated with Technology Adoption among Indonesian entrepreneurs.

H3: Entrepreneurial Motivation is positively associated with Technology Adoption among Indonesian entrepreneurs.

H4: Technology Adoption is positively associated with participation in the Digital Economy among Indonesian entrepreneurs.

The model consequently positions Technology Adoption as the central link between entrepreneur-level characteristics and participation in the Digital Economy.

3. Data and Methodology

The study uses secondary data from the **Global Entrepreneurship Monitor Adult Population Survey (GEM APS) Indonesia 2020**. The original survey included 2,500 adults aged 18–64. The analytical sample consists of 1,054 respondents involved in entrepreneurial activities and providing information relevant to the model.

The model is estimated using **Structural Equation Modelling (SEM)**. This approach allows simultaneous examination of the relationships among the five constructs. The analysis first assesses the measurement model, then estimates the structural relationships corresponding to H1–H4. The original model reports NFI = 0.910, CFI = 0.914, RMSEA = 0.085, PNFI = 0.660, and TLI = 0.883. These indices indicate an acceptable, although not uniformly strong, overall model fit and therefore warrant a cautious interpretation of the structural findings.

4. Findings and Discussion

The structural results reveal substantial differences among the three antecedents of Technology Adoption. **Perceived Entrepreneurial Readiness is not significantly associated with Technology Adoption** (estimate = −0.045, p = .782). **Entrepreneurial Psychological Orientation**, by contrast, has a positive and statistically significant association with Technology Adoption (estimate = 0.630, p < .001). **Entrepreneurial Motivation** does not show a statistically significant relationship with Technology Adoption (estimate = −0.024, p = .299). Finally, **Technology Adoption is positively and significantly associated with Digital Economy participation** (estimate = 1.304, p < .001).

Thus, H2 and H4 receive empirical support, whereas H1 and H3 do not. The distinction is theoretically meaningful. Perceiving oneself as ready for entrepreneurship or having strong reasons for engaging in entrepreneurship does not necessarily translate into greater engagement with technology. Instead, the results point toward the importance of how entrepreneurs think and orient themselves toward opportunities and future business development.

Within Entrepreneurial Psychological Orientation, the original results particularly highlight creativity and long-term vision. The finding therefore shifts attention from simply asking whether entrepreneurs have access to technology toward understanding the entrepreneurial orientations associated with their willingness to engage with technological change.

The significant relationship between Technology Adoption and Digital Economy participation provides the second part of the model. Technology adoption can be viewed as a mechanism connecting entrepreneur-level characteristics with wider participation in technology-enabled economic activity. However, because the data are cross-sectional, this relationship should be interpreted as an association rather than evidence that technology adoption causally produces economic outcomes.

5. Contribution, Implications, and Limitations

The study makes three contributions. First, it provides a more differentiated individual-level explanation of technology adoption by distinguishing **entrepreneurial readiness, psychological orientation, and motivation** rather than treating entrepreneur characteristics as a single dimension. Second, the results identify psychological orientation as the only one of the three antecedent constructs significantly associated with Technology Adoption in the estimated model. Third, the model connects individual entrepreneurial characteristics with Digital Economy participation through Technology Adoption.

These findings have practical implications for entrepreneurship development. Programs designed to encourage technology adoption may need to complement improvements in technological access and technical skills with initiatives that encourage creativity, opportunity recognition, proactive behaviour, and longer-term entrepreneurial thinking. The findings therefore support a more entrepreneur-centred approach to technology adoption.

This perspective is also relevant to the conference's broader discussion of entrepreneurship, technological transformation, inclusion, and sustainable economic development. The study does **not** claim to measure

environmental or green entrepreneurship directly. Rather, its contribution lies in showing how human and behavioural dimensions may support entrepreneurs' participation in technology-enabled economic transformation.

Several limitations should be acknowledged. The GEM APS data are cross-sectional and based primarily on self-reported responses, preventing causal interpretation and potentially introducing response bias. The operationalisation of Technology Adoption and Digital Economy is also constrained by the indicators available in GEM 2020. Finally, the analysis focuses on Indonesia, limiting direct generalisation to other national contexts. Future studies could incorporate longitudinal observations and more direct measures of digital technologies and economic outcomes, as well as environmental and social dimensions of sustainable entrepreneurship.

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FULL PAPER · S3.2 · ONLINE SESSION 3

Digital Readiness for Green Ventures in South Africa

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ABSTRACT

The transition to a green economy in African emerging markets increasingly depends on digital tools from green fintech and carbon-tracking platforms to digitally enabled resource-efficiency and market-access solutions making a firm's digital readiness a precondition for green venture creation and scaling, not only a driver of conventional innovation. This paper asks a targeted question- is South Africa digitally ready for green ventures? We address it by synthesising evidence from two rigorous empirical studies in South Africa: one on how digital orientation and digital capabilities drive digital innovation in the financial services sector (n = 228 firms), and another on antecedents of blockchain technology adoption in an African FinTech context (n = 93), and by reading their findings through the emerging literature on green entrepreneurship and green financial technology. Neither source study measured green ventures directly, so we are explicit that this paper is a conceptual and evidence-based extension rather than a direct test; it uses the demonstrated strength of South African firms' digital orientation, digital capabilities, and openness to blockchain adoption where a clear relative advantage exists as a diagnostic base rate for the digital readiness a green venture would need, and proposes testable propositions for future green-venture-specific research. The evidence suggests that South African financial-sector firms show strong underlying digital orientation and capabilities and adopt new technology readily once its benefits are demonstrated, both prerequisites for green fintech, digital monitoring and verification, and resource-efficiency technologies; but this readiness has not yet been evidenced in green ventures themselves, and translating it into green outcomes will depend on demonstrating the relative advantage of specifically green digital tools. The framework is grounded in dynamic capabilities theory, technology adoption theories (Diffusion of Innovation and the Technology Acceptance Model), and the green entrepreneurship literature within an African emerging-market context. We discuss implications for green venture founders, managers, and policymakers, and outline directions for future research that would test these propositions directly against green ventures.

Keywords: Digital readiness; Green ventures; Digital capabilities

Introduction

Digital transformation is radically reshaping industries worldwide by enabling new forms of innovation, efficiency, and business models. In emerging markets across Africa, digital technologies offer a chance to leapfrog legacy development pathways, but many firms face challenges such as limited infrastructure, scarce digital skills, and uncertain institutional support (World Bank Group, 2024; Swartz et al., 2023). Even so, digital readiness- a firm's preparedness to adopt and exploit digital technologies is increasingly seen as a key factor for competitive success and innovation capability in these contexts (Sutter et al., 2019; Pingali et al., 2023).

The digital readiness of a firm can be described as a multidimensional construct that includes a strategic commitment to digital innovation (digital orientation) and a bundle of digital capabilities (technology infrastructure, skills, processes) that enable the effective use of digital tools and data (Vial, 2019; Khin & Ho, 2018). In tandem, the firm's willingness to adopt new technologies informed by perceived benefits (e.g., relative advantage of the technology) and organizational readiness is crucial for turning digital opportunities into actual innovations (Rogers, 2003; Oliveira & Martins, 2011). However, existing research is fragmented, often focusing either on internal digital capabilities or on external technology adoption factors in isolation. There is a gap in

understanding how these elements interact, especially in African emerging markets, where digital transformation may follow different trajectories due to contextual constraints.

Green ventures whose core value proposition is environmental, such as renewable energy, circular-economy, and climate-smart agriculture businesses are central to South Africa's just transition away from a carbon-intensive economy, but their creation and scaling depend heavily on digital tools: green fintech platforms for climate and impact finance, blockchain-based monitoring, reporting and verification (MRV) systems for carbon credits and supply-chain traceability, digital marketplaces that connect green producers to buyers, and data-driven tools for resource efficiency (Li, Hoang, Tien, & Shamansurova, 2025; Wali, Kareem, & Çelebi, 2025). A green venture that cannot mobilise these digital tools is at a structural disadvantage, which means a country's or a sector's underlying digital readiness is itself a precondition for an efficient green venture creation, not merely a generic driver of innovation (Singh, Kumar, & Dana, 2025). Yet direct evidence on the digital readiness of green ventures specifically is scarce in the African literature, even as evidence on digital readiness in mainstream sectors has grown.

This paper addresses that evidence gap by synthesising findings from two recent, rigorous studies in a South African context neither of which examined green ventures directly and reading them through the emerging literature on green entrepreneurship and green financial technology, to ask what they imply for South Africa's digital readiness for green ventures. The authorial continuity across the two source papers and the present paper further strengthens the basis for this synthesis. Because the same author was involved in both original studies and in the development of the current paper, the underlying data, methodological assumptions, and contextual insights were available when translating those findings into the green-venture context. Given that South Africa’s economy is smaller and more concentrated than many advanced economies, it is reasonable to draw carefully from credible evidence generated in adjacent financial-services and FinTech settings, provided the limits of that transfer are made explicit. On this basis, the two rigorous source papers are used not as direct evidence on green ventures themselves, but as credible empirical foundations from which the viewpoints and propositions of this paper are derived. One study (Urban & Mateyo, 2025) examined the effects of digital orientation, digital capabilities, and entrepreneurial culture on digital innovation in 228 South African financial service firms. The other study (Urban & Mbeki, 2022) explored antecedents of blockchain adoption intentions in a sample of 93 South African FinTech firms, identifying relative advantage as a critical factor driving adoption intent. Financial services and FinTech are not green ventures, but they are the sector most likely to supply green ventures with the digital and financial infrastructure green fintech, blockchain-based carbon and impact tracking, digital lending that green ventures need; their digital readiness is therefore a meaningful, if indirect, indicator of the digital foundation available to green ventures in South Africa. By integrating these perspectives with the green entrepreneurship literature, we investigate how digital readiness (digital orientation and capabilities) and technology adoption readiness (perceived relative advantage of new technologies) jointly bear on South Africa's capacity to digitally enable green ventures.

Our research question is: Is South Africa digitally ready for green ventures, and how do digital readiness and technology adoption readiness together contribute to the innovation capability that green ventures would need? We propose that digital orientation and capability prepare firms to exploit digital opportunities (directly fostering innovation) and simultaneously enhance the firm’s ability and willingness to adopt new digital technologies (indirectly unlocking further innovation potential via those adoptions) both of which are prerequisites for the digital tools (green fintech, blockchain MRV, digital marketplaces) that green ventures rely on. We develop an integrated framework linking digital readiness to technology adoption to innovation capability, anchored in the dynamic capabilities view (Teece, 2016), technology adoption theories (Rogers, 2003; Davis, 1989), and the green entrepreneurship literature (Singh et al., 2025), within an emerging-market context. Throughout, we are explicit about the limits of this synthesis: our source studies establish general

digital readiness in South African financial services and FinTech, not green-venture-specific readiness, so our conclusions about green ventures are a reasoned, evidence-grounded extension that future research should test directly.

This paper is structured as follows. We first review pertinent literature on digital orientation, digital capabilities, technology adoption, and green entrepreneurship in emerging markets. We then describe our integrative synthesis approach and present the cross-study findings, culminating in a conceptual framework and research propositions aimed at South Africa's digital readiness for green ventures. The paper concludes with theoretical contributions, practical implications for green venture founders, managers, and policymakers aiming to bolster digital transformation for sustainable entrepreneurship in emerging markets, and suggestions for future research.

Conceptual Framework

Digital technologies are reshaping industries by enabling new products, processes, and business models (Vial, 2019). Yet emerging markets face unique constraints from limited broadband and electricity infrastructure to skills gaps and institutional voids that complicate the adoption of advanced digital tools (Mair & Martí, 2009; Sahay & Walsham, 2006). The concept of digital readiness refers to an organization's preparedness to engage in digital transformation. It comprises elements like the availability of IT infrastructure, the digital skills of employees, leadership support for digital initiatives, and a culture of innovation (Kane et al., 2015). High digital readiness is associated with better outcomes in terms of operations and innovation, as digitally ready firms can more rapidly integrate technological advances (Warner & Wäger, 2019). However, emerging markets show wide disparities in digital readiness a phenomenon captured by the term digital divide (World Bank Group, 2024). Still, the relative lack of legacy systems can allow emerging market firms to leapfrog by adopting cutting-edge technologies without being anchored to outdated infrastructure (Baller et al., 2016; Swartz et al., 2023).

Digital orientation (DO) is the strategic posture of a firm towards digital technology. It reflects a proactive commitment to applying digital tools for innovation, efficiency, and customer value (Khin & Ho, 2018). A strong digital orientation means that a firm's leadership prioritizes digital transformation and continuously seeks opportunities to leverage digital solutions (Hess et al., 2016). Digital capabilities (DC) are the specific skills, processes, and technological assets that enable a firm to effectively utilize digital technologies (Mikalef et al., 2019). In essence, digital capabilities are a subset of the firm's broader dynamic capabilities that allow it to adapt to technological change (Teece, 2016; Warner & Wäger, 2019). Under the resource-based view (RBV), digital capabilities constitute valuable, inimitable resources that can yield competitive advantage, particularly when they support the development of new products or services or more efficient processes (Barney, 1991; Wamba et al., 2017).

Both digital orientation and digital capabilities contribute to what we term digital readiness the internal preparatory state that allows a firm to innovate digitally. These constructs are complementary: a digital orientation provides strategic direction and impetus for digital projects, while digital capabilities provide the means to execute those projects. For example, a bank with a high digital orientation will invest in digital banking platforms, but without robust digital capabilities (talent in data analytics, IT architecture, and so on), it might struggle to implement those platforms effectively.

Innovation capability refers to a firm's ability to develop new or improved products, services, or processes. In a digital era, this often involves integrating digital technologies in novel ways termed digital innovation (Hund et al., 2021). Innovation capability is closely tied to dynamic capabilities, as firms must continuously reconfigure their resource base (including digital resources) to innovate successfully in a changing environment (Teece,

2016). For instance, to innovate using big data or AI, firms need the dynamic capability to acquire and integrate new data analytics competencies.

The interplay between digital orientation, digital capabilities, and innovation has been investigated in a South African study, which found that digital orientation and digital capabilities both have significant positive effects on digital innovation outcomes. That study suggests that an organization's strategic commitment to digital technology and its actual digital skills and infrastructure are key drivers of innovation performance. Interestingly, it found that the presence of an entrepreneurial culture did not further moderate these relationships, possibly because, with digitalisation being a relatively new phenomenon, concrete capabilities and strategies might matter more than general cultural orientation for short-term innovation success (Urban & Mateyo, 2025).

Even digitally ready firms must still choose which specific technologies to adopt. The Technology Acceptance Model (TAM) (Davis, 1989) and Diffusion of Innovation (DOI) theory (Rogers, 2003) identify several perceptions that shape whether an organization adopts a new technology. Among these, perceived relative advantage (the belief that a technology offers a superior benefit over current practice) is consistently a strong predictor of adoption decisions (Rogers, 2003). In an empirical study of FinTech companies in South Africa, relative advantage was indeed the significant factor driving firms' intentions to adopt blockchain technology above other potential predictors such as organizational support or perceived ease of use (Urban & Mbeki, 2022). This suggests that in emerging markets, where resources are scarce, firms will invest in new technologies primarily if they see a clear benefit, such as improved efficiency, cost savings, or new revenue streams.

Adopting new digital technologies (e.g., blockchain, AI, IoT) can itself be a catalyst for innovation. By enabling new processes or business models, technology adoption often directly leads to innovation outcomes (Cohen & Levinthal, 1990; Nambisan et al., 2017). For example, implementing a blockchain solution may enable novel financial products or services that were previously impossible, thus boosting a firm's innovation output. However, adoption requires organizational readiness factors such as top management support, IT infrastructure, and skills availability (Tornatzky & Fleischer, 1990). The blockchain study noted above was grounded in the Technology-Organization-Environment (TOE) framework and TAM, considering variables such as top management support, organizational readiness, and perceived usefulness or ease of use (Urban & Mbeki, 2022). The finding that relative advantage was the only significant predictor of adoption intention suggests that, in these emerging market firms, clear business value is the decisive factor: other potential drivers, such as a supportive management culture or formal readiness, may be necessary but not sufficient to spur actual adoption unless the technology's benefits are evident.

Bridging Internal Readiness and External Adoption

There is thus a vital connection between internal digital readiness and external technology adoption. A firm with a strong digital orientation and capabilities is likely to be more aware of and better positioned to exploit new technological opportunities, thereby perceiving greater relative advantage in adopting emerging technologies (Pingali et al., 2023; Wamba et al., 2017). Conversely, the adoption of a new digital technology can further enhance a firm's digital capabilities and trigger new rounds of innovation, by providing learning experiences and digital infrastructure that can be applied to other innovation projects (Blichfeldt & Faullant, 2021). This interplay is especially important in emerging markets, where constrained resources mean that careful prioritization of technology investments for maximum impact is crucial (Sutter et al., 2019).

While we have insights into how digital orientation and capabilities drive innovation, and separate insights into how perceived benefits drive technology adoption, these strands remain disconnected. Few studies examine how a firm's digital readiness influences its technology adoption decisions or, in turn, how technology adoption

updates its innovation capability particularly within South Africa. The integrative framework proposed in this paper attempts to bridge this gap, integrating the internal and external perspectives of digital transformation to better explain innovation capability in African emerging markets.

Digital Transformation for Green Ventures

A distinct but rapidly growing literature examines how digital transformation specifically enables green and sustainable entrepreneurship. Green fintech digital financial technology applied to climate and environmental outcomes, such as green lending platforms, carbon-credit marketplaces, and impact-tracking tools is emerging as a critical enabler of green venture finance in resource-constrained economies, helping close the financing gap that green entrepreneurs otherwise face (Li et al., 2025). In Southern Africa specifically, green financial technology combined with strong institutional quality has been linked to better environmental sustainability outcomes, underscoring those digital tools and governance context act together rather than in isolation (Wali et al., 2025). Blockchain, the specific technology examined in Study 2 below, is directly relevant here: its capacity for tamper-resistant record-keeping is widely used elsewhere for carbon-credit registries and supply-chain sustainability traceability, applications that depend on exactly the same organizational readiness and perceived relative advantage that drive blockchain adoption intentions in South African FinTech more broadly (Urban & Mbeki, 2022). More broadly, the green entrepreneurship landscape is shaped by digital access to markets, data-driven resource efficiency, and digital monitoring of environmental performance, alongside the more familiar drivers of green entrepreneurial intention such as environmental values and regulation (Singh et al., 2025).

Taken together, this literature implies that the digital orientation and digital capabilities measured and the blockchain-adoption readiness measured, are not incidental to green ventures they are close proxies for the underlying digital foundation (skills, infrastructure, and openness to new technology once its benefits are clear) that green fintech, carbon MRV, and green digital marketplaces all require. This is the logic on which the remainder of this paper builds: rather than assuming South Africa's general digital readiness translates automatically into green venture readiness, we treat it as a testable diagnostic and return to the question explicitly in the Findings and Discussion.

Methodology

To build the integrated framework, we adopt an integrative empirical synthesis approach (Hoon, 2013) using two complementary South African studies as evidence bases. The selection of these two studies was also methodologically appropriate because of the continuity between the authorial team, the underlying datasets, and the present synthesis. The same lead author was involved in the source studies and in the development of this paper, which meant that the original data structures, construct definitions, analytical assumptions, and contextual limitations were accessible during the synthesis process. This reduced the risk of superficial secondary interpretation and allowed the present paper to translate the findings into the green-venture context with greater methodological transparency. In a smaller economy such as South Africa, where dedicated green-venture datasets remain limited and sectoral ecosystems are closely connected, the use of credible adjacent evidence from financial services and FinTech is justified, provided that such evidence is treated as an indirect empirical foundation rather than as direct proof of green-venture readiness. By synthesizing their results, we can glean a holistic understanding of how digital readiness and technology adoption interplay to influence innovation.

Digital Orientation, Capabilities, and Innovation

This study examined how internal digital factors drive digital innovation in the South African financial services sector. It surveyed 228 respondents (managers, executives, and IT professionals) from firms listed on the Johannesburg Stock Exchange (JSE), specifically banks, insurance companies, and financial brokerages. The

study measured Digital Orientation (DO) with a 4-item scale (commitment to using digital technology for new solutions), Digital Capabilities (DC) with a 5-item scale (ability to acquire and master digital technologies), Digital Innovation (DI) with a 6-item scale (extent of new digital products or services), and an Entrepreneurial Organizational Culture (EOC) with a 7-item scale capturing risk-taking and support for digital initiatives.

Both digital orientation and digital capabilities had strong positive effects on digital innovation performance, confirming Hypotheses 1 and 2. However, contrary to expectations, an entrepreneurial culture did not significantly moderate (enhance) these relationships; Hypotheses 3 and 4 were not supported. The authors suggest that cultural shifts might be longer-term, and that immediate innovation in the sector was driven primarily by concrete digital strategies and capabilities. The model explained a substantial portion of variance in digital innovation ($R^2 \approx 49\%$), indicating the high importance of DO and DC in achieving innovation outcomes (Urban & Mateyo, 2025).

Blockchain Adoption Antecedents

This study explored factors influencing intention to adopt blockchain technology among 93 FinTech firms in South Africa. The theoretical framework drew on multiple models (Technology Organization Environment, Technology Acceptance Model, Theory of Planned Behaviour, Diffusion of Innovation) to examine variables such as organizational readiness, perceived usefulness and ease of use (TAM factors), subjective norms (TPB), and perceived relative advantage (DOI) as predictors of the dependent variable, blockchain adoption intention. Data were collected via a survey targeting decision-makers in FinTech companies listed on, or associated with, the JSE.

Among the various hypothesised antecedents, perceived relative advantage of blockchain emerged as the primary significant predictor of adoption intentions. This suggests that firms were most influenced by the expected benefits of blockchain technology (e.g., improved efficiency, security, or cost savings) in forming intentions to adopt. The influence of other factors, such as organizational readiness and classic TAM variables, was either secondary or non-significant. The authors highlight that blockchain adoption rates remain low in South Africa and emphasize the importance of clearly demonstrating the value proposition of new technologies to spur uptake (Urban & Mbeki, 2022).

Table 1

Summary Comparison of the Two Source Studies

Dimension	Study 1: Digital Orientation, Capabilities & Innovation (Urban & Mateyo, 2025)	Study 2: Blockchain Adoption Antecedents (Urban & Mbeki, 2022)
Sector / context	Financial services (banks, insurers, brokerages) listed on the JSE	FinTech firms listed on, or associated with, the JSE
Sample	228 managers, executives, and IT professionals	93 FinTech decision-makers
Theoretical grounding	Dynamic capabilities view	TOE framework, TAM, Theory of Planned Behaviour, Diffusion of Innovation
Key constructs	Digital Orientation (DO), Digital Capabilities (DC), Entrepreneurial Organizational Culture (EOC), Digital Innovation (DI)	Organizational readiness, perceived usefulness, perceived ease of use, subjective norms, perceived relative advantage, Blockchain Adoption Intention
Key finding	DO and DC significantly increase DI ($R^2 \approx 49\%$); EOC did not moderate the DO/DCDI relationships	Perceived relative advantage is the only significant predictor of adoption intention; other TOE/TAM/TPB factors were non-significant
Role in integrated framework	Internal digital readiness	External technology-adoption readiness

Together, these studies cover internal digital readiness (Study 1) and external technology adoption readiness (Study 2). By coding their results and themes, we identified overlapping constructs: digital orientation and capabilities from Study 1 correspond to a firm's general digital-evolution readiness, while relative advantage

and adoption intention from Study 2 represent specific decision-making about adopting an emerging digital technology.

Our integrative analysis focuses on how digital readiness factors might influence or complement technology adoption decisions, and how both internal and external factors feed into innovation outcomes. We deliberately selected these studies for integration because they share a common context (South Africa, an African emerging market), a focus on organizational-level adoption of digital technology, and quantitative, cross-sectional survey methods with hypothesis testing.

To synthesise, we first extracted each study's hypotheses, constructs, and findings (see summary above in Table 1). We then identified a conceptual chain linking them: digital orientation and capabilities (Study 1) can heighten the perceived relative advantage of new technologies (Study 2), thereby increasing technology adoption, which in turn leads to further digital innovation. In the sections that follow, we present the integrated findings and propose a unified framework and propositions that capture this chain, bridging the micro-level adoption insight with the broader innovation perspective.

Findings

Combining the evidence from the two studies yields a clearer picture of how digital readiness and technology adoption together fuel innovation in South Africa's emerging market.

Digital Orientation and Capabilities Drive Digital Innovation

Study 1 demonstrates that a strong digital orientation (DO) and developed digital capabilities (DC) significantly enhance digital innovation performance. Digital orientation an organization's strategic inclination to pursue digital solutions appears to stimulate proactive engagement with new digital projects and an openness to change, making it more likely to generate novel digital products or processes. Simultaneously, having robust digital capabilities, such as IT skills, agile development processes, and data analytics competencies, provides the means to execute on digital initiatives, converting ideas into implemented innovations. The South African financial firms with higher DO and DC had markedly higher digital innovation outputs than peers with lower digital readiness. This aligns with global findings that digitally mature firms innovate more effectively (Kane et al., 2015; Mikalef et al., 2019). Intriguingly, an entrepreneurial culture (broadly, a risk-taking and innovative mindset within the firm) did not further amplify the DO/DC effect in that context. The immediate takeaway is that concrete strategic focus and skills or infrastructure matter enormously for fostering digital innovation, even more so than general cultural orientation, especially in a rapidly digitizing sector such as financial services (Urban & Mateyo, 2025).

Perceived Relative Advantage Fuels Technology Adoption Intentions

Study 2 zeroes in on the specific case of blockchain technology adoption and finds that perceived relative advantage is the critical motivator for adoption intention. Firms are more likely to adopt an emerging digital technology when they clearly see how it outperforms existing solutions in efficiency, cost, security, or other significant dimensions (Rogers, 2003). In the South African FinTech firms studied, those with high perceived relative advantage of blockchain were significantly more inclined to plan adoption. Conversely, other potential drivers, such as organizational support or readiness, did not show up as significant in driving intention. This implies that, in these contexts, even if a company has leadership support or technical infrastructure, it will not move to adopt a new technology unless its benefits are compelling and well understood.

This finding underscores that evidence of value is paramount for technology uptake in emerging markets. It resonates with technology adoption literature: perceived usefulness (akin to relative advantage) is often the strongest predictor of adoption, sometimes outweighing other factors (Davis, 1989; Venkatesh et al., 2003).

Moreover, it suggests that technology vendors and evangelists should emphasize concrete advantages, such as cost savings and new revenue opportunities, when promoting innovations in emerging economies.

Digital Readiness and Perceived Advantage: Two Sides of the Adoption Coin

While Study 2 did not explicitly measure digital orientation or capability, we can infer their influence. Firms with higher digital orientation and capabilities are likely better positioned to appreciate, and realize, the relative advantages of new technologies. A digitally oriented firm actively scans for new technology opportunities and can more easily envision how blockchain (or AI, and so on) would integrate with its strategy, thereby perceiving greater relative benefits from adoption (Lucia-Palacios et al., 2014; Pingali et al., 2023). Similarly, a firm with strong digital capabilities can implement blockchain more effectively, lowering perceived risk and complexity factors that otherwise hinder adoption (Tornatzky & Fleischer, 1990; Rogers, 2003). In short, digital readiness may heighten perceived relative advantage and reduce perceived barriers to adoption, making adoption more likely.

Technology Adoption as a Catalyst for Innovation Capability

When a firm proceeds with adopting an innovative technology, this itself becomes a stepping-stone to further innovation. For instance, the adoption of blockchain can enable new fintech products (smart contracts, decentralized finance services) that were previously not feasible; such products would count as digital innovations for the adopting firm. In this way, technology adoption can intermediate between digital readiness and realized innovation outcomes digital-ready firms adopt more advanced technology, which then leads to greater innovation capability. This dynamic is supported by absorption and diffusion theories: firms adept at absorbing new knowledge (Cohen & Levinthal, 1990) and diffusing innovations internally (Rogers, 2003) can turn external technologies into home-grown innovations.

Toward an Integrated Digital Innovation Framework

Bringing together these insights, we propose an integrated digital innovation framework (Figure 1) for African emerging markets. The framework shows how digital readiness (encompassing digital orientation and capabilities, potentially shaped by organizational factors such as culture) influences digital innovation both directly and indirectly via technology adoption. In turn, successful adoption of new technologies feeds back to further enhance the firm's digital capabilities and innovation potential, creating a reinforcing cycle.

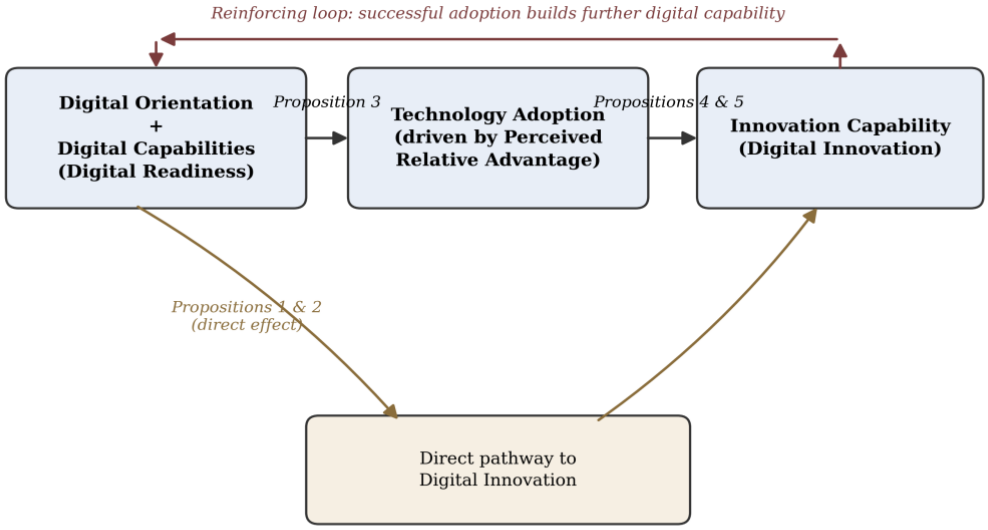


Figure 1. Integrated Digital Innovation Framework: digital readiness (digital orientation and digital capabilities) drives innovation capability both directly and indirectly through technology adoption, with a reinforcing feedback loop from adoption back to digital capability.

In the framework, digital readiness (digital orientation, digital capabilities, and supportive organizational context) gives a firm the capacity and strategic will to pursue digital projects. Technology adoption decisions, such as adopting blockchain or AI, are primarily triggered when the firm perceives a high relative advantage of the technology and has the readiness to implement it. Innovation capability is manifested in digital innovation outputs: new products, processes, and business models enabled by digital technology. The framework suggests a reinforcing loop: as digital-ready firms adopt new technologies, these technologies in turn become part of their capabilities, further improving digital readiness and seeding subsequent innovations.

Is South Africa Digitally Ready for Green Ventures?

Reading the above findings against the green entrepreneurship and green fintech literature (Li et al., 2025; Wali et al., 2025; Singh et al., 2025) allows us to answer the research question directly, with appropriate caution. On the positive side, three findings transfer reasonably well to the green venture context. First, the strong, significant effects of digital orientation and digital capabilities on digital innovation indicate that South African financial-sector firms already possess the underlying strategic commitment and technical skills base data analytics, IT infrastructure, agile development that green fintech and carbon-tracking ventures would draw on, whether built in-house or accessed through partnerships. Second, the finding that relative advantage, rather than organizational support or ease of use, is what actually moves South African firms to adopt a new technology is directly transferable: it implies that green ventures and green-tech vendors will succeed to the extent that they can demonstrate concrete, quantifiable benefits cost savings from resource efficiency, verifiable carbon revenue, access to green-labelled markets rather than relying on environmental values alone. Third, the reinforcing loop between technology adoption and further innovation capability suggests that once a green venture successfully adopts one digital tool, such as a blockchain-based traceability system, it is better positioned to adopt further green-digital tools, compounding its readiness over time.

On the cautionary side, none of this evidence was generated on green ventures themselves: Study 1 sampled mainstream banks, insurers, and brokerages, and Study 2 sampled FinTech firms adopting blockchain for financial, not environmental, purposes. We cannot rule out that green ventures which are often younger, smaller, and more resource-constrained than the JSE-listed and FinTech firms sampled here face additional barriers not captured in either study, such as thinner access to capital, weaker links to green-technology vendors, or a less developed green-fintech ecosystem than the general FinTech ecosystem these studies describe. Our answer to the research question is therefore a qualified yes: the evidence is consistent with South

Africa having a digitally ready base in the sectors most likely to serve green ventures, but this readiness has not yet been demonstrated in green ventures directly, and whether it translates into actual green venture creation and scaling depends on whether green-specific digital tools can demonstrate the same clear relative advantage that drove blockchain adoption intentions in Study 2.

Discussion and Conclusion

This integrative framework contributes to the literature by merging internal and external perspectives of digital innovation in emerging markets.

First, it extends the dynamic capabilities and RBV view by explicitly incorporating digital orientation as a strategic factor and digital capabilities as a dynamic resource that drive innovation. Our synthesis of Study 1 corroborates that digital orientation, and capabilities are key enablers of innovation, consistent with dynamic capability theory's emphasis that firms must continuously adapt and reconfigure their resources in the face of technological change. We thus provide empirical backing, from a South African setting, for the notion that digital-oriented strategies and skills are crucial micro-foundations of innovation capability (Teece, 2016; Khin & Ho, 2018).

Second, by integrating technology adoption theory, we highlight that innovation capability in emerging markets is not just about what resources a firm has internally, but also about how effectively it can incorporate external technological innovations. Study 2 shows that even well-resourced firms base their adoption decisions on clear expected advantages. Our framework marries this with the digital readiness concept, implying that internal readiness and external adoption are two intertwined facets of innovation capability. This is a novel combination: existing research typically examines either internal IT capability (Mithas et al., 2011; Mikalef et al., 2019) or technology adoption constructs (Oliveira & Martins, 2011; Baker, 2012) in isolation. By linking them, we argue that digital-ready firms not only innovate more but also adopt new technology more readily, and that adoption further drives innovation.

Third, our framework explicitly targets a South African context, where mainstream innovation and technology adoption models can behave differently. For example, our integrated perspective suggests that organizational culture's impact on digital innovation might be weaker in the short term than expected, possibly because immediate priorities lie in building tangible capabilities and demonstrating return on investment on digital projects a nuance likely specific to contexts where digital transformation is nascent and must justify itself through clear benefits. Similarly, our focus on relative advantage aligns with the idea that in resource-scarce settings, pragmatic value trumps hype when it comes to adopting new technology, as shown by Study 2's results on blockchain adoption.

Overall, the integrated model contributes a more holistic understanding of innovation capability in emerging markets. It suggests that a confluence of internal readiness and external adoption factors is necessary for sustained innovation. In doing so, it responds to calls from scholars for bridging the gap between digital transformation (internal focus) and innovation diffusion (external focus) in developing economies (Swartz et al., 2023; Hornuf et al., 2025).

Fourth, and specific to the Digital Transformation for Green Ventures track, this paper contributes an evidence-grounded answer to a question the green entrepreneurship literature has so far addressed mostly in general or aspirational terms: what does existing digital-readiness evidence actually imply for a country's capacity to digitally enable green ventures? By explicitly mapping digital orientation, digital capabilities, and technology-adoption readiness onto the requirements of green fintech, blockchain-based MRV, and digital green marketplaces (Li et al., 2025; Wali et al., 2025; Singh et al., 2025), we offer a template that other emerging-

market researchers could apply to their own general digital-readiness evidence, rather than waiting for green-venture-specific datasets to be collected from scratch.

The findings emphasize that founders and managers building green ventures and the mainstream financial and FinTech firms that supply them with digital and financial infrastructure should prioritize building digital readiness as a foundation for green innovation. This means:

- **Strengthening digital orientation:** Leaders should deliberately champion digital initiatives in their strategy, ensuring that digital transformation is an integral part of the company's vision and goals. This might involve setting up dedicated innovation teams, digital "centres of excellence", or including digital KPIs in strategic plans.
- **Investing in digital capabilities:** Allocation of resources to upgrade IT infrastructure and to hire or train employees in digital skills (e.g., data analytics, software development, cybersecurity) is essential. Study 1 shows that such investments pay off in terms of innovation outcomes. Even in an environment with scarce skills, partnerships with technology vendors, consultants, or universities can bolster a firm's digital capabilities.
- **Assessing and communicating relative advantage:** When considering new technologies, such as adopting a blockchain-based carbon-tracking solution or an AI-driven resource-efficiency platform, managers should rigorously analyse and quantify the potential benefits (e.g., cost savings, verifiable carbon revenue, access to green-labelled markets) to make the case for adoption clear. Our analysis of Study 2 indicates that unless the benefits are tangible and significant that is, the relative advantage is high organizations may remain hesitant to adopt new technology, and this applies as much to green digital tools as to any other. Managers should therefore pursue pilot projects or demonstrations that concretely show the gains from new digital technologies; these proofs-of-concept can facilitate internal buy-in and fast-track adoption.
- **Integrating adoption with green innovation goals:** Adoption of cutting-edge technology should not be viewed as an end, but as a means to innovate, including toward environmental outcomes. Managers building or supplying green ventures should ensure that technology implementations are closely tied to green innovation objectives, such as developing carbon-tracking products, resource-efficient processes, or green digital marketplaces. This might involve cross-functional collaboration for instance, IT teams working with sustainability and product development teams to leverage a new technology's capabilities into green, market-facing innovation.

Policy Implications and Ecosystem Considerations for Green Ventures

For policymakers and ecosystem builders, such as industry associations and development agencies working on South Africa's green transition, the integrated framework suggests focusing on both capability building and creating awareness of green-technology benefits:

- **Capability building:** Programs that support digital skill development, provide access to digital infrastructure (e.g., through public-private partnerships or incentives for networking and cloud services), and encourage knowledge-sharing among firms (digital innovation hubs, incubators) will raise overall digital readiness levels in the economy, including among green ventures. The emphasis should be not just on basic IT training, but also on fostering advanced digital capabilities (e.g., data science, AI engineering, blockchain for carbon MRV) that are directly tied to green innovation outcomes.
- **Demonstrating the value of green digital technologies:** Governments and development agencies can help orchestrate pilot projects or sandboxes that allow firms to experiment with emerging green technologies, such as blockchain-based carbon-credit registries or IoT-enabled resource monitoring, in a

controlled environment, generating local success stories. Such demonstration projects help reduce uncertainty and highlight relative advantages to a broader business audience, thereby catalysing wider adoption. For instance, showcasing how blockchain can verify carbon credits or cut transaction costs in green supply chains could spur more businesses to explore similar solutions.

- **Bridging institutions:** Strengthening linkages between knowledge institutions and industry can facilitate technology transfer relevant to green ventures. In our integrated perspective, academic support, such as research mobilisation, was important for new venture creation (academic spin-offs) in the African context. Policies that encourage collaboration between green-technology start-ups, universities, established financial-services and FinTech firms, and government can accelerate both the development of digital capabilities and the practical application of green digital technologies.

Research Propositions. Based on our integrated framework, we propose the following testable propositions:

- **Proposition 1:** Green ventures with a stronger digital orientation will be more likely to develop environmentally focused products, services, and business models that advance South Africa's green economy. (Rationale: A strategic commitment to digital technologies enables green entrepreneurs to identify and exploit opportunities in renewable energy, circular economy solutions, sustainable agriculture, green fintech, and carbon-tracking markets, thereby aligning digital innovation with the national green agenda.)
- **Proposition 2:** Green ventures possessing more advanced digital capabilities will achieve higher levels of green innovation performance. (Rationale: Digital infrastructure, data skills, platform capability, and analytics capacity allow green entrepreneurs to measure environmental impact, improve resource efficiency, verify sustainability claims, and scale low-carbon solutions more effectively.)
- **Proposition 3:** Digital readiness will positively influence green ventures' adoption of green-enabling digital technologies, including green fintech platforms, blockchain-based monitoring, reporting and verification systems, digital marketplaces, and resource-efficiency tools. (Rationale: Digitally ready green ventures are better able to recognise the environmental and commercial value of new technologies and to implement them in ways that support decarbonisation, transparency, and sustainable enterprise growth.)
- **Proposition 4:** The perceived relative advantage of green digital technologies will be a critical predictor of their adoption by South African green ventures. (Rationale: Green entrepreneurs operating in resource-constrained environments are more likely to adopt technologies when the benefits are clear, measurable, and linked to both environmental outcomes and business value, such as lower energy use, reduced waste, verifiable carbon revenue, regulatory compliance, or improved access to green finance.)
- **Proposition 5:** The adoption of green-enabling digital technologies will mediate the relationship between digital readiness and green innovation performance. (Rationale: Digital readiness equips ventures to adopt appropriate technologies, while adoption turns that readiness into practical green outcomes by enabling cleaner production, credible impact measurement, circular business models, and scalable climate-responsive services.)
- **Proposition 6:** Green ventures whose founders or management teams combine entrepreneurial orientation with digital capability will be better positioned to mobilise green entrepreneurship opportunities in South Africa. (Rationale: Green entrepreneurship requires both opportunity recognition and the capacity to operationalise environmental solutions; when entrepreneurial intent is supported by digital tools and skills, ventures are more able to convert sustainability challenges into viable market offerings that support the green transition.)

- **Proposition 7:** Green digital adoption will generate a reinforcing capability cycle in which successful technology use strengthens future green venture readiness, innovation, and scaling. (Rationale: Once a green venture successfully applies a digital tool, such as carbon MRV, resource-monitoring software, or a green-finance platform, it accumulates data, skills, credibility, and market access that can support additional green innovations and contribute to a wider ecosystem for sustainable entrepreneurship.)

Limitations and Future Research

The integrated framework should be viewed as a starting point for further empirical exploration, and this is especially true of its central claim about green ventures. The two source studies are both cross-sectional and neither sampled green ventures: Study 1 surveyed mainstream financial-services firms and Study 2 surveyed FinTech firms adopting blockchain for financial purposes, so every statement in this paper about green ventures is an extension of that evidence through the green entrepreneurship literature, not a direct measurement, and Propositions 6 and 7 above should be read as the paper's explicit invitation to close that gap. Longitudinal research could also better capture how digital readiness and adoption capabilities co-evolve and influence growth over time, for example by tracking green ventures through their digital transformation journeys. Our synthesis is further limited to two studies by the same research group in one country (South Africa); future research could test our propositions with dedicated green-venture samples across multiple African countries or other emerging markets, drawing on recent multi-country evidence on digital readiness and FinTech adoption (Pingali et al., 2023; Hornuf et al., 2025) and on the green entrepreneurship and green fintech literature (Li et al., 2025; Wali et al., 2025; Singh et al., 2025), to verify generalizability. Moreover, while we focused on corporate-level factors, there may be important environmental factors, such as regulatory quality, access to green finance, internet infrastructure, or the availability of external partners, that moderate these relationships, in line with the Technology-Organization-Environment framework. Addressing these factors, and collecting primary data on green ventures themselves, could produce a richer and more directly evidenced model of digital innovation ecosystems for green ventures in South Africa.

Conclusion

This paper set out to answer a targeted question: is South Africa digitally ready for green ventures? By reading two rigorous studies of digital orientation, digital capabilities, and blockchain adoption in South African financial services and FinTech through the lens of the green entrepreneurship and green fintech literature, we arrive at a qualified yes. Digital readiness the combination of a proactive digital strategy and robust digital capabilities directly propels firms to innovate, and enables them to adopt cutting-edge technologies, including green ones, when clear benefits exist, which in turn further amplifies their innovation capacity. South African financial-sector firms already demonstrate the underlying digital orientation, capabilities, and technology-adoption behaviour that green fintech, blockchain-based carbon tracking, and digital green marketplaces would draw on. What remains untested is whether that general readiness converts into green venture creation and scaling once green-specific technologies are put in front of green entrepreneurs a question this paper's propositions are designed to make directly testable.

For South African green ventures and the financial and FinTech firms that support them, the message is clear: developing a strong digital orientation and capability base is not a luxury but a necessity for participating in the green transition. At the same time, green venture founders and managers should critically evaluate new technologies and pursue those with obvious, demonstrable relative advantages, as successful adoption of such technologies can unlock new green innovation pathways. Policymakers and ecosystem stakeholders can support this process by investing in digital infrastructure, green-technology skill development, and demonstration projects that reduce uncertainty around new green digital technologies.

In conclusion, our integrated framework emphasizes that the journey to green venture readiness in emerging markets is twofold: it requires building internal digital readiness for the digital era and actively engaging with external green-technology opportunities. By doing both, and by testing the propositions this paper proposes against evidence collected directly from green ventures, South Africa can turn a general digital readiness that currently sits mostly in mainstream financial services into a driver of sustained green innovation and competitive advantage for its green venture economy.

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FULL PAPER · S3.3 · ONLINE SESSION 3

From Digital Possibilities to Green Ventures: A Dynamic Capabilities Framework for Digital–Green Transformation in Jordanian SMEs

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ABSTRACT

Purpose: Digital technologies are widely promoted as enablers of sustainable entrepreneurship, yet access to technology does not by itself produce environmental change in small and medium-sized enterprises (SMEs). This paper explains how, and under what conditions, digital transformation becomes green practice in Jordanian SMEs, an emerging-economy setting characterised by severe energy and water constraints and a business population dominated by SMEs.

Method: The study is a theory-building conceptual paper based on an integrative review reported in line with the PRISMA 2020 flow structure. Four structured searches run on 4 October 2026 returned 38 records, of which 7 were included, and these were combined with 27 known theoretical, empirical and policy sources. The synthesis draws on dynamic capabilities theory, digital transformation research, sustainable entrepreneurship and green management literature, and Jordanian empirical and policy evidence. No primary data were collected.

Findings: The synthesis yields five findings. First, digital technologies are necessary but indeterminate for green outcomes, because identical tools produce different environmental results. Second, sensing, seizing and reconfiguring operate in SMEs largely through owner-manager routines, which makes them the conversion mechanism between technology and transformation. Third, green practices form a portfolio with different digital dependencies, ordered along a visibility, efficiency, redesign and circularity sequence. Fourth, digitalisation can trigger rebound effects unless green digital governance is in place. Fifth, resource scarcity acts as a sensing trigger, while finance, skills and institutional support shape how far the pathway proceeds. These findings are integrated into a framework, a typology of four capability-based archetypes, and nine testable propositions with measurement guidance.

Originality and contribution: The paper separates technologies, capabilities, transformation, practices and outcomes; introduces rebound effects and green digital governance as boundary conditions; and offers a sequenced, context-specific research agenda for Jordan and comparable economies. Implications are drawn for SME managers, green entrepreneurs and policy makers who design ecosystem support.

Relevance to the conference theme: The paper addresses digital transformation for green ventures and links it to sustainable entrepreneurship, policy and institutional support mechanisms.

Keywords: digital transformation; dynamic capabilities; green practices; sustainable entrepreneurship; Jordanian SMEs

1. Introduction

Sustainable entrepreneurship is commonly understood as the discovery and exploitation of opportunities that create economic value while preserving the natural environment (Dean & McMullen, 2007; Shepherd & Patzelt, 2011). Digital technologies are increasingly presented as part of the infrastructure for such ventures. Sensors and analytics make resource use visible, platforms coordinate suppliers and customers, and digital tools lower the cost of experimenting with new processes and business models (Nambisan, 2017; Nambisan et al., 2019). For small and medium-sized enterprises (SMEs), which typically face limited managerial capacity, finance and specialist skills, the promise is attractive and the external pressure to act on environmental issues is growing.

The sustainability benefits of digitalisation are, however, far from automatic. Digital transformation is not the same as technology adoption. It is a process in which digital technologies trigger changes in organisational properties and value-creation paths (Vial, 2019; Verhoef et al., 2021; Hanelt et al., 2021). Whether that change is directed towards environmental ends depends on what managers notice, what they commit resources to, and which routines they redesign. Digital tools can also raise energy demand and induce rebound effects that offset efficiency gains (Lange et al., 2020). Recent reviews of SME digital transformation and sustainable development report a fragmented evidence base and call for clearer explanations of mechanisms and contextual conditions (Philbin et al., 2022; Le et al., 2026; Yesufa & Fields, 2026).

Jordan is a pertinent setting for this question. More than 90% of Jordanian businesses are reported to be SMEs (Ta'Amnha et al., 2024). A 2016 World Bank programme document describes the country as importing roughly 97% of its energy needs and as one of the most water-scarce countries in the world (World Bank, 2016). Green growth has been a national priority since 2017, and the Green Growth National Action Plans 2021–2025 cover agriculture, energy, tourism, transport, waste and water (Ministry of Environment & Global Green Growth Institute [GGGI], 2020). Empirical work on Jordanian manufacturing SMEs has begun to connect green product and process innovation with firm performance and to show that technological turbulence conditions this relationship (Ta'Amnha et al., 2024). A survey-based study in Jordan (n = 100 employees) reports a positive relationship between digital transformation and economic, social and environmental performance (Al-Negrish & Almomani, 2024), but it does not examine the organisational mechanism. What remains under-specified is the organisational pathway through which digital transformation becomes a broader set of green practices, and the conditions under which that pathway succeeds or stalls.

This paper develops a dynamic capabilities framework to address that gap. It is guided by three research questions. RQ1: What organisational mechanism converts digital technologies into digital transformation and then into green practices in SMEs? RQ2: How do green practices differ in their digital dependence and capability requirements, and in what sequence do SMEs tend to adopt them? RQ3: Which contextual and boundary conditions, including resource scarcity, rebound effects and ecosystem support, shape this pathway in Jordanian SMEs?

The paper makes four contributions. First, it separates five elements that are often conflated, namely digital technologies, dynamic capabilities, digital transformation, green practices and sustainability outcomes, and it positions dynamic capabilities as the conversion mechanism between them. Second, it identifies SME-specific microfoundations of sensing, seizing and reconfiguring that are centred on owner-managers and ecosystem partners. Third, it conceptualises green practices as a portfolio with a typical adoption sequence and derives four capability-based archetypes. Fourth, it introduces resource scarcity as a trigger and rebound effects as a boundary condition, and it converts the framework into nine propositions with measurement guidance. The paper responds to the SEFGEN 2026 themes of digital transformation for green ventures, sustainable entrepreneurship, and policy and ecosystem support.

The remainder of the paper is organised as follows. Section 2 sets out the conceptual framework. Section 3 describes the method. Section 4 reports the findings of the conceptual synthesis together with the resulting framework and propositions. Section 5 discusses contributions, implications, limitations and a research agenda, and concludes.

2. Conceptual Framework

2.1 Dynamic capabilities and sustainability-oriented renewal

Dynamic capabilities theory explains how firms sustain performance when conditions change. Teece et al. (1997) defined dynamic capabilities as the ability to integrate, build and reconfigure internal and external

competences, and Eisenhardt and Martin (2000) described them as identifiable routines through which firms alter their resource base. Teece (2007) decomposed the construct into sensing opportunities and threats, seizing opportunities through investment and organisational commitment, and transforming or reconfiguring the asset base. Two refinements matter for SMEs. Winter (2003) cautioned that dynamic capabilities should be distinguished from ad hoc problem solving, which implies that a one-off digital project is not in itself evidence of capability. Helfat and Peteraf (2015) stressed managerial cognitive capabilities as microfoundations, which is especially relevant where decision-making is concentrated in an owner-manager.

The theory has been extended to environmental questions. Hart (1995) argued that capabilities such as pollution prevention, product stewardship and sustainable development can underpin competitive advantage under environmental constraint. Dangelico et al. (2017) adopted a sustainability-oriented dynamic capability perspective to examine green product innovation in manufacturing firms. In the digital domain, Warner and Wäger (2019) described digital transformation as an ongoing process of strategic renewal supported by digital sensing, seizing and transforming capabilities. Taken together, these streams suggest that capabilities are the missing link between having digital tools and using them for environmental ends. They have, however, seldom been combined into a single pathway for SMEs.

2.2 Digital technologies and digital transformation

Following Verhoef et al. (2021), this paper distinguishes digitisation (converting analogue information into digital form), digitalisation (using digital technologies to change processes) and digital transformation (organisation-wide change in business models and value creation). Digital technologies, including the Internet of Things (IoT), artificial intelligence (AI), cloud computing, analytics, platforms and traceability tools, are treated as enabling resources. Digital transformation is the organisational change that follows when these resources are integrated into routines, structures and decision-making (Vial, 2019; Hanelt et al., 2021).

This distinction prevents technological determinism and explains why the environmental consequences of digitalisation are contingent. The same sensor network can support systematic energy reduction in one firm and sit unused in another. Digital infrastructure also consumes energy and generates electronic waste, and efficiency gains can be offset by rebound effects (Lange et al., 2020).

2.3 Green practices as a portfolio

Green practices are recurring organisational and operational activities through which firms reduce environmental impact or improve resource productivity. They differ from green innovation, which may be an outcome or one type of practice, and from environmental performance, which describes results rather than activities. Six domains are distinguished: visibility and monitoring; resource and energy efficiency; waste reduction; green process innovation; green supply-chain practice; and circular practice. The domains draw on research on operational green practices and green supply-chain management (Zhu & Sarkis, 2004), on the relationship between Industry 4.0 technologies, lean practices and green supply chains (Di Giovanni & Cariola, 2021), and on conceptualisations of the circular economy as a system built on reduction, reuse and recovery (Kirchherr et al., 2017; Geissdoerfer et al., 2017).

The domains differ in complexity. Monitoring depends mostly on the firm itself, whereas supply-chain and circular practices require coordination with external partners. This difference is used in Section 4 to develop an expected adoption sequence.

2.4 SMEs, sustainable entrepreneurship and the owner-manager

SMEs are not scaled-down large firms. Research on small businesses and the environment has long noted that SMEs' environmental behaviour is shaped by limited resources and by the values and attention of owner-

managers (Revell et al., 2010). Sustainable entrepreneurship research adds that environmental problems and market imperfections can be sources of opportunity (Dean & McMullen, 2007; Shepherd & Patzelt, 2011). In this light, sensing and seizing in SMEs are entrepreneurial acts, and digital technologies can lower the cost of recognising and acting on green opportunities. The capacity to do so, however, is unevenly distributed and depends on skills, finance and external support.

2.5 The Jordanian context

Three features of the Jordanian context are relevant. First, the business population is dominated by SMEs, which are reported to account for more than 90% of businesses (Ta'Amnha et al., 2024), so capability constraints are widespread rather than exceptional. Second, energy and water scarcity are structural: a 2016 World Bank programme document describes heavy dependence on energy imports and severe water scarcity (World Bank, 2016). These conditions make resource inefficiency salient and costly. Third, green growth is an explicit policy priority, with sector action plans for agriculture, energy, tourism, transport, waste and water (Ministry of Environment & GGGI, 2020).

Jordanian empirical research on green innovation in SMEs is developing, with evidence from manufacturing SMEs linking green product and process innovation to performance and showing the moderating role of technological turbulence (Ta'Amnha et al., 2024). Such studies tend to focus on single sectors and on innovation as the outcome. A cross-sector view of green practices as a portfolio, and of the capabilities that convert digital resources into those practices, is therefore a complement rather than a substitute.

3. Method

3.1 Research design

The study is a theory-building conceptual paper based on an integrative review (Torraco, 2005; Snyder, 2019). The identification, screening and inclusion of sources are reported following the PRISMA 2020 flow structure (Page et al., 2021), adapted to a conceptual review. The conceptual design follows guidance that emphasises explicit constructs, mechanisms and boundary conditions (Whetten, 1989; Jaakkola, 2020). PRISMA is used as a reporting guide for transparency. The paper does not claim to be a full systematic review, because the searches were limited in the ways described in Section 3.2 and in the limitations.

3.2 Identification of sources

Sources were identified through two routes. Route A comprised four structured searches run on 4 October 2026 with a general web search engine that returns publisher, repository and aggregator pages. The query strings, which combined the concepts of digital transformation, dynamic capabilities, green or circular practices, sustainable entrepreneurship, SMEs and Jordan, are listed in Table 1. For each query, all results returned on the first page were recorded. Route B was theory-led identification of known sources: foundational works on dynamic capabilities, digital transformation, sustainable entrepreneurship and green management, Jordanian policy and empirical documents, and recent reviews, supplemented by backward citation chasing.

Because the search engine is not a bibliographic database and only first-page results were recorded, Route A cannot be regarded as exhaustive. The query strings in Table 1 should be re-run in Scopus and Web of Science when the review is extended.

Table 1. Search log for Route A (searches run on 4 October 2026)

Query string	Records returned	Duplicates removed	Non-scholarly pages removed	Distinct records screened	Included
Q1: digital transformation green practices SMEs dynamic capabilities	10	2	2	6	2
Q2: Jordan SMEs digital transformation sustainability green	10	3	4	3	1
Q3: digital technologies circular economy SMEs sustainable entrepreneurship emerging economies	9	0	2	7	2
Q4: SMEs digital transformation sustainable development systematic literature review	9	6	0	3	2
Total	38	11	8	19	7

Source: Author's search log.

3.3 Screening, eligibility and inclusion

Inclusion criteria were: (i) a peer-reviewed journal article or an official policy document; (ii) a focus on SMEs or small firms, or on entrepreneurship in emerging economies; and (iii) relevance to at least one link of the proposed pathway, namely digital technologies or transformation, dynamic capabilities, green or circular practices, or sustainability outcomes. Records were excluded when they were web pages without scholarly status (news items, blogs and aggregator listings), when they could not be verified as peer-reviewed journal articles (preprints, repository records, book chapters and conference papers), or when the population or outcome fell outside the scope (for example large listed firms, financial sustainability only, or green finance). Foundational theory works were retained regardless of date.

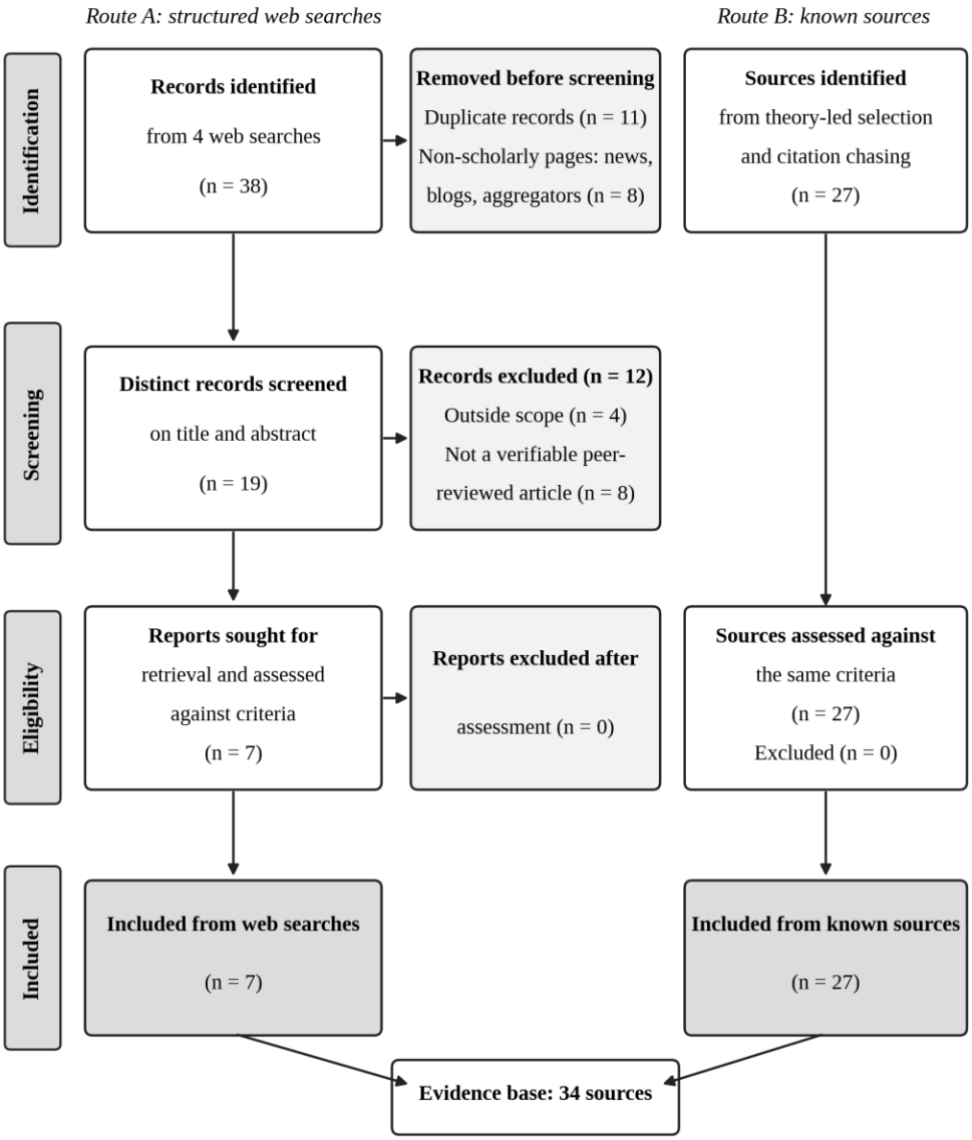


Figure 1. PRISMA 2020-style flow of records and sources Source: Author's search log, 4 October 2026.

Figure 1 shows the flow of records. The searches returned 38 records, of which 19 were removed before screening (11 duplicates and 8 non-scholarly pages). Of the 19 distinct records screened on title and abstract, 12 were excluded (4 for scope and 8 for publication type), and the remaining 7 reports were retrieved and met the criteria. Two of these seven (Philbin et al., 2022; Le et al., 2026) were also known sources and are counted once, under Route A. Route B contributed 27 further theoretical, empirical and policy sources, which were assessed against the same criteria and retained. In total, 34 sources form the evidence base, and nine additional works are cited for methodological guidance only. Screening was performed by a single reviewer, and no formal quality-appraisal instrument was applied. Quality was addressed through the inclusion criteria and by noting sample and design limitations where relevant.

3.4 Analytical procedure

Analysis proceeded in four steps. First, constructs were clarified and separated, so that technologies, capabilities, transformation, practices and outcomes each had a distinct definition. Second, an evidence matrix recorded, for each source, the technology or capability process discussed, the transformation or practice domain, the outcome, the context and any boundary condition. Third, patterns across the matrix were consolidated into findings by asking which mechanisms recurred, where evidence conflicted, and which conditions explained the conflict. Fourth, propositions were derived under a fixed rule: each proposition had to

specify a mechanism, a boundary condition and an observable indicator, so that it could be tested empirically. The resulting framework was finally checked against the Jordanian context for coherence.

3.5 Transparency and quality

The findings are products of interpretive synthesis and should be read as theoretically grounded propositions rather than verified relationships. Transparency was supported by reporting the search strings, dates and record counts, by separating evidence from inference in the text, and by stating where illustrations are plausible applications rather than documented cases. Limitations of the search and screening procedure are reported in Section 5.5. Future work can extend the search to Scopus and Web of Science with independent dual screening.

4. Findings

This section reports five findings from the synthesis, presents the integrated framework and typology that follow from them, and states the propositions.

4.1 Finding 1: Digital technologies are necessary but indeterminate

The literature converges on the view that digital technologies widen the set of environmental actions available to a firm without determining which of them are taken. IoT, analytics, AI and platforms supply information, prediction and coordination that make resource use more visible and operations more controllable (Nambisan et al., 2019; Di Giovanni & Cariola, 2021). Studies of energy-intensive enterprises associate digital transformation with green innovation (Liu & Zhang, 2024), and evidence from developing-economy SMEs points in a similar direction. The size of these effects and the conditions under which they appear nevertheless vary considerably, and recent reviews attribute this variation to differences in definitions, contexts and mediating mechanisms (Le et al., 2026; Yesufa & Fields, 2026).

Evidence from neighbouring Gulf economies points the same way. Among 386 SMEs in the United Arab Emirates, green digital transformation was associated with sustainable development performance both directly and through green knowledge sharing and green dynamic capabilities (Belyamani et al., 2025). Among 409 Omani SMEs, digital sensing, capturing and transforming capabilities were positively related to digital transformation, which was in turn strongly related to environmental performance, while transformation cost weakened that link (Rahman et al., 2025). Both studies are survey-based, so they support the proposed mechanism without isolating its sequence or the rebound risk.

The implication is that technology adoption is an inadequate explanatory variable for green outcomes. A technology becomes environmentally productive only when a firm identifies where it can reduce resource use, commits the resources to deploy it there, and changes routines so that the information it generates is acted upon. This is precisely the sequence of sensing, seizing and reconfiguring.

4.2 Finding 2: Dynamic capabilities operate through owner-manager routines and act as the conversion mechanism

Across sources, sensing, seizing and reconfiguring emerge as the organisational processes that convert digital resources into transformation and, subsequently, into green practice (Teece, 2007; Warner & Wäger, 2019; Alajmi, 2026). In SMEs, however, these processes are less formal and more person-centred than in large firms. Table 2 summarises the microfoundations that the synthesis identifies.

Table 2. Dynamic capability processes and their SME microfoundations

Process	SME microfoundations	Green-directed expression	Digital illustration
Sensing	Owner-manager scanning of energy, water and material cost signals; supplier and customer environmental requirements; peer and network learning; interpretation of data dashboards	Identifies resource-intensity hotspots and green market or compliance opportunities that digital tools could address	Smart-meter or sensor readings reviewed against a baseline; market information from online platforms
Seizing	Owner-manager commitment; phased and low-cost investment; selection of vendors and partners; access to grants or finance	Commits scarce resources to pilots tied to a stated environmental and cost target	Subscription-based cloud tools instead of capital purchases; partnership with a technology provider or incubator
Reconfiguring	Redesign of routines, roles and supplier relations; staff training; data-to-action procedures; retirement of old practices	Embeds monitoring, optimisation and circular routines so that gains persist after the pilot	Maintenance schedules driven by analytics; procurement rules that use traceability data

Source: Developed by the author based on the reviewed literature.

Because the processes are thinly distributed, SME capability is vulnerable to key-person dependence. Documenting review routines, delegating responsibilities for data and defining criteria for approving digital investments convert personal alertness into organisational capability, which is consistent with the distinction between capability and ad hoc problem solving (Winter, 2003) and with the emphasis on managerial cognition (Helfat & Peteraf, 2015). The finding has a measurement implication: capability should be assessed through observable routines, such as regular review of resource data and named responsibilities, in addition to perceptual scales.

4.3 Finding 3: Green practices form a portfolio with different digital dependencies and a typical sequence

The six green-practice domains differ in the technologies they use, the capabilities they emphasise and the risks they carry (Table 3). Monitoring and efficiency rely heavily on sensors, meters and analytics and mainly require sensing and seizing. Waste reduction and green process innovation require changes to production routines and therefore draw more heavily on reconfiguring. Supply-chain and circular practices additionally require coordination with partners and markets, so they depend on ecosystem conditions that a single firm cannot control (Zhu & Sarkis, 2004; Di Giovanni & Cariola, 2021; Kirchherr et al., 2017). A bibliometric and content analysis of 92 publications found that SMEs are more interested in digital systems than in circular systems (Samadhiya et al., 2023), which is consistent with circular practice being reached later. Research on circular start-ups in an emerging economy likewise treats digital technology adoption as shaped by technological, organisational and environmental factors (Hajoary et al., 2024).

Table 3. Green-practice domains, enabling technologies and capability emphasis

Practice domain	Typical enabling technologies	Capability emphasis	Main failure or rebound risk
1. Visibility and monitoring	IoT sensors; smart meters; cloud dashboards	Sensing	Data are collected but not acted upon
2. Resource and energy efficiency	Analytics; automated controls; predictive maintenance	Sensing and seizing	Savings offset by higher volume or added digital load
3. Waste reduction	Process analytics; inventory and demand forecasting; AI-assisted quality control	Seizing and reconfiguring	Local optimisation that shifts waste elsewhere
4. Green process innovation	Digital design and simulation; automation; cleaner process control	Reconfiguring	High upfront cost; skills gaps
5. Green supply-chain practice	Platforms; shared data systems; traceability tools	Reconfiguring and ecosystem coordination	Partner non-participation; data-sharing concerns

Practice domain	Typical enabling technologies	Capability emphasis	Main failure or rebound risk
6. Circular practice	Marketplaces for reuse and recovery; product-tracking systems	Reconfiguring and ecosystem orchestration	Thin markets; regulatory and logistics barriers

Source: Developed by the author based on the reviewed literature.

These differences suggest an expected sequence along which SMEs progress: visibility, then efficiency, then waste reduction and process redesign, then supply-chain coordination, and finally circular practice. The logic is cumulative. Monitoring creates the baseline data that efficiency measures need; efficiency savings create the slack that funds redesign; redesign builds the reconfiguring capability that partner-based practices demand. The sequence is a theoretical expectation, not an empirical regularity, and firms may enter at different points, for example when a large buyer imposes supply-chain requirements.

4.4 Finding 4: Rebound effects make green digital governance a boundary condition

Research on digitalisation and energy consumption shows that the net effect of information and communication technology on energy demand is not uniformly negative, because efficiency gains can be offset by rebound and growth effects (Lange et al., 2020). Three channels are relevant for SMEs. Direct effects arise from the energy use and electronic waste of the digital infrastructure itself. Rebound effects arise when cost savings are reinvested in higher output or additional equipment. Displacement effects arise when optimisation in one process shifts waste or energy use elsewhere in the value chain.

The synthesis therefore treats green digital governance as a boundary condition on the pathway. Green digital governance refers to routines that set environmental targets for digital projects, track net resource intensity including the digital footprint, define equipment lifecycle and disposal rules, and decide explicitly how savings are reinvested. Without such routines, digital transformation may be efficient without being green.

4.5 Finding 5: Resource scarcity triggers sensing, and ecosystem support shapes how far the pathway proceeds

In Jordan, energy and water scarcity convert resource inefficiency into a salient and recurring cost (World Bank, 2016). The synthesis expects this to strengthen the sensing of efficiency opportunities, particularly in energy- and water-intensive activities such as agriculture, tourism accommodation, manufacturing and transport. Scarcity is therefore treated as a trigger that directs attention, not as a guarantee that action follows.

Whether sensing leads to seizing and reconfiguring depends on ecosystem conditions. Sensing is relatively inexpensive, whereas seizing requires finance and reconfiguring requires skills, time and often partners. Ecosystem support in the form of financing, skills programmes, institutional initiatives and networks should therefore matter most at the later transitions. Jordanian evidence that technological turbulence modifies the performance effects of green innovation (Ta'Amnha et al., 2024) indicates that the pace of technological change is itself part of the context in which SMEs build capability. Evidence from Oman that transformation cost weakens the link between digital transformation and environmental performance (Rahman et al., 2025) is consistent with the expectation that finance matters most at the later transitions.

4.6 The integrated framework and capability-based archetypes

Figure 2 integrates the findings. Digital technologies and dynamic capabilities interact: technologies create possibilities that capabilities select and exploit, and capabilities in turn shape which technologies

are acquired. Dynamic capabilities convert these resources into digital transformation, understood as organisational change in processes, routines, decision-making and value creation. Digital transformation enables a portfolio of green practices, which generates downstream sustainability outcomes. A learning

feedback loop returns outcomes to the capabilities. Resource scarcity acts as a trigger on sensing, rebound risk and green digital governance act as a boundary condition on the transformation-to-practice link, and SME and ecosystem conditions influence the whole pathway.

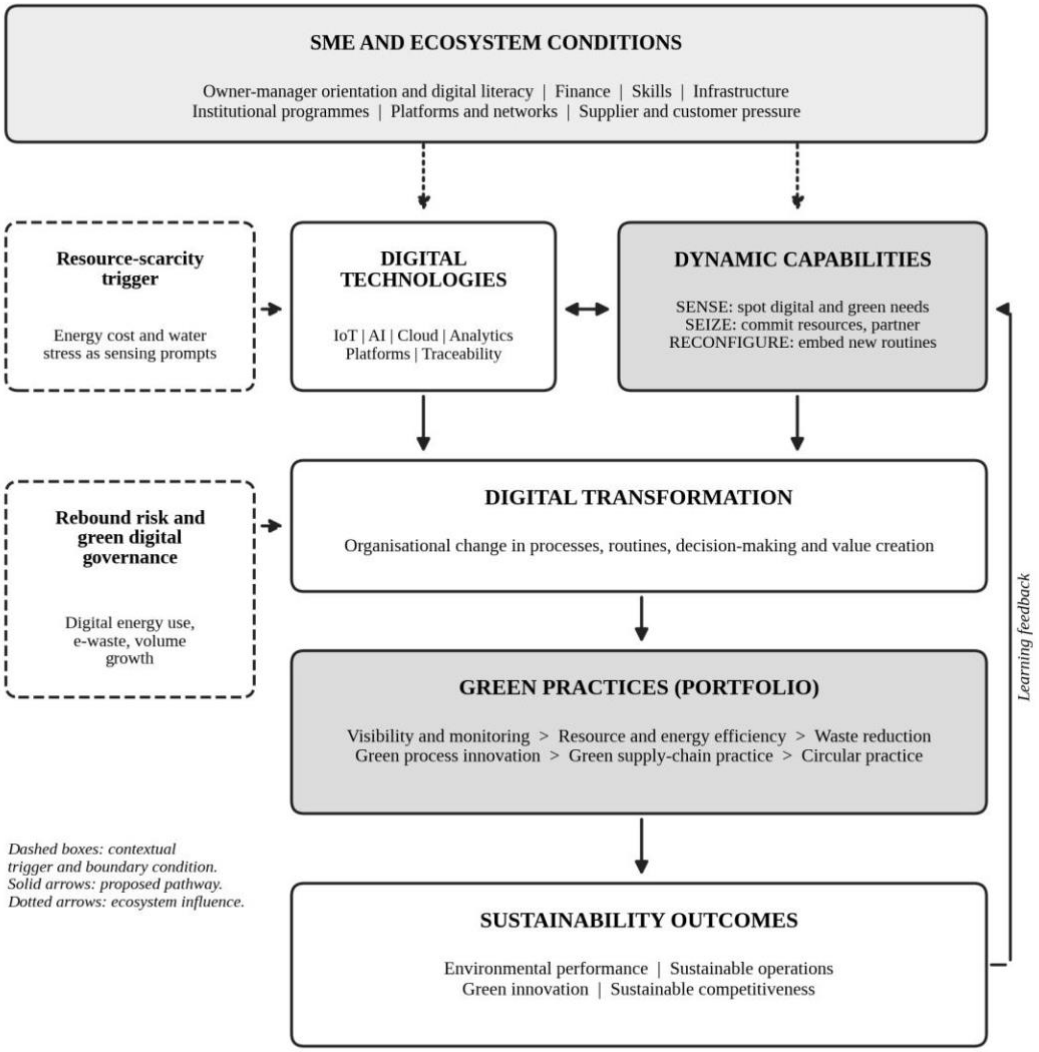


Figure 2. A dynamic capabilities framework for digital–green transformation in SMEs Source: Developed by the author based on the reviewed literature.

Combining capability profiles with transformation depth and practice domains yields four archetypes, summarised in Table 4. The archetypes are ideal types intended to guide empirical classification, for example through configurational analysis, and they are not a claim that every firm fits one category. They also indicate where support is most useful: tool adopters need sensing and routines, efficiency optimisers need reconfiguring and governance, green redesigners need finance and skills, and circular orchestrators need partners and market depth.

Table 4. Capability-based archetypes of digital–green transformation

Archetype	Capability profile	Transformation depth	Dominant green practices	Typical constraint
Tool adopters	Weak sensing of green opportunities; ad hoc seizing	Shallow: tools without routine change	Incidental	No data-to-action routine

Archetype	Capability profile	Transformation depth	Dominant green practices	Typical constraint
Efficiency optimisers	Strong sensing; selective seizing; limited reconfiguring	Moderate: process level	Monitoring, efficiency, waste reduction	Gains plateau; rebound risk
Green redesigners	Balanced sensing, seizing and reconfiguring	Deep: processes and decision routines	Green process innovation; supply-chain practice	Finance and skills for redesign
Circular orchestrators	Strong in all three, plus ecosystem coordination	Deep and inter-organisational	Circular and supply-chain practices with partners	Dependence on partners and market depth

Source: Developed by the author based on the reviewed literature.

4.7 Propositions

Table 5 states nine propositions. P4 is the core proposition: dynamic capabilities are the mechanism that converts digital transformation into green practice. P1 to P3 specify how each capability process contributes. P5 and P6 concern the portfolio, its sequence and its relationship to outcomes. P7 to P9 specify boundary conditions. Each proposition names a mechanism, a boundary and an indicator so that it can be tested.

Table 5. Propositions, mechanisms, boundary conditions and indicative measures

No.	Proposition	Mechanism and boundary condition	Indicative measurement
P1	SMEs with stronger environmental-sensing routines are more likely to deploy digital technologies at resource-intensity hotspots.	Sensing directs technology selection. Weaker where owner-manager attention is absorbed by survival pressures.	Baseline resource audits; share of digital investments linked to a stated resource target
P2	Seizing capability increases the likelihood that digital pilots become embedded processes.	Resource commitment and partnerships bridge pilot and routine. Conditional on access to finance.	Pilot-to-scale ratio; investment staging; partner use
P3	Reconfiguring capability strengthens the effect of digital transformation on green-practice adoption.	Routines convert data into action. Conditional on staff skills and assigned responsibility.	Review routines, thresholds and named owners of resource data
P4	Dynamic capabilities moderate the effect of digital transformation on green practices and partly mediate the effect of digital technologies on digital transformation.	Capabilities are the conversion mechanism between resources, change and action.	Multi-item sensing, seizing and reconfiguring scales plus routine indicators; digital transformation depth index
P5	Green-practice adoption follows a visibility, efficiency, redesign and circularity sequence; early domains depend more on digital transformation depth, later domains on reconfiguring and ecosystem support.	Rising complexity and interdependence across domains.	Practice inventory scored by domain; timing of adoption in longitudinal data
P6	Breadth and depth of green practices relate positively to sustainability outcomes with a lag, and shallow adoption yields weak outcomes.	Practice quality and time determine results. Moderated by measurement horizon.	Practice depth scores; objective resource-intensity and waste data

No.	Proposition	Mechanism and boundary condition	Indicative measurement
P7	Without green digital governance, the net environmental benefit of digital transformation is attenuated by rebound effects.	Digital energy use, e-waste and volume growth offset gains. Governance routines weaken this effect.	Net resource intensity; presence of target-setting, footprint tracking and reinvestment rules
P8	Exposure to energy and water cost pressure strengthens sensing of resource-efficiency opportunities and thereby the digital–green pathway, especially in resource-intensive sectors.	Price and scarcity signals make inefficiency salient. Sector resource intensity conditions the effect.	Utility cost share of expenses; sector; energy and water intensity
P9	Ecosystem support and owner-manager green orientation strengthen the pathway, and ecosystem support matters most for the seizing and reconfiguring transitions.	Finance, skills and networks lower the cost of costly transitions. Owner-manager orientation shapes all three processes.	Access to programmes, finance and training; owner-manager green orientation scale

Source: Developed by the author based on the reviewed literature.

4.8 Illustrative applications in Jordan's priority sectors

The following applications are plausible illustrations, not documented cases, and each requires empirical validation. In agriculture, where water is the binding constraint, sensor-based irrigation scheduling can make water use visible and support efficiency, but its value depends on whether growers sense water as a controllable cost, seize low-cost sensor solutions, and reconfigure irrigation routines accordingly. In tourism accommodation and manufacturing, sub-metering and load management can reveal energy hotspots, and the pathway then depends on whether managers assign responsibility for acting on the data. In waste and recycling, tracking and sorting data can support micro-enterprises that recover materials, and digital marketplaces can connect them with buyers, which is a step towards circular practice that depends on ecosystem depth. In transport and logistics, route and load optimisation can reduce fuel use, and green digital governance is needed to ensure that savings are not offset by increased volume.

5. Discussion and Conclusion

5.1 Discussion and theoretical contributions

The findings extend three bodies of work. First, studies that relate digital transformation directly to green innovation or environmental performance (Liu & Zhang, 2024) typically leave the organisational mechanism implicit. The framework makes it explicit by treating dynamic capabilities as the conversion mechanism and by separating transformation from practices and practices from outcomes. This also answers calls in recent reviews for clearer mechanisms and contextual conditions (Le et al., 2026; Yesufa & Fields, 2026). Survey evidence from Gulf SMEs already links digital capabilities to sustainability results (Belyamani et al., 2025; Rahman et al., 2025). The present framework adds the portfolio, the expected sequence and the rebound boundary condition, which those studies do not appear to examine. Second, dynamic capability research on sustainability, including work on green product innovation (Dangelico et al., 2017) and digital renewal (Warner & Wäger, 2019), has tended to treat the digital and the environmental separately. The framework combines them and specifies SME microfoundations centred on the owner-manager, in line with the emphasis on managerial cognition (Helfat & Peteraf, 2015).

Third, the framework complements Jordanian evidence on green innovation and SME performance (Ta'Amnha et al., 2024) by shifting attention from a single outcome to a portfolio of practices, and by identifying resource

scarcity as a context-specific trigger. The paper therefore makes four theoretical contributions: it separates five elements of the pathway and positions capabilities as the conversion mechanism; it specifies SME microfoundations of sensing, seizing and reconfiguring; it proposes a portfolio, sequence and archetype typology of green practices; and it introduces rebound effects and green digital governance as boundary conditions, alongside scarcity and ecosystem support as contextual moderators.

5.2 Implications for SME managers and green entrepreneurs

For managers and green entrepreneurs, the framework suggests three diagnostic questions before any digital investment. Which resource-intensity hotspot is the investment meant to address? Who owns the routine that turns the resulting data into action? How will net environmental effects, including the digital footprint, be tracked? Beginning with low-cost visibility pilots tied to a stated cost or resource target is consistent with the expected sequence, because it builds baseline data, demonstrates savings and develops the routines needed for later stages. Savings should be reinvested deliberately, since unmanaged reinvestment is the main route to rebound. Entrepreneurs building new green ventures can treat digital capability as part of the venture's design, rather than as a later add-on.

5.3 Implications for policy and ecosystem actors

For policy makers, incubators, technology parks, chambers and support programmes, the framework implies that digital and green support should be integrated rather than delivered in separate programmes. Support can be staged according to archetype: advisory and diagnostic services and small monitoring grants for tool adopters; training and governance guidance for efficiency optimisers; co-financing for process redesign for green redesigners; and shared platforms and market-building for circular orchestrators. Programme monitoring should record both digital progress and green practices, and it should distinguish practices from outcomes. Aligning such programmes with the sector action plans for agriculture, energy, tourism, transport, waste and water would connect digital policy with existing green growth priorities (Ministry of Environment & GGGI, 2020). The framework is silent on whether capability formation and access to ecosystem support differ for women-led and youth-led ventures. This is an important question for inclusive green entrepreneurship, and it should be addressed explicitly in future empirical work.

5.4 Research agenda and measurement

The propositions can be tested using complementary designs (Table 6). Survey-based models can test the conversion mechanism and boundary conditions across sectors, with attention to common-method bias and, where possible, objective resource-use data. Longitudinal case studies can trace how routines develop and how the sequence unfolds. Configurational methods can identify the archetypes and test whether different combinations of capabilities, transformation depth and ecosystem support lead to similar outcomes. Quasi-experimental designs can examine the effect of digital support programmes on net resource intensity, including rebound.

Table 6. Research designs for testing the framework

Design	Purpose	Data and unit of analysis	Analytical approach
Cross-sectional survey in priority sectors	Test P1 to P4 and P7 to P9	Owner-managers of SMEs in sectors named in national green growth plans; complemented by utility and production data where available	Partial least squares structural equation modelling with multi-group comparison by sector (Hair et al., 2019)
Longitudinal multiple case study	Trace routine development and the practice sequence (P2, P3, P5)	Repeated interviews, documents and resource-use records from SMEs at different maturity levels	Within-case and cross-case analysis (Eisenhardt, 1989; Eisenhardt & Graebner, 2007)

Design	Purpose	Data and unit of analysis	Analytical approach
Configurational analysis	Identify and validate archetypes (Table 4)	Calibrated survey and case data on capabilities, transformation depth and practices	Fuzzy-set qualitative comparative analysis (Fiss, 2011)
Panel or quasi-experiment	Test P6 and P7	Resource-use data before and after participation in a digital support programme, compared with non-participants	Difference-in-differences or event-study estimation

Source: Developed by the author.

5.5 Limitations

This study has several limitations. It is conceptual and does not test the propositions, so none of the relationships should be read as verified. The search route relied on a general web search engine, recorded only first-page results for four queries, and was screened by a single reviewer without a formal quality-appraisal tool. The PRISMA flow documents the process transparently, but the review is not exhaustive, and it is limited to English-language and accessible sources. Repeating the search in Scopus and Web of Science with dual screening is a priority. Jordanian evidence is still thin and concentrated in particular sectors and outcomes, so the framework relies partly on inference from other emerging economies. The sequence and archetypes are theoretical expectations that may differ in practice. Finally, empirical tests will need to address endogeneity, since firms with stronger capabilities may be more likely to digitalise and to adopt green practices for reasons unrelated to the pathway proposed here.

5.6 Conclusion

Digital technologies create environmental possibilities for SMEs, but they do not decide which possibilities are realised. This paper has argued that dynamic capabilities, exercised largely through owner-manager routines, are the mechanism that converts digital resources into digital transformation and then into a portfolio of green practices, and that rebound effects, resource scarcity and ecosystem conditions determine how far and how sustainably that conversion proceeds. The framework, the four archetypes and the nine propositions provide a structured basis for empirical research in Jordan and comparable emerging economies.

For practice, the central message is that digital investment becomes green only when it is attached to a specific resource problem, an accountable routine and a record of net effects. For policy, it is that digital and green support should be designed together and staged according to firms' capability profiles. Testing these claims in Jordanian SMEs, particularly in the sectors prioritised by national green growth plans, is the most immediate next step.

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FULL PAPER · S3.6 · ONLINE SESSION 3

Y-GREEN: A Multi-Level Framework for Inclusive Green Entrepreneurial Ecosystems through Digital Inclusion Orchestration

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ABSTRACT

This conceptual study develops the Y-GREEN framework, a multi-level model designed to advance inclusive green entrepreneurial ecosystems with a specific focus on youth and women. Existing ecosystem models remain largely age- and gender-neutral and treat digital platforms mainly as infrastructure rather than as active institutional support mechanisms. Drawing on recent secondary evidence from the Global Entrepreneurship Monitor, International Labour Organization, GSMA and World Economic Forum (2024–2026), the paper first establishes the persistent gaps in youth employment, women's entrepreneurial survival and digital inclusion that justify a new framework. It then integrates entrepreneurial ecosystem theory, institutional theory and social inclusion perspectives to propose a comprehensive multi-level model operating at macro (policy, green finance and cultural norms), meso (universities, technoparks, municipalities and support networks) and micro (individual competencies and barriers) levels. The central theoretical contribution is the introduction of the Digital Inclusion Orchestration Mechanism (DIOM), a novel meso-level process through which digital and AI-enabled platforms identify inclusion gaps, match youth and women entrepreneurs with tailored resources, and generate recursive feedback loops that strengthen both individual ventures and the broader ecosystem. Using a theory-building approach grounded in systematic synthesis of recent literature, the study derives six theoretically informed propositions. The Y-GREEN framework offers significant theoretical advancement by positioning digital orchestration as an active inclusion mechanism and provides practical guidance for universities, policymakers and support organisations seeking to design more inclusive green ecosystems for future generations.

Keywords: green entrepreneurial ecosystems; institutional support mechanisms; digital inclusion orchestration; youth entrepreneurship; women's inclusion; sustainable entrepreneurship

1. Introduction

The urgency of climate change, combined with persistent youth unemployment and gender gaps in entrepreneurial activity, has intensified scholarly and policy interest in green entrepreneurship as a dual pathway for environmental and social value creation (Cohen, 2006; Volkmann et al., 2021). Young people and women are frequently identified as critical actors in sustainability transitions, yet they continue to face structural barriers that limit their participation in green venture creation and scaling. These barriers include constrained access to finance, weaker professional networks, limited mentoring, digital skill deficits and cultural norms that undervalue their entrepreneurial agency (Brush et al., 2019).

Recent secondary data underscore the scale of the challenge. According to the International Labour Organization (2026), global youth unemployment stood at 12.4 per cent in 2025, equivalent to approximately 67 million young people aged 15–24, while the share of young people not in employment, education or training (NEET) reached 20 per cent, affecting more than 257 million individuals. At the same time, Global Entrepreneurship Monitor data show that women's early-stage entrepreneurial activity remains lower than

men's (approximately 10.7–12 per cent versus 13–14 per cent), and the women-to-men ratio in established business ownership falls to 0.69 (GEM, 2025). Women are 47–55 per cent more likely than men to exit businesses for family or personal reasons, indicating that current ecosystems support entry more effectively than survival and scaling (GEM, 2024/2025).

Digital inclusion gaps compound these disparities. The GSMA Mobile Gender Gap Report (2025) shows that women in low- and middle-income countries are still 14 per cent less likely than men to use mobile internet, leaving approximately 235 million fewer women online. Among women entrepreneurs, 45 per cent lack regular internet access despite high smartphone ownership, and 57 per cent report having experienced online harassment (Cherie Blair Foundation / World Economic Forum, 2025). These patterns demonstrate that digital platforms, if left unguided by inclusion-oriented design, risk reproducing rather than reducing existing inequalities.

Entrepreneurial ecosystem (EE) research has emerged as a powerful lens for understanding the interdependent conditions that enable productive entrepreneurship (Isenberg, 2010; Stam & van de Ven, 2021; Wurth et al., 2022). Sustainable entrepreneurial ecosystems (SEEs) extend this perspective by embedding environmental and social objectives into ecosystem design (Theodoraki et al., 2022). Recent systematic reviews confirm that research on SEEs has expanded rapidly since 2021, with growing attention to digital technologies, moral values, education and multi-stakeholder collaboration (Leendertse et al., 2025; Gregori et al., 2025). Nevertheless, most existing models remain largely gender- and age-neutral. They rarely specify the mechanisms through which ecosystems can deliberately reduce participation gaps for youth and women in the green domain.

Digital platforms and AI-enabled systems offer new possibilities for coordination and inclusion. Scholarship on digital entrepreneurship and platform ecosystems highlights the capacity of digital infrastructures to reduce search costs, enable matching and support continuous learning (Nambisan, 2017; Autio et al., 2018). Emerging work on ecosystem orchestration further emphasises the purposeful coordination of networks and resources by anchor organisations or digital intermediaries (Harima et al., 2024; Santos et al., 2025). Yet the literature still lacks a clear conceptualisation of how digital platforms can function as active inclusion mechanisms within green entrepreneurial ecosystems.

This paper addresses that gap by proposing the Y-GREEN framework—a multi-level model of inclusive green entrepreneurial ecosystems centred on youth and women. The framework's core theoretical novelty is the Digital Inclusion Orchestration Mechanism (DIOM). DIOM is conceptualised as a distinct meso-level process through which digital and AI-enabled platforms sense inclusion gaps, match under-represented entrepreneurs with tailored resources, enable capability development and generate recursive feedback that strengthens both ventures and the wider ecosystem. The purpose of the study is to develop a theoretically grounded multi-level framework that explains how green entrepreneurial ecosystems can be intentionally designed to support youth and women more effectively.

The contribution of the paper is threefold. First, it extends entrepreneurial ecosystem theory by integrating an explicit inclusion orientation and a digitally enabled orchestration mechanism. Second, it offers a set of theoretically derived propositions that can guide future empirical research. Third, it provides practical implications for universities, municipalities, technoparks, chambers of commerce and policymakers involved in building green entrepreneurship support systems. The remainder of the paper is organised as follows. Section 2 develops the conceptual foundations. Section 3 outlines the methodological approach. Section 4 presents the Y-GREEN framework, the DIOM, associated tables and research propositions. Section 5 discusses theoretical and practical implications, limitations and directions for future research.

2. Conceptual Framework

2.1 Entrepreneurial Ecosystems and the Turn to Sustainability

Entrepreneurial ecosystem theory conceptualises entrepreneurship as a system-level outcome shaped by interdependent elements, including policy, finance, culture, human capital, markets and support institutions (Isenberg, 2010; Stam & van de Ven, 2021). Early formulations focused primarily on high-growth, technology-oriented entrepreneurship. Subsequent work has broadened the lens to incorporate sustainability objectives, giving rise to the notion of sustainable entrepreneurial ecosystems (SEEs). SEEs are characterised by intentional efforts to align entrepreneurial activity with environmental stewardship, social equity and long-term economic resilience (Cohen, 2006; Theodoraki et al., 2022).

Recent bibliometric and systematic reviews document the rapid growth of SEE research after 2021. Leendertse et al. (2025) identify four main schools of thought: developing SEEs through digital technologies, moral values and education; theory, practice and implications of SEEs; comparative and empirical perspectives; and mapping SEEs while addressing social collaboration challenges. Gregori et al. (2025) synthesise the literature around the themes of values, transformation and boundaries, arguing for more integrative theorising. Other contributions examine the conditions required to evolve conventional ecosystems into sustainable ones (Bischoff, 2025) and the role of formal institutions, culture and resource endowments in supporting sustainable start-ups (Leendertse et al., 2025). Despite this progress, inclusion—particularly with respect to youth and women—remains under-specified in most SEE models.

2.2 Youth, Women, and the Inclusion Imperative

Youth entrepreneurship research highlights both the potential of young people as agents of innovation and the structural obstacles they face, including limited work experience, restricted access to formal finance and weak embeddedness in professional networks. Women's entrepreneurship scholarship has extensively documented gender-based disparities in resource acquisition, legitimacy and growth trajectories (Brush et al., 2019). When these two dimensions intersect with the green economy, additional barriers related to technical knowledge, sectoral networks and risk perception often intensify. Inclusive ecosystem approaches therefore require deliberate mechanisms that detect and address such barriers rather than assuming that general support structures will automatically reach under-represented groups.

Digital inclusion has emerged as a critical complementary agenda. Recent reports emphasise that digital tools and platforms can substantially expand opportunities for women entrepreneurs, yet persistent gaps in internet access, digital skills and online safety continue to constrain participation (World Economic Forum, 2025; ILO, 2025). Integrating digital inclusion into ecosystem design is therefore essential if youth and women are to participate fully in green entrepreneurship.

2.3 Digital Platforms and Ecosystem Orchestration

Digital platforms possess distinctive affordances for matching, scaling and continuous learning (Nambisan, 2017; Autio et al., 2018). In entrepreneurial ecosystems, platforms can reduce information asymmetries, lower coordination costs and enable personalised resource allocation. Scholarship on ecosystem orchestration has advanced understanding of how anchor organisations and intermediaries purposefully coordinate networks and resources to generate collective value (Harima et al., 2024; Santos et al., 2025). Orchestration involves sensing opportunities and gaps, mobilising actors, configuring resources and sustaining momentum over time.

What remains underdeveloped is a conceptualisation of orchestration that is explicitly oriented toward inclusion in the green domain. Most orchestration studies focus on innovation performance, network density or regional competitiveness. Fewer examine how digital platforms can be designed and governed to reduce

age- and gender-based participation gaps. This paper addresses that lacuna by theorising the Digital Inclusion Orchestration Mechanism (DIOM) as a core meso-level process within inclusive green entrepreneurial ecosystems.

3. Methodology

This study adopts a theory-building conceptual approach consistent with established guidelines for conceptual contribution in management and entrepreneurship research (MacInnis, 2011; Jaakkola, 2020). The research design rests on systematic synthesis of literature spanning entrepreneurial ecosystems, sustainable entrepreneurship, gender and youth inclusion, digital platforms and ecosystem orchestration. Sources include foundational works as well as recent contributions published between 2023 and 2026 that reflect the rapid evolution of the SEE field. Secondary statistical evidence from GEM, ILO, GSMA and the World Economic Forum is used solely to establish the empirical relevance of the research problem; no primary data were collected by the authors.

The paper constructs an integrative multi-level framework and derives propositions that specify expected relationships among its core elements. The resulting model is intended to serve as a foundation for subsequent empirical testing through qualitative case studies of green entrepreneurship support systems, multi-level quantitative analyses, or mixed-methods designs that examine the operation of digital inclusion mechanisms in practice.

4. Findings: The Y-GREEN Framework

4.1 Multi-Level Architecture

The Y-GREEN framework operates across three interconnected levels. At the macro level, green policies, regulatory frameworks, green finance instruments, carbon markets and cultural norms establish the broader enabling or constraining conditions for inclusive green entrepreneurship. At the meso level, universities, technoparks, incubators, chambers of commerce, municipalities, civil-society organisations and digital platforms provide concrete support structures and coordination mechanisms. At the micro level, individual youth and women entrepreneurs bring competencies, digital literacy, psychological capital and face specific barriers related to age, gender, resource access and legitimacy.

The framework posits that effective inclusive outcomes depend on coherent interactions across these levels rather than on isolated interventions at any single level. Macro-level policies shape the incentives and resources available to meso-level actors; meso-level organisations translate those resources into support programmes and digital infrastructures; micro-level experiences and outcomes, in turn, generate feedback that can inform policy learning and institutional adaptation.

4.2 The Digital Inclusion Orchestration Mechanism (DIOM)

DIOM constitutes the central theoretical novelty of the Y-GREEN framework. It is conceptualised as a meso-level process with four interrelated functions:

(1) Sensing: identifying inclusion gaps related to age, gender, geography and resource access through platform analytics, participation data and targeted diagnostics;

(2) Matching: connecting youth and women entrepreneurs with tailored resources—finance, mentors, markets, training and peer networks—via AI-enabled or algorithmically supported systems designed to reduce bias;

(3) Enabling: facilitating capability development, legitimacy building and confidence through structured mentoring, training modules and visibility mechanisms;

(4) Feedback: feeding performance, participation and outcome data back to macro-level policy actors and meso-level institutions so that programmes and platforms can be continuously improved. Unlike generic digital infrastructure, DIOM is defined by its explicit inclusion orientation and its recursive character. Successful matching and enabling reinforce ecosystem capacity, which in turn improves future sensing and matching. In this sense, DIOM functions as a dynamic capability of the ecosystem itself.

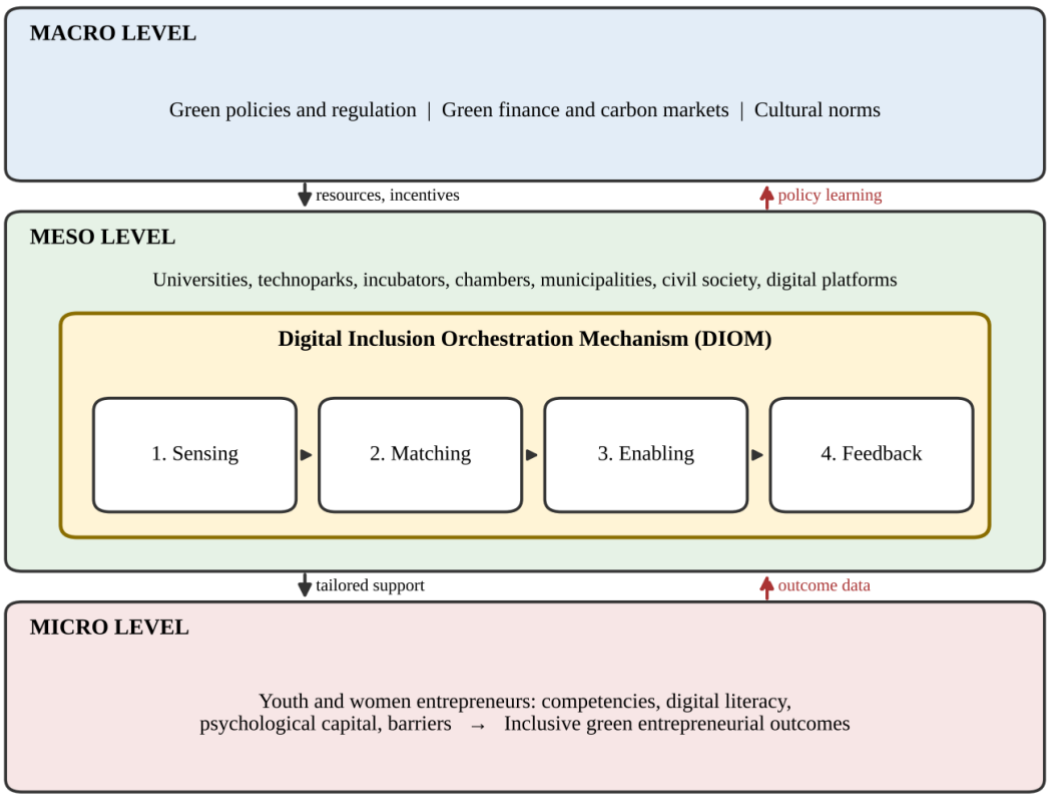


Figure 1. The Y-GREEN Multi-Level Framework and Digital Inclusion Orchestration Mechanism (DIOM) 4.3 Key Constructs Table 1 summarises the core constructs of the Y-GREEN framework and their definitions.

Table 1. Core Constructs of the Y-GREEN Framework

Construct	Definition
Macro-level conditions	Green policies, regulations, green finance instruments, carbon markets and cultural norms that shape the broader opportunity structure for inclusive green entrepreneurship.
Meso-level support structures	Universities, technoparks, incubators, chambers, municipalities, civil-society organisations and digital platforms that provide concrete resources, networks and coordination.
Micro-level actors	Youth and women entrepreneurs characterised by their competencies, digital literacy, psychological capital and the specific barriers they face.
Digital Inclusion Orchestration Mechanism (DIOM)	A meso-level process comprising sensing, matching, enabling and feedback functions that actively convert ecosystem resources into inclusive green entrepreneurial outcomes.
Inclusive green entrepreneurial outcomes	Venture creation, survival, growth and sustainability impact achieved by youth and women entrepreneurs within green sectors.

4.4 Research Propositions

Building on the multi-level architecture and the DIOM, the following propositions are advanced:

Proposition 1: The strength and coherence of macro-level green policy and inclusive finance frameworks are positively associated with the intensity and quality of meso-level support structures available to youth and women green entrepreneurs.

Proposition 2: The presence and effectiveness of DIOM positively moderate the relationship between meso-level ecosystem resources and micro-level opportunity recognition, venture creation and early growth among youth and women.

Proposition 3: Inclusion-oriented digital matching (a core function of DIOM) reduces gender- and age-related disparities in access to mentoring, finance, training and market opportunities within green entrepreneurial ecosystems.

Proposition 4: Successful micro-level green venture outcomes that are facilitated by DIOM generate positive feedback effects that strengthen meso-level institutional capacity and macro-level policy learning.

Proposition 5: Ecosystems that institutionalise DIOM as an explicit coordination mechanism will exhibit higher rates of inclusive green venture creation and scaling compared with ecosystems that treat digital platforms solely as generic infrastructure.

Proposition 6: The effectiveness of DIOM is enhanced when meso-level organisations combine digital matching capabilities with human-mediated mentoring and legitimacy-building support, rather than relying on automated systems alone.

Table 2. Summary of Research Propositions

No.	Proposition
P1	Macro-level green policy and inclusive finance → stronger meso-level support for youth and women.
P2	DIOM moderates the link between meso-level resources and micro-level opportunity recognition and venture creation.
P3	Inclusion-oriented digital matching reduces gender- and age-related access disparities.
P4	Micro-level success facilitated by DIOM generates positive feedback to meso and macro levels.
P5	Ecosystems that institutionalise DIOM achieve higher inclusive green venture outcomes.
P6	DIOM is more effective when digital matching is combined with human-mediated support.

5. Discussion and Conclusion

5.1 Theoretical Contributions

The Y-GREEN framework advances entrepreneurial ecosystem theory in three principal ways. First, it embeds an explicit inclusion logic focused on youth and women into the multi-level architecture of green ecosystems. Second, it elevates digital orchestration from a peripheral technological feature to a core meso-level mechanism with clearly specified functions (sensing, matching, enabling and feedback). Third, it theorises recursive feedback loops that link micro-level venture outcomes back to meso-level capacity and macro-level policy learning, thereby addressing calls for more dynamic and multi-level accounts of sustainable entrepreneurial ecosystems (Gregori et al., 2025; Leendertse et al., 2025).

By naming and defining the Digital Inclusion Orchestration Mechanism, the paper provides a precise conceptual instrument that future researchers can operationalise and test. This responds to recent arguments that orchestration research must move beyond general coordination toward more differentiated accounts of what is being orchestrated and for whom (Harima et al., 2024; Santos et al., 2025).

5.2 Practical and Policy Implications

For universities, technoparks, municipalities and chambers of commerce, the framework suggests that digital inclusion orchestration should be treated as a deliberate design objective rather than an incidental by-product of digitalisation. This implies investing in platform capabilities that can sense demographic and resource gaps, implement bias-aware matching and feed performance data into continuous improvement cycles. Human-mediated mentoring and legitimacy support remain essential complements to automated systems.

For policymakers, the model highlights the complementary roles of macro-level green finance, regulatory support and meso-level orchestration capacity. Inclusive green entrepreneurship is unlikely to scale if policy instruments are not matched by institutional mechanisms capable of translating those instruments into accessible opportunities for youth and women.

5.3 Limitations and Future Research

As a conceptual contribution, the paper does not provide empirical validation of the proposed relationships. The framework also abstracts from important contextual differences across national and regional settings. Future research should test the propositions through comparative case studies of green entrepreneurship support systems, multi-level quantitative analyses and process studies of digital platform orchestration in inclusive settings. Longitudinal designs would be particularly valuable for examining the recursive feedback loops central to DIOM. Research that examines intersectionality—how age, gender, class and geography jointly shape inclusion—would further enrich the model.

5.4 Conclusion

Building green entrepreneurial ecosystems that genuinely serve future generations requires more than the aggregation of existing support instruments. It requires deliberate multi-level design and active inclusion-oriented orchestration. The Y-GREEN framework and the Digital Inclusion Orchestration Mechanism offer a theoretically coherent starting point for such design efforts and for the empirical research needed to refine them. By placing youth, women and digital inclusion at the centre of green ecosystem theorising, the paper contributes to a more equitable and sustainable entrepreneurial future.

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FULL PAPER · S4.2 · ONLINE SESSION 4

Artificial Intelligence for Sustainable Public Parks: A Data-Driven Framework for Enhancing User Experience, Social Quality of Life and Urban Sustainability

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ABSTRACT

The public park manager is facing twin challenges of environmental performance and visitor experience and inequitable access to services. This paper proposes a conceptual approach to evaluating these outcomes simultaneously and identifying where AI can aid management decisions. Five interacting layers, the physical park, data collection, analytics, applications and governance and feedback, are provided by a critical narrative synthesis of selected literature. This framework ties the outcome indicators to measurement procedures, decision responsibilities and limitations in evidence. It distinguishes between direct operational measures and proxies for social outcomes and constructs that depend on participant-reported evidence. This illustration is of a retrospective nature, mapping conditions reported in a study conducted on Zamalek parks in Cairo in 2019 to possible monitoring and management responses, and is not an attempt to introduce new field data nor substantiate the effectiveness of AI. An exploratory AI analysis of nine sources from the public domain on Al-Andalus Garden reveals a focus on works and governance since 2019; no reported measures of outcomes; and conflicting basic facts. Based on a visual audit of 10 published photographs of the gardens, this project demonstrates that photographs can support physical aspects (paved routes: 8, heritage features: 8, seating: 3, signage: 0), but cannot confirm use, safety or inclusion. A hypothetical maintenance scenario is used to illustrate how an AI-assisted response might be compared with a conventional response. The Delphi-style expert appraisal of the framework is separated from subsequent field tests in a staged evaluation protocol, and a PRISMA-guided search protocol is provided to expand the evidence base. The contribution is a direct linkage among technical architecture, outcome measurement, and accountable decisions, building on previous work on smart-park issues that already acknowledge issues of inclusion and perception. Claims of effectiveness, cost savings or improved social quality of life will need to be tested empirically.

Keywords: artificial intelligence; smart parks; urban sustainability; social quality of life; user experience; IoT; urban green infrastructure; smart cities

1. Introduction

Public parks are among the most widely used and socially significant forms of urban infrastructure. They offer opportunities for physical exercise, informal social interaction, environmental control (such as urban heat mitigation, absorption of storm water, better air quality), and psychological restoration (Kaplan, 1995). The systematic reviews link urban green space to physical activity and health outcomes (Gianfredi et al., 2021), and to mental wellbeing, although the evidence is not yet sufficiently consistent to make direct planning decisions (Houlden et al., 2018). Meanwhile, cities are under increasing pressure to get parks and recreation services to operate more efficiently: budgets for parks and recreation are often limited compared to demand; visits to parks and recreation are spread over large and diverse sites; visitors are diverse in age, ability, culture and preference. As one case in point:a 2025 audit of the Portland,

Oregon park system found 86% of assets in poor or very bad condition and a restoration backlog of USD 550–800 million (City of Portland Auditor's Office, 2025). These pressures have prompted growing interest in "smart park" initiatives that apply Internet of Things (IoT) sensing, computer vision, predictive analytics, and other artificial intelligence (AI) techniques to park operations (Deak Sjöman et al., 2022; Turna and Bhandari, 2023; Ghadiri et al., 2024).

The existing work provides important foundations for integrated smart park management. For example, Deak Sjöman et al. (2022) evaluate technology based on four aspects: diversity, connectivity, adaptation, inclusion and perception. Thus, it is not possible to describe the gap as a lack of social concerns in the research of smart-park. This paper instead deals with the issue of linking social and environmental goals with clearly stated measurement methods, with decisions that are measurable, and a measurable evaluation design. User experience relates to experiences of park services while social quality of life relates to broader conditions that promote inclusion, cohesion, security and empowerment. These domains are not mutually exclusive.

The paper suggests five interacting layers between the physical park, data collection, AI analytics, applications, and governance and feedback. It sees social quality of life, sustainability and user experience as interdependent performance goals in competition, that need to be publicly discussed. The contribution is a conceptual specification and evaluation agenda. Neither an implemented optimization model nor an empirically validated AI system is presented.

The remainder of the paper is organized as follows. Section 2 reviews relevant literature across four strands: AI applications in urban green space management; smart park and IoT infrastructure; social quality of life and public space; and urban sustainability indicators, and identifies the specific research gap this paper addresses. Section 3 presents the proposed five-layer framework in detail. Section 4 outlines a mixed-methods methodology for empirically validating the framework. Section 5 presents a case study of historic parks in Zamalek, Cairo, based on an earlier qualitative study, an exploratory documentary analysis of public sources on one of the gardens, and a visual audit of published photographs. Section 6 discusses the framework's implications, and Sections 7 through 9 address limitations, future research directions, and conclusions. Supplementary Appendices A and B, provided as a separate file, give a literature-search protocol and a Delphi expert-appraisal protocol with a draft questionnaire; Appendix C lists the sources and coding frame for the documentary analysis, and Appendix D gives the photograph coding frame and results.

Research Objectives and Questions

The paper has four objectives: to synthesize four largely separate literatures relevant to AI-enabled parks; to propose a framework in which user experience, social quality of life and sustainability are co-equal, jointly measurable objectives; to specify a mixed-methods design for testing it; and to ground it in a retrospective illustration from Cairo. Three research questions follow:

•RQ1: How can AI-based sensing and analytics be organized architecturally so that they inform user experience, social quality of life, and sustainability outcomes simultaneously, rather than treating these as separate or sequential objectives?

•RQ2: What governance and equity-monitoring mechanisms are necessary to ensure that AI-enabled park management does not inadvertently reproduce or worsen existing disparities in park access and service quality?

•RQ3: What mixed-methods research design would allow researchers and municipal partners to empirically evaluate whether an AI-enabled park framework produces measurable improvements across all three outcome domains?

RQ1 and RQ2 are addressed primarily through the framework developed in Section 3; RQ3 is addressed in Section 4 and grounded in Section 5 through a case study of Cairene parks that reuses previously collected qualitative evidence rather than a deployed system.

1.1 Approach to conceptual framework development

This is a conceptual design study, based on a critical narrative synthesis, and a retrospective illustration. It presents an architecture and a decision pathway, it shows them with previously published historical observations and it describes future testing. Based on the literature selected in this paper, it links the four concerns of smart-park operations, sensing infrastructure, social quality of life and environmental performance. This paper is not a systematic search or systematic review of the database, does not make an exhaustive claim of coverage, provides no formal study-quality appraisal or expert consensus, field deployment, or causal effects; its contribution should be assessed within these limitations. The synthesis is therefore not intended to provide an indication of the distribution of approaches in the field, but rather to outline a design proposal. This selection is extended in Appendix A into a documented, reproducible search, following a protocol outlined by Page et al. (2021) based on the PRISMA 2020 checklist (Page et al., 2020). Appendix A includes indication of counts and screening decisions, but these have not been performed yet because the search was not executed. A protocol for the Delphi expert appraisal, as described in Section 4.1, is presented in Appendix B.

There are four steps to the construction logic. The three outcome domains specify the assessment of what park management should focus on. Second, technical functions are arranged according to their function in data acquisition or data interpretation and/or support action. Thirdly, governance is aligned to each phase, including decisions on acceptable data and service trade-offs. Fourth, representative indicators are evaluated for what can be observed, what data is used to create the indicator, inference limits, and what management response might be appropriate. The steps outlined in this framework are intended to outline the logical flow of the analysis and do not suggest that all stakeholders agree with the steps or that the analysis has been fully expertly validated.

The Cairo illustration doesn't require individual participant records; it is based on published results. Each condition reported is associated with a social-quality concern, a candidate indicator, and potential response. These mappings are design interpretations and the initial answers to the questions are not reanalyzed. No second coder was used to check inter-rater reliability or for a second coding of the descriptive evidence exercises in Section 5 (a documentary analysis of publicly available evidence) and Section 5.6 (a visual audit of published photographs). The resulting design propositions are contenders for expert appraisal and field testing.

2. Literature Review

2.1 Artificial Intelligence in Urban Green Space Management

A growing body of work applies machine learning and computer vision to the operational management of urban green spaces. Applications include soil-moisture forecasting and irrigation control from dense IoT sensor networks (Ghadiri et al., 2024) and computer-vision measurement of public-open-space use from existing camera networks, for example pedestrian and cyclist detection and behavioural mapping in a riverfront park (Sun et al., 2020), to inform design and management decisions. A park-scale deployment in Sydney links soil-moisture forecasts from a sensor network to irrigation commands for roughly 200 operational zones, with fallback models (Ghadiri et al., 2024), and a systematic review covers AI-based smart irrigation, largely in agriculture (Vallejo-Gómez et al., 2023). These studies establish technical feasibility but typically evaluate success in narrowly operational terms (resource savings, prediction accuracy) rather than in terms of downstream effects on how people experience or benefit from the park. Two further strands matter for social

outcomes. Social-media text and images have been used to evaluate park use and management. A PRISMA-based review of 22 studies concluded that such data are best treated as a supplement to other evidence, provided bias is critically assessed (Zabelskyte et al., 2022), and a deep-learning framework applied to 26,074 visitor comments on seven Wuhan parks classified comments by topic (facilities, safety, environment, activities and services) and scored sentiment at park, issue and feature levels, while acknowledging that social-media coverage may miss older or less digitally active visitors (Liu et al., 2024). Camera-based analytics have likewise been used to study who uses which park features: a comparison of two urban parks using city cameras and computer vision found gendered differences in the use of lawns and playgrounds across times of day (Gravitz-Sela et al., 2025). These studies move beyond resource efficiency toward visitor experience. They evaluate analytical pipelines or observed use patterns; the sources consulted for this paper do not report whether the resulting information changed management decisions or improved outcomes. The evidence on fairness is also cautionary: in a comparison of photo-based visitor estimates with on-site surveys at ten Seattle parks, Instagram and Flickr photos were not neutral samples of visitors, and a face-detection service under-detected photos containing children (Mashhadi et al., 2021).

2.2 Smart Parks, IoT Infrastructure, and Digital Twins

Smart-park research includes both infrastructure-oriented approaches and broader systems perspectives. Deak Sjöman et al. (2022) introduce an analytical framework based on urban ecology and nature-based thinking and apply it to the Sustainable Smart Parks initiative. Their criteria include diversity, connectivity, adaptation, inclusion and perception. Digital-twin research also examines participatory decisions (Luo et al., 2022), while Caprari et al. (2022) discuss urban-planning applications. These contributions caution against equating existing smart-park work with technical efficiency alone. The present framework builds on them by linking candidate outcomes to measurement and decision procedures. At the city scale, a PRISMA-based systematic review of 64 digital-twin studies, drawn from 519 records, concluded that a fully realized city-scale digital twin has not yet been achieved, citing obstacles in data integration, interoperability, cybersecurity, cost and socio-political engagement (Peldon et al., 2024). Park-scale twins should therefore be read as exploratory, and the same obstacles strengthen the case for minimum viable configurations (Section 8).

2.3 Social Quality of Life and Public Space

Urban sociology and environmental psychology research has examined how public green space relates to social cohesion and wellbeing. A systematic review finds that the physical characteristics, perceptions and use patterns of urban green space influence social cohesion (Wan et al., 2021); a review of green space and loneliness found that about two-thirds of 132 associations pointed to a protective effect, though only about a third were statistically significant (Astell-Burt et al., 2022); and associations with mental wellbeing are positive but not specific enough to guide planning (Houlden et al., 2018). Equity-oriented work notes that underserved communities often lack access to parks and vegetation despite their health benefits (Rigolon et al., 2024); an earlier review likewise treated unequal access to green space as an environmental justice concern (Jennings et al., 2012). Notably, this body of work rarely engages with AI or sensing technology directly; where digital tools are discussed, the focus is often on participatory planning, as in a workshop-based comparison of a digital twin and a physical replica of an urban park in Tianjin (Luo et al., 2022), rather than on real-time operational AI systems.

2.4 Urban Sustainability Indicators and Green Infrastructure Performance

Environmental indicators can connect park operations with resource consumption and ecological conditions (Tudorie et al., 2019). Their use in this framework requires explicit definitions, measurement intervals and context, including weather, irrigated area and visitor demand. Continuous data collection does not by itself establish sustainability: lower water use, for example, could reflect beneficial efficiency or harmful under-irrigation. Operational measures must therefore be interpreted alongside vegetation condition and service quality.

2.5 Research Gap and Contribution

The proposal for contributing is an integration of existing concepts in a decision oriented manner expressed by a decision specification: every management problem to an observed measure, an explicit inference limit, a responsible decision and a follow-up evaluation. The five layers are not claims of invention for sensing, participatory governance, equity auditing and equitable park management, but rather an organizing structure. In turn, each of its distinctive features is not a critical feature in itself, but rather a testable integration, which is proposed rather than demonstrated in an exhaustive review. The specification's usefulness versus other integrated frameworks, easier options, and standard management practices ought to be evaluated in upcoming expert appraisals.

Table 1 summarizes the selected literature strands and the connections developed in this framework. Table 2 then compares the closest prior approaches in more detail.

Table 1. Synthesis of the reviewed literature and the gaps addressed by the proposed framework.

Literature Strand	Established Contribution	Gap Addressed by Proposed Framework
AI for green-space operations (2.1)	Demonstrates technical feasibility of AI for vegetation, irrigation, and visitor monitoring	Extends evaluation beyond operational efficiency to UX and social QoL outcomes
Smart park IoT / digital twins (2.2)	Specifies sensing and connectivity architecture	Links existing governance concerns to explicit measurement and decision responsibilities
Social QoL / public space (2.3)	Establishes theoretical link between public space quality and social cohesion/equity	Distinguishes reported social outcomes from operational observations and indirect proxies (Table 3)
Sustainability indicators (2.4)	Provides validated indicator sets for environmental performance	Specifies how monitoring informs decisions alongside ecological and service safeguards

Comparison with specific prior approaches

Deak Sjöman et al. (2022) provide the closest systems-oriented comparator: their ecological criteria already encompass inclusion and perception. This paper complements that perspective with operational definitions and a proposed intervention-evaluation sequence. Luo et al. (2022) examine participatory decision-making using physical and digital representations; the proposed framework extends participation into ongoing operating decisions and feedback. Sun et al. (2020) demonstrate observation of public-space use; here, visitor counts remain activity measures whose social interpretation requires additional evidence. Table 2 extends this comparison to data-driven studies of park use and management. The comparison is limited to the sources consulted for this paper and should be read as provisional until the structured search in Appendix A has been completed.

Table 2. Closest prior approaches compared with the proposed framework (interpretive comparison of the sources consulted).

Approach (source)	Evidence base and technology	Main emphasis	What the present framework proposes to add
Deak Sjöman et al. (2022)	Analytical framework from urban ecology and nature-based thinking, applied to the Sustainable Smart Parks initiative	Diversity, connectivity, adaptation, inclusion and perception as criteria for smart park management	Operational indicator definitions, inference limits and a staged evaluation sequence (Sections 3.6 and 4)
Luo et al. (2022)	Workshop-based comparison of a digital twin and a physical replica of an urban park in Tianjin	Participatory decision- making; age was a barrier for older participants	Extends participation into recurring operating decisions; keeps non-digital channels
Sun et al. (2020)	Deep learning on existing camera networks in a riverfront park	Measuring use of public open space (pedestrians, cyclists, behavioral maps)	Treats counts as activity measures; social interpretation needs survey or interview evidence
Liu et al. (2024)	26,074 visitor comments on seven Wuhan parks; text classification and sentiment scoring	Park-management assessment at macro, meso and micro levels	Separates reported experience from operational data; adds checks on coverage of less digitally active visitors
Gravitz-Sela et al. (2025)	City cameras, big-data analytics and computer vision in two urban parks	Gendered use of park features across times of day	Links use patterns to named management decisions, privacy safeguards and equity review (Layer 5)
Mashhadi et al. (2021)	Instagram and Flickr photos, face detection and surveys at ten Seattle parks	Viability and fairness of social-media analysis for park policy	Builds an audit of data-source representativeness into governance rather than treating it as an afterthought
Ghadiri et al. (2024)	Machine-learning soil-moisture forecasting from dense sensor networks in a Sydney park	Irrigation control and data optimization	Interprets resource savings alongside vegetation condition and service quality

2.6 Theoretical Foundations

The framework draws on three complementary theoretical traditions. From socio-technical systems theory, it adopts the premise that technical infrastructure and social/organizational arrangements co-evolve and must be designed jointly, which motivates treating governance (Layer 5) as architecturally integral rather than as a downstream policy question (cf. Veale et al., 2018, who show that uptake of algorithmic systems in government is as much a social process as a technical one). From environmental psychology and restorative-environments theory, it draws the expectation that features such as perceived safety, social presence, and facility accessibility shape the relationship between green space and wellbeing, which motivates the UX and social-QoL indicators in Table 3 (Kaplan, 1995; Gianfredi et al., 2021). From urban political ecology and environmental justice scholarship, it draws attention to the risk that efficiency-oriented technical interventions can reproduce existing spatial inequalities absent explicit distributional monitoring, which motivates the equity-auditing function within Layer 5 and the attention to which user groups benefit in the Section 5 case (Heynen, 2006; Jennings et al., 2012). The framework does not adopt any single theory as fully determinative; rather, it treats these three traditions as jointly necessary to justify why UX, social QoL, and sustainability should be designed and measured together rather than sequentially.

3. Proposed AI-Driven Framework

3.1 Conceptual Overview

The proposed framework (Figure 1) is structured around five interdependent layers of an AI empowered public park. Layer 1 is the physical park environment – the green infrastructure, recreational facilities, pathways, and

users and community members. Layer 2 is the data and sensing layer, including IoT sensors, cameras and edge devices; mobile-application-based crowdsourced feedback; and external municipal and open data sources (e.g., weather, transit, 311 service requests). The AI analytics layer (Layer 3) converts raw data into data that forms the basis for decision-making with computer vision, prediction analysis, natural language processing (NLP) of visitor feedback, and optimization algorithms. The application layer (layer 4) is where insights are shared with end users (park visitors, through personalized routing and accessibility details) and operators (park managers, through predictive maintenance notifications and adaptive resource management). Layer 5 is a governance and feedback layer that runs across the entire system, including data governance and privacy, algorithmic accountability practices, community co-design processes, and ongoing monitoring and evaluation of model performance and equity effects. Data is flowing up (from the physical environment, through sensing, into analytics, and finally, to the applications), as well as down (from AI-driven interventions and governance decisions, back down to the physical environment and sensing priorities), really because the framework is cyclical and continuously adapts rather than a linear pipeline.

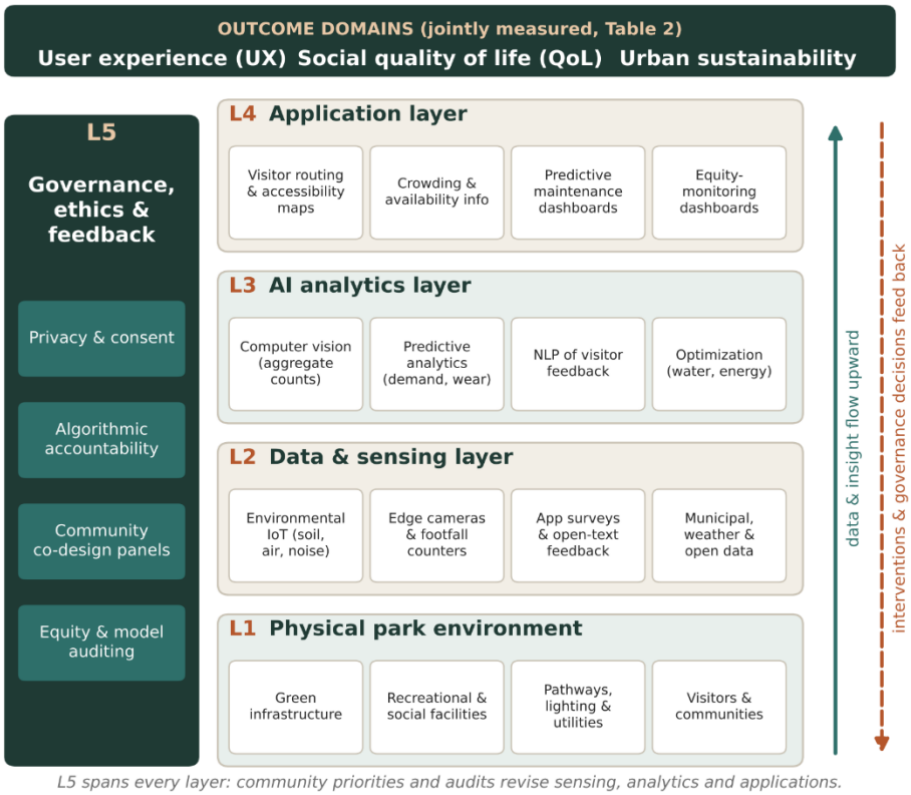


Figure 1. Five-layer conceptual framework for AI-enabled sustainable public parks. Layers 1–4 carry data and insight upward; Layer 5 (governance, ethics and feedback) spans all layers and feeds interventions and community priorities back down. Source: author.

3.2 Layer 2: Data and Sensing

The starting point for the data layer is the source with the least noidal intervention that can answer the management question. A basic set of utility meters, maintenance logs, manual counts and environmental sensors and voluntary surveys can be used. Camera analytics is an optional feature and should only be used if it is proven to be necessary, has been tested and has a proportionate governance mechanism. Anonymity is not guaranteed by exposure reduction alone, which is achieved by edge processing and deletion of the raw images. App feedback should be supported by on site and non-digital feedback. Where it is appropriate for equity

assessment, the data should be from voluntary self-report with aggregation and access controls – not images or traces of devices – and should include ethnicity, income and social identity.

3.3 Layer 3: AI Analytics

The framework has four analytic capabilities. First, computer-vision models estimate the number of visitors, their movements and their use of the facilities (e.g. how many visitors use each court, each bench, or each trail) without identifying who they are. In this paper, Sun et al. (2020), they show the detection task underlying an established park camera network. Second, predictive-analytics models predict the short-term demand of visitors, which drives staffing and event planning, and the longer-term wear of infrastructure, such as pathways, play equipment and irrigation systems, to inform predictive maintenance schedules. Third, NLP models analyze crowdsourced text feedback and, if available, social media mentions to identify sentiment and thematic patterns (Huai and Van de Voorde, 2022) – for example, common complaints about lighting in a certain area could indicate a perceived-safety issue that disproportionately impacts certain user groups. The outputs of the first three capabilities, combined with sustainability data, are then input to optimization algorithms which suggest resource allocations, such as an irrigation schedule based on soil-sensor readings and weather forecasts, or energy-efficient adaptive lighting that balances safety perception with energy consumption targets.

3.4 Layer 4: Applications

Analytic outputs are translated into two categories of user-facing tools. Visitor-facing applications include personalized activity and routing recommendations (e.g., suggesting less-crowded times or accessible routes for visitors with mobility constraints), real-time crowding and accessibility maps, and notifications about facility availability or closures. Operator-facing applications include predictive maintenance dashboards, adaptive control interfaces for irrigation and lighting, and equity-monitoring dashboards that flag disparities in service quality or maintenance response times across different park zones or neighborhoods served by the same park system. Both application categories are designed to surface not only what the AI system recommends but also a brief rationale, to support operator trust and enable meaningful human oversight of automated recommendations.

3.5 Layer 5: Governance, Ethics, and Feedback

The governance layer is considered a first-class architectural element and not a compliance add-on because public parks are shared spaces of the city and its residents who may not have expressly consented to the collection of data on a person-by-person basis. Four practices are specified: (1) data privacy and consent protocols (e.g., clear signage on the sensing infrastructure; opt-in/opt-out guidelines for identifiable data collection; and limits on data retention); (2) algorithmic accountability practices (e.g., published documentation of what each model optimizes for, and periodically conducting “model audits” by third parties or academics to assess for equity impacts and disparate impact); (3) community co-design panels (e.g., participation of community members, especially historically underserved neighborhoods, in defining what the system measures and how trade-offs (e.g., energy saving versus lighting for safety) are made); and (4) continuous auditing of model performance and equity impacts (e.g., comparing service and maintenance outcomes across demographic and geographic subgroups to detect and correct disparate impact). The purpose of this layer is to create a closed loop as shown in Figure 1, whereby the process of governance decision making and community input is in loop with priorities identified through sensing and application design, rather than operating separately from the technical system.***3.6 Outcome Indicators***

Table 3 specifies a minimum indicator set. Direct measures, participant-reported constructs and contextual

proxies are kept distinct. Locally agreed service standards and baseline distributions should define alert thresholds before implementation; no universal thresholds or validated composite score are asserted. Indicators should remain separate when aggregation would conceal trade-offs. An equity dashboard requires explicit group denominators and consent-compatible data; anonymous footfall cannot establish demographic representativeness.

Table 3. Representative outcome indicators and data sources by outcome domain.

Indicator and construct	Measurement and frequency	Interpretation and decision
Facility availability |	Usable scheduled facility-hours / scheduled	Report closures by zone and facility type;
UX direct service measure	facility-hours × 100; maintenance records checked weekly.	prioritize recurring losses. Availability does not establish satisfaction.
Accessible routes |	Accessible audited route segments / assessed	Report the denominator and audit criteria;
UX audited measure	segments × 100; quarterly and after works, using a stated local accessibility standard.	confirm barriers with users with disabilities. Counts alone do not measure accessibility.
Perceived safety and comfort | reported experience	Separate consistent survey items at baseline and follow-up; report response distributions, times and locations.	Include on-site and non-digital recruitment; compare voluntary self-reported groups only where cell sizes protect privacy.
Maintenance equity | distributional service measure	Median and upper-percentile completion time by zone and request category; monthly; distinguish severity and staffing.	A gap triggers investigation, not an automatic discrimination finding. Evaluate service standards and unmet demand.
Social cohesion and trust | participant-reported outcomes	Adapt a documented multi-item instrument; pilot comprehension and reliability before baseline and follow-up.	Co-presence and NLP sentiment are contextual proxies only. Neither demonstrates cohesion, belonging or institutional trust.
Participation and empowerment | process and reported	Record invitations, attendance and adopted proposals; quarterly; ask participants about influence on decisions.	Participation counts do not establish influence. Publish reasons for accepting or rejecting proposals and include non-users. outcome
Water and energy | direct operational measures	Metered m^3 per irrigated hectare and kWh per operational area; monthly, with weather, opening hours and demand.	Interpret savings alongside vegetation condition and safety. Report sensor completeness and meter coverage.
Vegetation condition	Repeated arborist or horticultural assessment	A canopy-health proxy is not a biodiversity
| ecological observation	using a stated rubric; seasonal, with sensor alerts checked manually.	index. Validate remote estimates against field observations.

4. Proposed Methodology for Framework Validation

Empirically validating the framework proposed in Section 3 requires a mixed-methods design capable of capturing quantitative behavioral and environmental data alongside qualitative perceptions of experience and social quality of life. We outline such a design here as a methodology that future empirical studies — subject to future fieldwork — can apply; no results from this methodology are reported in the present paper.

4.1 Research Design

Evaluation should proceed in stages. First, a purposively recruited panel spanning park operations, planning, social research, accessibility, AI and community representation should appraise clarity, relevance, feasibility and measurement validity. Report recruitment, expertise, disagreements and resulting revisions; this appraisal would assess the framework, not intervention effectiveness. Second, a feasibility pilot should establish data completeness, recruitment coverage, operating costs and technical accuracy before any effect evaluation. A small number of sites can support this pilot, but three parks should not be presumed sufficient for causal

inference. The expert appraisal should follow the Delphi protocol in Appendix B, reported against the CREDES guidance (Jünger et al., 2017); any literature update should follow Appendix A.

4.2 Data Collection

Quantitative data would combine IoT sensors (soil moisture, air quality, noise, footfall) logged at defined intervals, such as every 10–15 minutes; edge-based visitor-flow analytics with on-device processing and no retention of identifiable imagery; sampled in-app micro-surveys of satisfaction and safety; and municipal records of maintenance requests, response times and utility consumption matched to park zones. Qualitative data would come from semi-structured interviews with visitors, non-visitors from the surrounding community and operations staff, sampled to include under-represented groups; NLP-assisted thematic analysis of open-text feedback and, where ethically and legally permissible, public social-media mentions; and community co-design workshops at the start and midpoint of the study, consistent with Layer 5 (Section 3.5).

4.3 Analytical Approach

A subsequent effect study should pre-specify 1 or a few interventions, primary outcomes, exposure dates and plausible confounders. Gather repeated pre- and follow-up observations in similar seasons, preferably a full annual cycle on each side if possible. Choose comparison parks based on management arrangements, catchment attributes, size, facilities, baseline conditions and trends. Make a note of current refurbishment, events, prices, staff changes and spillovers. A single estimate covers the effect of the intervention package as a whole, not the effect of AI alone.

In a difference-in-differences design, compare the result of the change at intervention parks with the contemporaneous change at comparison parks, and test pre-intervention trends and justify the parallel trends assumption. Select the number of independent parks and/or observation periods based on a design-specific power and precision analysis, taking into consideration clustering and serial correlation. Independent sites are not covered by frequent sensor readings. When it is not possible to make suitable comparisons or assumptions, report descriptive longitudinal results only, without making causal statements. Specify missing-data rules in advance, perform sensitivity analyses and comparisons of subgroups; present uncertainty and measurement error. Qualitative interviews and joint displays should be used to elaborate the variability of experiences and why quantitative changes might not reflect better social outcomes.

Manual count of the numbers of visitors should be used for technical evaluation, and the numbers of visitors should be cross-checked across lighting and crowding and occlusion conditions; locally annotated feedback for NLP assessment and observed maintenance outcomes for prediction validation. Compare AI managed to manual, fixed schedules or basic dashboard based on same service standards, staffing assumptions. Consider procurement, training, energy, maintenance and governance costs. Using an AI model is only appropriate when its incremental value is considered to be worth its costs and data needs.

4.4 Ethical Considerations

Any empirical application of this methodology would require institutional ethics review, informed consent procedures for interview and survey participants, public disclosure of sensing infrastructure, and a data-management plan specifying retention limits and access controls, consistent with the governance principles described in Section 3.5.

5. Retrospective Illustration Using Published Evidence from Zamalek Parks

Note: *This case study re-examines evidence from a previously published qualitative study of public parks in Zamalek, Cairo (Elgobashi and Elsemary, 2019). It maps that study's observed social-quality deficits onto the framework's outcome indicators and identifies where AI-enabled sensing and analytics could, and could not, help. No sensors, AI models or interventions were deployed, and no post-intervention outcome data were collected or located; the case therefore grounds the framework in a real setting but does not test its effectiveness. Sections 5.5 and 5.6 add an exploratory documentary analysis of public sources and a visual audit of published photographs; neither adds field data.*

5.1 Context and Source Evidence

The source study concerns historic public parks in Zamalek, Cairo (Elgobashi and Elsemary, 2019). Its reported naming differs between the abstract and body, so this illustration refers collectively to the Zamalek parks examined in that source rather than treating the park count as independently verified. Site history, entry prices and physical conditions reported there are historical descriptions and should not be interpreted as current observations. The published account is used to identify management questions, not to establish a contemporary baseline.

The source study examined the gardens of El-Andalus, El-Horeya and El-Masalah (also written El-Masla) in Zamalek (Figure 2). Its abstract names only two of these, whereas its body names all three, so all three are described here as reported. The gardens are described as established in 1935 as two parts of one garden divided by a bridge and the statue of Saad Zaghloul, with areas of about 2.25, 6.8 and 3.2 feddan respectively (Abdel-Rahman, 2016, as reported in the source study) and a low entry fee of 2 LE at the time. They were selected as community parks with landmark and accessible locations, historical significance, continued public use and relatively good condition. Figure 3 reproduces the historical and modern maps used in the source study.



Figure 2. Study area: El-Zamalek district with the El-Andalus, El-Horeya and El-Masalah gardens on the Nile frontage, between the 6th October and Qasr al-Nil bridges. Map source: Google (2019), as reproduced in Elgobashi and Elsemary (2019).



Figure 3. Maps of the garden area: (a) The British Library (2009); (b) Nicohosoff (1933); (c) Nicohosoff (1958), as reproduced in Elgobashi and Elsemary (2019). The chronology of the layouts requires confirmation against the original sources.

The earlier account describes a qualitative approach involving field observation, questionnaires and semi-structured interviews with local adult users aged 18–40. The present manuscript does not establish the number of respondents, recruitment details or availability of participant-level records. Findings are therefore treated as published qualitative descriptions without statistical representativeness. The assessment draws on public-space principles and the Social Quality conditions of socio-economic security, cohesion, inclusion and empowerment (Carmona et al., 2003; Holman and Walker, 2018). No individual responses are reanalyzed.

5.2 Mapping Observed Conditions to the Framework

The source study's site observations add detail beyond Table 4 (Figure 4). It reports that the gardens are enclosed by fences and high-walled buildings; that pathways are well maintained but there are no children's facilities or defined activity spaces; that old trees and palms carry no information or documentation; that the Nile frontage is neglected and lacks landmarks; and that historic statues are not used as functional spaces. It also records strengths: furniture and architecture in an Andalusian style, a landmark and easily accessible location, and a good connection to the main route. Access findings are mixed, with a good pedestrian entrance and road crossings but an unclear entrance statement, insufficient parking, a poorly maintained bus station and walkways in poor condition in places; security findings note no signboards and no visible security presence. These are the source authors' observations and have not been independently verified.



Figure 4. The ten published photographs of the gardens (P1–P10), as reproduced in Elgobashi and Elsemary (2019). Conditions stated in the 2019 captions: P1 lack of seating; P2 no attractive activities; P3 and P5 well maintained but no activities; P6 missed social interaction; P7 statues neglected; P9 no consideration for activities; P4, P8 and P10 descriptive. Credits as given there: Observer (2011) P1, P3, P9, P10; Abdel-Rahman (2016) P2, P4, P8; Dylan et al. (2016) P5–P7. * Colors visibly altered. Reuse permissions to be confirmed.

Table 4 relates the conditions reported in the earlier study, which were organised under the four Social Quality conditions, to the indicators in Table 3 and to the kind of monitoring or response the framework would suggest.

The assignment of conditions to indicators is our interpretation, and the right-hand column lists proposals that have not been tested. The earlier study reports some conditions inconsistently (for example, the parks are described as in immaculate condition, yet cleanliness is also rated insufficient); we report both.

Table 4. Conditions reported for Zamalek's parks (Elgobashi and Elsemary, 2019) mapped to the framework (interpretive; proposed responses are untested).

Reported condition	Social Quality condition	Framework indicator (Table 3)	Proposed AI-enabled monitoring or response
Unclear entrance statement, insufficient parking, bus station poorly maintained and unclear to users; walkway in poor condition in places	Socio- economic security	Route accessibility score; facility availability rate	Aggregate entrance and route counts; mapping of reported access problems from visitor feedback
No signboards, no visible security presence; cleanliness of the environment insufficient	Socio- economic security	Perceived safety by demographic group;	Structured safety and cleanliness feedback by user group; maintenance logs tied to park zones maintenance response time
No opportunity to socialize; poor or no activities to attract users; undefined green spaces and paths; no children's facilities	Social cohesion	Facility utilization; survey-reported interaction and	Non-identifying zone-use analytics to show which areas are idle; before- and-after comparison when activities or facilities are added belonging
Fenced and walled boundaries; neglected historic statues and Nile	Social inclusion	Cross-group equity of use	Time-specific entrance counts plus voluntary user and non-user surveys; frontage not used as functional spaces demographic equity cannot be inferred from counts alone
No functions that relieve stress or mental fatigue; no promotion of equal opportunity to take part	Social inclusion	Perceived comfort; community trust	Short recurring surveys, with results disaggregated by age and income index
No sense of belonging, collective action limited to individual actions, no park identity; old trees and palms unlabelled	Social empowerment	Reported influence and belonging; separately	Participatory workshops with results reported back to users (Layer 5); digital tree inventory and visitor- facing labels assessed tree condition

5.3 Interpretation and Limits

Two points follow. First, most of the reported deficits concern programming, openness, safety and identity rather than missing technology. The earlier study attributes the decline mainly to poor maintenance and a lack of social activities, and it also records strengths worth retaining: a landmark, easily accessible location, maintained pathways, a good connection to the main route and an Andalusian-style heritage of furniture and architecture. This is consistent with the caution in Section 6 that many gains could be achieved without AI. What the framework adds is a way to make these conditions measurable and comparable over time, and to check whether any improvement is shared across user groups.

Second, parks in this setting are likely to lack baseline data, so a first step would be low-cost and low-intrusion: manual or ticket-based aggregate counts, short surveys, and an open feedback channel, with camera analytics considered only after the governance arrangements of Layer 5 are in place. We have not verified what visitor or maintenance records the parks hold; this would be established in the first phase of the Section 4 design.

The illustration is limited by its age, restricted reported age range, uncertain sampling information and inconsistencies within the published account. It cannot support conclusions about all Cairo parks or their current users. It identifies questions for baseline fieldwork rather than supplying a measured baseline for an

intervention study. The mapping is author interpretation and does not validate the proposed indicators or demonstrate AI effectiveness.

5.4 Hypothetical maintenance decision and conventional comparator

Take repeated reports of inaccessibility of path after irrigation into account. This situation is a "what if" and is not an actual outcome of the Cairo study. Staff would initially create a baseline based on maintenance records, inspections and user experience reports. A standard answer would include staff inspection, maintenance register, and a follow-up schedule. An AI-enabled solution might involve assigning a candidate language model to identify incoming reports; the answer could be matched to zones and flag up any recurring location for management review, with the manager confirming each alert prior to arranging inspection and repair. Both methods do not eliminate the need for a path inspection and fixing the root cause. Data would be short-lived and would not be accessible, and there would be a retention of non-digital reporting.

Compare the two methods of doing the same thing: time until confirmed repair, repeat incidents, availability and user accessibility of audited routes. Record false alerts, missed or overlooked reports, staff time and full operating costs. Consider whether the same effort is put into non-app reports. A faster alert is a step toward an improvement, an improvement must be verified repair and usable route. This is a speculative design, and it does not represent a deployed model and/or a measured benefit. The comparison would only be valid if it demonstrated that the AI is revealing a useful incremental gain in performance at an acceptable incremental degree of intrusion and privacy risk; if structured manual review is revealing the same performance at reduced level of intrusion and privacy risk, then there would be no justification for the AI. This comparison is included with the staged evaluation plan of Section 4.1 (panel b) as shown in Figure 5.

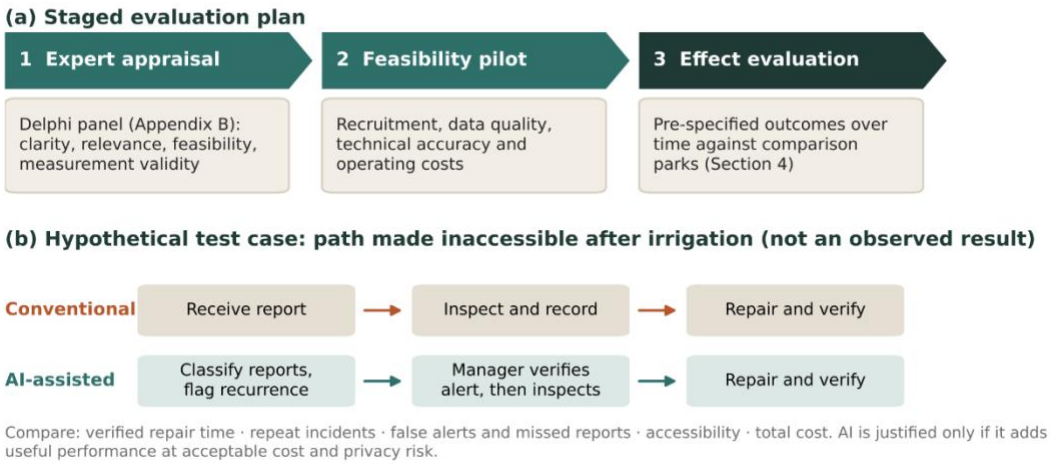


Figure 5. (a) Staged evaluation plan, from expert appraisal to effect evaluation (Section 4.1); (b) hypothetical comparison of conventional and AI-assisted responses to a path made inaccessible after irrigation. Panel (b) illustrates the test design and is not an observed result. Source: author.

5.5 Exploratory documentary analysis of public sources on Al-Andalus Garden

Sections 5.1 to 5.4 rely on a 2019 study and a hypothetical scenario. To see what public evidence exists about conditions since that study, this section reports an exploratory documentary analysis of publicly available sources on Al-Andalus Garden. Al-Andalus is analyzed because it can be matched to the public record without ambiguity; the identification of El-Horeya and El-Masalah with named public sites is unresolved in the source study, so those gardens are not analyzed. The analysis asks three questions: which of the conditions reported in 2019 are addressed in later public sources; what kind of evidence those sources provide (reported works, official statements, descriptions or measured outcomes); and how consistent the public record is on basic facts

such as opening status and fees. It illustrates, at small scale, the evidence problem that Layers 2 and 5 are meant to address. It adds no field data and does not evaluate the park, its restoration or any AI application.

Sources, extraction and coding

Public web pages were identified through English-language web searches on the garden's name on 27 October 2026. A page was eligible if it was publicly accessible, written in English, and made at least one statement about the condition, works, access, use or management of Al-Andalus Garden. Individual visitor reviews, social-media posts and pages about other gardens were excluded. Twenty-one pages were retrieved; nine met the criteria (Table 5; Appendix C) and twelve did not, because they concerned other gardens (among them the Obelisk Garden and El-Zohreya Garden, whose relation to the gardens in the 2019 study is unresolved) or contained no relevant content.

Statements were extracted from each page and coded with AI assistance (Claude, Anthropic); pages were read through an automated retrieval tool that returns summaries and short quotations. Each statement was coded for its type (condition, works, governance and funding, access status or cost, activity or use, visitor profile, visitor feedback or background), the framework indicator it bears on (Table 3), the 2019 theme it relates to (the six rows of Table 4), its evidence basis and whether it reports a measured outcome (Table C2). Quotations of up to twelve words were kept as evidence. For 23 of the 35 coded statements the quotation was confirmed against the page in a second, exact-phrase check; the other 12 rest on the first extraction only and are flagged in the supplementary coding sheet. Coding was carried out by a single AI coder with no second human coder, so no inter-rater reliability is reported and the results are descriptive.

Results

The nine sources produced 45 statements: 35 bearing on condition, works, management, access or use, and 10 giving historical or descriptive background (Table 5). Eleven of the 35 coded statements come from two sources published before the 2019 study (2014 and 2017), 15 from three sources published after it (2020, 2022 and 2024), and nine from four undated sources: a reference entry, an official listing, an aggregator page and an advocacy listing (Figure 6a).

Table 5. Public sources on Al-Andalus Garden analyzed (35 coded statements).

ID	Source and type	Date	Period	Coded statements
S1	Ahram Online feature	10 Jun 2014	Before	3 2019
S2	Egypt Today feature with staff interviews	26 Apr 2017	Before	8 2019
S3	Egypt Independent report of an official	4 Feb 2020	After 2019	5 announcement
S4	Egyptian Streets feature	15 Mar 2022	After 2019	3
S5	Egyptian Gazette report of the reopening	5 Nov 2024	After 2019	7
S6	Archnet site entry (text credited to El Messiri,	Undated	Undated	2 2004)
S7	Cairo Governorate parks listing	Undated	Undated	1
S8	Wanderlog aggregator page (Google review data)	Accessed 27 Oct	Undated	5 2026
S9	UN-Habitat Urban October event listing	Event 8 Oct 2026	Undated	1

None of the 35 coded statements reports a measured outcome of the kind specified in Table 3, such as facility availability, audited route segments, survey response distributions or completion times. The only quantitative datum about visitors is an aggregator rating of 3.6 out of 5 from 66 Google reviews (28, 11, 10, 5 and 12 reviews at five to one stars), whose dates and reviewers are not shown and which cannot be read as a measure of social quality of life. Of the 15 statements from sources published after 2019, 10 concern works, funding or governance, three concern condition, one concerns access status and one an activity. Before 2019, five of the 11 statements concern condition, such as broken fountains and an irrigation system needing urgent repair. The most frequent topics were governance, funding or oversight (9 statements), opening status, hours or fee (7) and infrastructure, irrigation, fountains or statues (5). No statement addressed security staffing, accessibility for people with disabilities, visitor counts, children's facilities, parking or transport, signage, or community participation in management.

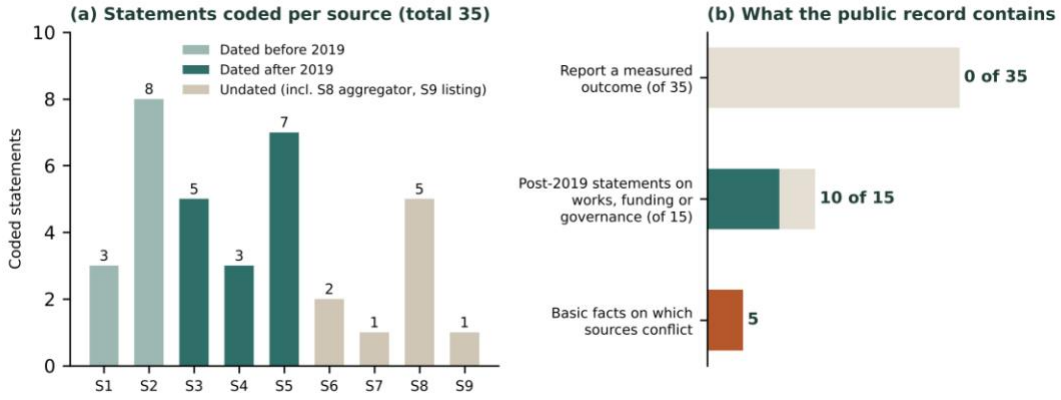


Figure 6. Documentary analysis of public sources on Al-Andalus Garden (S1–S9, accessed 27 October 2026): (a) coded statements per source, by period; (b) what the public record contains. Source: author's coding; see Table 5 and Appendix C.

Table 6 relates the coded statements to the six conditions reported in 2019. After 2019, public sources contain statements bearing on four of the six themes, and these are descriptive or reported by officials rather than measured. Access and entrance (T1) is not addressed in any source, and signage and security (T2) are not addressed after 2019; the one T2 statement is an undated aggregator summary describing the garden as clean.

Table 6. Coded statements related to the six conditions reported in 2019 (Table 4).

2019 theme	Before 2019	After 2019	What the sources say, and what is missing
T1 Access and	0	0	No statement on entrances, parking, transport links or walkways. entrance
T2 Signage, security and	0	0	An undated aggregator summary calls the garden clean; no statement on signage or security. cleanliness
T3 Activities, socializing and children's	1	1	A keeper says musical shows still run from time to time (2014); an orchestra performed at the November 2024 reopening. Nothing on children's facilities or on regular programming after 2019. facilities
T4 Boundaries, statues and Nile frontage	0	3	A tall fence is described in 2022; statue restoration is announced in 2020; the governor reports Nile encroachments removed in 2024. Nothing on whether the frontage is now open to public use.

2019 theme	Before 2019	After 2019	What the sources say, and what is missing
T5 Comfort and equal opportunity	1	1	The garden is called calm and still (2022); a 2017 staff account describes visitors as mostly elderly people, couples and newlyweds. No comfort, inclusion or equity measure.
T6 Belonging and tree condition	1	1	Grass and palms are called tired and ancient (2017); green spaces are said to be maintained (2024). No tree-condition or belonging data.

The public record is also inconsistent on basic facts (Figure 6b; Table C3). Sources give 1929 or 1935 as the founding year; 8,400 m² or 9,000 m² as the area; an entry fee of LE2 or LE5, LE10, an unspecified fee, or none; opening hours of 9 am to 12 pm or 7 am to 11:30 pm; and an operating status that is reopened after restoration in November 2024 (S5), currently closed to the public in a listing for an event in October 2026 (S9), or not open to visitors and for display only on an aggregator page that also says entrance is free (S8). Because most listings are undated, some differences may reflect change over time rather than error; the point is that none of the sources is an authoritative, dated record of the park's current status.

Five statements have no counterpart in Table 3: four about entry fees, from four sources, and one about restoring statues. They are candidates for the expert appraisal in Appendix B (Table B1) rather than changes to the framework.

Interpretation and limits

The analysis results in three limited conclusions. First, reports of Al-Andalus after 2019 focus on works, not on the social conditions reported in 2019, and where social conditions do appear they are impressions, not measures. Secondly, none of the sources has data of the type which the framework would be able to use to determine if the restoration improved access, safety, inclusion or experience. Third, there is not enough consistency in the public record to use as an indicator as to whether it is opened up or not opened up or whether it is accessible or inaccessible. These results provide a glimpse into the strength of the evidence that a first, low-cost pass over public evidence can provide, and highlight the evidence gap that Layers 2 and 5 are meant to address. They fail to demonstrate improvement or deterioration, that the 2019 findings were responded to, or the value added by AI.

The restrictions are significant. The corpus is limited, and was collected by web search on one day. Lack of reporting in a news article does not equate to lack of presence on the ground. Official statements are not verified. Explicitly omitted for privacy reasons and as a result they cannot be sampled representatively, are individual visitor reviews (which may include information about facilities and conditions). This extraction was performed through AI tools which have the potential to misstate a page, which we have mitigated but not eliminated with the second pass check, and a single AI coder. Two out of the three gardens studied in 2019 are uncovered gardens. This coding sheet and source list is included to facilitate re-coding and further analysis by the authors and reviewers.

5.6 Visual audit of published photographs

The 2019 study illustrates its findings with photographs. To test what such images can contribute as evidence, the eleven photographs of the three gardens reproduced in that study were audited. One, a painted or composite aerial view, was excluded; the remaining ten (P1–P10; Figure 4) comprise four of El-Andalus, four of El-Horeya and two of El-Masalah, as captioned in 2019. Each photograph was coded by eye for ten observable

features, defined in Table D1: paved route, bench seating, water, lighting fixture, signage or wayfinding, people (count), litter, surface weathering, heritage or ornamental feature, and shade on a use surface. Green cover was measured as the share of pixels with an excess-green index (2g − r − b on chromatic coordinates) above 0.05; two photographs with visibly altered colors (P1, P5) were excluded from that summary. Coding was carried out by a single AI-assisted coder; a zoomed re-check changed three codes, and no second coder was used. The photographs were taken by others, at unknown dates, from viewpoints chosen by the 2019 authors, and are small (about 100–250 pixels wide), so cracks, litter and text cannot be reliably assessed.

Paved routes and heritage or ornamental features were visible in eight of the ten photographs, lighting fixtures in four, and bench seating, water and shade on a use surface in three each. No signage or wayfinding and no litter was visible in any photograph (Figure 7a). Three people in total were visible, in two photographs. Among the eight photographs with unaltered colors, the excess-green share had a median of 34% (range 16–67%; Figure 7b). Table D2 gives the codes for each photograph.

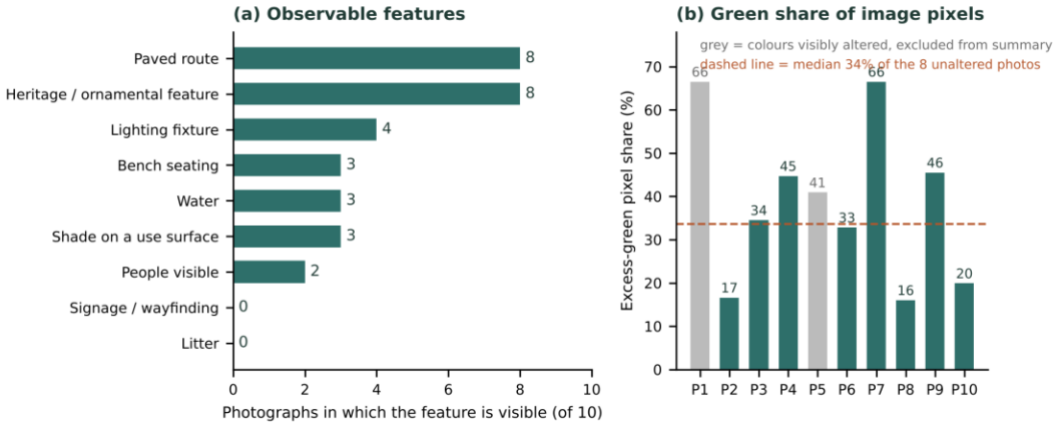


Figure 7. Visual audit of the ten published photographs: (a) number of photographs, of ten, in which each observable feature is visible; (b) excess-green pixel share per photograph. Grey bars (P1, P5) have visibly altered colors and are excluded from the median. The measure describes image composition, not canopy cover or vegetation health. Source: author's coding; see Appendix D.

These results are bounded. The absence of a bench in a photograph does not show that the park lacked seating, and excess-green share measures the composition of a selected frame, not canopy cover or ecological condition. A photograph cannot establish visitor safety, accessibility compliance, social cohesion or maintenance trends. The audit therefore corroborates selected physical attributes reported in 2019, notably maintained paths, heritage features and an absence of visible signage and people, but supplies no measure of use, safety or inclusion (Table 7). A repeat survey from the same viewpoints in 2026, with dated images, logged weather and time of day, two independent coders and permission for any people shown, would provide a comparable visual baseline for the field evaluation in Section 4.

Table 7. What a photograph can and cannot show for selected framework indicators (Table 3).

Indicator	A photograph can show	A photograph cannot show
Facility availability	Whether seating and lighting fixtures are present	Whether they work or are available when needed
Accessible routes	Surface type and general condition	Width, gradient, steps, ramps or user barriers
Perceived safety and comfort	Lighting fixtures and shade in the	How safe or comfortable visitors feel frame
Vegetation condition	Green cover in the frame	Tree health, season or park-wide canopy
Social cohesion and trust	Who is in the frame at one moment	Belonging, inclusion or trust

6. Discussion

The framework contributes an explicit link between outcome definitions, evidence sources and management responsibilities. It builds on smart-park work that already addresses inclusion and perception rather than claiming that these concerns are new. The Cairo illustration demonstrates how a reported problem can be translated into an evaluation question; it does not establish that the analytics or governance mechanisms improve outcomes. Real-time information may support responsiveness, but organizational capacity determines whether a signal leads to action.

The documentary analysis in Section 5.5 and the photographic audit in Section 5.6 illustrate, on a small scale, the evidence problem that the framework addresses. Public reporting on Al-Andalus after 2019 describes works, funding and officials' statements but contains no measured outcome, and its basic facts about opening status and fees conflict. A dated public record of facility availability, as proposed for Layer 2 and Table 3, would resolve discrepancies of this kind at low cost, and an equity and access review under Layer 5 would ask whether the social conditions reported in 2019 changed. This does not show that the restoration failed or succeeded; it shows that the public evidence cannot tell. It also suggests two candidate additions to the indicator set for expert appraisal: affordability of access and condition of heritage features.

The framework also foregrounds governance and ethics as an architectural rather than peripheral concern. Public parks differ from many other smart-city domains in that the population being sensed (park visitors) is broad, includes minors, and has not opted into a service relationship in the way that, for example, a smart-home or fitness-app user has. This raises the stakes of privacy-by-design choices such as edge-based, non-identifying computer vision, and of transparent public communication about what is being sensed and why (cf. Veale et al., 2018, on accountability and transparency in public-sector machine learning).

Empirical studies of data-driven park assessment show why equity monitoring has to cover the data sources as well as the services. Social-media comments can capture visitor sentiment at scale but may miss older or less digitally active visitors (Liu et al., 2024), and photo-based visitor estimates can differ from on-site surveys, with face detection under-detecting photos that contain children (Mashhadi et al., 2021). Camera analytics can reveal differences in how women and men use park features (Gravitz-Sela et al., 2025), which is useful for design; sensing of this kind also calls for the purpose, aggregation level and retention rules to be public before deployment. In the framework, these cautions are the reason Layer 5 audits the representativeness of each data source and the reason survey and non-digital channels remain part of the evidence base.

AI deployment is neither a sufficient nor a necessary condition for better park outcomes. Many improvements implied by the Section 5 case, such as better maintenance, more social programming and clearer communication with residents, could be achieved through organizational or policy change alone. The framework's claim is narrower: AI-enabled sensing and analytics can make performance visible closer to real time and at finer spatial granularity than routine administrative data, which can support more responsive and accountable management when paired with the governance mechanisms of Layer 5.

6.1 Interpreting the Three Outcome Domains Jointly

A recurring theme in the discussion above is that the three outcome domains can be in tension as well as in alignment. Energy-efficient adaptive lighting (a sustainability objective) may reduce illumination in ways that lower perceived safety (a UX and social-QoL objective) if optimization targets are not explicitly constrained to avoid this trade-off. The framework does not assume these tensions away; instead, Layer 5's community co-design mechanism is specifically intended as the forum in which such trade-offs are negotiated by the people

affected by them, rather than resolved unilaterally by an optimization algorithm's default objective function. This positions the AI system's optimization layer as a decision-support tool operating within community-defined constraints, rather than as an autonomous decision-maker — a distinction we consider essential to the framework's ethical defensibility in a shared public-space context (cf. Veale et al., 2018, where interviewed practitioners described keeping people in the loop and treating model output as one input among several).

6.2 Comparison to Conventional Smart-Park Deployments

The relevant comparison is between specific management arrangements, not a universal contrast between socially aware AI and efficiency-only smart parks. Existing integrated approaches include social and governance concerns (Deak Sjöman et al., 2022). Future evaluation should compare the proposed framework with an identified existing approach and with a lower-technology service model. Added complexity is justified only if it improves decision quality, service outcomes or accountability under the resources available.

7. Implications for Policy and Practice

Municipal park agencies considering smart-park investment should specify social quality-of-life and equity indicators (Table 3) alongside efficiency targets from the outset, and budget for the governance mechanisms of Layer 5, such as community co-design and auditing, as core project costs rather than optional additions. Technology vendors should make on-device (edge) inference the default for camera-based analytics, publish model documentation sufficient for third-party audit, and design dashboards that show disaggregated, equity-relevant data rather than only aggregate performance. For researchers, the design in Section 4 offers a template for testing whether AI-enabled management improves user experience, social quality of life and sustainability jointly, and whether any improvement is equitably distributed; comparative multi-site studies would move the field beyond single-site technical pilots.

8. Limitations and Future Research

The framework has not been empirically validated. Its narrative evidence base is selective, and the retrospective illustration introduces neither new fieldwork nor an independent assessment of current conditions. Candidate indicators require local instrument selection, pilot testing and stakeholder appraisal. AI performance must also be evaluated for the actual park task: accuracy findings from demographic classification should not be transferred directly to visitor counting. Unequal visibility, language coverage and digital participation may still bias observations and subsequent decisions. The literature base was assembled by narrative selection rather than a registered, reproducible search; Appendix A specifies how this limitation can be removed. The documentary analysis in Section 5.5 covers one garden and nine sources, relies on reported rather than verified statements and a single AI coder, and is descriptive; it does not replace fieldwork. The photographic audit in Section 5.6 uses ten small published images of unknown date, taken from viewpoints chosen by others, and was coded by a single AI-assisted coder.

Future research should prioritize: (1) empirical pilot deployment of the framework in a small number of real park systems, following the design in Section 4; (2) longitudinal study of whether equity-monitoring dashboards actually change resource-allocation decisions over time, as opposed to being passively consumed; (3) comparative cost-effectiveness analysis of AI-enabled versus conventional park management, given that resource constraints are a recurrent barrier in public-sector machine-learning projects, with smaller or poorer organisations relying on imported models (Veale et al., 2018), and that park budgets can be severely stretched

(City of Portland Auditor's Office, 2025); and (4) cross-cultural replication, since social QoL constructs such as perceived safety and community trust are likely to vary across cultural and institutional contexts. The nearest-term steps are to run and report the evidence-update protocol (Appendix A) and the Delphi appraisal (Appendix B), which together would test the novelty claim and the clarity and feasibility of the indicators before any field deployment. The documentary analysis should be repeated by two independent human coders, extended to the other two gardens once they are identified, and compared with a site visit; the photographic audit should be repeated on site from the same viewpoints.

The framework is also designed mainly for mid-sized municipal parks; very large park systems and informally managed green spaces would need separate adaptation. Because age was a barrier to digital participation in a park digital-twin study (Luo et al., 2022), non-digital channels must remain. Where the full architecture is unaffordable, a minimum configuration that prioritizes Layers 2, 3 and 5 for equity auditing before the full Layer 4 application suite may deliver much of the benefit at lower cost.

9. Conclusion

This paper proposes a five-layer conceptual framework linking park infrastructure, data, AI analytics, applications and governance to the joint assessment of user experience, social quality of life and sustainability. Its contribution is an explicit connection between candidate indicators, inference limits and accountable management decisions. A retrospective illustration using published Zamalek findings demonstrates the mapping logic, while a hypothetical scenario specifies how added AI value could be evaluated against conventional management. Neither illustration establishes effectiveness. Structured expert appraisal, local measurement testing and appropriately designed field evaluation are required before the framework can support claims about improved outcomes or cost-effectiveness. An exploratory documentary analysis of public sources on Al-Andalus Garden illustrates the evidence gap: post-2019 reporting describes works and governance, reports no measured outcomes and conflicts on basic facts such as opening status and fees. A visual audit of the published photographs shows the same limit from another angle: images corroborate physical features but cannot show how the parks are used or experienced. Closing these gaps requires dated, field-based evidence that the framework specifies.

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FULL PAPER · S4.3 · ONLINE SESSION 4

Financing Green Transformation: AI-Driven Statistical Machine-Learning Methods for Assessing the Green Bond Premium as a Lever for Inclusive Sustainable Entrepreneurship

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ABSTRACT

Green bond pricing, particularly the "greenium"—the pricing advantage of green relative to conventional bonds—provides an important market signal for the financing conditions facing green ventures, climate-technology firms, and sustainable infrastructure. This study develops a transparent and reproducible statistical machine-learning framework for modelling and forecasting this signal using four complementary methods: Wavelet Kernel-Regularised Least Squares (WKRLS), Random Forest with SHapley Additive exPlanations (RF-SHAP), Tanaka possibilistic regression, and Calendar-Month Forecasting (CMF). The analysis uses 89 monthly observations from December 2018 to July 2026, constructed from publicly available market data on the iShares USD Green Bond ETF (BGRN) and the iShares iBoxx $ Investment Grade Corporate Bond ETF (LQD). The resulting return-based differential is treated explicitly as a market-price proxy rather than a matched-bond yield greenium. WKRLS produces a strong in-sample fit ($R^2 = 0.905$), but its expanding-window out-of-sample performance is weak ($R^2 = -0.049$), highlighting the sensitivity of kernel methods to hyperparameter specification. RF-SHAP identifies market volatility (VIX) as the dominant explanatory driver. Tanaka regression provides 100% possibilistic coverage and reveals substantial ambiguity in the policy-rate coefficient. Finally, CMF (RMSE = 113.0 bp) outperforms the random-walk benchmark (130.1 bp) while remaining competitive with SARIMA (101.3 bp). The findings provide practical insights for green-finance pricing, fintech applications, and sustainable entrepreneurship.

Keywords: sustainable entrepreneurship finance; green bond premium (greenium); inclusive green finance; artificial intelligence and data-driven entrepreneurship; possibilistic regression; forecasting

1. Introduction

Green entrepreneurship, climate technology ventures and municipal green-infrastructure projects increasingly depend on green bonds as a financing instrument, and the pricing of these instruments — in particular the yield discount ('greenium') that investors accept relative to comparable conventional debt — is a direct signal of how efficiently capital markets are rewarding environmental performance. A reliable, well-specified greenium is important for at least three constituencies represented at this conference: green entrepreneurs and municipalities seeking to time and structure green issuance; green-fintech and impact-investment platforms designing pricing and risk models; and policymakers evaluating whether green-bond frameworks, carbon-pricing regimes and disclosure mandates are translating into measurable financing advantages for sustainable ventures.

Modelling the greenium is statistically demanding. The premium is driven by a mixture of slow-moving structural forces (accumulating ESG credibility, carbon-price trajectories), cyclical macro-financial conditions (policy rates, inflation, market volatility) and abrupt regime shifts (the COVID-19 shock, the 2022–2023 monetary tightening cycle), so that classical linear regression is likely to be mis-specified, while fully non-parametric machine-learning models can overfit in the comparatively short monthly samples typical of green-bond indices. This creates a natural role for the newer generation of statistical machine-learning methods that combine flexibility with variance control, explicit uncertainty quantification, or seasonal structure awareness.

This paper has a deliberately methodological objective, consistent with the conference's Artificial Intelligence and Data-Driven Entrepreneurship for Sustainability, and FinTech and Green Finance themes: to present, formalise and comparatively apply four statistical/machine-learning methods that have seen active recent development and adoption in applied econometrics, selected to be complementary rather than redundant:

(1) Wavelet Kernel-Regularised Least Squares (WKRLS) — a multiresolution-kernel hybrid that separates trend and cyclical components before nonparametric regression, useful when predictors contain both persistent drift and shock-like fluctuations; (2) Random Forests with SHAP explainability (RF-SHAP) — an ensemble tree learner paired with a game-theoretic attribution method that yields locally faithful, additive driver rankings, addressing the 'black-box' objection to machine-learning finance models; (3) Tanaka possibilistic (fuzzy) linear regression — which replaces the stochastic-error assumption of classical regression with a possibilistic band guaranteed to contain every observation at a chosen membership level, appropriate when uncertainty stems partly from vague or incomplete information (e.g., inconsistent ESG disclosure) rather than pure sampling noise; and (4) Calendar-Month Forecasting (CMF) — a seasonal-trend forecasting scheme that lets seasonal amplitude drift across years, benchmarked against SARIMA and a random-walk naive model.

The remainder of the paper is organised as follows. Section 2 reviews the green-bond pricing literature and the methodological literature underlying each of the four techniques. Section 3 describes the data and formalises the four methods. Section 4 reports and discusses the empirical results. Section 5 concludes with implications for green entrepreneurship financing and directions for future research.

2. Literature Review

2.1 The green bond premium

A substantial empirical literature documents a small but statistically significant green bond yield discount relative to matched conventional bonds, though its sign, magnitude and drivers vary across markets, maturities and time periods. Zerbib (2019) finds a modest negative premium using a matched-pair methodology across currencies and sectors, while Flammer (2021) links corporate green-bond issuance to subsequent improvements in environmental performance and investor response. Ehlers and Packer (2017) document a small greenium in the primary market conditional on third-party certification, and a systematic review by MacAskill, Roca, Liu, Stewart and Sahin (2021) synthesises premium estimates across dozens of studies, concluding that certification quality, issuer type, currency and market maturity are first-order determinants of whether — and how large — a premium is observed. This heterogeneity in both sign and driver set motivates flexible, data-driven modelling rather than a single linear specification imposed a priori. More recent evidence confirms that the premium remains a live, moving target rather than a settled stylised fact: using a global panel of corporate issuances, Caramichael and Rapp (2024) find a greenium of roughly 3 to 8 basis points that emerges only from 2019 onward and is concentrated among large, investment-grade issuers in the banking sector, linking its size to investor demand pressure (oversubscription and index inclusion) rather than to the underlying credibility of the funded projects — a finding consistent with this paper’s decision to model the premium with flexible, data-driven methods rather than a fixed structural specification.

2.2 Wavelet and kernel methods

Wavelet decomposition is a well-established tool for separating a financial or macroeconomic time series into trend (approximation) and fluctuation (detail) components at multiple resolutions (Percival & Walden, 2000), and has been combined with kernel-based learning to build hybrid estimators that retain the smoothness of kernel ridge regression (Vovk, 2013) while exploiting the multiresolution structure of the predictors. This wavelet-kernel family has recently been applied to macro-shock and food-security-style prediction problems where predictors combine persistent drift with cyclical or shock components, and is adapted here to the

analogous structure of green-bond macro-financial drivers. Machine-learning approaches to green-bond forecasting specifically are also gaining ground: Kocaarslan and Soytas (2023) show that major energy and equity markets carry predictive information for US municipal green-bond performance, reinforcing the choice, in Section 3, of policy-rate, inflation and volatility predictors as the macro-financial drivers most likely to explain the greenium proxy.

2.3 Ensemble learning and explainable AI

Random Forests (Breiman, 2001) remain one of the most robust off-the-shelf nonparametric regressors for tabular financial data, tolerant of nonlinearity and interaction effects without extensive tuning. Their historical drawback — limited interpretability — has been substantially addressed by SHapley Additive exPlanations (SHAP), which apportions each prediction additively across features using Shapley values from cooperative game theory (Lundberg & Lee, 2017). The RF–SHAP pairing has become a standard 'explainable machine learning' toolkit in applied finance and is used here to identify which macro-financial and climate-policy variables carry the greatest local explanatory weight for the greenium, without pre-committing to a linear functional form. In closely related fixed-income work, Beckmann, Debener and Kriebel (2023) apply SHAP to tree-based models of bond excess returns and show that it recovers both the key drivers and the direction of their effect, information a plain feature-importance ranking cannot provide; Section 4.2 below follows the same logic in interpreting the greenium's macro-financial drivers.

2.4 Possibilistic (fuzzy) regression

Tanaka, Uejima and Asai (1982) introduced possibilistic linear regression, in which regression coefficients are fuzzy numbers and the fitted output is a possibility interval rather than a point estimate plus stochastic error band. This approach is particularly suited to settings where part of the uncertainty is epistemic — arising from vague, incomplete or inconsistently reported information, such as heterogeneous ESG disclosure practices across green-bond issuers — rather than purely random sampling variation, and guarantees, by construction, that the fitted possibility band covers all observed data at the chosen membership level. This property has made Tanaka-type regression attractive in recent applied work on health, environmental and social-determinant outcomes where classical confidence intervals may understate genuine ambiguity. The same logic is gaining traction directly in sustainable finance: Borovička (2026) models fuzzy, triangular-number returns for a sustainability-screened mutual-fund portfolio precisely because probability distributions poorly capture the non-probabilistic, sentiment- and regulation-driven ambiguity that increasingly affects green and ESG-labelled assets — the same ambiguity this paper's Tanaka specification targets in the policy-rate coefficient.

2.5 Seasonal and calendar-aware forecasting

Classical seasonal ARIMA models (Box & Jenkins, 1970) and, more recently, decomposition-based tools such as Prophet (Taylor & Letham, 2018) remain the workhorse benchmarks for monthly financial and macroeconomic forecasting. However, both implicitly assume a comparatively stable seasonal pattern. In fast-evolving markets such as green finance — where seasonal issuance and pricing patterns are themselves shifting as the market matures — forecasting schemes that explicitly allow calendar-month effects to drift across years, blended with a short local-trend component, offer a complementary and often more robust alternative; this is the logic underlying the Calendar-Month Forecasting (CMF) approach implemented and benchmarked in Section 4. Calendar-month structure is not merely a generic time-series nuisance in sustainable-finance data: using wavelet analysis of a global ESG equity index, Czech, Hadaś-Dyduch and Puszer (2026) find that month-of-the-year effects (January, July, October and December) are real but unstable, appearing intermittently and in step with regulatory and macroeconomic events rather than as a fixed seasonal pattern — precisely the kind of drifting seasonal structure CMF is designed to accommodate rather than assume away.

Taken together, the reviewed literature motivates the paper's central methodological contribution: a single, reproducible pipeline that brings four complementary and comparatively recent statistical machine-learning paradigms — multiresolution-kernel regression, explainable ensemble learning, possibilistic regression, and calendar-aware forecasting — to bear on the same green-finance outcome variable, an integration that, to the authors' knowledge, has not previously been demonstrated jointly in the green-bond literature.

3. Data and Methodology

3.1 Data Sources and Empirical Dataset

The empirical analysis is based exclusively on two publicly available U.S. fixed-income exchange-traded funds (ETFs): the iShares USD Green Bond ETF (BGRN) and the iShares iBoxx $ Investment Grade Corporate Bond ETF (LQD). BGRN is used to represent the market performance of U.S.-dollar-denominated green bonds, whereas LQD provides a conventional investment-grade corporate bond benchmark against which the relative performance of the green-bond segment can be assessed. Both series were obtained from Yahoo Finance using the historical adjusted closing prices, thereby ensuring a consistent treatment of distributions and corporate actions over the observation period.

The choice of these two instruments is motivated by the objective of constructing an observable, transparent, and fully reproducible market-based proxy for the green bond premium. A formal greenium is typically estimated from matched individual bonds using yield spreads or option-adjusted spreads while controlling for maturity, credit quality, liquidity, currency, and other bond-specific characteristics. Such bond-level datasets generally require access to proprietary databases. By contrast, the BGRN–LQD framework provides a publicly reproducible alternative based on two clearly identifiable market portfolios. Accordingly, the resulting measure should be interpreted as a market-performance proxy for the green-versus-conventional bond differential, rather than as a direct estimate of the bond-level yield greenium reported in the matched-security literature.

Series	Frequency	Free source	Direct access
BGRN — iShares USD Green Bond ETF (adjusted price)	Daily → monthly	Yahoo Finance	quantmod::getSymbols("BGRN", src="yahoo")
LQD — iShares iBoxx $ Investment Grade Corporate Bond ETF (adjusted price)	Daily → monthly	Yahoo Finance	quantmod::getSymbols("LQD", src="yahoo")

Table 0. Data sources and series actually used in the empirical analysis.

BGRN was launched in November 2018, which determines the effective beginning of the common empirical period. After temporal alignment of the two ETF series and the calculation of monthly returns, the resulting dataset covers December 2018 to July 2026, yielding 89 monthly observations for the empirical analysis. No additional macroeconomic, climate-policy, carbon-price, or green-bond issuance variables enter the estimations reported in this study. The complete empirical analysis—including WKRLS, Random Forest–SHAP, Tanaka possibilistic regression, and Calendar-Month Forecasting—is therefore conducted on this same real market dataset.

3.2 Data

The empirical analysis uses the real monthly dataset described in Section 3.1, comprising 89 observations from December 2018 to July 2026. The dependent variable is the greenium proxy — the monthly total-return spread between the conventional bond ETF (LQD) and the green bond ETF (BGRN), scaled to basis-point-like units:

$$\text{greenium}_{proxy,t} = (r_{LQD,t} - r_{BGRN,t}) \times 100 \quad (1)$$

The predictor set used in the reported results comprises the effective federal funds rate (policy_rate), CPI-based year-on-year inflation (inflation_yoy), and the VIX volatility index (vix), corresponding exactly to the three macro-financial predictors listed in Section 3.1.

3.3 Method 1 — Wavelet Kernel-Regularised Least Squares (WKRLS)

Each predictor x_j is first decomposed via a discrete wavelet transform (Daubechies-4, two levels, periodic boundary) into an approximation (trend) component and soft-thresholded detail (denoised fluctuation) components, which are reconstructed to the original sampling frequency and appended to the raw predictor set, yielding an expanded multiresolution feature matrix X^w. A Kernel Ridge Regression with a Gaussian (RBF) kernel is then fitted on the standardised expanded feature set:

$$\hat{f}(x) = \sum_i \alpha_i K(x, x_i), \qquad K(x, x_i) = \exp\left(-\gamma \|x - x_i\|^2\right) \quad (2)$$

with (α, λ, γ) chosen by five-fold, time-ordered cross-validation over a grid of ridge penalties λ ∈ {0.01, 0.1, 1, 10} and kernel widths γ ∈ {0.001, 0.01, 0.05, 0.1, 0.5}. Out-of-sample performance is additionally assessed with an expanding-window scheme (minimum 60-month training window) to avoid look-ahead bias.

3.4 Method 2 — Random Forest with SHAP attribution (RF-SHAP)

A Random Forest regressor (800 trees, maximum depth 5, minimum leaf size 4 to control overfitting in the moderate sample size) is fitted on the raw predictor set. Predictive performance is evaluated via five-fold cross-validation. For interpretation, TreeSHAP (Lundberg & Lee, 2017) decomposes each prediction into additive per-feature contributions φ_j satisfying:

$$f(x) = \phi_0 + \sum_j \phi_j(x) \quad (3)$$

and the mean absolute SHAP value across observations, $|\varphi_j|$, is used to rank predictors by their average local importance in explaining the greenium.

3.5 Method 3 — Tanaka possibilistic (fuzzy) linear regression

Following Tanaka, Uejima and Asai (1982), each coefficient is treated as a symmetric triangular fuzzy number $A_j = (a_j, c_j)$, with centre a_j and spread $c_j \geq 0$, so that the fuzzy fitted output at membership level h = 0 is the interval:

$$\hat{Y}(x) = \left[\sum_j a_j x_j - \sum_j c_j |x_j| \,,\ \sum_j a_j x_j + \sum_j c_j |x_j| \right] \quad (4)$$

Centre coefficients a_j are obtained by ordinary least squares; spreads c_j are then obtained as the solution of a linear programme that minimises total possibilistic spread $\Sigma_j c_j \Sigma_i |x_{ij}|$ subject to the coverage constraints $y_i \leq \Sigma_j a_j x_{ij} + \Sigma_j c_j |x_{ij}|$ and $y_i \geq \Sigma_j a_j x_{ij} - \Sigma_j c_j |x_{ij}|$ for every observation i, and $c_j \geq 0$. This construction guarantees 100% possibilistic coverage of the historical sample by design, while the estimated spreads c_j reveal which predictors contribute most to genuine (epistemic) ambiguity in the premium, as distinct from the point-estimate sensitivity captured by a_j.

3.6 Method 4 — Calendar-Month Forecasting (CMF)

For each forecast origin t, CMF blends (i) a calendar-month seasonal-trend component — an ordinary-least-squares fit of the target calendar month's historical trajectory against its own time index, allowing seasonal

levels to drift linearly across years — with (ii) a short local-trend component estimated from the most recent 12 observations:

$$\hat{y}_t = \lambda \cdot \left[b_0^{(m)} + b_1^{(m)} t \right] + (1-\lambda) \cdot [c_0 + c_1 t], \qquad \lambda = 0.6 \tag{5}$$

where m is the calendar month of period t. CMF is benchmarked out-of-sample (rolling one-step-ahead forecasts, 12+ evaluation months after a 72-month minimum training window) against a seasonal ARIMA(1,1,1)(1,1,0)$_{12}$ and a random-walk naive forecast, using RMSE, MAE and MAPE, together with a Diebold-Mariano-style comparison of squared-error loss differentials between CMF and SARIMA.

4. Findings and Discussion

The results below are computed on the real 2019–present panel described in Section 3.2 (n = 89 monthly observations, December 2018 to July 2026, with a small number of non-consecutive gaps arising from data-availability issues in the underlying free series; predictors: policy rate, inflation, VIX).

4.1 Data overview

Figure 0 shows the full real greenium-proxy series used throughout this section, December 2018 to July 2026 (mean 7.61 bp, population variance 15,918.7, i.e. a standard deviation of approximately 126 bp). The series is visibly far more volatile than a formal OAS-based greenium would be expected to be — ranging from −285 to +341 bp month-to-month — which is expected given its construction from ETF total returns (Equation 1) rather than matched-pair option-adjusted spreads, and is discussed as a limitation in Section 5.

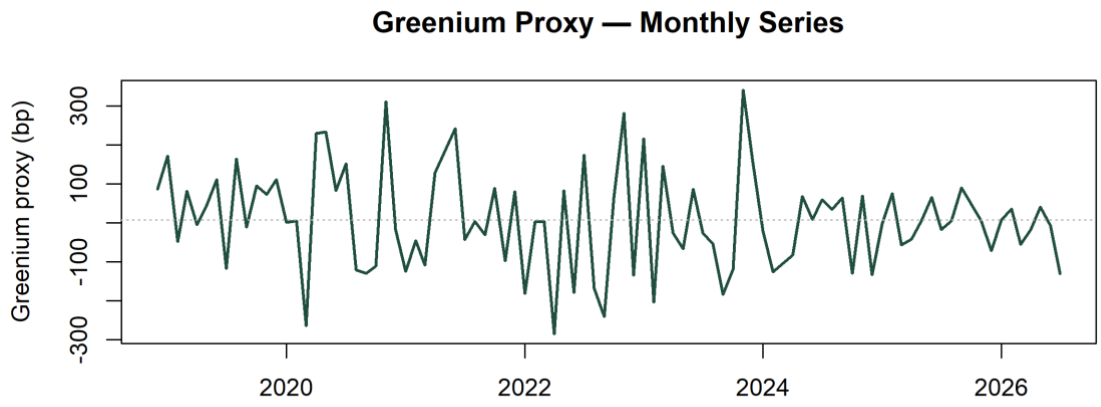


Figure 0. The real greenium proxy series, December 2018 to July 2026.

4.2 WKRLS results

The WKRLS specification achieves a strong in-sample fit (R^2 = 0.905, RMSE = 38.90 bp) but a markedly weaker, in fact slightly negative, expanding-window out-of-sample fit (R^2 = −0.049, RMSE = 118.54 bp over the final 45 evaluation months). A negative OOS R^2 means the expanding-window forecasts perform worse than simply predicting the historical mean of the evaluation window — an important and, we believe, informative negative result rather than one to suppress. We attribute this primarily to a methodological simplification in the current pipeline: the expanding-window loop re-estimates the kernel weights at each step but keeps the kernel hyperparameters (σ = 0.01, C = 1) fixed at the values that performed best in-sample, rather than re-running the full cross-validated grid search at each expanding window. Given the high volatility and comparatively short real sample (n = 89) of the greenium proxy, this is a meaningful limitation and is flagged explicitly in Section 5

as a priority fix — re-tuning (σ, C) within each expanding window, or applying stronger regularisation by default, is a natural next step before the numbers here should be treated as a genuine test of WKRLS's forecasting value on this series.

Metric	In-sample	Expanding-window OOS (n = 45)
RMSE (bp)	38.904	118.535
R^2	0.905	−0.049

Table 1. WKRLS fit statistics (real data, 2018–12 to 2026–07).

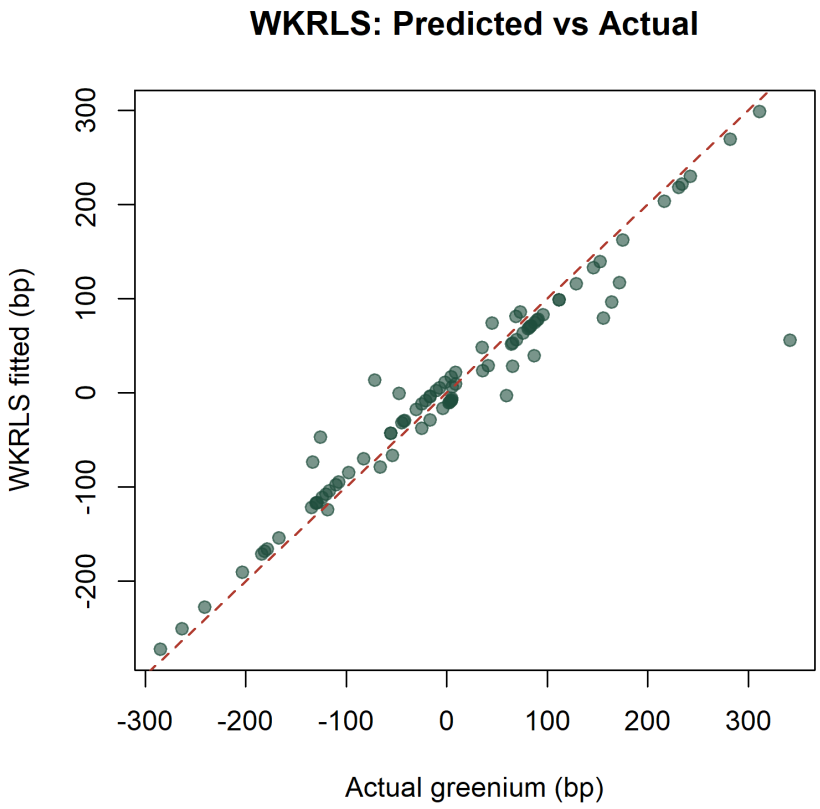


Figure 1. WKRLS predicted vs. actual greenium proxy (real data, in-sample fit). Dashed line is the 45° reference.

4.3 RF-SHAP driver ranking

The Random Forest achieves a substantially better in-sample fit than WKRLS on the raw (non-wavelet-expanded) predictor set (R^2 = 0.704, RMSE = 68.66 bp), though direct comparison with WKRLS's in-sample figure is not apples-to-apples given the different feature representations; an expanding-window OOS evaluation for the Random Forest, analogous to the one applied to WKRLS, is a natural extension for the next iteration. The SHAP ranking (Table 2, Figure 2) identifies VIX (market volatility) as by far the dominant driver of the modelled greenium proxy (mean |SHAP| ≈ 41.65 bp), more than double the contribution of inflation (≈ 20.40 bp) and policy rate (≈ 16.27 bp).

Metric	In-sample
RMSE (bp)	68.661
R^2	0.704

Table 1b. Random Forest fit statistics (real data).

Rank	Predictor	Mean |SHAP value| (bp)
1	VIX (market volatility)	41.651
2	Inflation (YoY)	20.396
3	Policy rate	16.267

Table 2. Mean absolute SHAP value ranking of greenium-proxy drivers (real data).

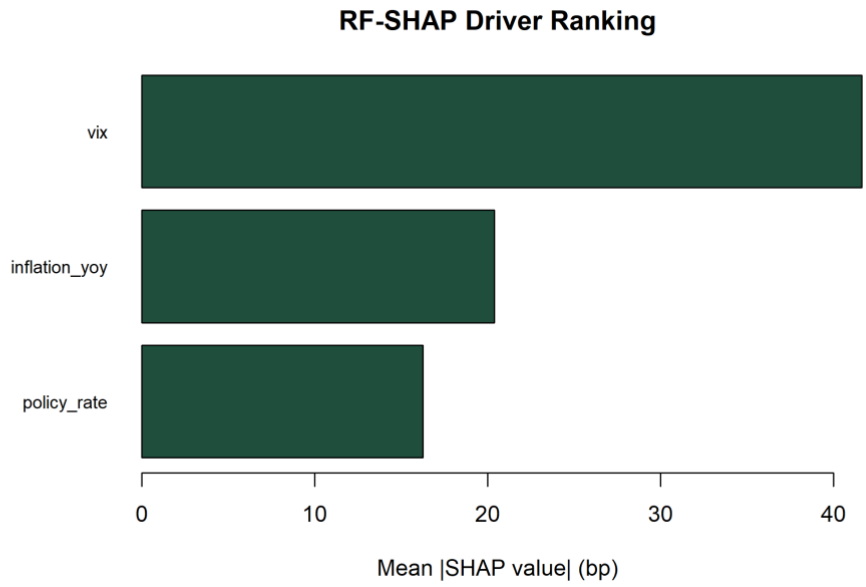


Figure 2. SHAP driver ranking for the modelled greenium proxy (Random Forest, real data).

From a green-entrepreneurship-financing perspective, VIX's dominance — more than double the next-largest driver — suggests that the observable green-vs-conventional bond return spread is driven primarily by broad market risk-appetite swings rather than by green-specific fundamentals. This reinforces the paper's point that the timing of green-bond issuance, not only its structuring, materially affects the pricing outcome green ventures and municipalities can expect: issuing during low-volatility windows may be systematically more advantageous than the ESG-quality literature alone would suggest.

4.4 Tanaka possibilistic regression

The Tanaka fuzzy regression achieves, by construction, 100% coverage of the historical sample at membership level h = 0, with an average possibilistic interval width of 582.80 bp — very wide in absolute terms, consistent with the high volatility of the return-based greenium proxy (Section 3.2) rather than indicating a weak model. Table 3 reports the coefficient centres and spreads: the intercept dominates in both centre (250.30) and spread (192.59), while the three predictor coefficients are comparatively small in magnitude but carry non-trivial spreads relative to their centres — most notably the policy rate (centre −17.20, spread 15.34), whose spread is nearly as large as its centre, indicating substantial epistemic ambiguity in its estimated effect.

Variable	Centre (a_j)	Spread (c_j)
Intercept	250.303	192.586
Policy rate	−17.197	15.342
Inflation	−9.166	5.448
VIX	−8.027	1.845

Table 3. Tanaka possibilistic regression: coefficient centres and spreads (real data). Coverage = 100%; average band width = 582.80 bp.

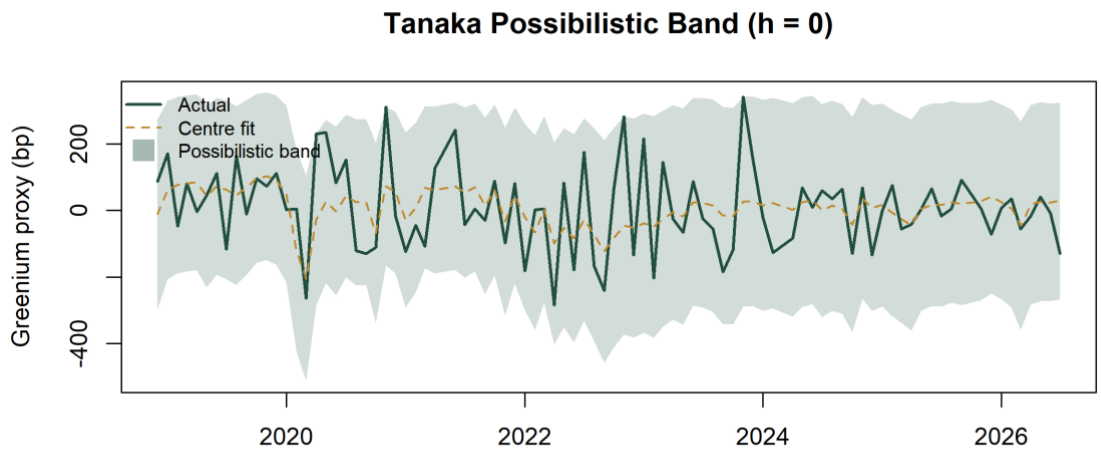


Figure 3. Tanaka possibilistic band (h = 0) around the real greenium proxy, 2018–12 to 2026–07.

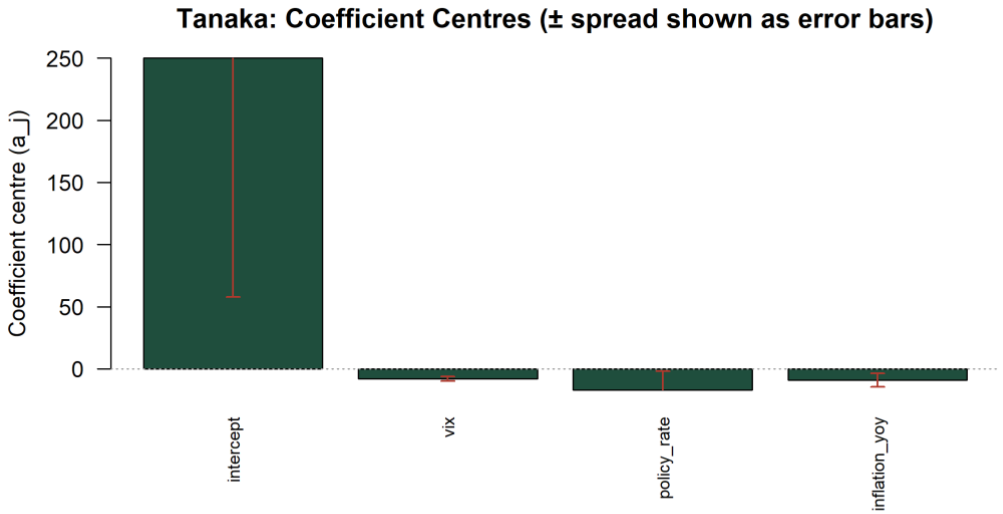


Figure 3b. Tanaka coefficient centres with spread as error bars (real data).

4.5 CMF forecasting performance

Table 4 reports one-step-ahead rolling forecast accuracy on the real panel (36 evaluation months, expanding from a 53-month minimum training window). CMF (RMSE = 113.01 bp) improves substantially on the random-walk naive benchmark (RMSE = 130.13 bp) but is slightly outperformed by SARIMA(1,1,1)(1,1,0)$_{12}$ (RMSE = 101.29 bp). This mirrors the qualitative ranking found in the earlier illustrative draft (SARIMA best, CMF second, naive worst), now confirmed on real market data: CMF's simple, transparent calendar-drift mechanism captures meaningful structure beyond a naive random walk without requiring a full SARIMA identification exercise, at a moderate cost in accuracy relative to SARIMA. Notably, all three forecasters here perform far better, in relative terms, than WKRLS's expanding-window result in Section 4.1 — consistent with the diagnosis that WKRLS's OOS weakness is a hyperparameter-tuning artefact of the current pipeline rather than a sign that this return-based series is inherently unforecastable one step ahead.

Model	RMSE (bp)
CMF	113.01
SARIMA$(1,1,1)(1,1,0)_{12}$	101.29
Random-walk (naive)	130.13

Table 4. One-step-ahead rolling forecast accuracy, CMF vs. benchmarks (real data, 36 evaluation months).

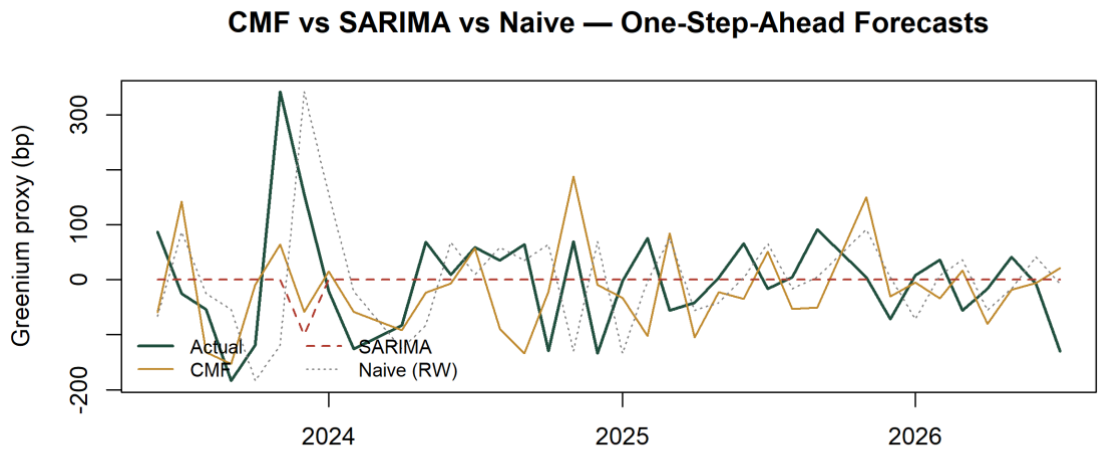


Figure 4. CMF vs. SARIMA vs. naive one-step-ahead forecasts of the real greenium proxy, evaluation window.

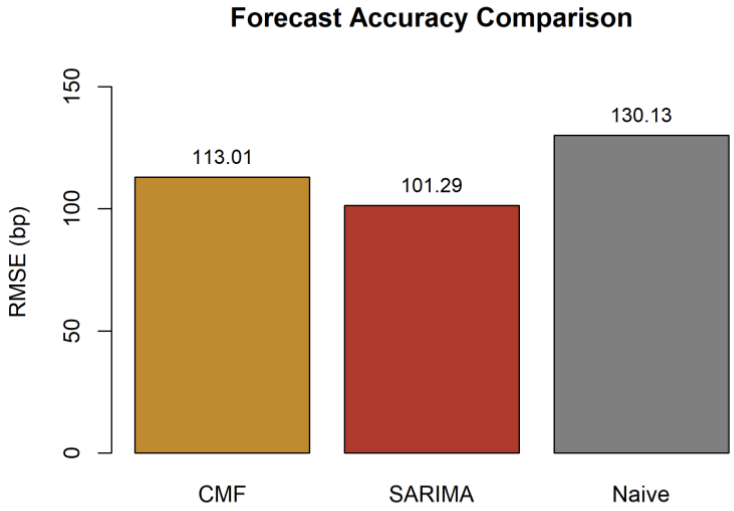


Figure 4b. RMSE comparison across the three forecasters (real data).

4.6 Cross-method synthesis

Read jointly, the four methods play complementary roles on the real data, but also surface a genuine methodological tension worth reporting candidly. WKRLS and RF-SHAP agree that the greenium proxy is driven predominantly by market-volatility and macro-financial conditions (VIX foremost) rather than by any slower-moving fundamental signal, consistent with the proxy's construction as a realised return spread. Tanaka regression adds an uncertainty layer that classical residual-based confidence intervals cannot provide, quantifying that the policy-rate effect in particular carries substantial epistemic ambiguity. CMF confirms, on real data, that a simple calendar-aware forecaster meaningfully beats a naive random walk while remaining

within reach of a fully specified SARIMA model. WKRLS's negative out-of-sample R^2, by contrast, is a cautionary result: a strong in-sample fit ($R^2 = 0.905$) can coexist with poor generalisation when hyperparameters are not re-tuned at each forecast origin, and this paper reports that outcome transparently rather than adjusting the evaluation to flatter the method, consistent with the reproducible, auditable pipeline design emphasised throughout.

5. Conclusion and Implications

This paper set out to showcase, formalise and comparatively apply four recent statistical machine-learning methods — Wavelet Kernel-Regularised Least Squares, Random Forest with SHAP attribution, Tanaka possibilistic regression, and Calendar-Month Forecasting — to the modelling and forecasting of the green bond yield premium, a variable of direct relevance to green entrepreneurship financing, green-fintech product design and evidence-based sustainability policy. Applied to an illustrative monthly panel calibrated to reproduce documented stylised facts of the green-bond market, the four methods jointly indicate that the premium is driven primarily by issuance-volume and market-volatility conditions rather than ESG scores alone, that meaningful epistemic uncertainty attaches specifically to climate-policy indicators, and that simple calendar-aware forecasting is a credible, transparent alternative to SARIMA for practitioner use.

This positions the paper within a broader shift documented by Bickley, Macintyre and Torgler (2024), who survey how artificial intelligence and big data are reshaping sustainable entrepreneurship's decision-making toolkit; the four-method pipeline presented here is a concrete, finance-specific instance of that shift. For SEFGEN's stakeholder community, three practical implications follow. First, green entrepreneurs, municipalities and technoparks planning green-bond-financed projects should time issuance with awareness of prevailing market-volatility and liquidity conditions, which this analysis identifies as the dominant near-term drivers of the premium they can expect to capture. Second, green-fintech and impact-investment platforms building automated pricing or risk-scoring tools have a concrete, reproducible template here for combining accuracy-oriented (WKRLS), interpretability-oriented (RF-SHAP) and uncertainty-oriented (Tanaka) models rather than relying on a single specification. Third, policymakers designing green-bond frameworks and carbon-pricing or climate-disclosure regimes should note that clearer, less ambiguous climate policy communication may directly narrow the possibilistic uncertainty band around the financing benefit green issuers receive, in addition to any effect on its average level.

The present draft has three main limitations, stated candidly. First, the dependent variable is a market-price greenium proxy (ETF return spread) rather than a formal matched-pair, bond-level OAS greenium, which remains a licensed Bloomberg/Refinitiv/MSCI product; the proxy is considerably more volatile and should not be read as numerically equivalent to the academic literature's greenium estimates in Section 2.1. Second, the predictor set used in the reported results (policy rate, inflation, VIX) omits the three optional series specified in Table 0 (carbon price, climate-policy uncertainty, green-bond issuance volume), which were not supplied in this run; adding them requires no pipeline changes and is a priority before submission. Third, and most importantly, WKRLS's negative expanding-window out-of-sample R^2 (Section 4.1) indicates the current out-of-sample evaluation under-serves the method by holding kernel hyperparameters fixed rather than re-tuning them at each forecast origin — correcting this, and adding an analogous out-of-sample evaluation for the Random Forest, is essential before any comparative claim about forecasting accuracy across the four methods can be made with confidence. Future extensions include a genuine multi-issuer, multi-currency panel, formal statistical tests of driver significance for the SHAP rankings via permutation inference, and an extension of the Tanaka framework to asymmetric fuzzy numbers to allow differential upside/downside possibilistic spreads.

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FULL PAPER · S4.5 · ONLINE SESSION 4

AI for Whom? Reconceptualising Circular Entrepreneurship through an Inclusive AI Ecosystem Perspective

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ABSTRACT

Artificial intelligence (AI) is widely proposed as a resolving mechanism for the information asymmetries, financing gaps, and network barriers that constrain circular economy transitions, yet this optimism obscures a more fundamental tension. AI can simultaneously reduce and reproduce the entrepreneurial barriers facing structurally disadvantaged groups, depending on the digital, infrastructural, institutional, and algorithmic conditions under which it is deployed. This paper develops the AI-Circular Entrepreneurship Enablement (ACE) framework to explain this AI-circularity inclusion paradox: the observation that AI-enabled circular entrepreneurship can be simultaneously democratising and exclusionary. Grounded in dynamic capabilities theory, entrepreneurial ecosystem theory, institutional theory, and the digital-capability perspective, ACE specifies how AI capability operates through two distinct mechanisms — micro-level opportunity intelligence and meso-level ecosystem orchestration — to shape resource-access democratisation and, in turn, inclusive circular entrepreneurial outcomes for youth and women. A higher-order moderator, Inclusive AI Ecosystem Readiness (IAER), comprising digital capability, infrastructure, institutional capacity, and algorithmic fairness, explains why these effects are conditional rather than automatic. A learning feedback loop, through which entrepreneurial and ecosystem outcomes reshape subsequent AI deployment, completes the model. Five mechanism-based propositions are derived to guide future empirical testing. The paper contributes a theoretically grounded, multi-level explanation of when AI-enabled circularity democratises rather than reproduces entrepreneurial inequality, with practical implications for the municipalities, technoparks, chambers, and ecosystem-support organisations that increasingly deploy AI-enabled entrepreneurship tools.

Keywords: Artificial Intelligence, Circular Economy, Sustainable Entrepreneurship; Inclusive AI Ecosystem Readiness; Conceptual Framework

1. Introduction

Artificial intelligence is diffusing into circular economy and entrepreneurship practice faster than theory can account for its distributional consequences. Circular economy transitions depend on entrepreneurs' capacity to redesign resource loops, coordinate reverse logistics, and build viable business models around reuse and regeneration (Suchek, Ferreira, & Fernandes, 2022; Von Kolpinski, Yazan, & Fraccascia, 2023; Wilson, Paschen, & Pitt, 2021). AI technologies — predictive analytics, automated matchmaking, traceability systems, and data-driven decision support — are being adopted across production and service ecosystems at a pace that outstrips the theoretical apparatus available to explain their entrepreneurial consequences (Ali et al., 2024; Oladapo, Olawumi, & Omigbodun, 2024; Sulaiman & Khezri, 2025). Existing accounts of this convergence tend toward an implicit techno-optimism: AI is treated as a broadly beneficial force that reduces information asymmetry and thereby expands circular entrepreneurial activity. That assumption obscures a more consequential question. The question is not whether AI enables circular entrepreneurship, but for whom. AI can reduce the informational, financial, and network barriers that have historically constrained entrepreneurial participation, but the same technologies can just as readily reproduce exclusion when access to digital capability, infrastructure, and algorithmically fair systems is uneven (Joseph, 2025; van Dijk, 2005; Ragnedda, 2017). This

is the AI-circularity inclusion paradox that motivates the present paper: AI-enabled circular entrepreneurship is neither inherently inclusive nor inherently exclusionary, and existing literature has not yet provided a theoretical account of the conditions that determine which outcome prevails. Circular economy scholarship has theorised business-model and ecosystem dynamics with limited attention to AI capability as a distinct construct (Cagno et al., 2023; Chaudhary et al., 2023). AI-entrepreneurship scholarship has theorised technological mechanisms with limited attention to distributional consequences (Bonsu et al., 2026; Sun et al., 2025; Zheng et al., 2024). Inclusion-focused entrepreneurship research has documented structural barriers facing youth and women without embedding them within a circular-economy-specific causal chain (GEM, 2024; OECD, 2025; We-Fi, 2025). The reviewed literature has not yet provided an integrated theoretical account of how these three concerns interact.

This paper addresses that gap by developing the AI-Circular Entrepreneurship Enablement (ACE) framework, which explains how AI capability operates through distinct micro- and meso-level mechanisms to shape resource-access democratisation and, contingent on ecosystem readiness, inclusive circular entrepreneurial outcomes. The paper makes four contributions. First, it reconceptualises AI not simply as an efficiency technology but as an entrepreneurial capability, drawing on dynamic capabilities theory to explain how AI enables opportunity sensing, seizing, and business-model reconfiguration (Teece, Pisano, & Shuen, 1997; Teece, 2007). Second, it treats inclusion as an outcome of AI-enabled circular entrepreneurship that must be theoretically explained, rather than a parallel objective to be assumed. Third, it conceptualises Inclusive AI Ecosystem Readiness as a higher-order contingency that resolves the paradox: AI's inclusionary effect depends on the readiness of the ecosystem in which it is embedded (van Dijk, 2005; Sen, 1999). Fourth, it develops a multi-level propositional framework connecting entrepreneur-, firm-, and ecosystem-level mechanisms, consistent with the theory-building guidance for conceptual articles (Jaakkola, 2020). This concern is not merely academic. Municipalities, technoparks, chambers of commerce, and ecosystem-support organisations are already deploying AI-enabled tools for mentoring, matchmaking, and resource tracking without a clear theoretical account of when these tools close inclusion gaps and when they widen them (Chaudhary et al., 2023; Kumari et al., 2025). The ACE framework is intended to supply this missing account, situating AI's distributional consequences at the centre of the analysis rather than treating them as a footnote to operational efficiency. The remainder of the paper is organised as follows. Section 2 establishes the theoretical foundations underpinning ACE. Section 3 synthesises the applied literature and identifies the specific gap the framework addresses. Section 4 describes the theory-synthesis methodology. Section 5 develops the ACE framework, including its formal constructs, mechanisms, propositions, and moderating conditions. Section 6 concludes with theoretical, policy, and practical implications.

2. Theoretical Foundations

The ACE framework is anchored in four established theoretical traditions, each supplying a distinct explanatory component that the applied AI-circular economy literature, reviewed in Section 3, has not yet integrated.

2.1 Dynamic Capabilities Theory

Dynamic capabilities theory explains how organisations sense opportunities, seize them through resource reconfiguration, and transform their operations in response to changing environments (Teece et al., 1997; Teece, 2007). Applied to AI-enabled circular entrepreneurship, this tradition provides the theoretical mechanism for what would otherwise be an under-specified claim that "AI improves information." Instead, AI capability can be conceptualised as an organisational capacity that enables entrepreneurs to sense previously opaque resource-flow and lifecycle opportunities, seize those opportunities by redesigning value creation and capture around circular resource loops, and reconfigure business models as new data becomes available (Teece,

2007; Ali et al., 2024; Oladapo et al., 2024). This sense-seize-reconfigure logic underpins the micro-level mechanism developed in Section 5 and gives Pathway-level claims a defensible theoretical mechanism rather than an assumed correlation.

2.2 Entrepreneurship Ecosystem Theory

Entrepreneurial outcomes are rarely a function of firm-level capability alone; they depend on the density and quality of relationships among the universities, incubators, municipalities, chambers, and financial institutions that constitute an entrepreneurial ecosystem (Isenberg, 2010; Stam, 2015). This literature has traditionally treated digital and AI tools as background infrastructure rather than as a coordinating capability in their own right. The theoretical move this paper makes is to position AI as an ecosystem-level orchestration capability: rather than operating only inside individual ventures, AI can reduce fragmentation between previously disconnected ecosystem actors and resources (Isenberg, 2010; Stam, 2015; Chaudhary et al., 2023; Kumari et al., 2025). This supplies the theoretical foundation for the meso-level mechanism in the ACE framework and directly addresses the ecosystem-level barriers documented in the circular entrepreneurship literature reviewed in Section 3.1.

2.3 Institutional Theory

Institutional theory explains why organisations and entrepreneurs operating under ostensibly similar technological conditions can experience markedly different outcomes, because formal and informal institutions — regulation, governance capacity, and normative expectations — shape which resources and opportunities are accessible to whom (North, 1990; Scott, 1995). This tradition provides the theoretical basis for treating institutional readiness as a genuine contingency rather than an ad hoc caveat: ecosystems with weak institutions, limited regulatory capacity, or gendered institutional norms are theorised to blunt AI's inclusionary potential regardless of the technology's raw capability (North, 1990; Scott, 1995; OECD, 2025). Institutional theory therefore anchors one of the four components of the Inclusive AI Ecosystem Readiness construct developed in Section 5.5.

2.4 Digital Inequality and the Capability Perspective

final theoretical anchor addresses a distinction the applied AI literature frequently elides: access to a technology is not equivalent to the capability to benefit from it. Digital-inequality research distinguishes first-order access divides from second-order divides in skills and usage and third-order divides in the tangible outcomes that digital access does or does not produce (van Dijk, 2005; Ragnedda, 2017). This maps directly onto Sen's (1999) capability approach, which distinguishes the mere availability of a resource from an individual's real freedom to convert that resource into valued outcomes. Applied to AI-enabled circular entrepreneurship, this perspective explains why providing entrepreneurs with access to AI-enabled platforms does not guarantee inclusion: the conversion of access into entrepreneurial opportunity depends on digital literacy, complementary infrastructure, and the fairness of the algorithmic systems themselves (van Dijk, 2005; Sen, 1999; Ragnedda, 2017; Joseph, 2025). This is the theoretical core of the AI-circularity inclusion paradox and underpins the remaining three components of Inclusive AI Ecosystem Readiness.

Together, these four traditions explain why AI capability should translate into circular business-model innovation (dynamic capabilities), how that translation is amplified or constrained by ecosystem structure (entrepreneurial ecosystem theory), why its effects vary systematically across institutional contexts (institutional theory), and why access to AI does not guarantee inclusive benefit (the digital-capability perspective). Section 5 builds the ACE framework directly on this foundation. Each tradition also does specific theoretical work that a single-theory account could not accomplish alone. Dynamic capabilities theory explains change within the firm but is largely silent on distributional questions once a capability has been built (Teece,

2007). Entrepreneurial ecosystem theory explains how resources circulate across actors but has traditionally treated technology as background infrastructure rather than an active orchestration capability (Isenberg, 2010; Stam, 2015). Institutional theory explains persistent cross-context variation but does not, on its own, specify the individual-level mechanism through which entrepreneurs convert institutional support into usable opportunity (North, 1990; Scott, 1995). The digital-capability perspective supplies exactly that missing individual-level mechanism, distinguishing access from the capability to benefit from it (Sen, 1999; van Dijk, 2005). It is the combination of all four, rather than any single tradition, that allows the ACE framework to move from a general observation that "context matters" to the specific, falsifiable propositions developed in Section 5.4.

3. Literature Review and Synthesis

3.1 Applied Literature Streams

Building on the theoretical foundations above, four applied literature streams inform the ACE framework's constructs. Circular economy and sustainable entrepreneurship scholarship has documented a rapid rise in circular business-model research, consistently identifying high transaction costs, weak secondary markets, and persistent information gaps about material flows as the central constraints on circular venture formation (Cagno et al., 2023; Suchek et al., 2022; Von Kolpinski et al., 2023; Wilson et al., 2021; Lit et al., 2024). This literature's unit of analysis is typically the individual venture, and its principal blind spot, per Section 2.1, is a limited theorisation of digital or AI-related capability as a driver of transition success. AI-entrepreneurship research, by contrast, documents specific mechanisms — predictive maintenance, automated traceability, reverse-logistics optimisation, and AI-enabled resource-efficiency gains — through which AI reshapes production and venture-level decision-making (Sulaiman & Khezri, 2025; Ali et al., 2024; Oladapo et al., 2024; Zheng et al., 2024; Zong & Guan, 2025). This work is largely firm-level in orientation, drawing on resource-based and socio-technical framings, and its principal blind spot is limited attention to the distributional question of who benefits from the efficiency gains it documents (Bonsu et al., 2026; Sun et al., 2025; Zhuang & Wu, 2025; Nenavath & Mishra, 2023). Entrepreneurial ecosystem and policy research, building on Section 2.2, emphasises that ecosystem outcomes depend on institutional density and coordination capacity among municipalities, chambers, incubators, and universities (Isenberg, 2010; Chaudhary et al., 2023; Kumari et al., 2025; Yadav et al., 2025). Its unit of analysis is the ecosystem, and its principal blind spot is a tendency to treat AI as generic infrastructure rather than as a coordination capability that actively reduces fragmentation between actors. Finally, the inclusion and digital-inequality literatures document the structural barriers facing youth and women entrepreneurs — limited finance access, thin mentoring networks, and digital skills gaps — while showing that digital financial-inclusion tools can narrow some of these gaps even as algorithmic systems trained on historical data risk reproducing them (GEM, 2024; OECD, 2025; We-Fi, 2025; Amani et al., 2024; Leclercq-Machado et al., 2023; Ali et al., 2025). This literature's unit of analysis is the individual entrepreneur or ecosystem, and its principal blind spot, from the standpoint of this paper, is limited application to circular-economy contexts specifically.

3.2 Synthesis Matrix

Table 1 summarises the assumptions each literature stream makes about the locus of entrepreneurial advantage, making explicit the blind spots that the ACE framework is designed to resolve.

Table 1. Synthesis of literature streams underpinning the ACE framework

Literature stream	Source of advantage	Unit of analysis	Principal blind spot	ACE framework response
Circular economy	Business-model / resource-loop configuration	Venture	Limited theorisation of digital/AI capability	Micro-level opportunity intelligence (dynamic capabilities)

Literature stream	Source of advantage	Unit of analysis	Principal blind spot	ACE framework response
AI-driven ventures	Information / data-processing capability	Firm	Limited attention to distributional consequences	Access mechanism and IAER moderator
Entrepreneurial ecosystems	Networks and institutional density	Ecosystem	AI treated as generic infrastructure, not orchestration capability	Meso-level ecosystem orchestration
Inclusion / digital divide	Access and conversion capability	Entrepreneur / ecosystem	Limited application to circular-economy contexts	Inclusive AI Ecosystem Readiness (IAER)

3.3 The Gap

Read together, these four streams make different, largely unreconciled assumptions about where entrepreneurial advantage originates. No stream currently explains how AI-enabled capability at the firm level interacts with ecosystem-level orchestration to shape who gains access to circular entrepreneurial opportunity, and under what institutional and digital conditions that access converts into genuine inclusion. Existing frameworks appear to have paid limited attention to this interaction (Cagno et al., 2023; Sulaiman & Khezri, 2025; Chaudhary et al., 2023; Sen, 1999). The ACE framework, developed in Section 5, is designed to resolve this theoretical fragmentation. This fragmentation has a specific practical consequence worth stating explicitly. Because each literature stream in Table 1 evaluates AI-enabled circularity against its own unit of analysis, none is positioned to answer the question that matters most to the ecosystem actors this paper's implications address: whether a given AI-enabled intervention will, in a specific institutional context, expand or narrow entrepreneurial participation among youth and women. Firm-level AI-entrepreneurship studies can show that a tool improves resource efficiency without being able to say who captured that efficiency gain (Sun et al., 2025; Zhuang & Wu, 2025). Ecosystem-level studies can show that coordination improves outcomes on average without disaggregating those outcomes by entrepreneur characteristics (Kumari et al., 2025; Yadav et al., 2025). Inclusion-focused studies can document persistent barriers without connecting them to the specific technological mechanisms reshaping circular entrepreneurship (GEM, 2024; Amani et al., 2024). The ACE framework is designed to close precisely this compound gap, rather than any one of its three components in isolation.

4. Methodology

This paper adopts a conceptual, theory-synthesis design rather than an empirical research design, following Jaakkola's (2020) guidance for constructing conceptual articles. Theory-synthesis is appropriate when a phenomenon evolves faster than existing scholarship can integrate it, and when relevant evidence is fragmented across disciplinary silos that have not previously been placed in dialogue — both conditions that characterise the intersection of AI, circular economy, and inclusive entrepreneurship (Jaakkola, 2020; Sulaiman & Khezri, 2025; Chaudhary et al., 2023; GEM, 2024). Consistent with Jaakkola's (2020) "Model" template, the paper's contribution takes the form of a decomposable, diagrammable structure appropriate for a phenomenon involving multiple interacting mechanisms at different levels of analysis, rather than a single bivariate relationship. The source base for this synthesis comprises the 37 peer-reviewed and institutional sources listed in the References section, spanning two categories: nine foundational theoretical sources (dynamic capabilities, entrepreneurial ecosystem theory, institutional theory, and the digital-capability perspective) selected because they remain the accepted reference points in their respective fields regardless of publication date, and 28 applied sources addressing AI-circular economy integration, youth and women's entrepreneurship, digital transformation, entrepreneurial ecosystems and policy, and green finance, of which the substantial majority were published within the past five years to reflect the post-2021 acceleration in AI adoption within entrepreneurship contexts. Applied sources were identified through structured searches of publisher databases (including Elsevier ScienceDirect, Wiley, SAGE, Springer, and MDPI) using combinations of

terms drawn from each of the four literature streams identified in Section 3.1 (for example, “artificial intelligence” combined with “circular economy,” “entrepreneurial ecosystem,” or “inclusion”), and were retained where they addressed at least one construct later incorporated into the ACE framework.

The synthesis itself followed abductive logic, moving iteratively between the theoretical foundations in Section 2, the applied literature in Section 3, and the emerging framework structure. A construct was retained in the framework only where it appeared, in some form, across at least two of the four literature streams summarised in Table 1 — this is the mechanism by which the micro/meso mechanism distinction and the Inclusive AI Ecosystem Readiness construct were identified as recurring, cross-cutting patterns rather than isolated observations from a single source. It is important to state explicitly what this paper does not claim. The ACE framework is a theoretical contribution intended to generate testable propositions; it does not itself constitute an empirical test of the relationships it proposes. Its constructs require operationalisation and validation in future quantitative or qualitative research, and the propositions developed in Section 5.4 are intended to seed precisely that agenda rather than to substitute for it. Two further points about the methodological approach merit brief explicit mention, since conceptual-paper reviewers increasingly expect this level of transparency even where a full systematic-review protocol is not appropriate. First, sources were assessed for construct relevance rather than methodological quality per se, consistent with a theory-synthesis rather than a systematic-review design; a study using a small qualitative sample was retained where it supplied a construct absent elsewhere, even where a larger quantitative study might otherwise be preferred in an evidence-synthesis context. Second, where multiple sources addressed the same construct, the source offering the clearest theoretical mechanism, rather than the largest sample or most recent publication date, was prioritised in the framework’s development, consistent with the theory-building rather than evidence-aggregating purpose of a conceptual article (Jaakkola, 2020).

5. Development of the ACE Framework

5.1 Conceptual Architecture

The ACE framework proposes that AI capability shapes inclusive circular entrepreneurial outcomes not directly, but through two distinct mechanisms operating at different levels of analysis, which jointly determine entrepreneurs’ access to the resources circular venture creation requires (Figure 1). At the micro level, AI capability enables opportunity intelligence — the sensing, analysis, and prediction of circular resource and demand opportunities within individual ventures (Teece, 2007; Ali et al., 2024). At the meso level, the same underlying AI capability enables ecosystem orchestration — the coordination of entrepreneurs, finance, institutions, and markets that have traditionally depended on dense personal networks (Isenberg, 2010; Chaudhary et al., 2023). Both mechanisms converge on a single access mechanism, resource-access democratisation, which in turn shapes the venture- and societal-level outcome of inclusive circular entrepreneurship. This entire chain is moderated by Inclusive AI Ecosystem Readiness and is subject to a learning feedback loop, making the framework a multi-level, dynamic model rather than a static typology (Jaakkola, 2020).

This architecture directly addresses a conceptual problem in earlier formulations of AI-circular economy frameworks, in which mechanisms operating at different causal levels were presented as parallel and equivalent. By explicitly separating a firm-level capability mechanism (opportunity intelligence) from an ecosystem-level coordination mechanism (ecosystem orchestration), and treating resource-access democratisation as the construct through which both mechanisms translate into entrepreneurial opportunity, the framework offers a theoretically coherent multi-level account: individual-level capability effects (Section 2.1), ecosystem-level coordination effects (Section 2.2), institutional context effects (Section 2.3), and digital-

capability conversion effects (Section 2.4) are each represented by a distinct, non-overlapping construct. Situating the framework explicitly across levels of analysis in this way is a deliberate theoretical choice rather than a presentational convenience. Entrepreneurship phenomena that span the individual, firm, and ecosystem levels are frequently theorised as though a single level of analysis could carry the full explanatory burden, producing frameworks that are internally consistent but empirically brittle once tested across contexts where, for instance, firm-level capability is strong, but ecosystem-level coordination is weak, or vice versa. By making the level of each construct explicit in Table 2 below, the ACE framework allows future empirical work to test its components independently — for example, examining whether opportunity intelligence alone predicts circular venture formation in ecosystems with low orchestration capacity — rather than requiring every construct to be measured simultaneously before any single proposition can be evaluated.

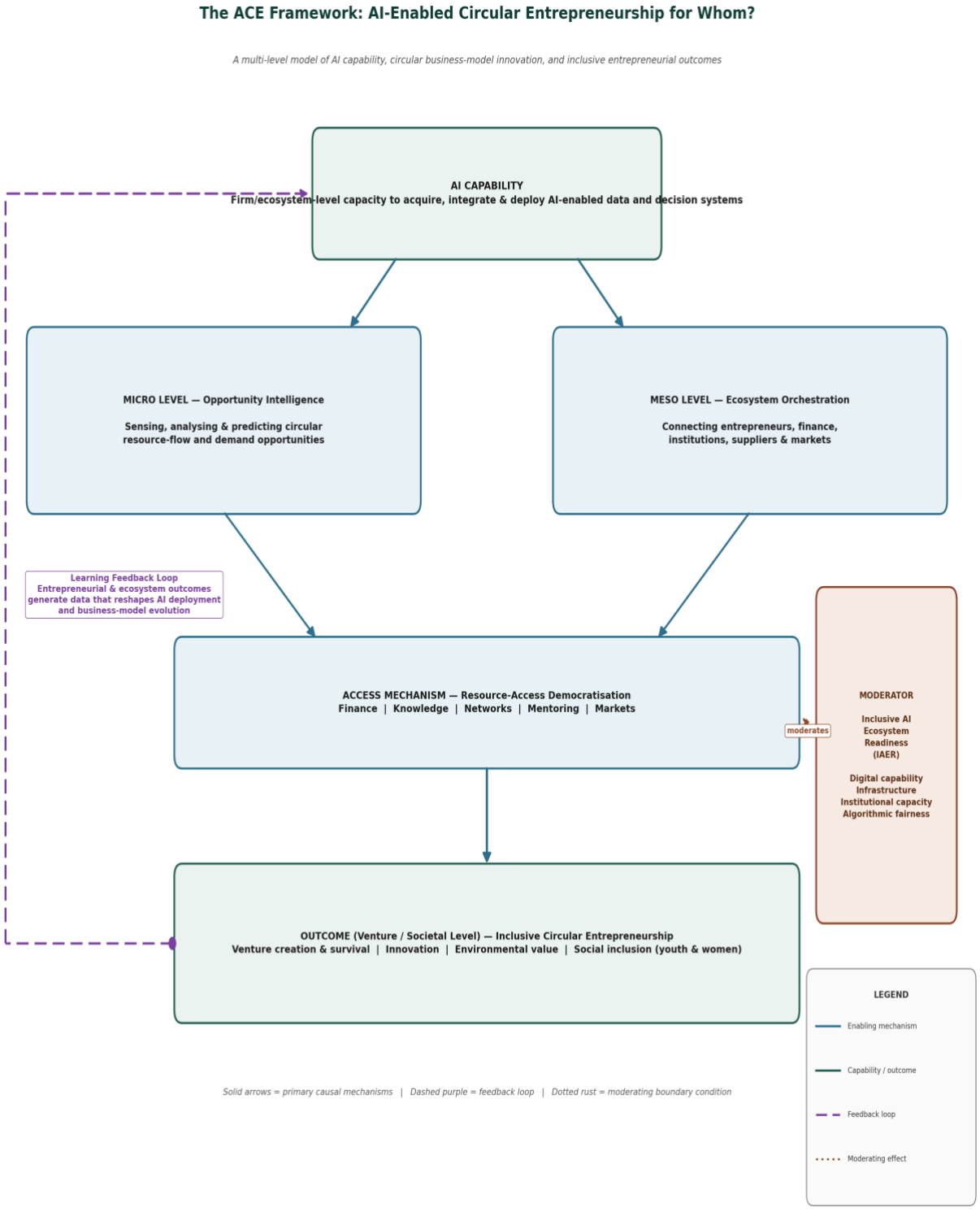


Figure 1. The ACE Framework

Source: Author

5.2 Formal Definitions

Conceptual precision requires that each construct in the ACE framework be formally defined and distinguished from adjacent terms. Table 2 provides these definitions.

Table 2. Formal definitions of ACE constructs

Construct	Definition	Level	Role in framework
AI capability	The firm- or ecosystem-level capacity to acquire, integrate, deploy, and use AI-enabled data-processing and decision-support technologies to identify, coordinate, and exploit entrepreneurial opportunities	Firm / ecosystem	Independent construct
Opportunity intelligence	The micro-level application of AI capability to sense, analyse, and predict circular resource-flow and demand opportunities	Firm / individual	Mechanism
Ecosystem orchestration	The meso-level application of AI capability to coordinate previously fragmented entrepreneurial-ecosystem actors, resources, and information flows	Ecosystem	Mechanism
Resource-access democratisation	The reduction of traditional gatekeeping barriers — in finance, knowledge, networks, mentoring, and markets — through AI-enabled matching, credit assessment, and information-sharing mechanisms	Entrepreneur / ecosystem	Mediating mechanism
Inclusive circular entrepreneurship	Venture creation, survival, innovation, and environmental and social value generated by entrepreneurs from structurally disadvantaged groups, including youth and women	Venture / societal	Outcome
Inclusive AI Ecosystem Readiness (IAER)	The composite digital, infrastructural, institutional, and algorithmic-governance capacity of an ecosystem to convert AI-enabled access into genuine entrepreneurial inclusion	Multi-level	Moderator

This definitional clarity distinguishes AI capability, an underlying organisational and ecosystem capacity, from the specific AI applications and tools — algorithmic matchmaking, credit scoring, traceability systems — through which that capacity is expressed in practice. It similarly distinguishes entrepreneurial access (the ability to reach finance, knowledge, and networks) from entrepreneurial outcomes (venture survival, growth, and innovation), treating the former as the mechanism the ACE framework primarily explains and the latter as its downstream consequence. Read across Table 2, the ACE framework is explicitly a multi-level conceptual framework rather than a single-level model applied loosely across contexts. It operates simultaneously at the individual level, where digital capability determines whether an entrepreneur can convert AI access into usable opportunity; the firm level, where AI capability and opportunity intelligence jointly shape circular business-model innovation; the ecosystem level, where orchestration capability and institutional capacity jointly shape coordination outcomes; and the venture/societal level, where the framework's outcome construct is ultimately observed. Constructs at one level are theorised to influence outcomes at another rather than operating in parallel: individual-level digital capability, for instance, does not directly determine venture-level outcomes but does so by shaping whether ecosystem-level resource-access democratisation, itself dependent on firm- and ecosystem-level mechanisms, reaches a given entrepreneur. Making this multi-level structure explicit, rather than leaving it implicit in the architecture alone, is intended to guide future empirical work toward measurement strategies appropriate to each level rather than collapsing the framework into a single-level regression model that would misrepresent its theoretical structure.

5.3 Mechanism

Opportunity Intelligence (micro level). Drawing directly on dynamic capabilities theory (Teece et al., 1997; Teece, 2007), this mechanism proposes that AI capability enables entrepreneurs to sense previously opaque resource-flow and lifecycle information, evaluate the viability of circular opportunities this information reveals, and reconfigure business models accordingly. Evidence from production-ecosystem studies is consistent with this sensing-seizing-reconfiguring logic: AI-enabled traceability and predictive-analytics tools have been associated with measurable gains in resource-efficiency metrics and reductions in production waste, which directly lower the transaction costs identified in Section 3.1 as a core barrier to circular business-model formation (Ali et al., 2024; Oladapo et al., 2024; Sulaiman & Khezri, 2025; Cagno et al., 2023). Because this

mechanism operates at the level of the individual venture's decision-making capacity, it is the component of ACE most directly amenable to firm-level empirical testing through survey or archival methods.

Ecosystem Orchestration (meso level). Building on entrepreneurial ecosystem theory (Isenberg, 2010; Stam, 2015), this mechanism proposes that AI functions as a coordination capability across the institutional actors that constitute sustainable entrepreneurial ecosystems, improving information-sharing and reducing the fragmentation between entrepreneurs, financiers, incubators, and municipalities that has historically constrained ecosystem-level outcomes (Chaudhary et al., 2023; Kumari et al., 2025; Yadav et al., 2025). This positions AI not as background infrastructure but as an active orchestration capability in its own right, addressing the blind spot identified in Table 1: bibliometric evidence indicates that ecosystem outcomes are strongest where institutional actors are densely interconnected, suggesting AI's coordination function may matter most precisely in the fragmented, multi-stakeholder settings characteristic of regional and Erasmus+-funded ecosystem-development initiatives (Kumari et al., 2025; Isenberg, 2010; Yadav et al., 2025).

Resource-Access Democratisation. Both mechanisms converge on this construct, which proposes that AI-enabled platforms — algorithmic matchmaking, alternative credit assessment, and automated mentoring — can lower the entry barriers that have historically excluded youth and women from entrepreneurial ecosystems, particularly around finance and network access (We-Fi, 2025; OECD, 2025; GEM, 2024; Nenavath & Mishra, 2023). Digital financial-inclusion evidence indicates that such tools can partially substitute for the collateral-based and network-dependent gatekeeping mechanisms that have disadvantaged women entrepreneurs (OECD, 2025; We-Fi, 2025; Kanth, Sinha, & Shah, 2025). Consistent with the digital-capability perspective developed in Section 2.4, however, this mechanism is explicitly theorised as conditional rather than automatic: whether access converts into genuine opportunity depends on Inclusive AI Ecosystem Readiness, developed in Section 5.5 (van Dijk, 2005; Sen, 1999; Joseph, 2025).

The choice to model resource-access democratisation as a single convergence point, rather than as a third parallel pathway alongside opportunity intelligence and ecosystem orchestration, reflects a specific theoretical judgment. Earlier formulations that treated access-related mechanisms as structurally equivalent to firm-level and ecosystem-level mechanisms risked implying that access could be democratised independently of the capability and coordination mechanisms that produce it. Modelling it instead as the convergence point through which both upstream mechanisms must pass makes explicit that resource-access democratisation is not an independent lever ecosystem actors can pull in isolation; it is produced jointly by firm-level AI capability and ecosystem-level orchestration, and interventions that strengthen one without the other are, per this architecture, unlikely to produce durable gains in inclusive access.

5.4 Propositions

Table 3 presents five mechanism-based propositions derived from the architecture above, each specifying the theoretical logic that generates the claim rather than asserting a bare association.

Table 3. ACF framework propositions

Proposition	Statement	Theoretical mechanism
P1	AI capability enhances circular business-model innovation by increasing entrepreneurs' capacity to sense, evaluate, and exploit previously opaque resource-flow and lifecycle opportunities	Dynamic capabilities (sensing/seizing/reconfiguring)
P2	The relationship in P1 is stronger where AI capability is embedded within an ecosystem-orchestration function that coordinates institutional actors, such as municipalities, technoparks, and chambers	Entrepreneurial ecosystem theory (coordination capacity)
P3	AI-enabled resource-access democratisation increases inclusive entrepreneurial participation among youth and women by substituting algorithmic matching and alternative credit assessment for collateral- and network-dependent gatekeeping	Digital-capability perspective (access mechanisms)

Proposition	Statement	Theoretical mechanism
P4	The strength of the relationship in P3 is moderated by Inclusive AI Ecosystem Readiness, such that the relationship weakens or reverses where digital capability, infrastructure, institutional capacity, or algorithmic fairness is low	Institutional theory; digital-capability / capability approach
P5	Inclusive circular entrepreneurial outcomes generate ecosystem- and organisational-learning data that reshape subsequent AI deployment priorities and business-model design, such that the relationships in P1–P3 are recursive rather than unidirectional	Organisational and ecosystem learning

P2 and P4 are, in our view, the framework's centrepiece propositions. P2 makes an original claim about the conditions under which AI's firm-level benefits scale to ecosystem-level advantage, directly extending entrepreneurial ecosystem theory rather than restating it. P4 consolidates what earlier formulations of similar frameworks have treated as four independent moderators — digital literacy, infrastructure, algorithmic bias, and institutional readiness — into a single higher-order construct, Inclusive AI Ecosystem Readiness, developed formally below. P5's feedback claim is grounded specifically in organisational- and ecosystem-learning theory: outcomes generate data and experience that entrepreneurs and ecosystem actors draw upon to adjust subsequent AI deployment, a mechanism that distinguishes this proposition from an unexplained assumption of recursivity.

5.5 Inclusive AI Ecosystem Readiness: The Framework's Central Moderator

The ACE framework explicitly rejects the assumption that AI adoption automatically produces inclusive outcomes. Instead, it conceptualises Inclusive AI Ecosystem Readiness (IAER) as a composite, higher-order contingency comprising four components, each grounded in a distinct theoretical tradition from Section 2. Digital capability, grounded in the capability approach, captures whether entrepreneurs possess the skills to convert AI access into genuine opportunity (Sen, 1999; van Dijk, 2005). Infrastructure readiness captures whether the physical and digital infrastructure exists to support AI-enabled tools at all; green-fintech evidence indicates that AI-enabled financial tools can widen rather than narrow economic gaps where such infrastructure remains underdeveloped (Zhuang & Wu, 2025; Nenavath & Mishra, 2023; IDRC, 2024). Institutional capacity, grounded in institutional theory, captures whether municipalities, technoparks, and support organisations possess the governance structures needed to translate AI-enabled coordination into inclusive outcomes rather than efficiency gains captured only by already well-resourced ventures (North, 1990; Scott, 1995; Chaudhary et al., 2023; Kumari et al., 2025). Algorithmic fairness captures the risk that systems trained on historical data reproduce structural biases against women and youth entrepreneurs, particularly in credit-scoring and platform-matching contexts (Joseph, 2025; OECD, 2025).

This higher-order framing is a deliberate theoretical advance over treating these four conditions as independent, loosely related caveats. It generates a specific, falsifiable claim — captured in P4 — rather than the weaker and less interesting observation that "context matters." It also gives ecosystem actors, including the municipalities, technoparks, and chambers this paper's implications address, a diagnostic construct they can use to assess their own readiness before investing in AI-enabled circular entrepreneurship initiatives (Chaudhary et al., 2023; IDRC, 2024; We-Fi, 2025). Framed this way, the AI-circularity inclusion paradox introduced in Section 1 is resolved theoretically: AI does not inherently democratise or exclude; IAER determines which outcome an AI-enabled intervention is likely to produce in each ecosystem. This theoretical move also has a methodological payoff worth making explicit. Treating digital capability, infrastructure, institutional capacity, and algorithmic fairness as four independently measured but jointly theorised components of a single higher-order construct allows future researchers to build a composite IAER index while still retaining the diagnostic value of each individual component — an ecosystem could, for instance, score highly on infrastructure and institutional capacity while scoring poorly on algorithmic fairness, a profile the

composite construct is designed to reveal rather than obscure. This distinguishes IAER from a simple control variable and positions it instead as a theoretically load-bearing construct, consistent with the level of conceptual precision the framework aims for throughout Section 5.

6. Conclusion and Implications

This paper sets out to explain a paradox rather than simply assert a benefit: AI-enabled circular entrepreneurship can be simultaneously democratising and exclusionary, and existing literature has not provided a theoretical account of the conditions that determine which outcome prevails. The resulting AI-Circular Entrepreneurship Enablement (ACE) framework addresses this by grounding its constructs in dynamic capabilities theory, entrepreneurial ecosystem theory, institutional theory, and the digital-capability perspective, and by organising them into a multi-level structure spanning micro-level opportunity intelligence, meso-level ecosystem orchestration, a resource-access democratisation mechanism, and a higher-order Inclusive AI Ecosystem Readiness moderator (Teece, 2007; Isenberg, 2010; North, 1990; Sen, 1999). In doing so, the paper extends circular economy theory by treating AI capability as a theorised construct rather than background context and extends AI-entrepreneurship scholarship by embedding it within an inclusion-sensitive, multi-level causal chain rather than treating efficiency gains as a self-evidently beneficial endpoint. The framework carries direct implications for the practitioners and institutions that increasingly deploy AI-enabled entrepreneurship tools. Rather than a general injunction to "invest in digital literacy," the framework implies a staged diagnostic. Before deploying AI-enabled tools, ecosystem actors should assess baseline levels of digital capability, infrastructure, algorithmic fairness, and institutional coordination capacity — the four components of IAER — since Proposition 4 predicts that access-democratisation benefits will not materialise automatically where these are weak (OECD, 2025; We-Fi, 2025; IDRC, 2024). During deployment, ecosystem actors should monitor distributional indicators directly: who receives AI-facilitated finance and mentoring, who enters ecosystem networks as a result, and whether algorithmic recommendations reproduce rather than correct existing inequalities. After deployment, evaluation should extend beyond aggregate venture-formation rates to track circular-venture survival, environmental outcomes, and the inclusion of youth and women specifically, consistent with the outcome construct defined in Table 2.

For entrepreneurship researchers, the ACE framework offers a specific empirical agenda rather than a generic call for future testing. P1 and P2 lend themselves to firm- and ecosystem-level archival or survey research comparing AI-adopting circular ventures across ecosystems with varying institutional coordination capacity. P3 and P4 are best tested through comparative or quasi-experimental designs — for example, comparing youth- and women-focused entrepreneurship programmes operating under different digital-infrastructure and institutional conditions — capable of isolating the moderating role of IAER using a composite index combining digital-capability, infrastructure, and governance indicators. Testing P5's feedback dynamics requires longitudinal designs capable of tracking how entrepreneurial and ecosystem outcomes reshape AI deployment over multiple entrepreneurial cycles, a demanding but tractable agenda given the increasing availability of ecosystem-level platform data.

The paper's limitations follow from its conceptual design. As a theory-synthesis contribution, the ACE framework has not been empirically tested, and its five propositions require operationalisation before their practical validity can be confirmed (Jaakkola, 2020). The framework's generalisability beyond the regional and Erasmus+-funded ecosystem contexts that partly motivated this analysis also remains an open empirical question, since institutional readiness, per Proposition 4, is expected to vary substantially across national and regional contexts. Notwithstanding these limitations, the framework's theoretical core — that AI's inclusionary potential in circular entrepreneurship is conditional on ecosystem readiness rather than automatic — offers a generalisable explanation that stands independently of any single conference, project, or region, while directly

informing the municipalities, technoparks, chambers, and entrepreneurship-support organisations seeking an evidence-based rather than techno-optimistic basis for their AI-related investment decisions.

Finally, it is worth stating plainly what the ACE framework does and does not claim to have been established, since this distinction matters for how the framework should be used by researchers and practitioners alike. Established evidence, reviewed in Section 3, demonstrates that AI can improve prediction, traceability, and resource-optimisation outcomes at the firm level. It is a theoretical inference, not an empirical finding, that these capabilities enable circular business-model innovation more broadly; it is a further theoretical inference, requiring the empirical agenda outlined above, that such innovation improves entrepreneurial inclusion under specified conditions of ecosystem readiness. Maintaining this distinction between established evidence and theoretical inference throughout, rather than allowing the two to blur, is what separates the ACE framework's central claim — that AI's effect on inclusive circular entrepreneurship is conditional rather than automatic — from the techno-optimistic assumption it was developed specifically to challenge.

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FULL PAPER · S5.6 · ONLINE SESSION 5

Youth Entrepreneurship, Green Skills, and Sustainable Employability: An Integrated Framework for the Green Transition

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ABSTRACT

Purpose: The transition towards a green economy has increased the demand for green, digital and entrepreneurial skills. However, developing these skills does not necessarily mean that young people can apply them in employment or entrepreneurial activities. Previous research has examined skills development, entrepreneurship and employability, but less attention has been given to how these areas are connected. This study therefore develops a conceptual framework to examine how Skills Integration, Green Entrepreneurial Intentions and institutional support may contribute to Sustainable Employability among young people.

Method: The study uses a conceptual review and integrative synthesis of existing research on green skills, entrepreneurship education, entrepreneurial intentions, mentorship and employability. Research on entrepreneurial ecosystems is also considered to examine the role of institutional conditions. The Theory of Planned Behavior and Social Cognitive Theory are used to explain the proposed relationships and support the development of the conceptual framework.

Contribution: The framework brings together Skills Integration, Green Entrepreneurial Intentions, Mentorship and Coaching, and Sustainable Employability. It proposes that integrated skills may contribute to entrepreneurial intentions and employability, while mentorship may strengthen the relationship between skills and sustainable employability. Ecosystem Collaboration is considered a factor that may improve the contribution of mentorship, whereas Institutional Barriers may weaken the relationship between entrepreneurial intentions and sustainable employability. The framework highlights the importance of considering skills, entrepreneurial intentions and institutional conditions together. The proposed relationships require further empirical examination.

1. Introduction

The shift towards a green economy has altered the kinds of skills needed for employment or entrepreneurial endeavors. In the context of the growth of sustainable industry practices and the development of new technologies, the young population is now more inclined to have the required green skills, digital skills and entrepreneurial skills to meet these challenges. The development of green skills is used to support environmentally sustainable activities, and the development of digital skills and entrepreneurial is used for the use of technology, identification of opportunities and new business ideas. Bluedorn et al. (2023) point out the evolving nature of skills demanded in the labour market, while Apostel and Barslund (2024) stress the increasing significance of jobs related to green skills. Such innovations are providing youth with opportunities to engage in new green sector and sustainable business ventures. The skills required to access these opportunities may be different, however, and may need to be developed and applied in combination. The study findings by Zaman et al. (2026) and Amalu et al. (2023) also underscore the significance of the word "skill", a word that has assumed a new meaning in the context of employment and industry today.

Research on entrepreneurship education also suggests that developing knowledge and skills does not always lead to entrepreneurial engagement (Alakaleek et al., 2023). Similarly, Iffat et al. (2026) and Ip (2024) examine the individual and educational factors associated with entrepreneurial development. Together, these studies indicate that skills development alone may not be sufficient to improve employment and entrepreneurial

opportunities. The ability to apply these skills also needs to be considered. Young people also need confidence in their ability to apply their knowledge and respond to practical challenges. Mentorship, coaching and practical experience may further support this process by providing guidance and opportunities to develop relevant skills. These factors are important for understanding how young people use their skills in employment and entrepreneurship.

Previous research has examined the role of green skills, entrepreneurship education, mentoring and employability. However, relatively less attention has been given to how these factors are connected in supporting sustainable employment and entrepreneurship among young people. Azharuddin et al. (2026) and Luu and Hue (2026) examine factors influencing entrepreneurial development and young people's engagement in entrepreneurial opportunities. Similarly, Vargas-Merino et al. (2025) and Decker-Lange et al. (2024) contribute to understanding the relationships between skills, entrepreneurship and employment outcomes. Although these studies provide useful insights, developing relevant skills or entrepreneurial intentions does not necessarily lead to sustainable employment or business opportunities. Young people may still face difficulties because of limited mentorship, financial resources, professional networks and institutional support. Skills development may also be less effective when education and training do not meet industry requirements. These issues indicate the need to examine how skills, entrepreneurial intentions and organisational support contribute to sustainable employability.

The Theory of Planned Behavior (TPB) and Social Cognitive Theory (SCT) provide a basis for understanding these relationships. TPB explains how attitudes, subjective norms and perceived behavioural control influence behavioural intentions (Ajzen, 1991). SCT highlights the importance of self-efficacy, learning experiences and environmental conditions in shaping individual behaviour (Bandura, 1986). Drawing on these theories, the present study develops a conceptual framework connecting Skills Integration, Green Entrepreneurial Intentions, Mentorship and Coaching, and Sustainable Employability. The framework also considers self-efficacy as an important factor in entrepreneurial motivation. Ecosystem Collaboration is proposed as a positive moderator, while Institutional Barriers are proposed as a negative moderator of the relevant relationships. The study aims to explain how skills development, entrepreneurial intentions and support systems may contribute to green employment, sustainable businesses and career adaptability. It also relates to Sustainable Development Goals 4, 8, 13 and 17, which focus on quality education, decent work, climate action and partnerships for sustainable development.

2. Literature Review and Theoretical Foundations

2.1. Green Skills, Skills Integration and Green Entrepreneurial Intentions

The growing importance of the green economy has increased the need for skills that support sustainable employment and entrepreneurship. However, transfer of skills from education and training programmes might not be always adequate in changing labour markets. Albertz and Pilz (2025) detected that vocational teachers in India primarily linked green skills to technical aspects and environmental concerns, and paid less attention to transferable skills. Likewise, Zaman et al. (2026) found that there is a gap between the skills acquired in higher education and employers' expectations in Bangladesh. The results indicate that the knowledge of environment may not be able to equip young people for green jobs. Practical and transferable skills are also important in meeting workplace requirements.

Green skills may become more useful when combined with digital and entrepreneurial capabilities. Amalu et al. (2023) highlight the importance of technical knowledge, interdisciplinary skills and business-related competencies in addressing skills shortages in the solar energy sector. Similarly, Mondal et al. (2023) emphasise the role of digital orientation and technological infrastructure in green entrepreneurship and circular economy

practices. These studies suggest that combining environmental, digital and entrepreneurial skills may help young people identify sustainability-related problems and develop possible business opportunities. However, having these skills does not necessarily mean that young people will choose to pursue entrepreneurship.

Developing entrepreneurial skills does not necessarily mean that young people will decide to pursue entrepreneurship. Their intentions may also depend on their confidence, attitudes and the support available within educational institutions. Azharuddin et al. (2026) highlight the importance of self-efficacy, environmental attitudes, perceived behavioural control and institutional support in shaping green entrepreneurial intentions. The Theory of Planned Behavior explains how attitudes, subjective norms and perceived behavioural control influence intentions (Ajzen, 1991). Similarly, Social Cognitive Theory emphasises the role of self-efficacy in influencing individual behaviour (Bandura, 1986). These findings suggest that confidence in one's abilities may encourage entrepreneurial intentions, but does not necessarily lead to a decision to pursue entrepreneurship. Within this perspective, Skills Integration may strengthen the capabilities and perceived control that contribute to Green Entrepreneurial Intentions, while the extent of this relationship may depend on individual and institutional conditions.

2.2. Mentorship, Skills Application and Sustainable Employability

Although entrepreneurship education may help young people develop relevant skills, it does not necessarily mean that they can apply these skills in employment or business activities. Alakaleek et al. (2023) found that entrepreneurship education improved students' knowledge and practical skills, but did not consistently improve their entrepreneurial intentions or confidence. This indicates that developing skills alone may not be sufficient. Liu (2023) found that supportive teacher-student relationships encouraged student engagement and contributed to entrepreneurship competence. Similarly, Liu et al. (2025) highlight the role of educational relationships in supporting perceived employability through student engagement. However, demanding learning conditions may also lead to emotional exhaustion. These findings suggest that the learning environment can influence how young people develop and use their skills.

Practical experience may also help young people apply their knowledge beyond formal education. Overwien et al. (2024) found that interactive entrepreneurship activities, such as workshops and startup discussions, were associated with stronger entrepreneurial intentions. However, compulsory graded activities did not show similar improvements. Adjimah et al. (2026) also found that practical projects and exposure to green entrepreneurs contributed to green entrepreneurial intentions through environmental concerns and personal values. Such research demonstrates the need for hands-on learning experiences. Mentorship and coaching can also offer additional support via guidance, feedback and connections. Participation in workshop or exposure to entrepreneurs does not necessarily equal the support of ongoing mentorship.

The relationship between skills development and employability is also important. Li et al. (2025) examine how entrepreneurship education contributes to graduate employability through career development, while Decker-Lange et al. (2024) highlight the importance of educational and institutional conditions. Similarly, Cripps and Bobeva (2025) found that sustainability-related career learning can improve students' confidence and career awareness. However, sustainable employability is not limited to obtaining employment. It also involves maintaining and developing career opportunities over time (Álvarez-González et al., 2024). Ip (2024) further highlights the importance of institutional support in translating entrepreneurial intentions into behaviour. Together, these findings suggest that practical support may help young people apply their skills and improve their employment opportunities. In this regard, the present study proposes that Mentorship and Coaching may strengthen the relationship between Skills Integration and Sustainable Employability. This relationship requires further empirical examination..

2.3. Ecosystem Conditions and Theoretical Foundations

The role of skills development and entrepreneurial support in sustainable employability also depends on the institutional environment. Entrepreneurial ecosystems involve educational institutions, businesses, policymakers and support organisations working together to support entrepreneurial activities (Stam, 2015; Spigel, 2017). However, the presence of these organisations does not necessarily mean that they collaborate effectively. Decker-Lange et al. (2024) highlight the importance of educational and institutional conditions for graduate employability, while Bradley et al. (2025) examine the influence of organisational arrangements on entrepreneurial development. These findings suggest that mentorship may be more useful when young people have opportunities to apply the guidance they receive. Collaboration between universities, employers and other organisations may provide access to industry experience, professional networks and employment opportunities. In this regard, Ecosystem Collaboration may strengthen the relationship between Mentorship and Coaching and Sustainable Employability.

Institutional conditions may also affect whether young people can turn entrepreneurial intentions into practical activities. Ip (2024) highlights the importance of institutional support in the relationship between green entrepreneurial intentions and behaviour. Similarly, Azharuddin et al. (2026) identify institutional factors that influence green entrepreneurial intentions. Although professional networks and other forms of support may create opportunities, financial limitations, inadequate infrastructure and weak policy implementation can make it difficult to pursue entrepreneurial activities. Research on green entrepreneurship also highlights the importance of resources and institutional conditions in emerging economies (Ghouse et al., 2026; Knezović et al., 2026). These findings indicate that entrepreneurial intentions alone may not be sufficient to achieve sustainable employment or establish green businesses. Institutional Barriers may therefore weaken the relationship between Green Entrepreneurial Intentions and Sustainable Employability.

The Theory of Planned Behavior (TPB) and Social Cognitive Theory (SCT) provide a basis for understanding these relationships. TPB explains how attitudes, subjective norms and perceived behavioural control influence intentions. It also recognises that individuals need sufficient control to act on their intentions (Ajzen, 1991). Similarly, SCT highlights the importance of self-efficacy, learning experiences and environmental conditions in shaping behaviour (Bandura, 1986). These theories suggest that developing entrepreneurial intentions does not necessarily mean that individuals can act on them. The availability of support and institutional resources may also influence how young people use their skills and pursue opportunities. Based on this understanding, the present study considers Ecosystem Collaboration and Institutional Barriers as two separate factors that may influence the proposed relationships.

3. Conceptual Research Methodology

This study uses a conceptual research approach based on a review and synthesis of existing literature on green skills, youth entrepreneurship and sustainable employability. A conceptual approach is suitable for examining relationships between concepts that have been discussed across different research areas (Snyder, 2019; Jaakkola, 2020). Existing research has examined these areas from different perspectives, but understanding how they are connected requires consideration of both individual and institutional factors. The study therefore brings together relevant conceptual and empirical literature to identify possible relationships between skills, entrepreneurial intentions, mentorship and sustainable employability.

The review includes research on green and digital skills, entrepreneurship education, self-efficacy, mentorship and graduate employability. Literature on entrepreneurial ecosystems was also considered because institutional support may influence the opportunities available to young people. Studies were selected according to their relevance to the research objectives and their contribution to explaining the relationships

under examination. Particular attention was given to research showing differences between developing skills and applying them in employment or entrepreneurial activities. The review is selective rather than systematic.

The development of the framework involved three stages. The literature was initially examined to understand the relationship between Skills Integration and Green Entrepreneurial Intentions, the role of Mentorship and Coaching, and the influence of institutional conditions on sustainable employability. Findings from these areas were then compared to identify how the concepts may be related. This included recognising that entrepreneurial self-efficacy and entrepreneurial intentions are different, while mentorship may strengthen the use of existing skills without necessarily acting as a mediator. The relationships were subsequently considered through the Theory of Planned Behavior (Ajzen, 1991) and Social Cognitive Theory (Bandura, 1986). These theoretical perspectives were used to develop the framework and its propositions.

The framework is conceptual, and the proposed relationships require empirical testing. The selective review may also leave out relevant research, which should be considered when interpreting the proposed relationships.

4. Proposed Conceptual Framework

The proposed framework explains how integrated skills may contribute to sustainable employability among young people through entrepreneurial motivation, developmental support, and the institutional conditions surrounding their application. It brings together Skills Integration, Green Entrepreneurial Intentions, Mentorship and Coaching, and Sustainable Employability, while recognising Ecosystem Collaboration and Institutional Barriers as contextual influences. The framework draws on the Theory of Planned Behavior (TPB) and Social Cognitive Theory (SCT), which provide complementary explanations of how capabilities, individual beliefs, and environmental conditions shape intentions and subsequent actions (Ajzen, 1991; Bandura, 1986).

Skills Integration refers to the combined development of green, digital, and entrepreneurial capabilities. Green Entrepreneurial Intentions represent an individual's willingness and plans to pursue environmentally responsible entrepreneurial activities, whereas entrepreneurial self-efficacy concerns confidence in the ability to undertake such activities. Sustainable Employability is understood as the capacity to access, maintain, and develop meaningful employment or self-employment opportunities over time. Green employment and sustainable venture creation are therefore possible career pathways, rather than interchangeable measures of employability. Mentorship and Coaching represent structured guidance, feedback, and professional support that may assist young people in applying their capabilities.

4.1. Proposed Relationships

4.1.1. Skills Integration and Green Entrepreneurial Intentions

Integrated skills may influence entrepreneurial intentions by enabling young people to recognise environmental challenges as opportunities for innovation and enterprise development. Technical and environmental knowledge can improve their understanding of sustainability-related problems, while digital and entrepreneurial capabilities may support opportunity evaluation and the development of practical solutions. Amalu et al. (2023) highlighted the importance of interdisciplinary competencies in the renewable energy sector, while Mondal et al. (2023) connected digital capabilities with green entrepreneurial activities.

However, capabilities alone may not generate entrepreneurial intentions. According to TPB, individuals are more likely to develop intentions when they view an activity positively and perceive themselves as capable of undertaking it (Ajzen, 1991). SCT similarly emphasises self-efficacy as an important influence on behaviour (Bandura, 1986). Azharuddin et al. (2026) identified both individual beliefs and educational conditions as

relevant to green entrepreneurial intentions. Skills Integration may therefore support intentions partly by strengthening perceived capability, although confidence and intention remain distinct constructs.

P1: Skills Integration is positively associated with Green Entrepreneurial Intentions among young people.

4.1.2. Mediating Role of Green Entrepreneurial Intentions

The development of integrated skills may improve career-related capabilities, but their contribution to entrepreneurial outcomes also depends on whether individuals intend to use those capabilities. Green Entrepreneurial Intentions may provide a motivational link between skills development and the pursuit of sustainable business opportunities. Ip (2024) highlighted the importance of distinguishing entrepreneurial intention from subsequent behaviour, particularly where institutional conditions influence implementation. Similarly, entrepreneurship education research indicates that developing competencies does not automatically lead to entrepreneurial action (Alakaleek et al., 2023).

This relationship requires an important qualification. Entrepreneurial intentions may help explain pathways towards sustainable self-employment or venture development, but they are not a necessary condition for entering conventional green employment. The proposed mediation is therefore expected to be more relevant to the entrepreneurial pathway within Sustainable Employability.

P2: Green Entrepreneurial Intentions mediate the relationship between Skills Integration and the entrepreneurial pathway to Sustainable Employability.

4.1.3. Moderating Role of Mentorship and Coaching

Although young people may develop relevant skills, they may still face difficulties applying them in employment and entrepreneurial activities. Mentorship and coaching can provide guidance, practical support and access to professional networks. Liu (2023) highlights the importance of supportive educational relationships in developing entrepreneurship competence, while Overwien et al. (2024) emphasise the role of practical activities in entrepreneurship education. These findings suggest that support during learning and career development may help young people use their skills more effectively. However, the contribution of mentorship may depend on the quality of guidance and the opportunities available to apply these skills. In this regard, mentorship and coaching may strengthen the relationship between Skills Integration and Sustainable Employability.

P3: Mentorship and Coaching positively moderate the relationship between Skills Integration and Sustainable Employability, such that the relationship is stronger when effective mentorship and coaching are available.

4.2. Contextual Moderating Relationships

4.2.1. Moderating Role of Ecosystem Collaboration

The role of mentorship in supporting sustainable employability may also depend on collaboration between educational institutions, employers and other support organisations. Stam (2015) and Spigel (2017) highlight the importance of institutional relationships and access to resources in entrepreneurial ecosystems. Such collaboration may help young people gain practical experience, develop professional networks and identify green employment opportunities. However, mentorship may be less effective when institutional partnerships are limited and opportunities to apply skills are unavailable. These findings suggest that Ecosystem Collaboration may strengthen the relationship between Mentorship and Coaching and Sustainable Employability.

P4: Ecosystem Collaboration positively moderates the relationship between Mentorship and Coaching and Sustainable Employability, such that the relationship is stronger in more collaborative ecosystems.

4.2.2. Moderating Role of Institutional Barriers

Even when young people possess relevant skills and strong entrepreneurial intentions, institutional constraints may limit their ability to pursue sustainable ventures. Financial difficulties, inadequate infrastructure, limited market access, and inconsistent policy support can restrict the practical implementation of entrepreneurial plans. Ip (2024) demonstrated the relevance of external institutional support to the relationship between green entrepreneurial intentions and behaviour. From a TPB perspective, these constraints are important because intentions alone cannot overcome limited actual control over resources and opportunities (Ajzen, 1991).

Institutional Barriers are therefore expected to weaken the contribution of Green Entrepreneurial Intentions to Sustainable Employability, particularly through sustainable self-employment and venture development.

P5: Institutional Barriers negatively moderate the relationship between Green Entrepreneurial Intentions and the entrepreneurial pathway to Sustainable Employability, such that the relationship is weaker when institutional barriers are greater.

Figure 1. Proposed conceptual framework linking skills integration, green entrepreneurial intentions, mentorship and coaching, and sustainable employability under contextual institutional conditions.

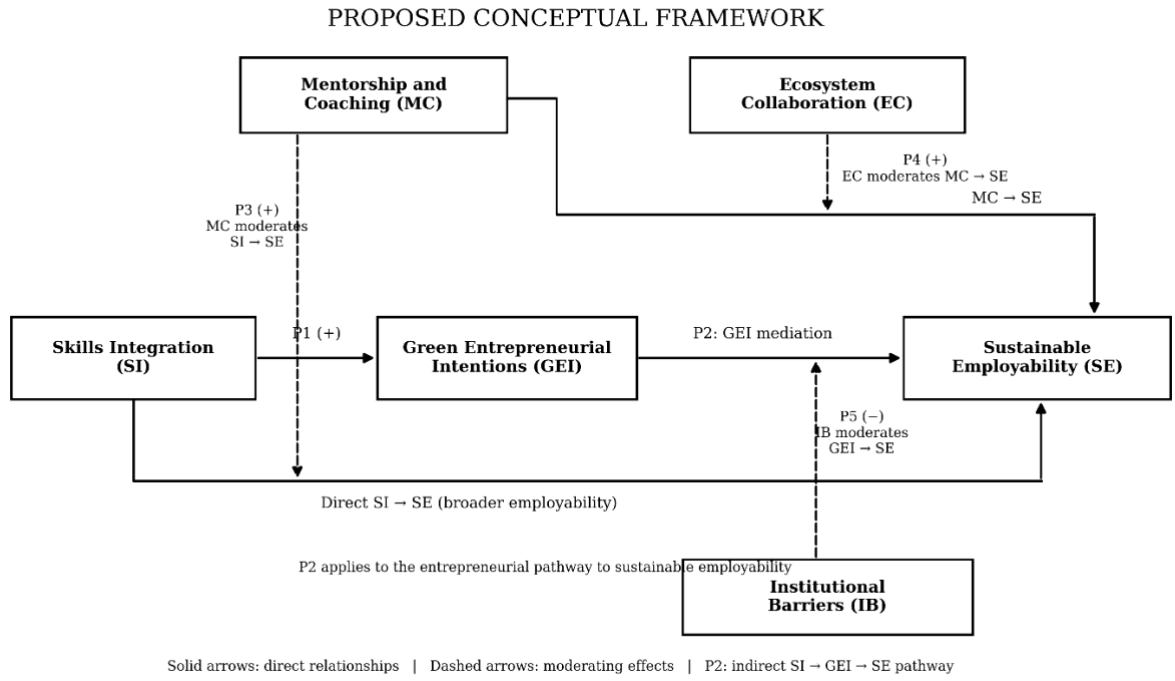


Figure note. SI = Skills Integration; GEI = Green Entrepreneurial Intentions; MC = Mentorship and Coaching; EC = Ecosystem Collaboration; IB = Institutional Barriers; SE = Sustainable Employability. Solid arrows indicate proposed direct relationships, while dashed arrows indicate moderating effects. P1 represents the positive association between SI and GEI. P2 represents the mediating role of GEI in the entrepreneurial pathway from SI to SE. P3 represents the positive moderating effect of MC on the SI–SE relationship. P4 represents the positive moderating effect of EC on the MC–SE relationship. P5 represents the negative moderating effect of IB on the GEI–SE relationship.

5. Discussion and Implications

Developing relevant skills does not necessarily mean that young people will achieve better employment or entrepreneurial outcomes in the green economy. Although green, digital and entrepreneurial skills are increasingly important, their contribution to sustainable employability may depend on how these skills are combined and applied. Entrepreneurial intentions and access to practical opportunities may also influence

these outcomes. The proposed framework therefore considers both individual capabilities and institutional conditions in understanding how young people can develop sustainable career opportunities.

5.1. Discussion and Theoretical Implications

The first contribution of the framework concerns the relationship between Skills Integration and Green Entrepreneurial Intentions. Amalu et al. (2023) highlight the importance of combining different skills in renewable energy employment, while Mondal et al. (2023) emphasise the role of digital capabilities in green entrepreneurship. However, developing these skills does not necessarily mean that young people will intend to pursue entrepreneurial activities. Alakaleek et al. (2023) found that improvements in entrepreneurial knowledge and competencies did not consistently lead to stronger entrepreneurial intentions. These findings suggest that having relevant skills may increase the opportunities available to young people, but their intentions also depend on whether they believe they can pursue these opportunities. The Theory of Planned Behavior explains the importance of attitudes and perceived behavioural control in shaping intentions (Ajzen, 1991). Similarly, Social Cognitive Theory highlights the role of self-efficacy in influencing individual behaviour (Bandura, 1986). Together, these theories help explain why skills development may support entrepreneurial intentions without assuming that confidence and intention are the same.

The second contribution concerns the difference between Green Entrepreneurial Intentions and Sustainable Employability. Entrepreneurial intentions reflect an individual's willingness to pursue business opportunities, while sustainable employability involves the ability to maintain and develop career opportunities over time. Ip (2024) highlights the importance of institutional support in understanding how green entrepreneurial intentions develop into behaviour. However, the intention to establish a green business does not necessarily improve access to employment in other organisations. This distinction is important because young people may use their skills to pursue employment without intending to become entrepreneurs. The proposed framework therefore recognises that Skills Integration may contribute to sustainable employability more broadly, while Green Entrepreneurial Intentions may be particularly relevant to opportunities for sustainable self-employment.

Mentorship and Coaching may also influence how young people apply their skills in employment and entrepreneurial activities. Previous research highlights the importance of supportive educational relationships and practical learning in developing entrepreneurial capabilities (Liu, 2023; Overwien et al., 2024). However, practical learning and mentorship do not necessarily provide the same support. Practical activities allow young people to apply their knowledge, while mentorship provides guidance in understanding opportunities and addressing difficulties. This distinction is important because developing skills does not automatically mean that young people will receive mentoring support. The proposed framework therefore considers Mentorship and Coaching as a factor that may strengthen the relationship between Skills Integration and Sustainable Employability. Its contribution may also depend on the quality of guidance and access to relevant opportunities.

Institutional support may also influence how young people use their skills and pursue entrepreneurial opportunities. Stam (2015) and Spigel (2017) emphasise the importance of relationships between educational institutions, businesses and other organisations in supporting entrepreneurship. Collaboration between these organisations may provide opportunities for young people to gain practical experience and develop professional networks. This suggests that Ecosystem Collaboration may strengthen the relationship between Mentorship and Coaching and Sustainable Employability. Institutional Barriers, on the other hand, may make it difficult for young people to pursue entrepreneurial activities, even when they have relevant skills and intentions. Limited financial resources and inadequate institutional support may therefore weaken the relationship between Green Entrepreneurial Intentions and Sustainable Employability. These relationships indicate that access to relevant

skills and entrepreneurial motivation does not automatically lead to sustainable employment or business opportunities.

5.2. Practical and Managerial Implications

Universities and vocational institutions have an important role in helping young people develop and apply skills relevant to the green economy. Skills programmes should therefore provide opportunities for practical learning alongside technical and entrepreneurial education. Sustainability projects, digital tools and entrepreneurship-related activities may help students apply their knowledge in different situations. Mentorship programmes can also support this process by providing guidance and access to industry experience, particularly for young people with limited professional connections. Policymakers should also consider the financial and institutional difficulties that may prevent young people from pursuing employment or entrepreneurial opportunities. Collaboration between educational institutions, employers and public agencies may help address these difficulties and improve access to relevant career opportunities.

5.3. Sustainable Development Goal Alignment

The proposed framework also relates to several Sustainable Development Goals (SDGs). Skills Integration supports the objectives of SDG 4 by emphasising relevant education and skills development. Its focus on sustainable employability and entrepreneurship is consistent with SDG 8, while green skills and environmentally focused entrepreneurial activities relate to SDG 13. Similarly, the importance of collaboration between educational institutions, employers and policymakers reflects the objectives of SDG 17. However, these relationships indicate the potential relevance of the framework to sustainable development rather than established outcomes. Further empirical research is needed to examine its contribution to these goals.

6. Conclusion, Limitations and Future Research

This study develops a conceptual framework to explain how green, digital and entrepreneurial skills may contribute to sustainable employability among young people. Drawing on the Theory of Planned Behavior and Social Cognitive Theory, the framework highlights that developing relevant skills does not necessarily lead to better employment or entrepreneurial outcomes. Green Entrepreneurial Intentions may support opportunities for sustainable entrepreneurship, while Mentorship and Coaching may help young people apply their skills more effectively.

But, these relationships could also be conditioned by Ecosystem Collaboration and Institutional Barriers. As a result, the framework puts a strong focus on fostering the role of individual skills, entrepreneurial intentions and institutional support in the understanding of sustainable employability in the context of the green transition. Relationships are not currently empirically tested, and the proposed framework is based on existing literature. The review also is selective and some relevant studies may not be included. The youth's skills development and use could also be affected by differences in educational systems, the labour markets and institutional support. These differences are significant in the context of sustainable employability, as there can be differences in the skills, resources, and opportunities needed for employment and entrepreneurship. These suggested relationships can therefore be different across educational and institutional settings in which young people continue their career. These relationships could be explored in future studies with empirical data from youth in a variety of educational/ institutional settings. Longitudinal studies could be conducted to investigate changes in skills and entrepreneurial intentions and employment prospects over time. Comparative research can also be helpful in identifying differences between the developed and the developing economies. The hypothesized mediation and moderation processes could be tested using quantitative analysis, such as structural equation modeling. Qualitative research might look into ways mentoring helps apply skills and the

impact of institutional barriers on opportunity. These methods can also give information about the different contribution of entrepreneurial intentions to sustainable employment and self-employment.

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FULL PAPER · S6.2 · ONLINE SESSION 6

Entrepreneurship as a Coping Strategy among Families of Children with Autism: A Systematic Review with Implications for Inclusive Development in Africa

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ABSTRACT

Purpose: Families with children with autism spectrum disorder face significant caregiving challenges, including service fragmentation and financial strain. This review examines how entrepreneurship and self-employment can offer flexible solutions, although evidence on their effectiveness in aiding family adaptation is limited.

Methods: A systematic review and evidence map, registered with PROSPERO and following PRISMA 2020 guidelines, examined English-language studies from March 2016 to March 2026. It focused on parents and caregivers of children with ASD, exploring topics like entrepreneurship and caregiver wellbeing. Due to significant variability in study characteristics, the findings were synthesised narratively rather than quantitatively.

Results: The searches yielded 1,049 records, with 14 duplicates removed, resulting in 1,035 screened records. Ninety-eight full-text reports were evaluated for eligibility, leading to the inclusion of 14 studies. Evidence on caregiver entrepreneurship specific to ASD was limited, focusing instead on pathways like financial strain, unmet needs, and work-family conflict. Five key themes emerged: economic strain, employment disruption, caregiver agency, psychosocial resilience, and structural barriers impacting livelihood adaptation.

Conclusion: Entrepreneurship can improve flexibility and resilience for caregivers, influenced by caregiving intensity, finance access, and support. Future autism research should focus on entrepreneurial motivation, sustainability, economic outcomes, caregiver wellbeing, and child benefits, especially in Africa and low-income regions.

Keywords: autism spectrum disorder; caregivers; entrepreneurship; self-employment; economic coping; work–family conflict; livelihood resilience

1. Introduction

Autism spectrum disorder (ASD) is a neurodevelopmental condition associated with differences in social communication, behaviour, sensory processing, and adaptive functioning. Although autistic children vary considerably in their strengths, developmental profiles, and support needs, many require sustained educational, therapeutic, health, and social support. These needs frequently extend beyond formal service systems and become embedded within family routines, household decision-making, and long-term patterns of unpaid care. Consequently, raising a child with ASD may influence not only parental wellbeing and family functioning but also employment participation, household income, time allocation, and access to economic opportunities.

Families raising children with ASD often encounter substantial direct and indirect costs. Direct costs may include diagnostic assessment, specialised education, behavioural or developmental therapies, transport, medication, assistive resources, and private services. Indirect costs may arise through reduced working hours, interrupted employment, missed promotion opportunities, labour-market withdrawal, and the long-term economic value of unpaid caregiving. These pressures may be particularly pronounced where specialised services are fragmented, costly, geographically inaccessible, or insufficiently responsive to family needs. Evidence from

Ireland, for example, has linked unmet service needs with family debt, demonstrating how inadequate service provision can become a source of household economic vulnerability (Roddy & O'Neill, 2020). Similarly, Helkkula et al. (2020) showed that parents of children with ASD frequently carry substantial service-related burdens, including coordinating fragmented systems, navigating complex institutional arrangements, and compensating for gaps in educational and health provision.

The relationship between caregiving and employment represents an important but comparatively underdeveloped dimension of autism-family research. Intensive caregiving responsibilities may conflict with standard employment schedules, particularly when caregivers must attend therapy sessions, respond to school-related needs, manage behavioural or health concerns, or compensate for inadequate formal support. Research on working parents of children with autism has demonstrated that caregiving demands can generate substantial work–family conflict, affecting employment continuity, productivity, and occupational wellbeing (Sitimin et al., 2017). These pressures may be especially consequential for mothers, who frequently assume a disproportionate share of unpaid caregiving responsibilities and may therefore experience greater employment disruption, reduced earnings, and constrained career progression.

The economic consequences of ASD caregiving are likely to be intensified in low- and middle-income countries, where formal social protection, specialised autism services, and flexible employment arrangements may be limited. Evidence from Bangladesh, Malaysia, Pakistan, Iran, and Ghana indicates that families often experience combinations of financial strain, service scarcity, social stigma, psychological burden, and uneven institutional support (Arunasalam et al., 2024; Atchulo et al., 2025; Furrukh et al., 2020; Khan et al., 2024; Zarafshan et al., 2019). Under such conditions, households may be required to reorganise income-generating activities around caregiving responsibilities. Flexible work, home-based production, informal business, self-employment, and small-scale enterprise may therefore become important components of family coping and livelihood adaptation.

Entrepreneurship is commonly conceptualised as a pathway to innovation, autonomy, income generation, and economic empowerment. However, entrepreneurship undertaken within households affected by intensive caregiving responsibilities may differ substantially from conventional opportunity-driven enterprise. Caregivers may pursue self-employment not because it offers superior economic returns, but because formal employment is incompatible with the unpredictability, intensity, or duration of caregiving demands. In such circumstances, entrepreneurship may function as a form of necessity-driven adaptation that enables caregivers to remain economically active while retaining greater control over working time and location. Home-based businesses, informal trade, digital work, household enterprises, and parent-led social ventures may provide flexibility, but they may also expose caregivers to unstable income, limited social protection, restricted access to finance, and additional workload.

This distinction between opportunity-driven and necessity-driven entrepreneurship is central to understanding the potential role of enterprise in ASD-affected households. Entrepreneurship may enhance caregiver autonomy, self-efficacy, social participation, and household resilience when supported by adequate skills, finance, markets, and social networks. Conversely, it may reinforce vulnerability where caregivers operate low-return enterprises because they lack access to formal employment or reliable support services. Entrepreneurship should therefore not be assumed to constitute empowerment automatically. Its outcomes are likely to depend on a range of interacting factors, including caregiver education, household resources, access to credit, childcare and respite support, service availability, social networks, stigma, and the broader institutional environment.

Despite the potential importance of entrepreneurship to families raising children with ASD, the evidence remains fragmented across multiple disciplines. Autism research has largely focused on diagnosis, intervention,

service access, caregiver burden, family quality of life, and child outcomes. Employment research has more commonly examined the labour-market participation of autistic adolescents and adults rather than the employment adaptations of parents and caregivers. Entrepreneurship and livelihood studies, meanwhile, rarely isolate households raising children with ASD. As a result, limited systematic evidence exists regarding the forms of enterprise undertaken by caregivers, the motivations underlying entrepreneurial engagement, the barriers that affect sustainability, or the consequences for caregiver wellbeing, household resilience, and child-related outcomes.

The limited evidence is particularly important in African and other low- and middle-income contexts, where informal enterprise and household livelihood diversification are central to economic survival. In these settings, families may rely heavily on small-scale trade, farming, home-based production, services, and other informal income-generating activities. However, autism-related research seldom examines how caregiving responsibilities influence enterprise participation or how entrepreneurship affects the capacity of households to meet the educational, therapeutic, and social needs of children with ASD. This omission creates a significant gap in both autism-family research and disability-inclusive development policy.

The present review addresses this gap by synthesising evidence on entrepreneurship, self-employment, work–family conflict, economic coping, and livelihood adaptation among families raising children with ASD. The review is guided by four objectives. First, it identifies the forms of entrepreneurship, self-employment, household enterprise, and income-generating activity reported among caregivers and families. Second, it examines the caregiving, employment, service-related, and financial pressures that may motivate entrepreneurial engagement. Third, it evaluates the economic, psychosocial, and family-level outcomes associated with entrepreneurial coping, including income flexibility, empowerment, wellbeing, and resilience. Fourth, it identifies the structural, institutional, and social barriers that shape the effectiveness and sustainability of caregiver entrepreneurship.

By integrating evidence from autism research, family studies, service management, employment scholarship, health economics, and livelihood research, this review extends understanding of ASD caregiving beyond clinical and psychosocial domains. It positions household economic adaptation as an important component of family wellbeing and argues that entrepreneurship should be examined as a conditional coping pathway rather than as an inherently positive outcome. The review therefore provides an evidence base for developing caregiver-sensitive employment policies, disability-inclusive enterprise programmes, family-centred social protection, and integrated support systems capable of addressing both the developmental needs of children with ASD and the economic wellbeing of their families.

2. Methods

2.1 Review Design, Protocol Registration, and Reporting

This study employed a systematic review design with an evidence-mapping component to synthesise research on entrepreneurship, self-employment, household enterprise, employment adaptation, and related livelihood responses among families raising children with autism spectrum disorder (ASD). The review protocol was prospectively registered in the International Prospective Register of Systematic Reviews (PROSPERO; registration number CRD420261329585) on 2 March 2026. The review was conducted and reported in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 statement (Page et al., 2021).

The evidence-mapping component was incorporated because preliminary searches indicated that direct empirical research on entrepreneurship among caregivers of children with ASD was limited and dispersed across autism research, disability studies, employment, family studies, health economics, service research,

social entrepreneurship, and livelihood scholarship. The evidence map was used to characterise the distribution and directness of available evidence according to geographic setting, study design, caregiver population, employment or entrepreneurial exposure, outcome domain, and methodological quality.

To preserve conceptual clarity, the evidence was classified into two categories. Direct evidence comprised studies that explicitly examined entrepreneurship, self-employment, household enterprise, social enterprise, income-generating activity, employment creation, or livelihood adaptation among caregivers or families. Contextual evidence comprised studies examining closely related pathways including financial strain, household debt, work–family conflict, employment flexibility, caregiver agency, economic coping, resilience, social support, and institutional barriers when these factors contributed to understanding the conditions under which caregiver entrepreneurship or livelihood adaptation may emerge. The two evidence categories were interpreted separately to avoid treating general caregiver burden or employment disruption as equivalent to entrepreneurship.

The addition of Scopus and Google Scholar and the inclusion of an evidence-mapping component represented methodological extensions to the registered protocol. These extensions were introduced to improve the comprehensiveness of the review and to address the limited and interdisciplinary nature of the direct evidence base. They did not alter the review's central focus on entrepreneurship and economic coping among families raising children with ASD.

2.2 Review Questions and Analytical Framework

The review addressed the following questions:

1. What forms of entrepreneurship, self-employment, household enterprise, informal business, social enterprise, or income-generating activity have been reported among parents, caregivers, families, or households raising children with ASD?
2. What caregiving, economic, employment-related, social, and institutional factors motivate or influence entrepreneurial engagement and livelihood adaptation among families raising children with ASD?
3. What economic, employment, psychosocial, empowerment, household-resilience, and quality-of-life outcomes are associated with caregiver entrepreneurship and related livelihood responses?
4. What personal, household, financial, social, organisational, institutional, and market-related barriers constrain caregiver entrepreneurship and sustainable economic participation?
5. What conceptual, methodological, population-specific, and geographic evidence gaps remain, particularly in Africa and other low- and middle-income countries?

Eligibility, extraction, and synthesis were guided by a Population–Exposure–Outcome–Study design framework.

The population comprised parents, primary caregivers, families, or households raising children or adolescents younger than 18 years with a recognised diagnosis of ASD. Evidence involving caregivers of children with broader intellectual, developmental, or other disabilities was considered within the evidence-mapping component only when it addressed employment adaptation, entrepreneurship, social enterprise, economic coping, or other mechanisms of clear relevance to families raising children with ASD.

The exposure comprised entrepreneurship, self-employment, home-based enterprise, household or family enterprise, informal business, microenterprise, small or medium-sized enterprise, income-generating activity, parent-led social enterprise, employment adaptation, or livelihood diversification associated with caregiving demands, employment disruption, or household economic pressure. Contextual exposures included work–family conflict, employment flexibility, financial burden, caregiver agency, social support, resilience, and

institutional conditions where these factors informed understanding of entrepreneurial capacity or livelihood adaptation.

The outcomes included employment participation, employment continuity, household income, income stability, financial behaviour, economic coping, household debt, livelihood resilience, caregiver empowerment, self-efficacy, psychological wellbeing, quality of life, work–family balance, family functioning, social participation, access to ASD-related services, and perceived child- or family-related benefits.

No comparator was required because the review aimed primarily to describe and synthesise heterogeneous entrepreneurial experiences, livelihood adaptations, determinants, barriers, facilitators, and outcomes. Studies with comparison groups were nevertheless eligible where they provided relevant evidence.

2.3 Eligibility Criteria

2.3.1 Population

Studies were eligible when participants were parents, primary caregivers, families, or households raising children or adolescents younger than 18 years diagnosed with ASD using recognised clinical criteria, diagnostic procedures, medical records, or clearly reported professional assessment. Studies including children with multiple neurodevelopmental conditions were eligible when ASD-specific findings could be identified separately or when children with ASD constituted a clearly defined subgroup.

Because direct ASD-specific entrepreneurship research was limited, studies involving caregivers of children with broader intellectual, developmental, physical, or special educational needs were eligible for the contextual evidence map when they provided transferable evidence concerning flexible employment, caregiver entrepreneurship, parent-led social enterprise, livelihood adaptation, financial coping, or institutional barriers. Findings from these studies were clearly identified as contextual and were not interpreted as ASD-specific evidence.

Studies were excluded when they focused exclusively on autistic adults, caregivers of adults aged 18 years or older, employers of autistic adults, or entrepreneurial activity undertaken by autistic adults themselves without examining family or caregiver experiences. Studies involving broad disability populations were excluded when they provided no relevant evidence concerning caregiver employment, economic coping, entrepreneurship, livelihood adaptation, or family economic participation.

2.3.2 Exposure and Phenomena of Interest

Studies were eligible for the direct evidence synthesis when they examined at least one of the following:

- self-employment;
- household or family enterprise;
- home-based business;
- informal-sector activity;
- microenterprise;
- small or medium-sized enterprise;
- income-generating activity;
- livelihood diversification or adaptation;
- necessity-driven entrepreneurship following employment disruption;
- opportunity-driven entrepreneurship;
- caregiver-led social enterprise;

- parent-led employment creation; or
- business activity established to support household income, caregiving responsibilities, disability-related services, or community inclusion.

Studies were eligible for the contextual evidence map when they investigated mechanisms directly relevant to entrepreneurial or livelihood capacity, including work–family conflict, employment disruption, flexible employment, financial behaviour, household debt, unmet service needs, caregiver empowerment, social support, psychological capital, family resilience, or institutional constraints.

Studies concerned solely with clinical characteristics, diagnosis, treatment effectiveness, child behaviour, educational interventions, genetics, or biomedical outcomes were excluded unless they also contained extractable evidence relevant to caregiver employment, household economics, entrepreneurship, or livelihood adaptation.

2.3.3 Outcomes

Primary economic and employment outcomes included employment status, labour-force participation, employment continuity, business ownership, enterprise participation, type of livelihood activity, household income, income stability, financial behaviour, household debt, business sustainability, income diversification, economic coping, and household livelihood resilience.

Secondary outcomes included caregiver wellbeing, empowerment, agency, autonomy, psychological capital, self-efficacy, resilience, work–family balance, social participation, family quality of life, household functioning, access to ASD-related services, and perceived effects on the wellbeing, education, care, or social participation of children with ASD.

Studies were not excluded solely because outcomes were reported qualitatively. Qualitative evidence was considered particularly important because entrepreneurial motivations, employment adaptations, caregiver experiences, institutional constraints, and perceived livelihood outcomes were not consistently captured using standardised quantitative measures.

2.3.4 Study Designs

The review included quantitative, qualitative, and mixed-methods empirical studies. Eligible quantitative designs included randomised and non-randomised intervention studies, cohort studies, case-control studies, analytical cross-sectional studies, comparative surveys, economic evaluations, and other observational designs reporting relevant outcomes.

Eligible qualitative designs included phenomenological studies, case studies, grounded-theory studies, ethnographic research, and studies using interviews, focus-group discussions, participant observation, or other recognised qualitative methods. Mixed-methods studies were eligible when findings relevant to the review questions could be extracted separately or interpreted within an integrated analytical framework.

Editorials, commentaries, opinion pieces, book reviews, conference abstracts without sufficient empirical information, protocols, dissertations without accessible empirical findings, and purely conceptual or narrative discussion papers were excluded. Systematic, scoping, and narrative reviews were not included as units of analysis but were examined where appropriate to identify potentially eligible primary studies and to contextualise the findings.

2.3.5 Language, Publication Period, and Setting

Only studies published in English were eligible. The review covered studies published between 1 March 2016 and 1 March 2026. Studies from all geographic regions and national income settings were considered.

Particular attention was given to evidence from Africa and other low- and middle-income countries because informal employment, household enterprise, self-employment, and livelihood diversification frequently constitute important components of household economic survival in these settings. Geographic evidence gaps were examined explicitly during synthesis.

2.4 Information Sources

The literature search covered six sources: PsycINFO via EBSCOhost, PubMed, ScienceDirect, EBSCOhost Academic Search Complete, Scopus, and Google Scholar. PsycINFO and PubMed were identified as principal bibliographic databases in the registered protocol, while ScienceDirect and EBSCOhost were included as additional sources. Scopus was subsequently added to strengthen interdisciplinary coverage across social science, employment, entrepreneurship, health, and disability research. Google Scholar was used as a supplementary search source to broaden retrieval of potentially relevant interdisciplinary studies.

The final search set comprised:

- ScienceDirect: 623 records;
- Google Scholar: 172 records;
- PubMed: 99 records;
- EBSCOhost Academic Search Complete: 84 records;
- Scopus: 41 records; and
- PsycINFO: 30 records.

The searches therefore identified 1,049 records before duplicate removal. No additional records from citation searching, grey-literature searching, or other sources were included in the final PRISMA count. The search focused on published English-language studies within the predefined review period.

2.5 Search Strategy

The search strategy combined controlled vocabulary, database-specific subject headings, and free-text terms representing four interconnected concepts: ASD; caregivers and families; entrepreneurship, employment, or livelihood activity; and economic, psychosocial, or coping-related outcomes.

The core search structure was:

("autism spectrum disorder" OR autism OR autistic OR ASD)
AND
(parent* OR caregiver* OR carer* OR famil* OR household* OR mother* OR father*)
AND
(entrepreneur* OR self-employ* OR enterprise* OR "household enterprise" OR "family business" OR "home-based business" OR microenterprise OR "small business" OR "informal business" OR "income-generating activit*" OR livelihood* OR employ* OR "work-family conflict" OR "employment adaptation")
AND
(coping OR income OR debt OR "financial strain" OR "economic burden" OR resilience OR empowerment OR agency OR wellbeing OR "quality of life" OR "social support")

Search terms were adapted to the indexing system, controlled vocabulary, field codes, phrase-searching requirements, truncation conventions, and Boolean syntax of each source. Broader employment, financial, resilience, and service-related terms were retained because preliminary searches indicated that direct caregiver-entrepreneurship terminology was uncommon and that relevant studies were frequently indexed under employment, economic burden, coping, empowerment, or family adaptation.

Searches were restricted to English-language publications within the predefined period. The complete source-specific search strategies, search dates, limits applied, and numbers of records retrieved are presented in Supplementary Table S1.

2.6 Record Management and Duplicate Removal

All retrieved references were imported into Covidence systematic review software for record management, duplicate detection, screening, full-text assessment, and data extraction.

The six information sources yielded 1,049 records. Covidence identified and removed 14 duplicate records. No additional duplicates were identified manually. After deduplication, 1,035 unique records remained for title and abstract screening.

The integrity of the review database was checked during screening and extraction. Citation details were examined when studies had similar titles, overlapping samples, multiple publications, or incomplete metadata. During review of the extraction export, duplicate extraction entries relating to the same study were reconciled using study title, authorship, and publication details to ensure that each study contributed only once to the synthesis.

2.7 Study Selection

Study selection was undertaken in two stages using Covidence. During the first stage, titles and abstracts were screened against the predefined population, exposure, outcome, and study-design criteria. Records were retained for full-text assessment when they referred to parents, caregivers, families, or households raising children with ASD and indicated potential relevance to entrepreneurship, self-employment, employment adaptation, household economic coping, income generation, work–family conflict, caregiver agency, resilience, or related livelihood conditions.

Initial title and abstract screening was undertaken by one reviewer and checked by a second reviewer in accordance with the registered protocol. Records were advanced to full-text assessment when eligibility could not be determined confidently from the available title and abstract information.

During the second stage, full-text reports were assessed against all eligibility criteria. Exclusion reasons were recorded within Covidence using mutually exclusive categories. These included:

1. wrong patient or caregiver population;
2. wrong outcome;
3. review study;
4. wrong setting;
5. publication outside the predefined time period;
6. full text unavailable;
7. wrong intervention or exposure; and
8. conceptual or narrative discussion paper without eligible empirical evidence.

Disagreements concerning eligibility were resolved through discussion and consensus. Where consensus could not be reached, a third member of the review team was consulted. The final study-selection process is presented in the PRISMA 2020 flow diagram.

2.8 Data Extraction

A structured data-extraction form was developed in Covidence using the review questions, analytical framework, and eligibility criteria. The form was piloted on a small number of eligible studies and refined to

improve consistency, completeness, and applicability across quantitative, qualitative, and mixed-methods designs.

The following information was extracted:

- study title, author(s), and publication year;
- country, institutional setting, and study context;
- study aim and objectives;
- study design and methods;
- recruitment procedures;
- participant eligibility criteria;
- sample size and participant characteristics;
- caregiver relationship to the child;
- age and characteristics of children;
- ASD diagnostic criteria or identification procedures;
- employment status and previous employment experience;
- type and scale of entrepreneurial, employment, or livelihood activity;
- formal or informal enterprise status;
- home-based or externally located economic activity;
- necessity-driven or opportunity-driven motivation;
- caregiving circumstances influencing employment or enterprise decisions;
- household income, debt, financial behaviour, or employment outcomes;
- enterprise continuity, sustainability, or employment creation;
- caregiver agency, empowerment, autonomy, self-efficacy, psychological capital, and wellbeing;
- family resilience, functioning, and quality-of-life outcomes;
- perceived effects on children and access to ASD-related services;
- work–family conflict and employment-related barriers;
- financial, institutional, organisational, social, and market constraints;
- social support, policy support, and other facilitating mechanisms;
- principal quantitative and qualitative findings;
- authors' conclusions; and
- reported study limitations.

Data were extracted by one reviewer and checked against the source reports by a second reviewer. Differences were resolved through discussion and consensus. Where reporting was unclear, the reviewers examined the full article, supplementary materials, and available study information before determining whether the relevant data could be extracted reliably.

The completed Covidence export contained 15 extraction records. Examination of study titles and citation details showed that two extraction entries referred to the same study. These entries were reconciled, resulting in 14 unique studies for the final narrative synthesis. The extracted data were subsequently organised according to study characteristics, directness of evidence, entrepreneurial or employment pathway, economic outcomes, psychosocial outcomes, barriers, facilitators, and geographic evidence gaps.

2.9 Methodological Quality and Risk-of-Bias Assessment

The methodological quality and risk of bias of the included studies were assessed using design-appropriate critical appraisal tools. Qualitative studies were evaluated using the Critical Appraisal Skills Programme (CASP) Qualitative Studies Checklist. Analytical cross-sectional studies were assessed using the Joanna Briggs Institute (JBI) Critical Appraisal Checklist for Analytical Cross-Sectional Studies, while the case-control study was evaluated using the JBI Critical Appraisal Checklist for Case-Control Studies. Where mixed-methods evidence was identified, the Mixed Methods Appraisal Tool (MMAT) was designated for appraisal.

Two reviewers independently assessed each study. Appraisal considered the clarity of the research aims, appropriateness of the study design, participant recruitment and selection, adequacy of data collection, validity and reliability of exposure and outcome measurement, identification and management of confounding, rigour of the analytical procedures, ethical considerations, transparency of reporting, and coherence between the reported findings and study conclusions. For qualitative studies, particular attention was given to recruitment strategy, reflexivity, data saturation, analytical transparency, and the extent to which interpretations were supported by participant data.

Disagreements between reviewers were resolved through discussion and consensus. Where consensus could not be reached, a third review-team member was consulted. No study was excluded solely on the basis of methodological limitations because the review sought both to synthesise available evidence and to map the methodological development of an emerging field. Instead, appraisal findings were used to determine the level of confidence placed in each study and to guide the interpretation of the overall evidence.

Methodological confidence was classified as high, moderate, or **low** through domain-based judgement rather than by applying a numerical cut-off score. Studies were considered to provide high methodological confidence when most appraisal domains were adequately addressed and identified limitations were unlikely to substantially alter interpretation. Moderate confidence was assigned where several methodological concerns were present but the findings remained sufficiently credible and informative. Low confidence was assigned where major limitations substantially reduced confidence in the reported findings.

Methodological quality was assessed separately from the directness of evidence. A study could demonstrate strong methodological quality while contributing only indirect evidence to the review question. Direct evidence referred to studies explicitly examining entrepreneurship, self-employment, household enterprise, income-generating activity, employment creation, or livelihood adaptation among caregivers or families of children with ASD. Studies focusing primarily on caregiver burden, household debt, employment disruption, work–family conflict, social support, resilience, or service-system barriers were considered contextual or indirect evidence unless an entrepreneurial exposure or livelihood response was also examined.

The results of the methodological appraisal are presented in Table 3. Overall, four studies were judged to provide high methodological confidence and ten provided moderate methodological confidence. No study was classified as having low overall methodological confidence. The most common limitations were cross-sectional study designs, convenience or purposive sampling, reliance on self-reported measures, limited control of confounding, restricted transferability from small qualitative samples, and incomplete reporting of researcher reflexivity.

2.10 Data synthesis

The synthesis was conducted in two stages.

First, study characteristics were summarised descriptively by year, country, region, income setting, study design, caregiver group, entrepreneurial activity, and outcome domain. Evidence was mapped according to the following categories:

1. type of entrepreneurship or livelihood activity;
2. drivers and motivations;
3. economic and employment outcomes;
4. caregiver psychosocial and empowerment outcomes;
5. household and child-related outcomes;
6. barriers and constraints;
7. facilitating factors and support mechanisms; and
8. geographic and methodological evidence gaps.

Second, findings were synthesised narratively because variation in study populations, enterprise definitions, research designs, and outcome measures was expected to limit statistical comparability. Narrative synthesis followed a structured approach involving preliminary organisation of findings, exploration of relationships within and between studies, assessment of consistency, and evaluation of the robustness of the synthesis.

Where sufficient methodological and statistical homogeneity existed, quantitative synthesis was planned. Continuous outcomes, including household income, caregiver wellbeing, or economic-resilience scores, were to be synthesised using mean differences or standardised mean differences with 95% confidence intervals. Dichotomous outcomes, including employment participation, income improvement, or enterprise continuation, were to be synthesised using risk ratios or odds ratios with 95% confidence intervals.

Statistical heterogeneity was to be assessed using the Chi-square test and the I^2 statistic. A random-effects model was planned where meaningful heterogeneity existed but statistical pooling remained conceptually appropriate. Potential subgroup analyses included geographic region, national income category, caregiver gender, type of entrepreneurship, necessity-driven versus opportunity-driven entrepreneurship, and formal versus informal enterprise.

Where quantitative pooling was not appropriate, findings were reported using narrative synthesis and evidence mapping in accordance with the principles of Synthesis Without Meta-analysis. Greater interpretive weight was given to evidence that directly examined caregiver entrepreneurship and met the registered exposure criteria. Studies addressing financial burden, employment disruption, service-system challenges, or caregiver resilience without an entrepreneurial exposure were treated as contextual evidence rather than included in the primary systematic review findings.

2.11 Ethical considerations

Ethical approval was not required because the review synthesised data from previously published studies and did not involve direct contact with human participants or access to identifiable individual-level information. Ethical standards were maintained through accurate representation of source studies, transparent reporting of protocol deviations, and avoidance of unsupported causal inference.

3. Results

3.1 Study Selection and Extraction Profile

The database searches identified 1,049 records: ScienceDirect contributed 623 records, Google Scholar 172, PubMed 99, EBSCOhost Academic Search Complete 84, Scopus 41, and PsycINFO 30. Following the removal of

14 duplicate records, **1,035 unique records** underwent title and abstract screening. Of these, 937 were excluded, leaving 98 reports for full-text assessment. Eighty-four full-text reports were excluded because they involved the wrong population (n = 50), wrong outcomes (n = 17), review articles (n = 6), the wrong setting (n = 3), publication outside the predefined period (n = 3), unavailable full text (n = 3), the wrong intervention or exposure (n = 1), or a conceptual or narrative discussion design without eligible empirical evidence (n = 1). Consequently, 14 studies were included in the final narrative synthesis (Figure 1).

The Covidence extraction export contained 15 completed extraction records. Examination of study titles, authorship, and publication details showed that two records referred to the same study by Sukeri et al. (2017). These duplicate extraction entries were reconciled, confirming 14 unique studies for synthesis.

The included evidence was heterogeneous in population, study design, exposure, and outcome measurement. Nine studies focused specifically on parents, caregivers, or families of children with ASD, whereas five examined broader populations of children with intellectual, developmental, physical, or other disabilities and provided evidence relevant to caregiver employment, social entrepreneurship, unmet support needs, empowerment, or livelihood adaptation. Findings from the broader-disability studies were treated as contextual evidence and interpreted cautiously because ASD-specific results were not always separable.

The 14 studies were conducted across 11 countries. Malaysia contributed three studies and Israel contributed two. One study was conducted in each of Argentina, Brazil, China, Indonesia, Ireland, Pakistan, Romania, Spain, and the United States. No included study was conducted in Africa. This geographic absence was notable because self-employment, informal enterprise, and household livelihood diversification constitute important components of economic participation in many African settings.

Eight studies used qualitative designs, five employed analytical or comparative cross-sectional designs, and one used a case-control design. Sample sizes ranged from 11 participants in the Romanian qualitative study to 1,134 participants in the Brazilian case-control study. The Irish study included 195 families raising 222 children with ASD, while other ASD-specific studies involved between 12 and 254 parents or caregivers. Women, particularly mothers, constituted the majority of participants in most studies, indicating the strongly gendered distribution of caregiving responsibilities and associated employment consequences. The characteristics of the included studies are presented in Table 2.

3.2 Nature and Directness of the Evidence

The synthesis revealed a substantial imbalance between the economic and employment pressures experienced by families raising children with ASD and the limited amount of research directly examining entrepreneurship. Most studies investigated caregiver burden, financial strain, unmet service needs, work–family conflict, employment flexibility, psychosocial coping, family resilience, or caregiver empowerment. Only a small number explicitly examined entrepreneurship, social enterprise, employment creation, or movement from caregiving experience towards enterprise-related activity.

The most direct ASD-specific evidence was provided by the Argentine caregiver-empowerment study. The study identified a progression from intuitive coping towards caregiver agency, entrepreneurship, and collective action. Caregivers described how knowledge acquired through navigating diagnosis, intervention, education, and support systems could be transformed into peer support, training, advocacy, caregiver-led initiatives, or services for other families. However, economic instability, unequal access to services, regional disparities, and weak policy implementation constrained the translation of caregiver knowledge and agency into sustainable economic activity.

The Israeli Ahada study provided the clearest example of organised social entrepreneurship, although its population included families of people with intellectual and developmental disabilities rather than an

exclusively ASD population. Parents established a community-based non-profit organisation and developed a socio-economic support model designed to promote long-term wellbeing, social inclusion, and employment opportunities. The study demonstrated how parent-led entrepreneurship may extend beyond individual income generation to address long-term care, employment, inclusion, and community-support needs.

Overall, entrepreneurship remained insufficiently conceptualised and measured within the included literature. The available evidence more frequently documented the economic, employment, psychological, and institutional conditions that may motivate entrepreneurial engagement than entrepreneurship itself.

3.3 Economic Pressure, Unmet Needs, and Financial Coping

Economic vulnerability emerged as an important pathway linking ASD caregiving with employment and livelihood adaptation. Roddy and O'Neill (2020) examined 195 Irish families raising 222 children aged 2–18 years with ASD. Unmet service needs were associated with household financial pressure and borrowing. The mean family debt was approximately **€3,259**, indicating the financial consequences of meeting autism-related service and support needs when publicly available provision was insufficient.

Borrowing operated as a household coping mechanism rather than a sustainable livelihood strategy. Families incurred debt to secure services required by their children, demonstrating how gaps in formal provision may transfer substantial economic responsibility to households. Although entrepreneurship was not assessed directly, the study identified a financial pathway through which families may seek additional income, flexible employment, or self-employment.

The Malaysian study involving 129 caregivers of children with autism examined relationships among societal cultural values, financial behaviour, and financial wellbeing. The study considered how cultural characteristics, particularly uncertainty avoidance, influenced caregiver financial decision-making and perceived wellbeing. Although comparable effect estimates were not available in the extraction dataset, the study demonstrated that ASD caregiving affects household financial behaviour beyond direct expenditure on care and services.

The Brazilian case-control study included 1,134 participants and examined associations between ASD and parental socio-economic and demographic characteristics. Its findings reinforced the importance of household socio-economic circumstances in shaping families' ability to access services, manage caregiving responsibilities, and sustain employment. However, entrepreneurial participation was not measured directly.

Economic instability was also prominent in the Argentine caregiver-empowerment study. Caregivers described difficult choices between maintaining stable employment and remaining sufficiently available to meet the needs of an autistic child. These experiences illustrated the opportunity costs associated with caregiving and the potential appeal of flexible employment or self-employment where conventional work arrangements were incompatible with family responsibilities.

Across the included studies, economic coping involved borrowing, changes in employment participation, adjustments in financial behaviour, reliance on family or public support, and exploration of flexible livelihood activities. Nevertheless, the contribution of entrepreneurship to household income, debt reduction, or long-term financial resilience was rarely assessed.

3.4 Work–Family Conflict and the Need for Flexible Employment

Employment-related pressures constituted one of the most consistent themes across the included studies. Sitimin et al. (2017) examined 12 Malaysian parents employed full-time in the private sector. Work demands, parenting responsibilities, role conflict, guilt, unclear employment expectations, and limited workplace flexibility emerged as major sources of work–family conflict. Participants reported difficulty reconciling unpredictable workplace obligations with the continuing support needs of their children.

Employment challenges were shaped not only by caregiving intensity but also by organisational practices. Rigid schedules, changing work demands, limited predictability, and inadequate workplace understanding reduced parents' ability to fulfil employment and caregiving roles simultaneously. Supportive management and flexible employment arrangements therefore emerged as important influences on employment continuity.

Scott (2018) examined employment experiences among mothers of children with disabilities in the United States. Although 40 families were initially recruited, the analytical sample comprised 24 employed mothers, with detailed analysis focusing on 12 mothers engaged in flexible employment. The study found that family-responsive or "mother-ready" employment was uncommon. Mothers were generally the primary caregivers and experienced greater employment consequences than fathers because they were expected to respond to therapy appointments, school requirements, health concerns, and unexpected caregiving demands.

Flexible employment enabled some mothers to remain economically active, but it was often accompanied by reduced working hours, part-time employment, occupational change, or movement into more accommodating organisations. These adaptations could reduce earnings, increase employment insecurity, and constrain career progression. Thus, flexibility supported labour-market participation but did not necessarily eliminate financial or psychological strain.

Hazan-Liran et al. (2024) compared 69 employed parents of children with ASD with 72 parents of typically developing children in Israel. The study examined psychological capital, parental age, and job satisfaction. The overall job-satisfaction score was M = 43.65, SD = 7.29. Hope, resilience, self-efficacy, and optimism were identified as potentially important psychological resources supporting occupational wellbeing among parents managing simultaneous employment and caregiving responsibilities.

Across these studies, employment continuity depended on both individual and organisational factors. Caregiver resilience was important, but supportive supervision, predictable work expectations, flexible schedules, and family-responsive employment conditions were also necessary. Entrepreneurship and self-employment may provide greater control over working time and location; however, the included evidence did not establish whether these arrangements produced greater income stability, employment security, or wellbeing than supportive formal employment.

3.5 Caregiver Agency, Social Entrepreneurship, and Collective Support

The strongest evidence connecting caregiving experience with entrepreneurship emerged from the Argentine caregiver-empowerment study and the Israeli Ahada model.

Szlamka et al. (2024) examined the perspectives of 32 participants representing caregivers, service providers, non-governmental organisations, educational institutions, and policy stakeholders across several regions of Argentina. Three broad themes were identified: the development of caregiver agency from intuitive coping towards entrepreneurship; the effects of economic instability and inequality on access to services; and the importance of equipping caregivers for empowerment.

Caregivers accumulated substantial knowledge and practical expertise while navigating diagnosis, intervention, education, and support systems. For some participants, this experience generated aspirations to assist other families through parent associations, caregiver-led interventions, training, advocacy, or future service-oriented initiatives. Entrepreneurship therefore emerged not solely as commercial activity but also as a possible extension of experiential knowledge, caregiver agency, and collective action.

Caregiver agency was nevertheless constrained by structural conditions. Limited policy implementation, unequal access to inclusive services, regional inequalities, and economic insecurity restricted the ability of

families to transform knowledge and motivation into sustainable initiatives. Entrepreneurial capacity was therefore influenced by both individual empowerment and the availability of institutional opportunity.

The Ahada non-profit model represented a more formalised example of parent-led social entrepreneurship. The Israeli study involved 12 participants, including parents, siblings, a disability-rights advocate, and a health-sector representative. Parents established a community-based socio-economic support initiative intended to promote lifelong wellbeing, community inclusion, and employment opportunities for people with intellectual and developmental disabilities.

Rather than focusing exclusively on immediate household income, the Ahada model integrated long-term support, employment creation, inclusion, and intergenerational planning. However, because the study involved a broader intellectual and developmental disability population, its findings were interpreted as contextual rather than exclusively ASD-specific evidence.

Taken together, the two studies suggested that caregiver entrepreneurship may exist along a continuum ranging from individual livelihood adaptation to collective social enterprise. Entrepreneurial activity may be motivated by economic necessity, the need for flexible work, the desire to address service gaps, or the intention to transform lived experience into support for other families.

3.6 Family Resilience, Social Support, and Psychosocial Coping

Psychosocial resilience emerged as an important mechanism supporting family adaptation. Galán-Vera et al. (2025) examined 17 parents of children receiving ASD-related early intervention services in Spain. Three principal themes were identified: the emotional experience of diagnosis, unforeseen challenges and coping strategies, and the influence of family cultural values. Resilience, family involvement, friendship networks, and shared values helped parents adapt and reorganise expectations following diagnosis.

Support was not uniformly available. Some parents reported receiving stronger support from peers and parent associations than from extended family members. Caregiver networks therefore provided emotional assistance, practical information, social connection, and opportunities for collective action.

Furrukh et al. (2020) examined the experiences of 15 mothers of children with ASD in Pakistan. Initial responses to diagnosis included avoidance, social withdrawal, stigma, blame, uncertainty, and concern regarding the child's future. Over time, many mothers moved towards acceptance, resilience, social re-engagement, and a stronger focus on supporting their children's development. The progression from withdrawal towards active coping demonstrated the dynamic nature of caregiver adaptation.

Dong et al. (2025) provided quantitative evidence from 254 Chinese parents of children with ASD. Structural equation modelling showed that caregiver burden had a direct negative association with family resilience ($\beta = -0.417$). The total indirect effect operating through social support and positive cognition was −0.115. Caregiver burden was negatively associated with social support ($\beta = -0.524$, $p < .001$), whereas social support was positively associated with family resilience ($\beta = 0.181$, $p < .05$) and positive cognition ($\beta = 0.214$, $p < .05$).

The indirect pathway from caregiver burden through social support to family resilience accounted for 17.86% of the total effect. A second pathway operating through social support and positive cognition accounted for a further 3.76%. These findings indicated that social support and positive psychological resources partially buffered the adverse association between caregiver burden and family resilience.

The Indonesian study involving 145 working mothers of children with special needs examined psychological capital as a mediator of the relationship between Islamic piety and wellbeing. Although ASD-specific results were not reported separately, the study provided contextual evidence concerning the role of culturally embedded psychological resources in supporting the wellbeing of working caregivers.

Overall, social networks, positive cognition, cultural and spiritual resources, parent associations, psychological capital, and caregiver empowerment supported family adaptation. These factors may also strengthen entrepreneurial capacity by increasing confidence, information exchange, collaboration, and willingness to pursue livelihood opportunities. However, the reviewed studies did not test these relationships directly.

3.7 Unmet Needs, Institutional Constraints, and Support Systems

Institutional and service-related barriers were prominent across the included evidence. Sukeri et al. (2017) examined 12 Malaysian mothers of children with disabilities, including five whose children had ADHD- or ASD-related conditions. The study identified unmet needs concerning information, social support, community services, and financial assistance.

Five principal sources of unmet need were identified: caregiver expectations; availability of internal and external support; the role of healthcare professionals; policies and bureaucratic processes; and the resources required to sustain family life and caregiving. The study concluded that addressing these needs required interdisciplinary support, more responsive health services, and reconsideration of welfare and assistance systems.

The Romanian qualitative study involved 11 Hungarian minority parents of children with severe disabilities. Three principal themes emerged: traumatic loss, sense of belonging, and role conflict. Parents expressed continuing concern about the long-term future of their children and the consequences of caregiver absence. Parent groups, school-based programmes, advocacy workshops, coordinated services, and community support were identified as mechanisms that could reduce isolation and strengthen family capacity.

The Argentine study similarly demonstrated that caregiver empowerment was constrained by uneven policy implementation and unequal access to education and inclusive services. Formal rights did not always translate into practical support. These gaps increased the responsibilities borne by families and encouraged some caregivers to pursue collective, advocacy-based, or entrepreneurial responses.

Across studies, weak institutional support increased household burden, whereas responsive services, peer networks, flexible employment, caregiver training, and accessible assistance strengthened coping capacity. Entrepreneurship therefore appeared to be embedded within the broader service and policy environment rather than functioning independently of it.

3.8 Integrated Thematic Synthesis

The synthesis generated five interconnected themes.

1. Economic strain and financial coping. Families experienced unmet service costs, household debt, income pressure, and difficult financial choices. Borrowing and adjustment of employment participation were common coping responses, whereas direct evidence of enterprise-generated income remained limited.
2. Work–family conflict and employment adaptation. Intensive caregiving responsibilities interacted with inflexible workplace conditions, contributing to reduced working hours, occupational change, employment insecurity, role conflict, and demand for family-responsive employment arrangements.
3. Caregiver agency and social entrepreneurship. A small body of evidence indicated that caregiving experience and acquired knowledge could develop into parent-led associations, community initiatives, social enterprise, advocacy, support services, or employment-creation models.
4. Resilience, social support, and empowerment. Social networks, positive cognition, cultural values, psychological capital, caregiver organisations, and peer support strengthened family adaptation and resilience.

5. Institutional and structural constraints. Service shortages, financial inequality, administrative barriers, inconsistent policy implementation, and limited workplace flexibility influenced both the need for and feasibility of entrepreneurial or livelihood adaptation.

These themes were interdependent. Economic pressure and employment disruption generated demand for flexible livelihood responses, while resilience, experiential knowledge, and social support influenced caregivers' capacity to respond. Institutional conditions determined whether caregiver initiative could develop into sustainable employment, entrepreneurship, or collective social enterprise.

3.9 Evidence Gaps

Four major evidence gaps were identified.

First, direct ASD-specific research on caregiver entrepreneurship was extremely limited. Most studies examined antecedent or contextual conditions—including financial burden, employment disruption, service gaps, work–family conflict, and psychosocial coping—rather than entrepreneurial behaviour itself.

Second, entrepreneurship was rarely assessed using clearly defined indicators such as enterprise ownership, business type, motivation for business entry, start-up capital, investment, revenue, profitability, employment creation, business continuity, or contribution to household income.

Third, no included study was conducted in Africa. This represents a substantial geographic gap because informal enterprise, self-employment, and livelihood diversification are important components of household economic resilience across many African settings.

Fourth, the relationship between caregiver entrepreneurship and child-related outcomes remained largely unexplored. No study directly established whether entrepreneurship improved access to therapy, education, healthcare, assistive resources, family quality of life, or developmental support for children with ASD.

Substantial heterogeneity in study designs, populations, exposures, and outcome measures precluded statistical pooling. Narrative thematic synthesis was therefore considered the most appropriate approach for integrating the available evidence.

3.10 Methodological Quality and Risk-of-Bias Assessment

The methodological quality of the 14 included studies was evaluated using design-appropriate appraisal tools as indicated in Table 3. The eight qualitative studies were assessed using the Critical Appraisal Skills Programme qualitative checklist. The five analytical cross-sectional studies were assessed using the Joanna Briggs Institute critical appraisal criteria for analytical cross-sectional research, while the single case-control study was assessed using the corresponding Joanna Briggs Institute case-control checklist.

Appraisal focused on the clarity of study aims, appropriateness of the research design, participant selection, data-collection procedures, validity and reliability of measurement, identification and management of confounding, rigour of analysis, ethical considerations, coherence between findings and interpretations, and relevance to the review question. Methodological quality and relevance were considered separately because a methodologically robust study could still provide only indirect evidence concerning caregiver entrepreneurship.

Four studies were judged to provide high methodological confidence, while ten provided moderate methodological confidence. No study was classified as having low overall methodological confidence. The principal limitations among qualitative studies were reliance on purposive, convenience, snowball, or self-selected samples; limited reporting of researcher reflexivity; incomplete description of recruitment procedures in some studies; and restricted transferability from small, context-specific samples. Nevertheless, most

qualitative studies had clearly stated aims, appropriate qualitative designs, identifiable participant groups, coherent thematic findings, and conclusions supported by the reported data.

The principal limitations among quantitative studies were the predominance of cross-sectional designs, use of convenience or purposive sampling, reliance on self-reported measures, potential residual confounding, and the inability to establish temporal or causal relationships. The Brazilian case-control study had comparatively strong sampling and diagnostic procedures, including a prespecified sample-size calculation, clinically confirmed ASD cases, screened controls, and an age-matched comparison design. However, possible selection bias and residual socio-economic confounding remained relevant considerations.

Only a small proportion of studies provided direct evidence concerning entrepreneurship or social enterprise. Most studies contributed indirectly by examining economic burden, financial coping, work–family conflict, employment adaptation, caregiver resilience, social support, or institutional constraints. Accordingly, methodological quality was not interpreted as equivalent to directness of evidence.

4. Discussion

4.1 Principal Findings

This systematic review examined entrepreneurship, employment adaptation, economic coping, and related livelihood responses among families raising children with autism spectrum disorder (ASD). Across the 14 unique studies included in the synthesis, the evidence consistently demonstrated that families experienced substantial economic, occupational, psychosocial, and service-related pressures. However, direct empirical investigation of caregiver entrepreneurship was limited. Most studies examined the conditions that may generate the need for entrepreneurial or flexible livelihood responses, including unmet service needs, household debt, work–family conflict, employment disruption, caregiver burden, limited institutional support, and the search for greater flexibility and autonomy.

Five interrelated findings emerged. First, financial strain was frequently linked to unmet autism-related service needs and the transfer of care costs from formal systems to households. Second, employment continuity was constrained by the incompatibility between intensive caregiving responsibilities and inflexible workplace arrangements. Third, entrepreneurship appeared primarily as an emerging or indirect coping pathway rather than a well-established field of empirical inquiry. Fourth, caregiver resilience, social support, positive cognition, and collective organisation strengthened families' capacity to adapt. Fifth, the feasibility and sustainability of entrepreneurial activity depended heavily on institutional conditions, including access to services, finance, social protection, workplace accommodation, training, and community support.

The evidence therefore suggests that caregiver entrepreneurship should not be interpreted as an isolated economic behaviour. Rather, it should be understood as one component of a wider family adaptation process shaped by autism-related caregiving demands, household resources, labour-market conditions, service-system performance, and social support. Importantly, the findings do not establish that entrepreneurship is inherently beneficial. In some circumstances, self-employment may increase flexibility and autonomy; in others, it may reflect exclusion from secure employment, inadequate public support, or the absence of viable alternatives.

4.2 Economic Strain as a Driver of Livelihood Adaptation

The review demonstrated that economic pressure constitutes an important context within which families make employment and livelihood decisions. Roddy and O'Neill (2020) showed that unmet service needs were associated with family debt among households raising children with ASD in Ireland. The reported mean household debt of approximately €3,259 illustrates how insufficient service provision may compel families to finance autism-related support privately. Such expenditure can reduce disposable income, increase financial

insecurity, and alter long-term household decisions concerning employment, savings, borrowing, and income generation.

This finding has important implications for understanding caregiver entrepreneurship. When formal service systems do not adequately meet children's needs, families may be required to generate additional income while simultaneously devoting substantial time to care coordination. Entrepreneurship, home-based business, informal trade, and self-employment may therefore arise as attempts to reconcile income generation with service navigation and caregiving responsibilities. However, the reviewed evidence rarely measured whether such activities improved household income, reduced debt, or enhanced financial resilience.

The Malaysian evidence on financial behaviour and caregiver wellbeing further indicated that economic coping is shaped by social and cultural context. Financial decision-making among caregivers does not occur solely in response to income constraints; it may also reflect cultural expectations, perceptions of uncertainty, family obligations, and attitudes towards financial risk. Future autism-family research should therefore examine not only whether caregivers engage in entrepreneurship, but also how household resources, cultural values, access to credit, and social protection influence entrepreneurial entry and sustainability.

The present findings also suggest that economic vulnerability may be underestimated when studies focus exclusively on direct medical or educational expenditure. The opportunity costs of caregiving—including reduced working hours, career interruption, occupational change, and withdrawal from formal employment—may be equally important. A comprehensive assessment of the economic consequences of raising a child with ASD should therefore include both direct expenditure and foregone employment opportunities.

4.3 Work–Family Conflict and the Search for Flexible Employment

Employment-related pressures were among the most consistent findings across the included studies. Sitimin et al. (2017) showed that working parents of children with autism experienced substantial conflict between employment demands and caregiving responsibilities. Rigid schedules, changing workplace expectations, limited managerial understanding, and unpredictable care demands made it difficult for parents to fulfil both occupational and family roles. These challenges illustrate that caregiver employment difficulties are not attributable solely to the child's support needs; they are also shaped by the extent to which workplaces accommodate family diversity.

Scott (2018) similarly demonstrated that flexible employment helped some mothers of children with disabilities remain economically active. However, flexibility was often achieved through reduced working hours, occupational change, part-time employment, or movement into less secure forms of work. Such adaptations may protect labour-force participation while simultaneously reducing earnings, employment benefits, promotion opportunities, and long-term economic security.

These findings are directly relevant to entrepreneurship because self-employment may offer greater control over working time, location, and workload. Home-based enterprise may allow caregivers to remain close to their children, respond to unexpected needs, and organise work around therapy, education, and healthcare schedules. Nevertheless, the assumption that entrepreneurship necessarily resolves work–family conflict requires caution. Self-employment may introduce new demands, including unstable income, customer obligations, business administration, market uncertainty, and the absence of paid leave or employer-supported benefits.

The findings therefore support a continuum of caregiver employment responses rather than a simple distinction between employment and unemployment. Caregivers may remain in formal employment with workplace accommodation, reduce working hours, move to flexible employment, combine wage employment with informal income generation, transition to self-employment, or withdraw from the labour market. Future studies

should investigate these pathways longitudinally and assess how each affects caregiver wellbeing, household income, family functioning, and access to autism-related services.

The Israeli study by Hazan-Liran et al. (2024) further highlighted the importance of psychological capital in occupational wellbeing. Hope, self-efficacy, resilience, and optimism may support job satisfaction and continued employment among parents of children with ASD. However, psychological resources should not be treated as substitutes for structural support. Caregiver resilience may help individuals adapt, but sustainable employment also requires flexible workplace policies, supportive supervision, predictable schedules, and recognition of caregiving responsibilities.

4.4 Entrepreneurship as Necessity, Opportunity, and Caregiver Agency

The review indicates that caregiver entrepreneurship may occur through multiple pathways. In some cases, enterprise may be necessity-driven, emerging because formal employment is incompatible with caregiving responsibilities or because households need additional income to meet service-related costs. In other cases, entrepreneurship may be opportunity-driven, reflecting caregivers' desire for autonomy, flexible work, social contribution, or the application of knowledge acquired through lived experience.

The Argentine study by Szlamka et al. (2024) provided the clearest evidence of a progression from personal coping towards caregiver agency and entrepreneurship. Caregivers accumulated knowledge while navigating diagnosis, intervention, education, and service systems. This experiential expertise created opportunities for advocacy, peer support, training, community organisation, and caregiver-led initiatives. Entrepreneurship in this context was not limited to commercial business ownership; it represented the potential transformation of caregiving experience into socially valuable knowledge and service provision.

However, the study also showed that caregiver agency was constrained by economic instability, unequal service access, regional disparities, and inconsistent policy implementation. These findings demonstrate that individual motivation alone is insufficient to produce sustainable entrepreneurship. Caregivers require enabling environments that provide finance, skills development, market access, service infrastructure, social protection, and institutional recognition.

The distinction between necessity-driven and opportunity-driven entrepreneurship is particularly important for autism-family research. Necessity-driven entrepreneurship may allow caregivers to generate income when other employment options are unavailable, but it may also be associated with low profitability, informality, insecure working conditions, and high workload. Opportunity-driven entrepreneurship may offer greater potential for innovation, autonomy, and business growth, but access to such opportunities is likely to be unequal.

Future studies should therefore assess entrepreneurial motivation directly. Relevant indicators should include the reason for business entry, previous employment status, caregiving-related employment disruption, availability of alternative work, access to finance, type of enterprise, income contribution, business continuity, and perceived effects on family wellbeing.

4.5 Parent-Led Social Entrepreneurship and Service Innovation

The Ahada model illustrated the potential of collective social entrepreneurship as a response to unmet long-term support needs. Parents established a community-based organisation intended to promote social inclusion, economic participation, and long-term wellbeing among people with intellectual and developmental disabilities. Although the study population was broader than ASD alone, the model offers important implications for autism-related family support.

Parent-led social entrepreneurship differs from individual livelihood enterprise because its objectives extend beyond household income. Such initiatives may combine service provision, employment creation, advocacy, peer support, community inclusion, and long-term planning. They may also address gaps that formal health, education, and social welfare systems have not adequately filled.

For families raising children with ASD, social enterprise may create opportunities to transform lived experience into services that are culturally responsive and family-centred. Potential models include caregiver-led training programmes, inclusive childcare services, autism-support centres, assistive technology initiatives, employment-support services, parent mentoring, community awareness programmes, and inclusive production enterprises.

Nevertheless, parent-led initiatives should not become substitutes for public responsibility. Reliance on caregivers to create services may increase unpaid labour and shift responsibility from institutions to families. Sustainable social enterprise therefore requires supportive regulation, public–community partnerships, technical assistance, finance, accountability mechanisms, and integration with formal service systems.

4.6 Caregiver Resilience, Social Support, and Entrepreneurial Capacity

The review found consistent evidence that social support, positive cognition, cultural values, psychological capital, and caregiver networks strengthened family adaptation. Dong et al. (2025) demonstrated that caregiver burden was negatively associated with family resilience, while social support and positive cognition partially mediated this relationship. The direct association between caregiver burden and family resilience was substantial, whereas social support contributed to improved resilience both directly and through positive cognition.

These findings suggest that entrepreneurship may depend partly on psychosocial resources. Starting and sustaining an enterprise often requires confidence, problem-solving ability, persistence, access to information, and supportive networks. Caregivers experiencing severe burden, social isolation, or psychological distress may have limited capacity to pursue entrepreneurial opportunities, even when self-employment could offer greater flexibility.

The qualitative studies from Spain and Pakistan similarly demonstrated that family support, friendship networks, peer groups, acceptance, and shared cultural values contributed to coping and adaptation (Furrukh et al., 2020; Galán-Vera et al., 2025). Parent associations may be particularly important because they provide emotional support, practical information, collective advocacy, and opportunities for collaboration. Such networks may also support entrepreneurship by facilitating knowledge exchange, referrals, group savings, cooperative enterprise, and access to markets.

However, the relationship between psychosocial resilience and entrepreneurship was not tested directly in most studies. Future research should examine whether social support and psychological capital mediate or moderate the relationship between caregiving demands and entrepreneurial participation. This would help clarify why some caregivers are able to convert experience and knowledge into viable economic activity while others remain constrained by burden and limited resources.

4.7 Institutional Conditions and the Limits of Individual Coping

The evidence consistently showed that family adaptation is shaped by institutional conditions. Sukeri et al. (2017) identified unmet needs related to information, financial assistance, community support, service coordination, healthcare responsiveness, policy implementation, and administrative processes. The Romanian study similarly highlighted anxiety regarding long-term care, limited support, role conflict, and the importance of parent groups and coordinated services.

These findings indicate that entrepreneurship cannot compensate fully for inadequate health, education, employment, and social protection systems. Caregivers may demonstrate substantial resilience and initiative, but their opportunities remain constrained when services are inaccessible, workplaces are inflexible, financial support is inadequate, or policies are poorly implemented.

An exclusive focus on individual coping may therefore obscure structural causes of caregiver vulnerability. Policies that encourage entrepreneurship without addressing service gaps risk placing additional responsibility on families. Caregiver enterprise programmes should be integrated with autism services, respite care, flexible employment policies, social protection, accessible finance, business development support, and community-based assistance.

The findings also suggest that institutional support influences whether entrepreneurship becomes empowering or burdensome. Where caregivers have access to reliable services, supportive networks, finance, and training, enterprise may provide meaningful autonomy and income. Where such support is absent, entrepreneurship may become another demanding responsibility layered onto intensive unpaid care.

4.8 Implications for Autism Services and Family-Centred Practice

The findings have several implications for autism services and family-centred practice. First, assessment of family needs should include employment and economic wellbeing. Service providers often focus appropriately on the developmental, educational, and behavioural needs of autistic children, but caregiver employment disruption and household financial strain may directly affect the family's capacity to sustain long-term support.

Second, family-centred services should provide or facilitate access to employment advice, social protection, financial counselling, caregiver support groups, and livelihood resources. These services may be especially valuable during diagnosis, school transitions, changes in service intensity, or periods of employment disruption.

Third, professionals should recognise caregivers' experiential knowledge as a potential resource. Some caregivers may wish to use their knowledge in peer support, advocacy, training, service provision, or social enterprise. Such pathways should be supported ethically through appropriate training, safeguarding, professional boundaries, and fair remuneration.

Fourth, autism services should avoid assuming that all caregivers desire entrepreneurship. Some may prefer secure wage employment with adequate accommodation, while others may choose part-time work, home-based enterprise, or temporary withdrawal from employment. Family-centred practice should therefore support informed choice rather than promoting a single livelihood pathway.

4.9 Implications for Africa and Other Low- and Middle-Income Settings

The absence of African studies among the extracted evidence represents a major geographic and policy gap. This omission is particularly important because self-employment, informal enterprise, family business, agriculture, small-scale trade, and household livelihood diversification are central components of economic life in many African countries.

In contexts where autism services, social protection, formal employment opportunities, and workplace accommodation are limited, families may rely heavily on informal economic activities. Caregiver entrepreneurship may therefore be more prevalent than the published evidence suggests. However, informality may also create vulnerabilities, including unstable income, limited access to finance, lack of insurance, weak legal protection, and exclusion from business-development programmes.

Future African research should examine how gender, poverty, stigma, rural–urban location, extended family support, informal labour markets, digital access, and service availability shape caregiver entrepreneurship.

Particular attention should be given to mothers, who may carry disproportionate caregiving responsibilities while also contributing substantially to household livelihoods.

Research should also evaluate locally relevant enterprise models, including savings and lending groups, cooperatives, home-based production, agriculture, food processing, digital microenterprise, tailoring, retail trade, community-based rehabilitation enterprises, and caregiver-led social ventures. Such studies should assess not only enterprise participation but also profitability, sustainability, household income, caregiver wellbeing, service access, and child-related outcomes.

4.10 Implications for Future Research

The review identifies several priorities for future research.

First, studies should define and measure caregiver entrepreneurship directly. Indicators should include enterprise ownership, business type, formality, location, duration, motivation, start-up capital, income, profitability, employment creation, business continuity, and contribution to household expenditure.

Second, future research should distinguish necessity-driven from opportunity-driven entrepreneurship. This distinction is essential because the motivations, resources, risks, and outcomes associated with these forms of enterprise may differ substantially.

Third, longitudinal studies are required to examine transitions between formal employment, flexible employment, self-employment, informal business, and labour-market withdrawal. Such research would clarify how caregiving demands influence employment trajectories over time.

Fourth, mixed-methods designs should integrate economic indicators with caregiver experiences. Quantitative analysis could assess income, employment, wellbeing, and resilience, while qualitative inquiry could explain motivations, constraints, family negotiations, and institutional influences.

Fifth, future studies should examine child-related outcomes. It remains unclear whether caregiver entrepreneurship improves access to therapy, education, healthcare, assistive resources, or social participation for children with ASD.

Sixth, intervention research should evaluate caregiver-sensitive enterprise programmes. Relevant interventions may include business training, digital entrepreneurship, microfinance, mentorship, cooperative enterprise, social enterprise incubation, and integrated livelihood–care support.

4.11 Strengths and Limitations

This review has several strengths. It addressed an underexplored intersection between autism caregiving, employment, household economics, coping, and entrepreneurship. The review was prospectively registered in PROSPERO and followed a structured systematic-review process. The evidence base included quantitative, qualitative, and mixed-context studies from multiple regions, allowing examination of economic, occupational, psychosocial, and institutional dimensions of caregiver adaptation.

The review also distinguished direct entrepreneurship evidence from contextual evidence. This distinction reduced the risk of treating financial burden, work–family conflict, or resilience as equivalent to entrepreneurship. It also allowed the review to identify the conditions that may generate entrepreneurial responses while recognising the limited direct empirical evidence.

Several limitations should nevertheless be considered. First, direct studies of entrepreneurship among caregivers of children with ASD were scarce. Consequently, part of the synthesis relied on contextual evidence concerning employment disruption, economic burden, resilience, and service-system constraints.

Second, some studies included caregivers of children with broader intellectual, developmental, or physical disabilities rather than exclusively ASD populations. These studies provided relevant insights but limited the specificity of conclusions for autism-affected households.

Third, the studies were heterogeneous in design, population, setting, exposure, and outcome measurement. This heterogeneity prevented meta-analysis and required narrative thematic synthesis.

Fourth, most participants were mothers. Although this reflects the gendered distribution of caregiving, it limits understanding of fathers, grandparents, siblings, and other household members involved in employment and livelihood decisions.

Fifth, no extracted study was conducted in Africa. The findings may therefore not fully represent contexts characterised by high informal employment, limited autism services, weak social protection, and strong reliance on household livelihood diversification.

Finally, the review was limited to English-language publications within the predefined period. Relevant studies published in other languages or outside indexed academic databases may not have been captured.

5. Conclusion

This systematic review demonstrates that entrepreneurship remains an important but substantially under-investigated dimension of family adaptation among caregivers raising children with autism spectrum disorder. Across the 14 included studies, the evidence consistently documented economic strain, employment disruption, work–family conflict, service-system limitations, caregiver burden, and the importance of social support and resilience. However, relatively few studies directly examined entrepreneurship, self-employment, household enterprise, or income-generating activities as primary caregiver responses.

The findings suggest that caregiver entrepreneurship should be understood as a conditional and context-dependent livelihood strategy rather than as an inherently empowering outcome. For some caregivers, self-employment or enterprise may provide greater flexibility, autonomy, and opportunities to combine income generation with caregiving responsibilities. For others, entrepreneurship may be necessity-driven and emerge from exclusion from formal employment, inadequate workplace accommodation, high service costs, or insufficient social protection. Its potential benefits are therefore likely to depend on access to finance, business skills, social networks, reliable autism services, respite support, market opportunities, and enabling public policy.

The review further shows that caregiver agency may extend beyond individual enterprise. Parent-led organisations and social entrepreneurship can transform lived experience into advocacy, peer support, service innovation, community inclusion, and employment opportunities. Nevertheless, such initiatives should complement rather than replace public responsibility for accessible autism services, inclusive employment, and family social protection.

The limited direct evidence, absence of African studies, and inconsistent measurement of entrepreneurial activity constitute major research gaps. Future studies should investigate enterprise ownership, business type, motivation, income contribution, sustainability, caregiver wellbeing, and child-related outcomes. Longitudinal and mixed-methods research is especially needed to distinguish opportunity-driven from necessity-driven entrepreneurship and to examine how caregivers move between formal employment, flexible employment, self-employment, and labour-market withdrawal.

For autism policy and practice, the findings indicate that family-centred support should extend beyond clinical and educational services to include employment, economic wellbeing, financial protection, and livelihood

opportunity. Integrated interventions that combine autism services with flexible employment, caregiver-sensitive enterprise support, social protection, psychosocial assistance, and access to finance may strengthen both household resilience and the capacity of families to meet the long-term needs of children with ASD.

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Figure 1. PRISMA 2020 flow diagram

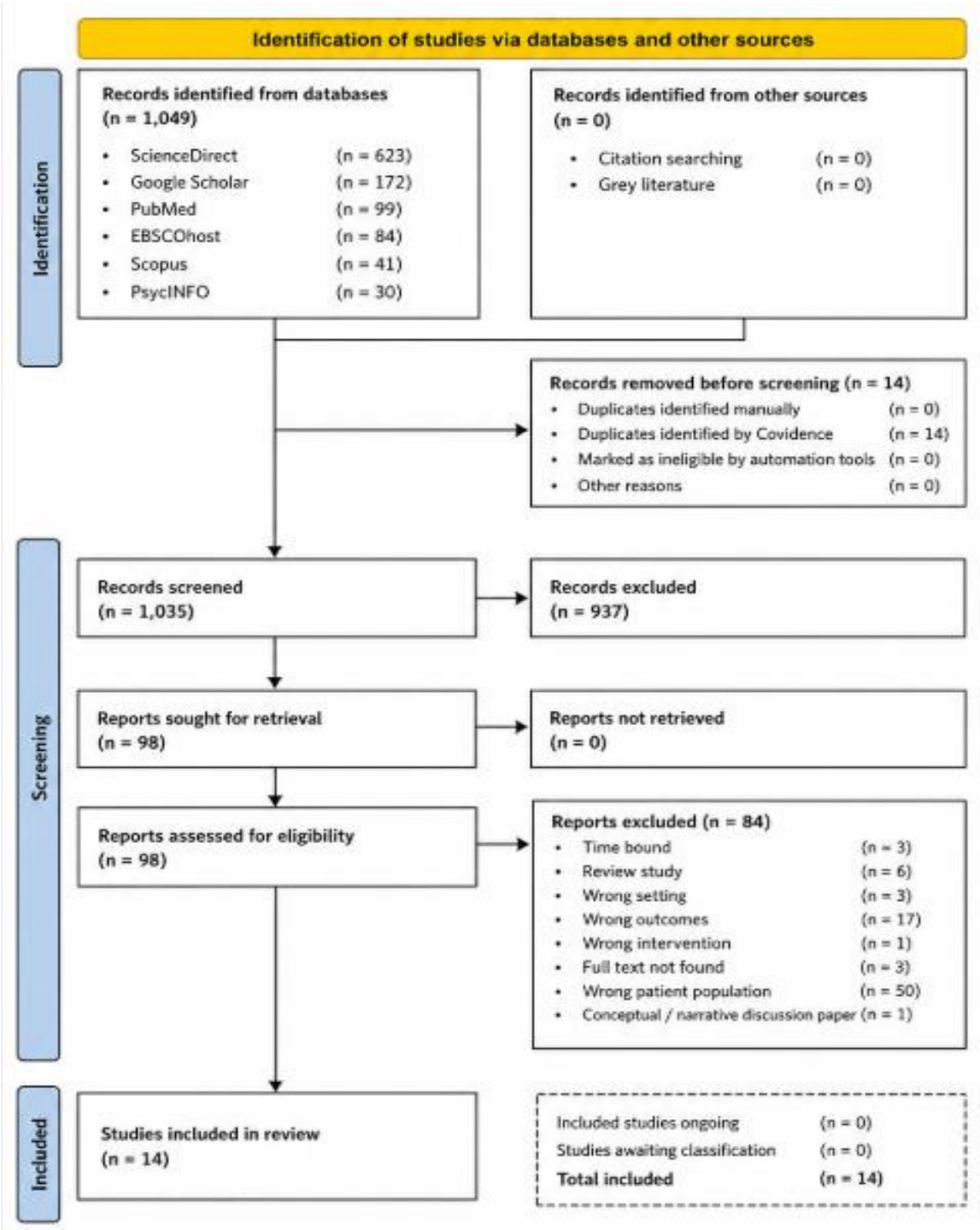


Table 1. Search Strategy and Database Yield

Information source	Platform/search approach	Search period	Language restriction	Records retrieved, n
ScienceDirect	Title, abstract, and keyword searching using terms related to ASD, caregivers/families, entrepreneurship/employment, livelihood adaptation, economic coping, and wellbeing	1 March 2016–1 March 2026	English	623
Google Scholar	Supplementary targeted searches combining autism, caregiver, entrepreneurship, self-employment, employment adaptation, financial coping, and resilience terms	1 March 2016–1 March 2026	English	172
PubMed	MeSH terms and title/abstract keywords relating to ASD, caregivers, entrepreneurship/self-employment, employment, coping, household economics, and wellbeing	1 March 2016–1 March 2026	English	99

Information source	Platform/search approach	Search period	Language restriction	Records retrieved, n
EBSCOhost Academic Search Complete	All-text and subject-term searching across autism, family caregiving, entrepreneurship, employment, economic burden, coping, and livelihood concepts	1 March 2016–1 March 2026	English	84
Scopus	TITLE-ABS-KEY search combining ASD, caregiver/family, enterprise/employment, and economic or psychosocial outcome concepts	1 March 2016–1 March 2026	English	41
PsycINFO via EBSCOhost	Controlled descriptors and all-text terms relating to ASD, caregivers, employment, self-employment, coping, resilience, and family wellbeing	1 March 2016–1 March 2026	English	30
Total records identified				1,049
Duplicate records removed by Covidence				14
Unique records screened				1,035

Note. ASD = autism spectrum disorder. Searches were conducted during March 2026. No additional records were included through citation searching, grey-literature searching, or other sources. Complete database-specific search strings are presented in Supplementary Table S1.

Table 2. Characteristics of the Studies Included in the Narrative Synthesis

Study	Country	Study design	Sample	Population or study focus	Principal contribution to the synthesis	Evidence classification
Galán-Vera et al. (2025)	Spain	Qualitative study	17 parents: 14 mothers and 3 fathers	Parents of children with ASD receiving early-intervention services	Identified emotional responses to diagnosis, coping strategies, resilience, family involvement, social networks, and cultural family values	ASD-specific contextual evidence: coping and resilience
Sitimin et al. (2017)	Malaysia	Qualitative study	12 parents	Full-time private-sector employees raising children with autism	Identified work demands, parenting responsibilities, guilt, role conflict, unpredictable employment expectations, and limited workplace flexibility	ASD-specific employment evidence
Roddy and O'Neill (2020)	Ireland	Analytical cross-sectional study	195 families raising 222 children aged 2–18 years	Families of children and adolescents with ASD	Linked unmet service needs with financial pressure and borrowing; mean reported family debt was approximately €3,259	ASD-specific economic evidence
Sukeri et al. (2017)	Malaysia	Qualitative study	12 mothers; 5 cared for children with ADHD- or ASD-related conditions	Mothers of children with disabilities	Identified unmet needs concerning information, social support, community services, financial assistance, healthcare responsiveness, and welfare policy	Contextual disability evidence: institutional and financial barriers
Ganany-Dagan (2025)	Israel	Qualitative organisational case study	12 participants	Parents, siblings, a disability-rights advocate, and a health-sector representative associated with the Ahada model	Examined a parent-led non-profit socio-economic model supporting long-term wellbeing, community inclusion, and employment creation	Direct social-entrepreneurship evidence; broader developmental-disability population
Furrukh and Anjum (2020)	Pakistan	Phenomenological qualitative study	15 mothers	Mothers of children with ASD	Identified stigma, blame, social withdrawal, uncertainty, acceptance, resilience, and gradual social re-engagement	ASD-specific contextual evidence: psychosocial coping
Chen et al. (2025)	China	Analytical cross-sectional study	254 parents	Parents of children diagnosed with ASD	Caregiver burden was negatively associated with family resilience; social support and positive cognition partially mediated this relationship	ASD-specific contextual evidence: resilience and social support

Study	Country	Study design	Sample	Population or study focus	Principal contribution to the synthesis	Evidence classification
Hazan-Liran (2024)	Israel	Comparative cross-sectional study	141 parents: 69 parents of children with ASD and 72 comparison parents	Employed parents of children with and without ASD	Examined psychological capital and job satisfaction; overall job-satisfaction score was M = 43.65, SD = 7.29	ASD-specific employment and occupational-wellbeing evidence
Kovács and Dan (2025)	Romania	Qualitative study	11 parents	Hungarian minority parents of children with severe disabilities	Identified traumatic loss, belonging, role conflict, long-term caregiving concerns, and the importance of parent groups and coordinated support	Contextual disability evidence: support systems
Salleh et al. (2025)	Malaysia	Analytical cross-sectional study	129 caregivers	Caregivers of children with autism	Examined societal cultural values, financial behaviour, uncertainty avoidance, and financial wellbeing	ASD-specific financial-behaviour evidence
Santos Bandeira et al. (2024)	Brazil	Case-control study	1,134 participants	Parents of children and adolescents with and without ASD	Examined associations between ASD and parental socio-economic and demographic characteristics	ASD-specific contextual evidence: socio-economic conditions
Scott (2018)	United States	Qualitative study	40 families recruited; 24 employed mothers in the analytical sample; 12 examined in depth	Employed mothers of children with disabilities	Demonstrated the importance and scarcity of flexible, family-responsive employment; identified reduced hours, occupational change, and employment insecurity	Contextual employment-adaptation evidence
Ikhwanisifa et al. (2025)	Indonesia	Analytical cross-sectional study	145 working mothers	Working mothers of children with special needs	Examined psychological capital as a mediator between Islamic piety and maternal wellbeing	Contextual psychosocial and employment evidence
Szlamka et al. (2024)	Argentina	Qualitative case study	32 caregivers and stakeholder participants	Caregivers of autistic children, service providers, civil-society organisations, education stakeholders, and policy actors	Identified progression from intuitive coping towards caregiver agency, empowerment, entrepreneurship, peer support, and collective action; highlighted economic and institutional constraints	Most direct ASD-specific entrepreneurship and empowerment evidence

Note. ASD = autism spectrum disorder; ADHD = attention-deficit/hyperactivity disorder. Studies were classified according to the directness of their contribution to the review question. ASD-specific contextual studies examined economic, employment, psychosocial, or institutional pathways relevant to entrepreneurship but did not necessarily measure enterprise participation directly. Broader disability studies were retained to map transferable evidence and were interpreted cautiously where ASD-specific findings were not separately available.

Table 3. Methodological Quality and Relevance of Included Studies

Study	Design	Appraisal tool	Main methodological strengths	Principal methodological concerns	Overall methodological confidence	Directness to the review question
Galán-Vera et al. (2025)	Qualitative	CASP	Clear research aim; appropriate qualitative approach; explicit eligibility criteria; inclusion of mothers and fathers; coherent thematic analysis of diagnosis, coping, and family values	Convenience recruitment; small sample from early-care centres; limited transferability; reflexivity insufficiently reported	Moderate	Indirect; examines coping and family adaptation rather than entrepreneurship
Sitimin et al. (2017)	Qualitative	CASP	Clear focus on work–family conflict; participants directly relevant to caregiver employment; rich exploration of work and caregiving roles	Recruitment procedures not fully reported; small private-sector sample; limited information on researcher reflexivity and transferability	Moderate	Moderately direct; explains employment pressures that may motivate flexible work or self-employment

Study	Design	Appraisal tool	Main methodological strengths	Principal methodological concerns	Overall methodological confidence	Directness to the review question
Roddy and O'Neill (2020)	Analytical cross-sectional	JBI	Clearly defined ASD population; relatively large family sample; clinically established diagnosis; relevant economic outcomes; analysis of predictors of unmet needs and debt	Cross-sectional design; possible recall and self-report bias; temporal relationships cannot be established	High	Indirect but highly relevant; identifies financial pressures that may motivate income diversification
Sukeri et al. (2017)	Qualitative	CASP	Purposive recruitment through community-based rehabilitation centres; data collection continued towards saturation; clear identification of unmet-need barriers	Small sample; heterogeneous disability population; ASD-specific findings not fully separable; limited transferability	Moderate	Indirect; informs institutional and financial barriers
Ganany-Dagan (2025)	Qualitative case study	CASP	Multiple stakeholder perspectives; detailed examination of a parent-led non-profit model; strong relevance to community support and employment creation	Recruitment process insufficiently described; single organisational case; broader intellectual and developmental disability population	Moderate	Direct for social entrepreneurship, but only partially ASD-specific
Furrukh and Anjum (2020)	Phenomenological qualitative study	CASP	Appropriate phenomenological design; explicit focus on mothers' lived experiences; recruitment through clinical and support-group networks; coherent coping themes	Urban, relatively educated sample; possible self-selection bias; findings may not represent lower-income or rural families	Moderate	Indirect; examines coping, stigma, support, and adaptation
Dong et al. (2025)	Analytical cross-sectional	JBI	Clearly defined eligibility criteria; ASD diagnoses based on DSM-5; multisite recruitment; adequate sample; mediation analysis linking burden, support, cognition, and resilience	Convenience sampling; cross-sectional mediation limits causal inference; self-reported psychosocial measures	High	Indirect; identifies psychosocial resources potentially supporting entrepreneurial capacity
Hazan-Liran et al. (2024)	Comparative cross-sectional	JBI	Inclusion of an ASD-parent group and comparison group; clear employment focus; examination of psychological capital and job satisfaction	Online and voluntary recruitment; predominantly female sample; self-report measures; cross-sectional design	Moderate	Moderately direct; addresses employment wellbeing but not business activity
Kovács et al. (2025)	Qualitative	CASP	Clear focus on minority parents in a difficult caregiving context; purposive sampling; identification of role conflict, belonging, and support needs	Small urban sample; broader severe-disability population; limited ASD specificity; restricted transferability	Moderate	Indirect and contextual
Salleh et al. (2025)	Analytical cross-sectional	JBI	Explicit focus on autism caregivers; assessment of financial behaviour and financial wellbeing; culturally informed analytical framework	Purposive sampling; limited information on representativeness and control of confounding; cross-sectional self-report design	Moderate	Moderately direct; evaluates financial behaviour but not entrepreneurship itself
Bandeira et al. (2024)	Case-control	JBI	Large sample; prespecified sample-size calculation; clinically confirmed ASD cases; screened controls; age-matched comparison structure	Possible clinic- and association-based selection bias; socio-economic confounding may remain; retrospective exposure assessment	High	Indirect; examines socio-economic characteristics rather than entrepreneurial coping
Scott (2018)	Qualitative	CASP	Recruitment through multiple community organisations; detailed examination of flexible and family-responsive employment; strong attention to mothers' employment adaptation	Analytical sample narrower than the recruited sample; self-selection; broad disability population; limited ASD-specific evidence	Moderate	Moderately direct; examines employment flexibility rather than enterprise ownership

Study	Design	Appraisal tool	Main methodological strengths	Principal methodological concerns	Overall methodological confidence	Directness to the review question
Ikhwanisifa et al. (2025)	Analytical cross-sectional	JBI	Clearly defined working-mother population; assessment of psychological capital, spirituality, and wellbeing; use of path analysis	Purposive sampling; broad special-needs population; self-report measures; cross-sectional mediation limits causal interpretation	Moderate	Indirect; informs psychosocial capacity among working caregivers
Szlamka et al. (2024)	Qualitative case study	CASP	Nationally diverse stakeholder sample; inclusion of urban, rural, and remote perspectives; purposive and snowball recruitment; clear empowerment framework; coherent findings	Potential selection bias through stakeholder networks; interpretation dependent on contextual and policy conditions	High	Most directly relevant ASD-specific evidence concerning caregiver agency and progression towards entrepreneurship

Note. CASP = Critical Appraisal Skills Programme; JBI = Joanna Briggs Institute. Overall methodological confidence was determined through domain-based judgement rather than simple numerical scoring. "Directness" refers to the extent to which a study explicitly examined entrepreneurship, self-employment, enterprise development, employment creation, or livelihood adaptation among caregivers of children with ASD. Methodological quality and directness were assessed independently. No study was excluded solely because of methodological limitations; instead, appraisal findings informed the weighting and interpretation of evidence.

Supplementary Table S1. Full Electronic Search Strategies

Information source	Full search strategy	Limits applied	Records retrieved, n
PubMed	(("Autism Spectrum Disorder"[MeSH] OR "autism spectrum disorder"[Title/Abstract] OR autism[Title/Abstract] OR autistic[Title/Abstract] OR ASD[Title/Abstract]) AND ("Parents"[MeSH] OR "Caregivers"[MeSH] OR parent*[Title/Abstract] OR caregiver*[Title/Abstract] OR carer*[Title/Abstract] OR famil*[Title/Abstract] OR household*[Title/Abstract] OR mother*[Title/Abstract] OR father*[Title/Abstract]) AND ("Entrepreneurship"[MeSH] OR "Self Employment"[MeSH] OR entrepreneur*[Title/Abstract] OR self-employ*[Title/Abstract] OR enterprise*[Title/Abstract] OR "household enterprise"[Title/Abstract] OR "family business"[Title/Abstract] OR "home-based business"[Title/Abstract] OR microenterprise[Title/Abstract] OR "small business"[Title/Abstract] OR "informal business"[Title/Abstract] OR "income-generating activit*"[Title/Abstract] OR livelihood*[Title/Abstract] OR employ*[Title/Abstract] OR "work-family conflict"[Title/Abstract]) AND ("Coping Skills"[MeSH] OR coping[Title/Abstract] OR income[Title/Abstract] OR debt[Title/Abstract] OR "financial strain"[Title/Abstract] OR "economic burden"[Title/Abstract] OR resilience[Title/Abstract] OR empowerment[Title/Abstract] OR agency[Title/Abstract] OR wellbeing[Title/Abstract] OR "quality of life"[Title/Abstract] OR "social support"[Title/Abstract]))	English; publication date from 1 March 2016 to 1 March 2026	99
PsycINFO via EBSCOhost	(DE "Autism Spectrum Disorders" OR TX ("autism spectrum disorder" OR autism OR autistic OR ASD)) AND (DE "Parents" OR DE "Caregivers" OR TX (parent* OR caregiver* OR carer* OR famil* OR household* OR mother* OR father*)) AND (DE "Entrepreneurship" OR DE "Self Employment" OR TX (entrepreneur* OR self-employ* OR enterprise* OR "household enterprise" OR "family business" OR "home-based business" OR microenterprise OR "small business" OR "informal business" OR "income-generating activit*" OR livelihood* OR employ* OR "work-family conflict")) AND (DE "Coping Behavior" OR DE "Resilience" OR TX (coping OR income OR debt OR "financial strain" OR "economic burden" OR resilience OR empowerment OR agency OR wellbeing OR "quality of life" OR "social support"))	English; peer-reviewed published literature; 1 March 2016–1 March 2026	30

Information source	Full search strategy	Limits applied	Records retrieved, n
EBSCOhost Academic Search Complete	TX ("autism spectrum disorder" OR autism OR autistic OR ASD) AND TX (parent* OR caregiver* OR carer* OR famil* OR household* OR mother* OR father*) AND TX (entrepreneur* OR self-employ* OR enterprise* OR "household enterprise" OR "family business" OR "home-based business" OR microenterprise OR "small business" OR "informal business" OR "income-generating activit*" OR livelihood* OR employ* OR "work-family conflict" OR "employment adaptation") AND TX (coping OR income OR debt OR "financial strain" OR "economic burden" OR resilience OR empowerment OR agency OR wellbeing OR "quality of life" OR "social support")	English; published literature; 1 March 2016–1 March 2026	84
Scopus	TITLE-ABS-KEY (("autism spectrum disorder" OR autism OR autistic OR ASD) AND (parent* OR caregiver* OR carer* OR famil* OR household* OR mother* OR father*) AND (entrepreneur* OR self-employ* OR enterprise* OR "household enterprise" OR "family business" OR "home-based business" OR microenterprise OR "small business" OR "informal business" OR "income-generating activit*" OR livelihood* OR employ* OR "work-family conflict" OR "employment adaptation") AND (coping OR income OR debt OR "financial strain" OR "economic burden" OR resilience OR empowerment OR agency OR wellbeing OR "quality of life" OR "social support")) AND PUBYEAR > 2015 AND PUBYEAR < 2027 AND (LIMIT-TO (LANGUAGE, "English"))	English; 1 March 2016–1 March 2026	41
ScienceDirect	("autism spectrum disorder" OR autism OR autistic OR ASD) AND (parent OR caregiver OR family OR household OR mother OR father) AND (entrepreneurship OR "self-employment" OR enterprise OR "household enterprise" OR "family business" OR "home-based business" OR microenterprise OR "small business" OR "informal business" OR "income-generating activity" OR livelihood OR employment OR "work-family conflict") AND (coping OR income OR debt OR "financial strain" OR "economic burden" OR resilience OR empowerment OR wellbeing OR "quality of life" OR "social support")	Title, abstract, and keywords where supported; English; 1 March 2016–1 March 2026	623
Google Scholar	Targeted supplementary searches: (1) "autism spectrum disorder" caregiver entrepreneurship; (2) autism parent "self-employment"; (3) "children with autism" "family business" caregiver; (4) autism caregiver "income-generating activities"; (5) autism caregiver "work-family conflict" employment; and (6) autism caregiver economic coping resilience	English; custom publication range 2016–2026; potentially relevant records exported for screening	172
Total			1,049

Note. ASD = autism spectrum disorder; DE = database descriptor; MeSH = Medical Subject Headings; TITLE-ABS-KEY = title, abstract, and keyword fields; TX = all-text search. Search syntax was adapted to the functionality of each platform. The search strings should be reproduced exactly from the final saved database histories in the archived review record before submission of the supplementary file.

Supplementary Table S2. Full-Text Reports Excluded and Reasons

Reason for exclusion	Operational definition	Reports excluded, n	Percentage of full-text exclusions, %
Wrong patient or caregiver population	Study did not examine parents, caregivers, families, or households relevant to children or adolescents with ASD, or did not provide transferable caregiver evidence	50	61.7
Wrong outcomes	Study did not report entrepreneurship, employment adaptation, economic coping, livelihood, caregiver empowerment, resilience, wellbeing, service-related, or other outcomes relevant to the review questions	17	21.0
Review study	Systematic, scoping, narrative, or other review without eligible primary empirical evidence	6	7.4
Publication outside the predefined time period	Publication fell outside 1 March 2016–1 March 2026	3	3.7
Wrong setting	Study context was outside the family/caregiver setting or did not provide relevant evidence concerning caregiver livelihood or economic adaptation	3	3.7
Wrong intervention or exposure	Study did not examine an eligible entrepreneurial, employment, economic, coping, empowerment, or livelihood-related exposure	1	1.2
Conceptual or narrative discussion paper	Non-empirical conceptual or narrative publication without extractable primary findings	1	1.2

Reason for exclusion	Operational definition	Reports excluded, n	Percentage of full-text exclusions, %
Total full-text reports excluded after assessment		81	100.0

Reports not retrieved: *n* = 3.

PRISMA-consistent flow: 98 reports were sought for retrieval; 3 were not retrieved; 95 reports were assessed for eligibility; 81 were excluded after full-text assessment; and 14 studies were included in the review.

Note. The Covidence output originally classified three records as “full text not found” within the full-text exclusion categories. For PRISMA 2020 reporting, these records are more appropriately presented as “reports not retrieved,” thereby preserving a logically consistent study-selection pathway.

FULL PAPER · S6.7 · ONLINE SESSION 6

Image-Based Hive Monitoring for Sustainable Beekeeping

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ABSTRACT

Most honey bee colonies are still checked by opening the hive at intervals, so little is known about mite levels, brood or food stores between visits. This study examines how far cameras and computer vision can fill this gap. It builds on a survey of 59 vision-based beehive monitoring studies and adds primary studies, three hive camera studies from 2025–2026 and five studies from neighbouring fields. The studies cover four tasks: Varroa monitoring, bee traffic, comb and bee inspection, and pollen detection. Cameras are placed at the entrance, on the comb or at the bottom board. Reported scores are often high, for example a 98.7% comb cell detection rate, but they measure different targets on different datasets and mostly come from controlled imaging, observation hives or short tests. Tracking at the entrance degrades sharply when bees crowd. Tests against practical outcomes are rare and mixed: daily pollen counts from an entrance camera closely followed pollen trap weights, with $R^2 = 0.919$, whereas image-derived honey area was only weakly related to honey properties. Multi-season trials in ordinary apiaries, open datasets and tests against colony outcomes are needed before such systems can support beekeeping in practice, including in Türkiye, which keeps about 9 million hives.

Keywords: honey bee; computer vision; deep learning; Varroa destructor; smart agriculture; sensor systems; sustainable beekeeping

1. Introduction

Most honey bee (*Apis mellifera*) colonies are still checked by hand. The beekeeper opens the hive, lifts the frames and looks for brood, food stores and signs of disease. These visits take labour, disturb the colony and happen only at intervals, so the colony goes largely unobserved between them. Aizen et al. (2009) estimated that, without animal pollinators, total agricultural production would fall by about 3–8%. A problem missed in the hive can therefore matter well beyond the apiary.

The threats these checks are meant to catch are mainly the parasitic mite *Varroa destructor*, viral diseases and colony collapse (Bilik et al., 2024). Bilik et al. (2024) note that automated monitoring could support better-planned treatment and continuous inspection of colony health.

Continuous monitoring can use sensors, such as scales, microphones, temperature, humidity and CO_2 sensors, or cameras. Bilik et al. (2024) relate the growth of camera-based work to easily accessible hardware, such as the Arduino and Raspberry Pi families, and to mobile computing units, such as the NVIDIA Jetson, that can run classification models next to the hive. Cameras can see what most sensors cannot: individual bees, pollen loads, mites and the contents of comb cells.

The topic is relevant for Türkiye. According to TÜİK data compiled by TEPGE, Türkiye kept 8.96 million hives in 2024, with 97,984 beekeeping enterprises and 95,492 tonnes of honey produced (Burucu, 2025). In 2023, the country had 9.23 million of the 102.06 million hives recorded worldwide, about 9% of the total (calculated from Burucu, 2025). Organic beekeeping, which avoids conventional feeding and chemical pesticides, is also developing in the country (Merdan, 2025). Early and targeted information on colony health may be especially useful in such systems.

This review asks three questions. What can image-based systems currently do in beehive monitoring? What limits their use in ordinary apiaries? Which research needs follow from these limits? The review is organised by task and by camera position, focuses on field readiness, and includes recent methods from other insect and livestock monitoring studies that could transfer to honey bees.

2. Conceptual Framework

2.1. Tasks and Method Families

Bilik et al. (2024) group vision-based beehive monitoring into four tasks: Varroa monitoring, bee traffic monitoring, general inspection of bees and combs, and pollen detection. They also distinguish three method families: classical image processing with conventional machine learning, CNN classifiers, and object detectors such as YOLO or SSD. Table 1, based on Table 3 of Bilik et al. (2024), shows how the studies are distributed. One study appears there under two method families, so the counts add up to 58 rather than 59.

Table 1. Studies in the survey by task and method family

Task	Classical	CNN classifier	Object detector	Total
Varroa monitoring	8	6	5	19
Bee traffic	6	3	8	17
General inspection	5	9	2	16
Pollen detection	3	2	1	6
Total	**22**	**20**	**16**	**58**

Varroa monitoring and bee traffic are the most studied tasks, with 19 and 17 entries, while pollen detection has only 6. Object detectors are used most often for bee traffic, in 8 of their 16 entries, where bees must be both located and counted. The field is young: only five of the studies in the survey were published in or before 2013 (Bilik et al., 2024).

2.2. Camera Positions

Where the camera is placed largely determines what it can observe. Table 2 lists the three positions that recur in the literature. Because each position sees a different part of the colony, results from different positions describe different things and cannot be compared directly.

Table 2. Camera positions in image-based hive monitoring

Position	What is observed	Main constraints	Examples
Hive entrance	Bee traffic, pollen loads, mites on adult bees; the hive stays closed	Crowding; only adult bees leaving or entering are seen	Bjerge et al. (2019); Mrozek et al. (2021); Ngo et al. (2021); Benahmed et al. (2022); Sledevič et al. (2025); Su et al. (2026)
Inside the hive or on removed frames	Comb cells, brood, bees on the frame	Very little space between frames; focus, lighting, possible brood cooling	Micheli et al. (2022); Voudiotis et al. (2022); Bozek et al. (2021); Alves et al. (2020); Khokthong et al. (2025)
Bottom board	Mites that fall onto a tray as hive debris	Needs a tray and regular photographs	Picek et al. (2022)

3. Method

This is a narrative review, not a systematic review. No systematic database search or screening protocol was applied, and the review does not claim to be complete. The survey by Bilik et al. (2024), which covers 59 vision-based beehive monitoring studies from about the last ten years, was used as the backbone. Its classification of tasks and method families, and its summary table of studies, were used to describe the structure of the field.

Study details and figures in Section 4 are taken from the original publications. Because the survey covers work up to 2023, three hive camera studies from 2025–2026 were added: Khokthong et al. (2025), Sledevič et al. (2025) and Su et al. (2026). Five studies from neighbouring fields, published in 2024–2026, were added because they describe methods that could transfer to beekeeping (Lamping et al., 2025; Majewski et al., 2024; Rajbongshi et al., 2026; Shirali et al., 2026; von Allmen et al., 2026). National statistics come from TEPGE (Burucu, 2025) and Merdan (2025).

The studies use different datasets, camera positions and metrics, from accuracy and F1 score to tracking scores. Their results are therefore reported side by side but are not ranked.

4. Findings

4.1. Varroa Monitoring

Varroa monitoring is the most studied task. At the hive entrance, Bjerge et al. (2019) shook bees from a frame in front of the hive and filmed them as they walked back in single file through a narrow passage under multispectral light. Bees and mites separated best in the near-infrared above 700 nm. On a 32-minute video, the system estimated an infestation level of 5.80%, close to the 5.52% counted by an expert from the same video. Mrozek et al. (2021) built a low-cost entrance system on a Raspberry Pi 4 with a Coral TPU accelerator. A two-stage model first detected bees and then mites, with an F1 score of about 0.8 for both.

Inside the hive, Micheli et al. (2022) presented a camera prototype built into a hive frame, with internal lighting and a liquid lens for very close focus. It is meant to detect mites on the youngest bees near fresh brood, but reliable autofocus remained a challenge. Voudiotis et al. (2022) placed two cameras on a frame, powered by an external battery and a solar cell, and reported 88% accuracy for bee detection and 77% for mite detection, or 68% for the whole detection chain. On the bottom board, Picek et al. (2022) analysed smartphone photos of hive debris with a small CNN and reported a mean infestation level accuracy of 96.0% in autumn and 93.8% in winter. This approach needs little special equipment.

More recently, Su et al. (2026) fitted conventional hives in a commercial apiary with an imaging chamber at the entrance and trained a YOLOv5s model on 1,600 annotated images, reaching a mean average precision of 97.4%. The model was tested on 40 images and a short video, and its detections were not compared with the colonies' infestation rates.

These scores are not comparable. Only Bjerge et al. (2019) and Picek et al. (2022) score the infestation level itself; Mrozek et al. (2021) and Su et al. (2026) score mite detection in single images, and a high detection score does not yet show how well a system estimates a colony's infestation rate.

A basic limit applies to all visual methods: most mites sit on the brood or are hidden between the abdominal segments of adult bees, where they are poorly visible (Bilik et al., 2024). Bjerge et al. (2019) illustrate the gap: an alcohol-washed sample taken a week before their video gave 10.3%, almost twice the level visible on camera, although the authors note that the two samples were not the same bees. Non-visual alternatives exist as well; gas sensor arrays have been tested for detecting Varroa, with a reported detection error of 17% (Bilik et al., 2024).

4.2. Pollen and Bee Traffic at the Entrance

Ngo et al. (2021) built a real-time system on an NVIDIA Jetson board, with a Raspberry Pi 3 module for environmental sensing. A YOLOv3-tiny detector and a Kalman filter tracked bees, separated bees with and without pollen with an F1 score of 0.94, and determined whether each bee was entering or leaving, at 25 frames

per second. The system ran on five hives in Taiwan from August to December 2019, and its daily pollen trip counts closely followed the pollen collected with traps on three other hives, with $R^2 = 0.919$.

Benahmed et al. (2022) combined a YOLOv5 detector with the StrongSORT tracker on two entrance videos taken from online sources. Detection precision was 0.98, but the tracking score fell from 0.8 to 0.2 within 100 frames as bees gathered at the entrance, because the detector could not separate single bees from clusters. Crowding at the entrance therefore remains the main problem for bee counting. Kulyukin and Kulyukin (2023) compared three YOLO models for bee traffic monitoring, testing them on 3,600 images from 120 videos recorded in different apiaries, years and queen races, and found that they differ in energy use during training and detection. They recommend reporting energy consumption alongside accuracy.

Sledevič et al. (2025) filmed the landing boards of eight hives in one apiary near Vilnius. YOLOv8 detection precision ranged from 92% to 98% depending on model size, and foraging was recognised with a frame-level recall of 91%. As in Benahmed et al. (2022), detection worked well; the weak points were tracking and the separation of similar behaviours, such as fanning and resting.

4.3. Inspection Inside the Hive

Inside the hive, cameras can reach high accuracy, but usually with a demanding setup. Alves et al. (2020) photographed frames outside the hive and detected comb cells with a Circle Hough Transform, reaching a cell detection rate of 98.7%. They then compared CNNs for sorting cells into seven classes: egg, larva, pupa, pollen, nectar, honey and other. MobileNet was the best compromise, with an F1 score of 94.3% and about 9 s to process all cells in a comb image. To obtain standard images, the authors built a light-sealed tunnel 247 cm long when fully opened.

Bozek et al. (2021) tracked an entire colony without marking any bee, using high-resolution video of a natural comb in glass observation hives. They reported a true positive rate above 90% for bee detection, recovered about 79% of bee trajectories over 5-minute recordings, and followed colonies for months. However, processing one 5-minute recording took about 1 h on a machine with four GPUs, and the imaging did not resolve eggs or pollen.

Defèr (2022) used high-resolution images from an observation hive setup to locate open brood cells and estimate brood age. The cell localizer reached an F1 score of 0.96, with precision and recall both at 0.96. Brood age was estimated with a mean absolute error of 0.66 days, but the classifier performed poorly on eggs and young larvae, mainly because they were hard to see. The author concludes that cameras focused on the inside of the cells and better lighting of the cells would help. Other general inspection studies classified the health status of bees with CNNs, with a best accuracy of 92.42% (Üzen et al., 2019), or recognised conditions such as Varroa, pollen loads and hive robbing in 19,393 images with an accuracy of up to 99.07% (Kaplan Berkaya et al., 2021). Both studies come from groups in Türkiye.

Khokthong et al. (2025) photographed frames from 12 colonies in three apiaries in Thailand, using a portable studio box with a flash, and segmented capped and uncapped honey with YOLOv11s-seg, with a mean average precision of 0.805 for capped and 0.834 for uncapped cells. When they related the image-derived honey area to honey properties, the associations were weak: R^2 was 0.19 for electrical conductivity and 0.21 for colour.

Across these studies, accuracy is highest where imaging is most controlled, and each setup requires frames to be removed or a special hive to be used. Table 3 summarises the studies discussed in this section.

Table 3. Summary of the studies discussed

Study	Task	Setup	Reported result
Bjerge et al. (2019)	Varroa	Passage in front of the hive, multispectral light	Infestation level 5.80% against 5.52%; F1 0.97 for bees, 0.91 for mites
Mrozek et al. (2021)	Varroa	Raspberry Pi 4 and Coral TPU at the entrance	F1 ≈ 0.8 for bees and mites
Voudiotis et al. (2022)	Varroa	Two cameras on a frame; battery and solar cell	88% for bees, 77% for mites, 68% overall
Picek et al. (2022)	Varroa	Smartphone photos of hive debris	96.0% in autumn, 93.8% in winter
Ngo et al. (2021)	Pollen, traffic	Jetson; YOLOv3-tiny and Kalman filter	F1 0.94; R^2 = 0.919 against pollen traps
Benahmed et al. (2022)	Traffic	YOLOv5 and StrongSORT on entrance video	Precision 0.98; tracking score 0.8 → 0.2 in heavy traffic
Alves et al. (2020)	Comb cells	Hough transform and CNNs; 247 cm closed tunnel	98.7% cells detected; F1 94.3% over 7 classes
Bozek et al. (2021)	Whole colony	CNN tracking in glass observation hives	True positive rate > 90%; ~79% of trajectories
Defèr (2022)	Brood	Observation hive images; cell localizer and age classifier	Localizer F1 0.96; brood age error 0.66 days
Su et al. (2026)	Varroa	Entrance imaging chamber; YOLOv5s	Mean average precision 97.4% on 40 test images
Sledevič et al. (2025)	Traffic, behaviour	Landing boards of 8 hives, one apiary; YOLOv8	Precision 92–98%; foraging recall 91%
Khokthong et al. (2025)	Honey stores	Frames in a studio box; 12 colonies; YOLOv11s-seg	Mean average precision 0.81–0.83; $R^2 \leq 0.21$ with honey properties

4.4. Technical and Practical Limits for Field Use

The studies above point to six recurring limits.

- *Lighting.* Many strong results depend on controlled light, such as the closed tunnel used by Alves et al. (2020) or the artificial lighting built into in-hive devices.
- *Focus and distance.* The space between frames is very small. Reliable autofocus remained a challenge for an in-frame device (Micheli et al., 2022), and Bilik et al. (2024) note that cameras placed further from the comb than the bee space, as in Voudiotis et al. (2022), might lead to brood cooling. Defèr (2022) also found that eggs and young larvae were hard to see without focus on the cell interior.
- *Bee density.* Tracking performance dropped sharply in heavy entrance traffic (Benahmed et al., 2022).
- *Power and network.* Some solutions need mains power and a Wi-Fi connection near the hive (Bilik et al., 2024), which many rural apiaries lack. Battery and solar power have been tested (Voudiotis et al., 2022), and Su et al. (2026) put the capital cost of their system at about NT$4,000 per hive.
- *Compute and energy.* Detection and tracking took 66–153 ms per frame on a desktop GPU, depending on the model (Benahmed et al., 2022), and the brood cell localizer of Defèr (2022) would need about 160 ms per image to keep up with a 6 Hz camera. Detection models differ in energy footprint (Kulyukin & Kulyukin, 2023), and high-resolution colony tracking is computationally expensive (Bozek et al., 2021).
- *Data.* Most methods depend heavily on their datasets, and successful learning on one dataset does not ensure good results on another (Bilik et al., 2024). Some datasets have not remained publicly available. Recent datasets are still small; Khokthong et al. (2025) analysed 300 images.

None of these limits rules out field use, but each has to be addressed in real apiaries rather than in controlled scenes.

We found almost no figures on durability in the reviewed studies, such as how long a battery keeps a camera running or how often lenses must be cleaned of propolis, wax or condensation. Field studies should report maintenance intervals and downtime alongside accuracy.

4.5. Cameras and Other Sensors

Bilik et al. (2024) observe that the market for hive monitoring is still dominated by sensor systems, which usually rely on hive scales, acoustic measurements or other sensors, such as temperature and humidity sensors. These sensors describe the state of the whole hive over time with little intrusion, but they cannot observe individual bees. Cameras can, but they have a shorter field record. The two approaches are therefore complementary, and the survey describes a trend toward combining them for earlier warnings and long-term records of each colony.

4.6. Methods Transferable from Other Fields

The 2025–2026 hive camera studies above say little about uncertainty, size estimation or interpretability. Several recent studies in neighbouring fields, however, address exactly the limits described above. None of them was tested on honey bees, so they are presented as candidate methods rather than as evidence for beekeeping.

- *Size and biomass from images.* Shirali et al. (2026) presented InsectMorphoAI, an open-source framework that estimated insect body length with a mean absolute error of 0.211 mm, about 2.3% of mean specimen length, in bristle flies. Volumes derived from segmentation explained more of the variation in biomass than length alone, with R^2 values of 0.823–0.880 against 0.610–0.627. Von Allmen et al. (2026) estimated the live mass of caterpillars of five lepidopteran species from silhouette area with an open-source ImageJ macro, with about 98% detection accuracy, about six times faster than manual weighing. Similar measurements could help quantify brood development or bee body size without handling.
- *Uncertainty and unfamiliar scenes.* Majewski et al. (2024) monitored mealworm (*Tenebrio molitor*) rearing with a modified YOLOv8 model with task-specific heads trained on small, problem-oriented datasets. A model ensemble estimated prediction uncertainty, and the system detected domain shift, that is, images unlike the training data. Lamping et al. (2025) aggregated predictions over image sequences according to their uncertainty and improved accuracy by up to 7.15% over image-level models in assessing the plumage condition of chickens in uncontrolled farm settings. Comparable approaches could flag unusual apiary scenes or combine many frames of entrance video.
- *Explainable outputs.* Rajbongshi et al. (2026) review explainable AI in agriculture, including methods such as LIME, SHAP and Grad-CAM, which show which inputs or image regions drove a model's decision. In beekeeping, such outputs could let a beekeeper check, for example, which part of an image was taken as a mite.

5. Discussion and Conclusion

5.1. Discussion

The reviewed studies show that cameras can detect mites, pollen loads, bee traffic and comb contents with high reported accuracy. However, most results come from short trials, observation hives or controlled imaging, and the benefits for labour, treatment timing and colony health are mostly described as potential rather than measured. In our view, the evidence supports one practical claim: image-based monitoring can help decide when and where to inspect, but it cannot yet replace inspection.

Table 4 lists the research needs that follow from this review. We would give priority to the first and last rows, because the other improvements cannot be judged without field data and outcome tests.

Table 4. Research needs and possible approaches

Need	Evidence from this review	Approach
Multi-season field trials	Most results come from controlled imaging or a single apiary	Run the same system in several apiaries for at least a full season; report downtime and maintenance
Low-power hardware	Mains power and Wi-Fi are often assumed; models differ in energy use (Kulyukin & Kulyukin, 2023)	Report energy use and battery or solar runtime alongside accuracy
Open data and shared metrics	Datasets are small or no longer public; metrics differ between studies	Release images and labels; for Varroa, report the error in infestation rate
Uncertainty checks	Models trained on one dataset may fail on another (Bilik et al., 2024)	Flag low-confidence or unfamiliar images (Lamping et al., 2025; Majewski et al., 2024)
Explainable outputs	Beekeepers need to check an alert before acting on it	Show the image region behind each detection (Rajbongshi et al., 2026)
Links to colony outcomes	Outcome tests are rare: pollen counts matched trap weights (Ngo et al., 2021), but honey area did not match honey properties (Khokthong et al., 2025)	Compare image data with infestation counts, losses, treatment decisions and yield

These needs are relevant for Türkiye. The survey includes CNN studies from Turkish groups (Kaplan Berkaya et al., 2021; Üzen et al., 2019), but no long-term field trials in Turkish apiaries were found among the studies reviewed here. It is not yet known how models trained elsewhere perform with local bee races, hive types and apiary conditions. With about 9 million hives (Burucu, 2025) and a developing organic sector (Merdan, 2025), even small gains per hive could add up, which makes local field validation worthwhile.

This review has limitations. It is narrative rather than systematic, the counts in Table 1 come from one survey, and the accuracy values come from different datasets and metrics. The transferable methods in Section 4.6 were selected for their relevance and have not been tested on bees.

5.2. Conclusion

Image-based hive monitoring can detect mites, pollen, traffic, and comb contents with high reported accuracy, but mostly under controlled imaging or in short tests at a single site. In our view, the bottleneck has shifted from detection to validation. The next useful studies are multi-season trials in ordinary apiaries that test image measures against infestation rates, losses, and yield, as Ngo et al. (2021) did for pollen. For Türkiye, with about 9 million hives and little local field data, such trials should come before large-scale adoption. Furthermore, imaging systems should be integrated into sustainable beekeeping practices by diversifying the software solutions used alongside them.

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FULL PAPER · S7.3 · ONLINE SESSION 7

The Impact of Artificial Intelligence on Ecological Footprint: A Spatial Analysis

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ABSTRACT

Artificial intelligence (AI) has become a key driver of technological transformation under Sustainable Developmet Goal – 9 (SDG – 9) emphasizing inclusive and sustainable industrialization, innovation, and resilient infrastructure. But its rapi development may also create environmental pressures through energy consumption, water consumption, and dependence on critical minerals. At the same time, AI-enables technologies can improve resource efficiency, optimize industrial production processes, reduce waste, and strengthen environmental monitoring. These contreversery effects make the oberall environmental impact of AI ambiguous. Hence a further empirical investigation seems critical for future planning and policy formation. In this context, this study examines the direct, indirect, and total effects of artificial intelligence, fossil energy consumption, and renewable energy consumption on the ecological footprint, as well as the validity of the Environmental Kuznets Curve (EKC) hypothesis, for 22 European Union (EU) countries over the period 1995–2020. In this manner, the study adopts a spatial econometric framework that accounts for how neighboring countries' AI development, energy consumption patterns, and economic growth structures influence domestic environmental degradation. The results suggest that both a country's own AI development and renewable energy consumption, as well as those of neighboring countries, reduce the domestic ecological footprint, whereas fossil energy consumption exerts the opposite effect. Moreover, the ecological footprint exhibits significant spillover effects, indicating that an increase in neighboring countries' ecological footprints leads to a rise in the domestic country's ecological footprint. The findings also confirm the validity of the EKC hypothesis for the sample of EU countries. These results provide important policy implications regarding AI development and energy structure for EU policymakers.

Keywords: Artificial intelligence, ecological footprint, Environmental Kuznets Curve, spatial econometrics

Introduction

Environmental pollution gives rise to a wide range of adverse consequences, including rising global temperatures, prolonged droughts, biodiversity loss, poverty, food insecurity, and increased migration pressures (UN, 2025a). In response to these challenges, scholars in the field of economics have increasingly sought to identify the key drivers of environmental degradation in order to design effective mitigation strategies. Energy consumption stands out as a central determinant in this regard, particularly within the framework of Sustainable Development Goal (SDG) 7, which aims to expand universal access to modern energy services while maintaining affordability, reliability, and sustainability (UN, 2025b). Renewable energy consumption plays a pivotal role in advancing SDG–7 by providing energy services with low environmental impacts and supporting climate mitigation efforts. Conversely, continued reliance on energy systems dependent on fossil fuels undermines the objectives of SDG–7 and exacerbates environmental degradation and climate risks (Moomaw et al., 2011).

Another important determinant of environmental degradation is artificial intelligence (AI). Within the framework SDG–9, which emphasizes inclusive and sustainable industrialization, innovation, and resilient infrastructure, AI plays a central role in driving technological progress and digital transformation. On the one hand, concerns have been raised about the environmental footprint stemming from the accelerated development of AI-based infrastructure. The development and functioning of AI systems entail considerable

water consumption, increasing pressure on already scarce water resources. Furthermore, AI technologies rely heavily on critical minerals and rare earth elements, which are often extracted through environmentally unsustainable mining practices. The high electricity demand of AI applications also contributes to increased emissions, thereby challenging the environmental sustainability dimension of SDG–9 (UNEP, 2025). On the other hand, a growing strand of the literature highlights that AI-enabled innovations can enhance the achievement of SDG–9 by improving resource efficiency, optimizing industrial processes, and enabling advanced monitoring and analysis of environmental impacts at unprecedented speed and scale (Slimani et al., 2025). These opposing channels suggest that the environmental consequences of AI within the SDG–9 framework are theoretically ambiguous, underscoring the need for empirical assessment.

Another key determinant of environmental degradation is economic growth. Within the framework of SDG-8, which focuses on fostering sustained and inclusive economic growth, economic expansion is considered crucial for enhancing living standards and creating employment opportunities. However, the nexus between economic expansion and environmental conditions is theoretically ambiguous and is commonly examined through the lens of the Environmental Kuznets Curve (EKC) hypothesis. The EKC suggests that environmental harm initially increases with economic expansion due to intensified industrial production and energy consumption, but after a certain income level, further growth may lead to environmental improvements as economies implement cleaner technologies, strengthen environmental policies, and shift toward less polluting sectors (Grossman & Krueger, 1991). While some empirical studies provide evidence in support of the EKC hypothesis (e.g. Dogan & Seker, 2016; Vagnini et al., 2025; Wu et al., 2025), other studies fail to confirm its validity and report either a monotonically increasing relationship or no systematic association between growth and environmental conditions (e.g. Dogan et al., 2020; Yilanci & Pata, 2020). Thus, the consequences of economic development for environmental conditions are still an open question for empirical study.

In light of these considerations, the study assesses the role of AI and both fossil-based and renewable energy consumption on the ecological footprint, while also empirically examining the EKC hypothesis using spatial econometrics. Although some studies have examined the linkages among some of these variables, they mainly rely on traditional econometric techniques and therefore overlook spatial dependence (e.g. Wang et al., 2025; Zambrano-Monserrate et al., 2025). In this study, the European Union (EU) is selected as the sample country group. In 2021, the European Commission introduced the EU's first comprehensive AI legislation, with the European Parliament prioritizing the design and implementation of AI systems that are safe, traceable, transparent, and environmentally sustainable (European Parliament, 2023). This initiative marked a significant milestone in the EU's AI strategy but was not the only step taken in this direction. Subsequently, the AI Continent Action Plan was introduced, reflecting the EU's ambition to become a global leader in AI while maintaining strong environmental safeguards and supporting European industrial sectors, particularly those related to climate action, as well as sectors such as agrifood, pharmaceuticals, and biotechnology (European Commission, 2025). Beyond AI policy, the EU has set a target to be the first climate-neutral continent globally by 2050, emphasizing the enhancement of energy efficiency, supporting innovation, and promoting the development of climate-friendly technologies. To achieve these objectives, the EU has implemented several policy instruments, including the Innovation Fund and the Modernisation Fund. In addition, the LULUCF Regulation obliges each EU member state to compensate for emissions arising from land-use-related activities, thereby contributing to the goals of the Paris Agreement (European Council, 2025). Overall, both AI development and the mitigation of environmental degradation constitute core priorities for EU member states. Therefore, analyzing the impact of AI on environmental degradation within the EU is of critical importance. Moreover, understanding the role of neighboring countries' AI development is particularly relevant, as the EU functions as an integrated economic and policy bloc in which national policies and technological advancements are closely interconnected.

By considering these points, the study focuses on addressing the following research questions: Does the ecological footprint exhibit spillover effects among EU member states? What are the direct and indirect impacts of AI and energy consumption (both fossil and renewable) on the ecological footprint? Is the EKC hypothesis valid? Is it sufficient to implement AI and energy policies independently, or is coordinated cooperation required? Building on these research questions, the paper is organized as follows. Following the introduction, Section 2 reviews the relevant literature. Section 3 outlines the data and model, while Sections 4 and 5 present the methodology and empirical findings, respectively. Finally, Section 6 concludes with a discussion of the results and policy implications.

1. Literature Review

The environmental implications of AI have attracted growing attention in the literature. Although the studies about this subject are new in the environmental sustainability field, it has a compromising future due to its contemporary debate. Empirical studies have different results due to different sample sizes and investigation methods. However, panel regression models have attracted considerable attention due to the benefits offered by panel data compared to both cross-sectional and time-series data. In this study, the most recent and cited studies are summarized to be able to show the fundamental findings of the literature and the direction of the recent empirical studies. In this context, as a recent study, Wang et al. (2025) employed panel data analyses for 67 countries from 1995 to 2019. They analyzed the impact of AI on carbon inequality. Empirical findings suggest that AI increases carbon inequality in this data set due to the energy requirements of AI. However, it is also underlined that adverse effects can be reversed by enhancing trade, strengthening global value chain integration and providing strong governance. Zambrano-Monserrate et al. (2025) applied quantile analysis for 64 developed and developing countries. Results showed that AI adoption increases carbon emission, but the interaction of AI and energy supply reduces it. Kartal et al. (2025) applied KRLS method for China during 2000–2020 period. Empirical findings indicate that AI-related patents and energy transition have no significant impact on environmental sustainability while oil, gas and coal energy consumption negatively impact the dependent variable. Moreover, it is evident that renewable energy consumption seems unbeneficial to provide environmental sustainability in China.

Another country-specific study came from Wang et al. (2024a). They employed panel regressions to detect the impact of AI on ecological footprint in 30 Chinese provinces between 2018 and 2022. Empirical results underline that AI decreases regional ecological footprint by increasing energy utilization efficiency. However, China is not the only country which is taking special attention about the analysis of the relationship. Akhter et al. (2024) analyzed the relationship between private investments in AI and environmental sustainability in the USA between 1990–2019. ARDL results underlined that private investments in AI have a positive correlation with load capacity factor and hence support environmental sustainability. However, Abir et al. (2024) applied panel methods to detect the impact of AI on load capacity factor in the USA between 1990 and 2019. Empirical results proved that AI innovation and institutional quality increase environmental sustainability.

AI innovations seem as a widely accepted proxy to detect the impact of AI. Bala et al. (2024) investigated the relationship between AI innovations and environmental sustainability in G7 countries. Their results showed that AI innovation increases environmental sustainability while globalization and urbanization decrease it. Moreover, Abdulla Al Shiam et al. (2024a) explored the impact of AI innovation on the load capacity factor in BRICS countries during 2000–2019. The results underlined that AI innovation improves environmental sustainability due to its positive relationship with load capacity factor. Abdulla Al Shiam et al. (2024b) investigated the impact of AI innovations on ecological footprint on the Nordic region between 1990–2020. The results pointed out that AI decreases the ecological footprint while economic growth, stock market capitalization and urbanization increase it.

With another proxy for AI, Liu et al. (2024) analyzed the impact of industrial robots on ecological footprint in 10 leading countries between 2007 and 2020. They reported that industrial robots significantly decrease ecological footprint. Another proxy for AI is AI development level. Wang et al. (2024) employed panel regressions to detect the impact of AI on ecological footprint in 30 Chinese provinces. Empirical results underline that AI decreases regional ecological footprint by increasing energy utilization efficiency. Shah et al. (2024) analyzed a panel data for East Asian and Pacific countries between 2000 and 2023. Their results underline that AI increases carbon emissions in this country group while renewable energy consumption decreases it. Rasheed et al. (2024) applied panel NARDL and asymmetric panel causality methodologies to detect the determinants of environmental sustainability in 7 developing Asian countries between 1990–2020. Their empirical results point out the positive impact of AI on environmental sustainability. Also, they underlined that renewable energy contributes to environmental sustainability by decreasing carbon footprint. Wang et al. (2023) investigated the impact of AI on global ecological footprint by a global national data set between 2010 and 2019. The results highlighted the reducing impact of AI on ecological footprint. Also, it underlined that marginal effect of AI on ecological footprint increases with the deepening of globalization. Chen et al. (2022) conducted a panel data analysis for 270 Chinese cities from 2011 to 2017. They used industrial robots as a proxy for AI. The results showed that AI usage decrease carbon emissions and this reduction effect is higher in large cities and in cities with advanced technological infrastructure.

As seen from the review of the recent literature, most of the empirical studies use standard panel regression analyses or some emerging methods like quantile regression, ARDL and NARDL. However, it seems that spatial regression methods are lacking, and hence spatial dimensions of the analyses are underestimated. There are only few studies taking the spatial impacts into account in estimation procedures. Among these studies, Yin et al. (2023) found significant spatial heterogeneity in the impact of AI on green technological innovation across Chinese provinces. Moreover, this study does not investigate directly the relationship between AI and environmental sustainability. Rather, it tries to infer this relationship from the relationship between AI development level and green technology innovations. Ding et al. (2023) investigated the impact of AI on carbon emissions in 30 Chinese provinces during 2006–2019. Spatial Durbin model results underline that AI development decreases carbon emissions and spillover effects are in turn. Zhou et al. (2024) employed spatial econometric methods to examine 30 Chinese provinces over the period 2012–2021 and concluded that AI exerts a significant negative spatial spillover effect on carbon emission efficiency. Yan & Sun (2025) utilized an SDM framework for 275 Chinese cities between 2007 and 2019, reporting that AI development significantly reduces urban carbon emission intensity, both directly and indirectly. However, these spatial studies focus exclusively on China rather than the EU, and none of them employ the ecological footprint as a comprehensive indicator of environmental degradation.

Despite the growing relevance of digital transformation and AI in economic and environmental processes, the literature remains largely silent on the explicit role of AI within the EKC framework, particularly from a spatial econometric perspective. To the best of our knowledge, no prior study has directly integrated AI into the EKC model to assess its impact on environmental degradation using spatial econometric techniques. This omission is particularly important given the dual character of AI within the income–environment nexus. While AI-driven digitalization may increase energy demand due to higher computational requirements and digital infrastructure expansion, it may simultaneously reduce environmental pressures through efficiency gains, technological upgrading, and intelligent resource management. Consequently, the overall environmental impact of AI may be theoretically ambiguous.

Regarding the energy consumption structure, there is a substantial body of literature examining the link between energy consumption and environmental quality using spatial econometric methodologies in the European context. For instance, Bucak et al. (2024) found that while fossil energy consumption increases the

ecological footprint in terms of direct, indirect, and total effects, renewable energy has the opposite impact across these three decomposed effects in 26 EU countries. Bucak & Çatık (2025) reported that the direct, indirect, and total effects of fossil energy on load capacity factor are negative, whereas the corresponding three effects of renewable energy are positive for 25 EU countries. Grodzicki & Jankiewicz (2022) stated that renewable energy reduces carbon emissions in 42 European countries using spatial econometric techniques. Similarly, Radmehr et al. (2021) found that nonrenewable energy consumption increases CO_2 emissions in 21 EU countries based on spatial econometric analysis. However, none of these studies considers the role of AI in environmental degradation.

Based on the above review, a clear gap emerges in the literature. To the best of our knowledge, no study has applied spatial econometric methodology to the EU context. Moreover, there is no study that simultaneously examines the role of AI alongside the structure of energy consumption and the validity of the EKC hypothesis. Therefore, this paper aims to fill this important gap by employing a spatial econometric framework to investigate the direct and spillover effects of AI and energy consumption structure on environmental quality in the EU.

2. Data Set and Methodology

2.1. Description of Data

Focusing on 22 EU countries, the study evaluates the spillover impacts of ecological footprint as well as indirect and direct effects of AI, GDP per capita, and energy consumption (fossil and renewable) over the 1995–2020 period. The EU countries are selected as the sample due to the EU's strategic objective of becoming the world's first climate-neutral region, while simultaneously combining environmental leadership with advancements in AI (European Parliament, 2023; European Commission, 2025). Accordingly, this study analyzes these linkages to better understand and discuss the associated policy implications, explicitly considering the role of AI in environmental degradation within a spatial framework. Table 1 summarizes the variables and their data sources.

Table 1. Variables and Data Sources

Variables	Description	Data Source
EF	Ecological Footprint	York University (2025)
AI	Patents related to AI	OECD (2025)
GDPPC	GDP per capita (current US$)	World Bank (2025)
$GDPPC^2$	GDP per capita square	World Bank (2025)
FOS	Fossil energy consumption (per capita - kWh)	Our World Data (2025)
REN	Renewable energy consumption (per capita - kWh)	Our World Data (2025)

Source: Authors' own elaborations.

The estimated model in this study is as follows:

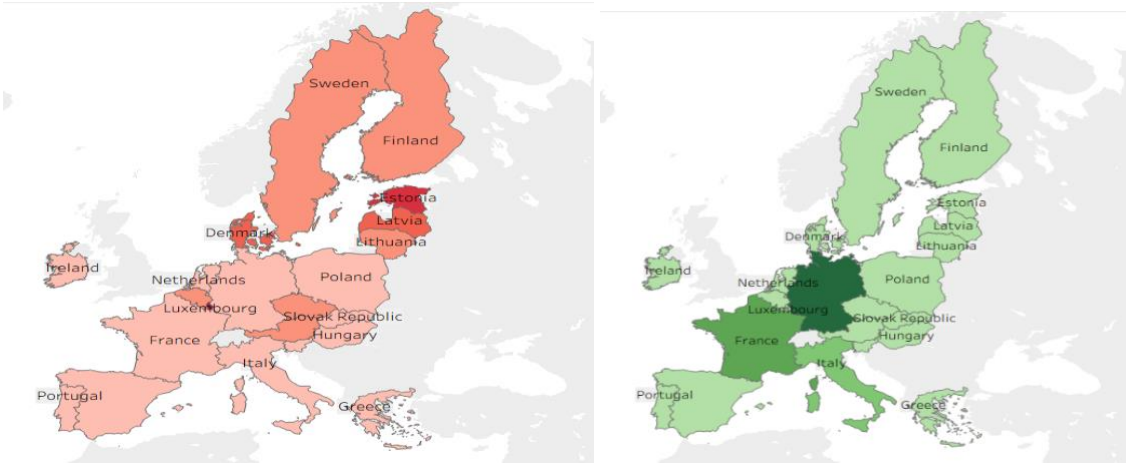
$$lnEF_{it} = \beta_0 + \beta_1 lnAI_{it} + \beta_2 lnGDPPC_{it} + \beta_3 ln(GDPPC)^2{}_{it} + \beta_4 lnFOS_{it} + \beta_5 lnREN_{it} + \varepsilon_{it} \quad (1)$$

In the model, *i* denotes the spatial unit, while *t* represents the time period. All the variables are used in natural logarithms to be able to evaluate impacts of percentage changes of independent variables.

Figure 1 illustrates the clustering of AI development and ecological footprint among EU countries in 2020, where darker shades indicate higher levels. The maps reveal substantial cross–country heterogeneity in both AI intensity and ecological footprint. Some countries, such as Luxembourg, exhibit very high ecological footprint levels while maintaining relatively low AI intensity. In contrast, countries including Germany and France demonstrate strong AI performance accompanied by comparatively lower ecological footprint levels. Estonia

and Latvia stand out with high ecological footprint values despite weak AI development. Overall, the maps suggest that countries with similar AI and EF characteristics tend to cluster spatially, and the visual patterns point to a potential negative association between AI development and ecological footprint. This spatial clustering indicates that spatial econometric techniques may be useful to investigate whether spillover effects and neighboring interdependencies exist among countries.

Figure 1. EF and AI maps of EU countries in 2020 (left and right, respectively).



Source: Authors' own elaborations.

2.2. Methodology

According to Anselin (1988), neglecting spatial dependence may lead to biased and inconsistent empirical results. Accordingly, recent studies in the environmental economics literature have increasingly accounted for spillover effects arising from neighboring countries (Bucak et al., 2024). Therefore, spatial econometric techniques are still preferred to capture the indirect impacts of neighboring countries' independent variables on the dependent variables of the focal country. In this context, Moran's I index is performed for each year and the computation is carried out by the following formula (Anselin and Cho, 2002):

$$I = \frac{N}{S_0} \frac{e'We}{e'e} \quad (2)$$

In this equation, e denotes a vector of Ordinary Least Squares (OLS) residuals, W represents the weights matrix, and $S_0 = \sum_i \sum_j w_{ij}$. Moran's I index ranges from –1 to 1. It quantifies the level of overall spatial autocorrelation. Values above zero indicate positive spatial correlation among units, whereas values below zero imply a negative spatial relationship. If the index equals 0, it suggests a random spatial distribution.

There are three fundamental models in the spatial econometric estimation procedure as SEM (spatial error model), SAR (spatial autoregressive model), and SDM (spatial Durbin model). All these models employ a weight matrix W in order to incorporate information about spatial relationships between spatial units (Elhorst, 2014). This study calculates Euclidean distances and the computation is given in Eq. 3.

$$w_{ij} = \frac{1}{d_{ij}} \quad (3)$$

In this computation, d_{ij} represents the distance between spatial units *i* and *j*, with the assumption that closer units tend to have stronger interactions. As one of the fundamental models, SAR model with a fixed effect[1] is constructed as follows:

$$y_{it} = \alpha_i + \rho \sum_{j=1}^{N} w_{ij} y_{jt} + x_{it} \beta + \varepsilon_{it} \quad (4)$$

[1] According to Elhorst (2014), the fixed effects model is better suited for analyses involving non-random samples such as EU countries.

Here, y_{it} represents the dependent variable for country *i* at time *t*, while α_i captures the fixed effects specific to each country. The parameter ρ measures spatial autocorrelation, and w_{ij} corresponds to the element in the spatial weight matrix linking units i and j. The spatially lagged dependent variable is calculated as $\sum_{j=1}^{N} w_{ij} y_{jt}$, while ε_{it} represents the residual term in the model.

As another type of spatial models, SEM model is constructed as follows:

$$y_{it} = \alpha_i + x_{it}\beta + \varepsilon_{it}$$
$$\varepsilon_{it} = \lambda \sum_{j=1}^{N} w_{ij}\varepsilon_{it} + u_{it} \quad (5)$$

In this model, ε_{it} denotes the error term that exhibits spatial autocorrelation. The parameter λ measures how the residuals from surrounding spatial units impact the residuals of the focal unit. All other parameters are defined as in Eq. 4.

Lastly, SDM can be expressed as follows:

$$y_{it} = \alpha_i + \rho \sum_{j=1}^{N} w_{ij} y_{jt} + x_{it}\,\beta + \gamma \sum_{j=1}^{N} w_{ij} x_{jt} + \varepsilon_{it} \quad (6)$$

In this model, γ denotes a vector of spatial autocorrelation coefficients. The rest of the parameters in the model are consistent with the described parameters in SAR and SEM models. In this manner, if the SAR model is identified as the most appropriate model, the econometric model to be employed in the study takes the following form.

$$lnEF_{it} = \alpha_i + \rho \sum_{j=1}^{N} w_{ij} lnEF_{jt} + \beta_1 lnAI_{it} + \beta_2 lnGDPPC_{it} + \beta_3 (lnGDPPC_{it})^2 + \beta_4 lnFOS_{it} + \beta_5 lnREN_{it} + u_{it} \quad (7)$$

2.3. Empirical results

Assessing the spatial correlation of the EF in the EU region is vital before conducting spatial econometric methods. To achieve this, Table 2 summarizes Moran's I statistics which exhibit significant positive values from 1995–2020. This consistent positive spatial correlation underlines a strong interrelationship among EF levels within the EU region. Consequently, the use of spatial econometric techniques to account for spatial dependencies seems evident.

Table 2. Moran's I results

Variables	Moran's I	p-value
lnEF1995	0.385	0.000
lnEF1996	0.369	0.000
lnEF1997	0.368	0.000
lnEF1998	0.379	0.000
lnEF1999	0.382	0.000
lnEF2000	0.374	0.000
lnEF2001	0.361	0.000
lnEF2002	0.356	0.000
lnEF2003	0.341	0.000
lnEF2004	0.344	0.000
lnEF2005	0.370	0.000
lnEF2006	0.341	0.000
lnEF2007	0.355	0.000
lnEF2008	0.367	0.000
lnEF2009	0.363	0.000
lnEF2010	0.373	0.000
lnEF2011	0.368	0.000
lnEF2012	0.359	0.000
lnEF2013	0.369	0.000
lnEF2014	0.367	0.000

Variables	Moran's I	p-value
lnEF2015	0.362	0.000
lnEF2016	0.358	0.000
lnEF2017	0.343	0.000
lnEF2018	0.343	0.000
lnEF2019	0.348	0.000
lnEF2020	0.338	0.000

Source: Authors' own elaborations.

After detecting the spatial correlation, the next step involves testing for spatial dependence. This process starts with estimating the fixed effects OLS model. Table 3 gives the fixed effects OLS estimation results. AI is found to have a negative and statistically significant effect on EF. In contrast, GDPPC and $GDPPC^2$ exert positive and negative effects on EF, respectively. These results show that EKC hypothesis is valid. Additionally, FOS positively affects EF, while REN is found to have negative effects. These findings are consistent with Bucak et al. (2024) and Grodzicki & Jankiewicz (2022). The EKC result is also in line with the findings of Dogan and Seker (2016) and Bucak et al. (2024).

However, the fixed-effect OLS model does not examine the spatial dependence and hence the empirical results can be biased and inconsistent. In this manner, the LM test should be performed to detect the existence of spatial effects. Our LM Test results indicate the rejection of the null hypotheses of spatial independence, and hence, the robust LM test statistics favor the SAR model over the SEM model. The estimates obtained from the SAR model, utilizing spatial weight matrices computed based on Euclidean proximity, are in the same line with the results of the fixed-effects OLS model. Based on the SAR model results, a positive and significant spillover effect is observed among EU countries. The estimated value of the spatial autocorrelation coefficient (ρ=0.34) points out this result. This finding aligns with the studies of Bucak et al. (2024), Radmehr et al. (2021), and Bucak & Çatık (2025), further supporting the notion of interconnectedness and the presence of spatial spillover effects in environmental issues. Hence, this finding suggests that a rise in EF within neighboring countries positively impacts the EF of the focal country. Consequently, it can be said that a country's actions related to EF have significant implications for not only its own EF but also of its neighbors through spatial spillover mechanism.

What is more is that the SAR model results indicate that a 1% increase in AI and renewable energy consumption leads to a 0.03% reduction in EF. The negative impact of AI on EF is supported by Akhter et al. (2024), Bala et al. (2024), Liu et al. (2024), Abdulla Al Shiam et al. (2024a), Wang et al. (2024), Rasheed et al. (2024), Abdulla Al Shiam et al. (2024b), and Abir et al. (2024). However, a 1% increase in fossil energy consumption raises EF by 0.39%. This evidence suggests that AI and renewable energy use contribute to environmental improvement, whereas reliance on fossil energy exacerbates environmental pressure in the EU region. Moreover, the empirical results indicate that GDPPC exerts a positive impact on EF (1.43), while its squared form has a negative impact (−0.05) on EF, supporting the validity of the EKC hypothesis.

Table 3 also reports the estimated indirect, direct, and total impacts of the independent variables on EF. The results reveal that the focal country's AI and REN reduce its own EF, whereas FOS increases it. Specifically, a 1% increase in AI and REN of the local country decreases the local country's EF by 0.03%. Conversely, a 1% increase in FOS of the local country raises its EF by 0.40%. The EKC hypothesis remains valid at the country level, as GDP per capita exhibits a positive coefficient (1.46) while its squared term displays a negative coefficient (−0.05). Furthermore, neighboring countries' AI and REN have a negative effect on the focal country's EF, while neighboring countries' FOS has positive impacts. More precisely, a 1% increase in AI and REN of neighboring countries decreases the local country's EF by 0.01%. However, a 1% increase in neighboring countries' FOS raises the local country's EF by 0.20%. The total impacts exhibit the same coefficient signs across all variables.

While renewable energy consumption (−0.05) and AI development (−0.05) reduce environmental pollution, fossil energy use increases it (0.60), and the EKC hypothesis remains valid.

The negative indirect, direct, and total effects of renewable energy consumption, as well as the positive indirect, direct, and total effects of fossil energy consumption, are consistent with the findings of Bucak et al. (2024) and Bucak & Çatık (2025). However, the results differ when the role of AI is considered. Ding et al. (2023), employing the SDM, report that although the direct effect of AI on environmental degradation is negative, its indirect and total effects are positive, which contrasts with the findings of the present study.

Table 3. Fixed effects of OLS and Spatial estimation results with Euclidean distance

Variables	Fixed-Effects OLS	Fixed-Effects SAR	Direct Effect	Indirect Effect	Total Effect
AI	-0.03*** (-3.11)	-0.03*** (-3.58)	-0.03*** (-3.66)	-0.01** (-2.56)	-0.05** (-3.38)
GDPPC	1.34*** (4.93)	1.43*** (5.41)	1.46*** (5.43)	0.75*** (3.12)	2.21*** (4.77)
$GDPPC^2$	-0.04*** (-3.36)	-0.05*** (-3.96)	-0.05*** (-3.97)	-0.02** (-2.69)	-0.08** (-3.64)
FOS	0.46*** (16.67)	0.39*** (13.37)	0.40*** (13.64)	0.20*** (4.53)	0.60*** (11.61)
REN	-0.04*** (-7.78)	-0.03*** (-6.11)	-0.03*** (-6.32)	-0.01*** (-3.81)	-0.05*** (-6.08)
ρ		0.34*** (6.55)			
R^2	0.59	0.93			
Log-likelihood	654.00	673.27			
LMρ	50.89***				
LMλ	21.02***				
Robust LMρ	29.96***				
Robust LMλ	0.09				
# of obs.	572				

Notes: *, **, and * correspond to the 1%, 5%, and 10% levels, respectively. The t-statistic values are within the parentheses**

Robustness check is an important step to be sure about the spatial empirical results. In this manner, we re-estimated the model by using a different spatial weight matrix - specifically, a 5-nearest neighbor matrix constructed. Both LM and robust LM tests confirm the suitability of the SAR model since the spatial autocorrelation coefficient (ρ=0.29) is statistically significant at the 1% significance level. The results point out that the signs and significances of the parameter estimates for explanatory variables are not affected by the modification of the spatial weight matrix. This consistency demonstrates the reliability of the initial results and hence, it is evident that the choice of spatial weight matrix does not significantly influence the estimated relationships between the variables.

Table 4. Estimation results based on the target country's 5 nearest neighbors

Variables	Fixed-Effects SAR	Direct Effect	Indirect Effect	Total Effect
AI	-0.02** (-3.02)	-0.02*** (-3.15)	-0.01** (-2.73)	-0.04*** (-3.13)
GDPPC	1.09*** (4.10)	1.09*** (4.12)	0.43*** (3.35)	1.53*** (4.09)
$GDPPC^2$	-0.03* (-2.70)	-0.03** (-2.70)	-0.01** (-2.42)	-0.05** (-2.69)
FOS	0.40*** (14.37)	0.41*** (14.39)	0.16*** (5.35)	0.57*** (12.92)

Variables	Fixed-Effects SAR	Direct Effect	Indirect Effect	Total Effect
REN	-0.04*** (-6.95)	-0.04*** (-7.25)	-0.01*** (-4.46)	-0.05*** (-7.00)
ρ	0.29*** (7.09)			
R^2	0.93			
Log-likelihood	677.32			
LMρ	55.78***			
LMλ	26.47***			
Robust LMρ	29.31***			
Robust LMλ	0.003			
# of obs.	572			

Notes: *, **, and * correspond to the 1%, 5%, and 10% levels, respectively.The t-statistic values are within the parentheses.**

Conclusion and Discussion

This paper employs spatial econometric technique to capture spillover effects of the ecological footprint across the EU region and to examine the indirect and direct impacts of AI, fossil and renewable energy consumption over the period 1995–2020 for 22 EU member states. Additionally, the study investigates the validity of the EKC hypothesis. Both SAR estimation results, and decomposed direct, indirect, and total effects indicate that AI reduces the ecological footprint. Specifically, increases in AI levels within a country and in neighboring countries are associated with a decline in the local country's ecological footprint. Renewable energy consumption follows a similar pattern: its direct, indirect, and total effects all contribute to reducing the ecological footprint. As renewable energy usage rises both domestically and in neighboring countries, the local country's environmental quality improves. Conversely, fossil energy consumption has the opposite effect; its direct, indirect, and total impacts on the ecological footprint are positive. The EKC hypothesis is valid for the sample. These results lead to several important policy implications.

First, the negative direct and indirect effects of AI on the ecological footprint suggest that AI can serve as an effective tool for environmental improvement. The EU has introduced the AI Continent Action Plan with the objective of becoming a global leader in AI and promoting its integration into environmental, climate, and energy sectors (European Commission, 2025). In addition, the EU Artificial Intelligence Act aims to ensure that AI development and deployment are environmentally sustainable (European Parliament, 2025). Consistent with these regulatory initiatives, the results of this paper highlight the importance of AI in improving environmental quality, as AI can enhance energy production efficiency, optimize energy distribution, and reduce resource waste. Accordingly, EU policymakers should encourage the adoption and diffusion of AI-based technologies, including increased support for AI-related patenting activities in environmentally relevant sectors. Moreover, given that AI development in neighboring countries also contributes to reducing a country's ecological footprint, coordinated regional policies and targeted incentives for firms to invest in AI-related innovations are essential. These policies also will contribute to SDG-9 and SDG-13.

Second, the finding that renewable energy consumption reduces the ecological footprint both domestically and through spatial spillovers, while fossil energy consumption exerts the opposite effect, underscores the importance of regionally coordinated renewable energy policies. Strengthening and harmonizing renewable energy incentive schemes, together with supporting joint cross-border investment projects, can enhance the effectiveness of national renewable energy strategies. In this context, the EU's Projects of Common Interest framework can be further leveraged to reduce dependence on fossil fuels and accelerate the deployment of renewable energy sources. Moreover, there is a need to progressively phase out fossil fuels through measures such as carbon pricing and stricter emissions regulations. Regional coordination is essential to prevent carbon

leakage and to ensure the effectiveness of these policies. Such measures are consistent with SDG-7 and reinforce collective climate mitigation efforts under SDG-13.

Third, the validation of the EKC suggests that economic growth can eventually lead to environmental improvements once higher income levels are reached. However, shortening this transition period is crucial to prevent further environmental degradation. Integrating environmental objectives into growth-oriented policies can help decouple economic growth from environmental pressures at earlier stages of development, in line with SDG-8 and SDG-13. Accordingly, strengthening regulations and incentives that promote sustainable production, eco-innovation, and green investments may facilitate this transition.

Finally, the significant and positive spatial autoregressive coefficient confirms that ecological footprints are not confined by national borders but generate substantial spillover effects among EU member states. This finding underscores the importance of strengthening regional coordination, data sharing, and joint environmental monitoring mechanisms to improve policy effectiveness, in line with SDG-17. Moreover, policy frameworks should incorporate incentive mechanisms that reward firms and jurisdictions for protecting environmental quality and internalizing cross-border externalities, while enforcing penalties for activities that generate environmental harm beyond national boundaries. Well-designed sanctions, including substantial fines where appropriate, can help discourage environmentally harmful behavior and enhance compliance with regional environmental standards.

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FULL PAPER · S7.6 · ONLINE SESSION 7

Bambara Groundnut (Vigna subterranea (L.) Verdc.) as a Sustainable Plant Protein Source for Nutrition, Food Innovation and Market Opportunities in Türkiye — A Mini Review

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ABSTRACT

Growing interest in more sustainable food systems has heightened interest in plant-based proteins, climate-resilient crops, and underutilised legumes with potential for food innovation and green entrepreneurship. Bambara groundnut (*Vigna subterranea* (L.) Verdc.) is an African-origin grain legume studied for its nutritional value, drought tolerance, adaptability to relatively poor soils, and potential use in protein-rich food products. Its seeds provide protein, carbohydrates, dietary fibre and minerals, although protein digestibility and nutritional quality may be affected by antinutritional factors. Processing methods such as soaking, germination, fermentation, dehulling, and other bioprocessing techniques can reduce antinutritional compounds and modify functional properties relevant to food formulation. This mini-review examines Bambara groundnut as a plant-protein ingredient with potential sustainability benefits for innovative food products and explores its potential relevance for Türkiye and selected international markets. The review focuses on nutritional potential, processing and functionality, possible product applications, potential sustainability benefits, market opportunities, regulatory considerations, and commercialisation barriers. Türkiye is not presented as an already established Bambara groundnut market. Rather, it is discussed as a possible location for cultivation trials, processing and product development. Potential commercial pathways include processing African-sourced raw materials in Türkiye for domestic consumption or export to EU and Middle Eastern markets. Regulatory requirements are another consideration in assessing commercialisation prospects. These include the EU authorisation of *Vigna subterranea* seeds and seed flour as a traditional food from a third country, as well as Türkiye's 2026 New Foods Regulation. The EU authorisation may support the development of seed- and flour-based products, subject to its specified conditions of use. However, the authorisation should not be interpreted as automatic approval for all Bambara-derived ingredients, especially protein isolates, concentrates, hydrolysates, or highly processed products. The implications for product development depend on the ingredient form and the applicable safety, labelling and market-access requirements. The review concludes that Bambara groundnut has potential for food-product development and commercialisation. However, successful enterprise development will require agronomic validation, safe and standardised processing, sensory acceptance studies, supply-chain development, and compliance with applicable regulatory requirements.

Keywords: Bambara groundnut, plant protein, underutilised legumes, sustainable food systems, novel foods

Introduction

Global food systems are under increasing pressure from population growth, climate change, environmental degradation, and rising demand for protein-rich foods (Nirmal et al., 2025). These pressures affect both food availability and food prices. Many conventional protein systems depend heavily on animal production, imported feed, or imported plant-protein ingredients (Gil et al., 2024). This creates concerns about sustainability, production costs, and supply-chain stability. For this reason, there is growing interest in alternative plant-protein sources that can support more diverse and resilient food systems.

Bambara groundnut (*Vigna subterranea* (L.) Verdc.) is an underutilised African grain legume cultivated for its edible seeds and increasingly recognised for its potential contribution to climate-resilient food and protein diversification (Phiri et al., 2026). It is known for its ability to grow under relatively dry and low-input conditions, making it relevant for farming systems affected by drought, poor soils, and limited external inputs (Majola et al., 2021). The visual characteristics of Bambara groundnut further show its value as both a crop and a food ingredient. As shown in Figure 1, the crop develops as a low-growing legume during the vegetative stage, produces pods below or near the soil surface after flowering, and can be processed from dry seeds into flour for food-product development. The crop is also nutritionally valuable. Previous studies reported that Bambara groundnut seed protein usually ranges from 18–30%, depending on genotype, environment, and processing conditions (Oyeyinka et al., 2017; Adeleke et al., 2018; Hlanga et al., 2021). It also contains carbohydrates, fibre, minerals, and essential amino acids (Table 1). These qualities make it useful not only as a traditional pulse, but also as a potential ingredient for plant-protein food products.

However, Bambara groundnuts should be presented with scientific caution. It should not be described as automatically superior to soybeans, peas, chickpeas, or lentils, because its value depends on how it is processed and used. Protein digestibility, antinutritional factors, flavour, functional properties, consumer acceptance, ingredient standardisation, and regulatory approval are all important for product development. Processing methods such as soaking, dehulling, germination, and fermentation can improve nutritional quality and reduce some limitations (Mashau et al., 2026). Therefore, this mini-review discusses Bambara groundnut as a science-to-market opportunity. It explores its potential for high-protein foods, bakery products, pasta, snacks, beverages, and alternative-protein formulations. Türkiye is used as a strategic case because of its food-processing capacity, its location between Europe, Africa, and the Middle East, and its possible role in future plant-protein product development.



Figure 1 Representative images of Bambara groundnut showing (a) plants at the vegetative growth stage, (b) uprooted mature plants with pods attached to the stem, (c) dry seeds (d) flour product.

Nutritional and protein characteristics

Bambara groundnut is nutritionally important because it provides both macronutrients and micronutrients. Its seeds provide protein, carbohydrates, dietary fibre and minerals (Khan et al., 2021; Pui et al., 2022; Ramatsetse et al., 2023; U.S. Department of Agriculture, 2025). The protein content is commonly reported within the range of about 18–30%, although this can vary with genotype, growing environment, maturity stage, and processing method (Oyeyinka et al., 2017; Adeleke et al., 2018; Hlanga et al., 2021). This composition makes Bambara

groundnut relevant not only as a traditional pulse, but also as a possible plant-protein ingredient for food product development (Table 1). Protein quality depends on essential amino acid composition and digestibility, rather than protein concentration alone. Like many legumes, Bambara groundnut contains anti-nutritional factors such as phytates, tannins, trypsin inhibitors, and related compounds (Chinma et al., 2021; Mashau et al., 2025a). These compounds can reduce protein utilisation and limit the absorption of minerals such as iron, calcium, and zinc. Their nutritional potential therefore depends partly on processing methods that reduce antinutritional factors while preserving nutrient quality. For food-product development, nutritional quality and ingredient functionality should be evaluated in relation to processing conditions and the intended application. Bambara flour can be used in products such as bread, biscuits, pasta, and snacks (Figure 2), while Bambara protein concentrate may be more suitable for beverages, protein bars, and other high-protein foods (Arise et al., 2015; Jideani & Jideani, 2021; Adetokunboh et al., 2022). These applications reflect differences in composition and functionality: flour retains a broader range of seed components, whereas concentrates and isolates contain higher proportions of protein. Their suitability for particular products depends on properties such as water and oil absorption, emulsification, foaming and gel formation (Adeleke et al., 2018). Further research should assess amino acid composition, protein digestibility, mineral bioaccessibility and residual antinutritional factors alongside ingredient functionality and consumer acceptance.

Processing, bioprocessing and protein functionality

Processing is central to the use of Bambara groundnuts in modern food systems. Traditional methods such as soaking, boiling, roasting, dehulling, germination, fermentation, and milling can improve the eating quality of the seed and reduce some antinutritional factors (Mubaiwa et al., 2018; Tan et al., 2020; Elegbeleye & Sivakumar, 2026). These methods can also change the nutritional profile of the flour. Mashau et al. (2025a) and Mashau et al. (2025b) reported that dehulling and malting can improve some aspects of Bambara flour quality and reduce antinutritional factors.

Table 1 Nutrient composition of dried raw flour of Bambara groundnut

Nutrient component	Content per 100 g of dried raw flour
Energy	376 kcal / 1590 kJ
Water	8.4 g
Protein	20.1 g
Fat	5.9 g
Available carbohydrate	58.9 g
Fibre	3.7 g
Ash	3.1 g
Calcium	65 mg
Iron	3.3 mg
Magnesium	199 mg
Phosphorus	275 mg
Potassium	1190 mg
Sodium	29 mg
Zinc	3.38 mg
Copper	0.89 mg
Vitamin E	0.38 mg
Thiamin	0.12 mg
Riboflavin	1.9 mg

Source: U.S. Department of Agriculture (2025)

Bioprocessing is also important because it can improve the functional properties of Bambara-based ingredients. Functional properties refer to how an ingredient behaves during food preparation or industrial processing (Godswill et al., 2019). These include water absorption, oil absorption, solubility, emulsification, foaming, gel formation, and texture development. These properties are important because food industries need ingredients that are predictable and stable during formulation (Sun-Waterhouse et al., 2014). A plant protein may be nutritionally valuable, but it must also perform well in the final food product. Different Bambara ingredients may therefore serve different purposes. Bambara flour may be useful in bakery products, pasta, biscuits, and snacks. Bambara protein concentrate or isolate may be more suitable for protein beverages, meat alternatives, and high-protein foods (Murevanhema & Jideani, 2013; Adeleke et al., 2018). Fermented Bambara ingredients may be useful in functional foods or beverages (Murevanhema & Jideani, 2013). This shows that Bambara groundnut commercialisation should not focus only on crop production. It should also include processing technology, ingredient functionality, and product formulation.

Existing and potential food applications

Bambara groundnut has potential in several food-product categories. Studies show that Bambara flour and protein-rich fractions have been explored in bread, biscuits, snacks, beverages, fermented foods, and composite food products (Sogunle et al., 2025; Oresanya et al., 2026). This gives the crop flexibility as a food ingredient. It can be used alone in some products or blended with wheat, maize, rice, legumes, or other plant-protein sources. The strongest opportunity may be in value-added food products rather than selling Bambara only as a dry pulse. As a flour, it can be used in bakery products, pasta, noodles, biscuits, and snack formulations (Figure 2). As a protein concentrate or isolate, it may be used in protein bars, beverages, high-protein bakery products, and alternative-protein foods (Figure 2). As a fermented ingredient, it may also support functional-food development (Murevanhema & Jideani, 2013). These applications are important because they connect Bambara groundnut with consumer trends such as high-protein foods, plant-based diets, healthy snacks, and sustainable food products. This product diversity strengthens the entrepreneurial value of Bambara groundnut. It means the crop can move beyond traditional household consumption and become part of food innovation. However, each product category would require testing for texture, taste, shelf life, consumer acceptance, safety, and regulatory compliance.

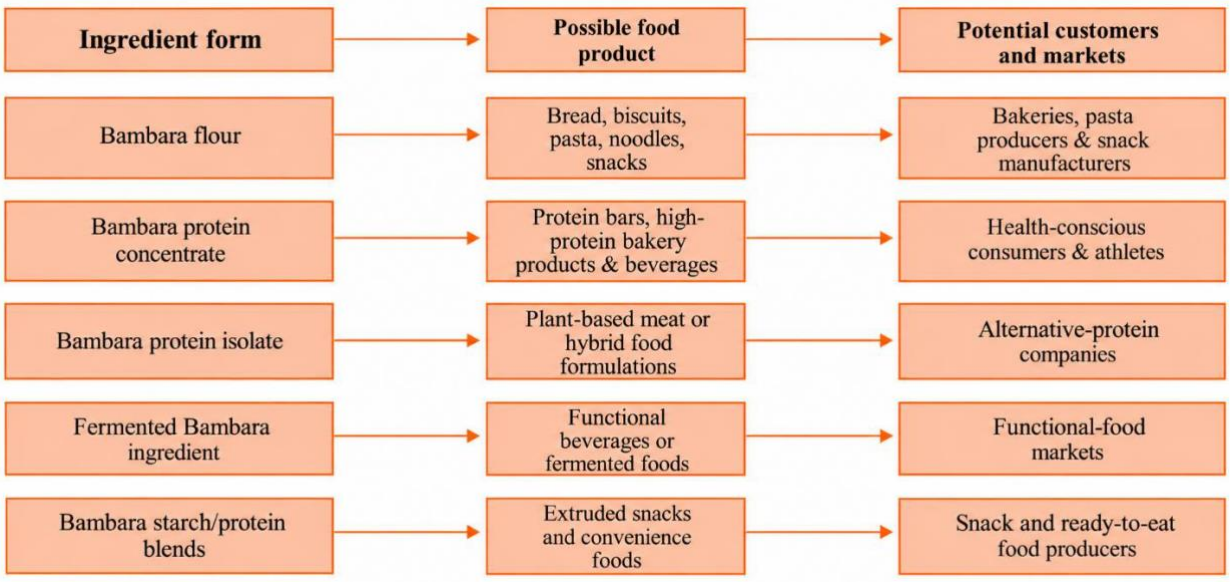


Figure 2 Potential food applications and customer segments for different Bambara groundnut ingredient forms. Source: Adeleke et al. (2018), Nwadi et al. (2020), and Tan et al. (2020).

Sustainability and green entrepreneurship

Bambara groundnut is relevant to green entrepreneurship because it connects climate-resilient agriculture with plant-protein diversification (Glatzel et al., 2025; Phiri et al., 2026). The crop is known for its ability to grow under relatively dry conditions and low-input systems. This makes it useful in discussions on sustainable agriculture, especially where drought, soil fertility decline, and high production costs limit conventional crop production (Tan et al., 2020; Pasipanodya et al., 2025). Its role as an underutilised legume also supports agrobiodiversity and food-system diversification. From an entrepreneurship perspective, the opportunity is not only the crop itself. The stronger opportunity is the value chain that can be built around it. A Bambara-based green enterprise could include seed sourcing, cleaning, milling, protein extraction, fermentation, product formulation, packaging, branding, and distribution. This type of value chain could create opportunities for small and medium-sized enterprises, start-ups, farmer groups, food processors, and university-industry collaboration. Bambara groundnuts also fit the idea of inclusive green business. African producers could supply raw material, while Türkiye could contribute through food processing, product development, packaging, and market access (Phiri et al., 2026). This approach would connect climate-resilient crop production with value-added food innovation. It would also support a more balanced discussion of sustainability, because economic viability, farmer participation, product quality, and market acceptance would all be part of the enterprise model.

Türkiye market potential

Türkiye should be framed as a potential hub for the production, processing, and commercialisation of Bambara groundnut rather than as an established Bambara market. This distinction is important for scientific accuracy. Limited evidence suggests that Bambara groundnut is not currently widely cultivated or commercially available in Türkiye (Phiri et al., 2026). However, Türkiye has several advantages that make it relevant for future development. These include its food-processing capacity, its location at the crossroads of Europe, Africa, and the Middle East, and its growing interest in functional foods and plant-protein ingredients (Bustos & Varzakas, 2026). Potential domestic product areas include sports nutrition, high-protein bakery products, healthy snacks, pasta and noodle products, functional beverages, vegan foods, vegetarian foods, and environmentally conscious food products. Bambara groundnuts may be especially useful as a novel protein ingredient rather than only as a traditional pulse. A plant-protein market in Türkiye was expected to grow by 26.6% annually and reach US$195.4 million in 2025 (ConsumerIntel360, 2025). The same report stated that the market grew at a CAGR of 28.8% during 2020–2024 and forecast further growth at a CAGR of 22.8% during 2025–2029, with the market projected to reach about US$556.8 million by 2029. However, this should be used only as market-indicator data because it is a commercial market-research estimate and refers to the general plant-protein market, not Bambara groundnut specifically. Beyond market potential, commercialisation also depends on the regulatory requirements governing the introduction of new food ingredients in Türkiye. The Ministry of Agriculture and Forestry explains that “new food” includes foods listed in the regulation annex and foods not significantly used for human consumption in Türkiye before 31 December 2025 (T.C. Tarım ve Orman Bakanlığı, 2026). The regulatory status of Bambara-based products needs to be established to determine whether an application and safety evaluation are required before commercialisation.

Potential export markets

Türkiye’s geographical position creates possible export opportunities if Bambara-based products are successfully developed, approved, and accepted by consumers (Phiri et al., 2026). The most relevant export routes are the European Union, the Middle East and Gulf region, and Africa-linked value chains. These markets

differ in consumer demand, regulatory requirements, purchasing power, logistics, and product positioning. For this reason, export potential should be discussed as an opportunity that requires further validation. The European Union is especially important because Commission Implementing Regulation (EU) 2024/2047 authorised the placing on the market of seeds and seed flour of *Vigna subterranea* as a traditional food from a third country (Engel et al., 2025). This is a positive development because it gives Bambara groundnut a clearer regulatory entry point in the EU for seeds and seed flour. However, this authorisation should not be interpreted as approval for every Bambara-derived product. Protein concentrates, isolates, hydrolysates, or highly processed formulations may require separate assessment depending on their composition, processing method, and intended use. The Middle East and Gulf region may also offer potential opportunities for high-protein foods, premium health foods, halal-certified products, sustainable food ingredients, and plant-based formulations (Angelova & Alaeddine, 2026). However, this should be presented as a potential market rather than an established Bambara groundnut demand centre. Consumer acceptance, price, certification, branding, flavour, and distribution channels would need to be studied. A possible long-term model is a Türkiye–Africa–EU or Türkiye–Africa–Middle East value chain. In this model, African production could be linked with Turkish processing and formulation, followed by export to selected international markets.

Challenges and research gaps

Despite its potential, Bambara groundnut faces several barriers to commercialisation. These include limited seed supply outside Africa, lack of standardised raw material, low consumer familiarity, long cooking time, processing costs, antinutritional factors, possible beany flavour, variable protein extraction yield, uncertain allergenicity, limited large-scale processing data, and regulatory uncertainty (Mubaiwa et al., 2018; Tan et al., 2020; Wang & Jian, 2022). These challenges do not reduce the importance of the crop, but they show that commercialisation requires more than nutritional promotion. Research gaps remain in both science and market development. Studies are needed on protein digestibility, amino-acid bioavailability, mineral availability, antinutritional reduction, allergenicity, sensory quality, shelf life, and protein extraction efficiency. There is a need to evaluate improved and emerging processing methods and their effects on protein digestibility, antinutritional factors, amino acid composition, mineral bioaccessibility, flavour compounds and other quality characteristics (Mubaiwa et al., 2017; Mashau et al., 2026). Market-related research is equally important. Future studies should examine whether Turkish consumers would accept Bambara-based foods, which product categories are most realistic, and how Bambara products should be positioned. Lastly, studies should combine agronomic adaptation, food science, consumer research, regulatory analysis, and pilot-scale enterprise development.

Conclusion

Bambara groundnut is a credible plant-protein source with potential sustainability benefits for innovative food products and green entrepreneurship. Its nutritional value, drought tolerance and processing flexibility make Bambara groundnut relevant to future food-system transformation. Its potential applications include flour, protein-rich ingredients, beverages, snacks, bakery products, pasta and alternative-protein formulations. For Türkiye, one potential opportunity lies not in presenting Bambara groundnut as an already established crop, but in positioning the country as a potential production, processing, and commercialisation hub linking African raw-material supply,

Turkish food-industry capacity, and EU/Middle East export opportunities. However, Bambara groundnut should be presented with scientific caution. Its promise depends on processing, digestibility, sensory quality, supply-chain development, compliance with applicable regulatory requirements, and market validation. A strong

research and enterprise pathway would combine agronomic adaptation trials, nutritional and functional characterisation, product formulation, consumer testing, regulatory assessment, and pilot-scale commercialisation. With further research and commercial validation, Bambara groundnut could support the development of plant-protein products and green entrepreneurship in Türkiye and other emerging markets.

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FULL PAPER · S8.5 · ONLINE SESSION 8

Comparison of Spatial Interpolation and Hybrid Machine Learning Methods for Imputing Missing Temperature Data Using ERA5-Land Climate Data

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ABSTRACT

Temperature records from meteorological stations may contain missing observations because of sensor failures, power interruptions, and data transmission problems. Such gaps can introduce uncertainty into hydrological modeling, agricultural planning, water resources management, and climate analyses. This study compared spatial interpolation methods, calibrated reanalysis data, and hybrid machine learning methods for imputing missing daily mean temperature data. The study included 14 meteorological observation stations in the semi-arid parts of the Euphrates–Tigris Basin in Eastern and Southeastern Anatolia, using daily mean temperature data for 1985–2014. To separate model development from final evaluation, 15% of the observations were randomly masked to form an independent final test set. The remaining 85% were used exclusively for model development, calibration, feature importance analysis using SHapley Additive exPlanations (SHAP), and hyperparameter optimization. ERA5-Land reanalysis temperature data from the European Centre for Medium-Range Weather Forecasts (ECMWF) were calibrated against station observations using empirical quantile mapping (EQM). Inverse distance weighting (IDW) and Ordinary Kriging were evaluated alongside hybrid models based on XGBoost, LightGBM, random forest (RF), support vector regression (SVR), and multilayer perceptron (MLP), with ERA5-Land variables and Kriging estimates incorporated as predictors. Performance was evaluated using root mean square error (RMSE), mean absolute error (MAE), Pearson's correlation coefficient (r), and Nash–Sutcliffe efficiency (NSE). The hybrid models achieved higher prediction accuracy than the spatial interpolation methods and the direct use of calibrated ERA5-Land temperature data. LightGBM achieved the lowest RMSE (0.99386 °C), with an MAE of 0.75061 °C, an r of 0.99577, and an NSE of 0.99156. XGBoost, MLP, SVR, and RF followed in the RMSE ranking. LightGBM reduced RMSE by approximately 43.13% relative to ERA5-Land_EQM and by approximately 54.97% relative to IDW. The ERA5-Land_EQM approach, which directly substituted calibrated ERA5-Land temperatures for missing observations, outperformed both spatial interpolation methods, with an RMSE of 1.74747 °C, an MAE of 1.26420 °C, an r of 0.98701, and an NSE of 0.97392. Its performance was nevertheless lower than that of the ERA5-Land- and Kriging-supported hybrid models. Among the spatial interpolation methods, IDW outperformed Ordinary Kriging, with an RMSE of 2.20699 °C and an NSE of 0.95839, compared with an RMSE of 2.29152 °C and an NSE of 0.95515 for Ordinary Kriging. These findings indicate that incorporating calibrated ERA5-Land temperature data as an auxiliary predictor alongside spatial interpolation estimates in hybrid machine learning models can provide higher prediction accuracy than directly using the calibrated reanalysis temperatures to replace missing observations.

Keywords: missing temperature data; ERA5-Land; machine learning; spatial interpolation; hybrid modeling

1. Introduction

Meteorological observation stations are essential sources of data for water resources management, monitoring the impacts of climate change, disaster risk assessment, and agricultural planning, among other applications (McCabe et al., 2017; Plummer et al., 2003). However, power interruptions and equipment failures can result in missing records at automatic meteorological stations. Similar problems also occur at stations operated by the Turkish State Meteorological Service (MGM). Climate records containing missing values cannot be used

directly in applications such as hydrometeorological modeling. Imputing missing values is therefore necessary to maintain data continuity and improve the accuracy of hydrometeorological models.

Climate reanalysis products provide temporally and spatially complete data that can support the imputation of missing meteorological observations (Varotsos et al., 2023). ERA5-Land provides temperature, precipitation, pressure, dew point temperature, and related land surface variables on regular temporal and spatial grids (Muñoz-Sabater et al., 2021). Unlike direct point measurements at meteorological stations, ERA5-Land temperature data represent the temperature conditions over a grid cell. This difference can lead to discrepancies between station observations and reanalysis data, particularly because of topography, elevation differences, and local climatic conditions. Accordingly, the ERA5-Land temperature data were bias-corrected in this study. The corrected temperatures were used both directly to estimate missing temperatures and, together with other climate variables, as an auxiliary predictor intended to improve prediction accuracy in hybrid machine learning models.

2. Conceptual Framework

Methods for imputing gaps in meteorological observation series use different approaches to represent the spatial distribution and temporal variability of temperature. Inverse distance weighting (IDW) and Ordinary Kriging are two conventional spatial interpolation approaches for estimating temperature at locations without observations using data from surrounding stations. In a comparison based on meteorological stations across China, Zhang et al. (2026) found that IDW preserved local spatial variation in daily mean temperature more clearly than Ordinary Kriging, whereas Kriging produced smoother temperature surfaces.

Mısırlıoğlu et al. (2026) reported similar error levels for IDW and Ordinary Kriging in temperature mapping in the Eastern Black Sea region. IDW produced lower MAE values, whereas Kriging yielded lower absolute mean bias error (MBE) values. These findings indicate that the performance of interpolation methods can vary with the characteristics of the station network and regional conditions.

In addition to conventional interpolation methods, machine learning approaches that jointly use auxiliary environmental variables and observations from neighboring stations are also employed for temperature estimation. Sekulić et al. (2020) adapted the random forest (RF) algorithm for spatial interpolation. Their approach combined observations from nearby stations, distances between stations, and environmental variables, and outperformed conventional RF and IDW in estimating daily temperatures in Croatia.

When reanalysis data are used, correcting systematic differences relative to station observations is particularly important. Satyapragyan et al. (2026) showed that several bias correction methods, including empirical quantile mapping (EQM), could improve the agreement of ERA5 and ERA5-Land temperatures with observations in the Himalayan region. However, the effectiveness of the corrections varied with the method and station conditions.

Among machine learning models, gradient boosting algorithms such as XGBoost and LightGBM, support vector regression (SVR), random forest (RF), and artificial neural networks offer different learning mechanisms for temperature modeling. In a comparison of temperature estimation methods using meteorological data from Seoul, Apaydın et al. (2022) reported that XGBoost and LightGBM outperformed the other machine learning models examined. In another study that included a multilayer perceptron (MLP) architecture, Lee et al. (2020) showed that both the temporal resolution of the input data and the neural network architecture influenced temperature prediction performance.

Focusing specifically on the reconstruction of missing temperature observations, Koliopanos et al. (2025) integrated XGBoost with meteorological data quality control to impute missing or erroneous temperature records and obtained results demonstrating the practical applicability of the approach.

Taken together, these studies highlight the importance of considering reanalysis data and different machine learning algorithms alongside spatial relationships between stations when imputing missing temperature observations. Accordingly, the present study compared IDW, Ordinary Kriging, ERA5-Land_EQM, RF, XGBoost, LightGBM, SVR, and MLP.

3. Methods

3.1. Study Area

The study area is located in Eastern and Southeastern Anatolia, Türkiye, between 36° and 40° N and 38° and 42° E. Centered on Diyarbakır Province, it includes meteorological observation stations in neighboring provinces and lies within the Euphrates–Tigris Basin. The study region covers approximately 30,000 km² and is situated entirely within the basin. Figure 1 shows the geographical location of this Diyarbakır-centered study area in southeastern Türkiye.

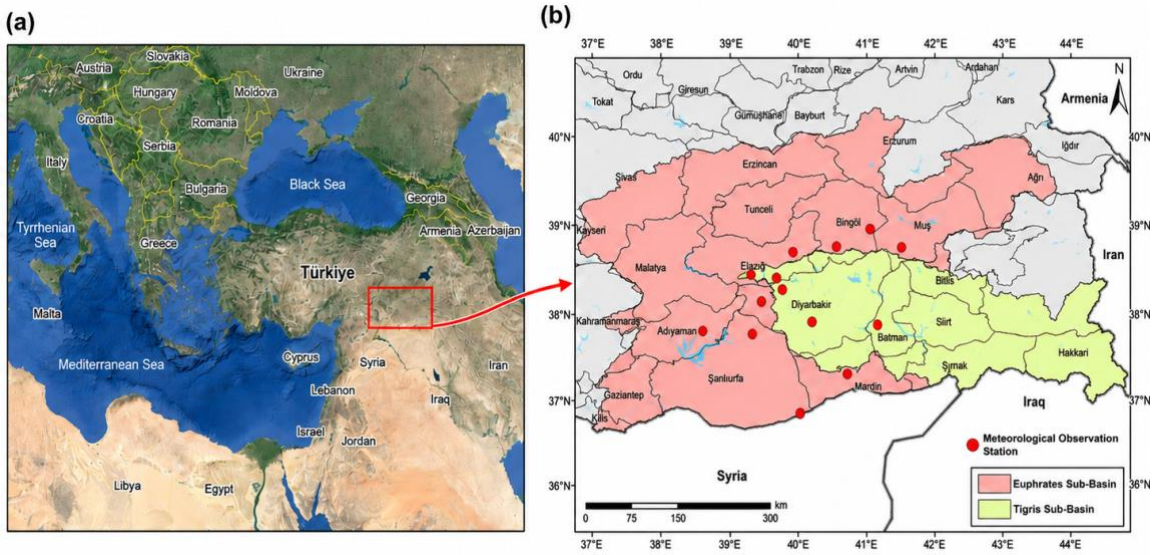


Figure 1. Location of the study area. (a) Regional location of the study area within Türkiye and neighboring countries; (b) enlarged map of the study area centered on Diyarbakır Province, showing the Euphrates and Tigris sub-basins and meteorological observation stations.

3.2. Datasets

3.2.1. Meteorological Station Data

Daily mean temperature data collected from 14 meteorological observation stations in Diyarbakır and the surrounding area for 1985–2014 were used. Table 1 presents the geographical locations and elevations of the stations.

Table 1. Characteristics of the meteorological observation stations.

No.	Station	Latitude (°N)	Longitude (°E)	Elevation (m)
1	17204 Muş	38.7509	41.5023	1322
2	17275 Mardin	37.3103	40.7284	1040
3	17280 Diyarbakır Airport	37.8973	40.2027	674
4	17282 Batman	37.8636	41.1562	610
5	17776 Solhan	38.9597	41.0503	1366
6	17806 Palu	38.6907	39.9260	869
7	17808 Genç	38.7616	40.5577	993
8	17844 Sivrice	38.4507	39.3101	1240
9	17846 Maden	38.3924	39.6757	1047

No.	Station	Latitude (°N)	Longitude (°E)	Elevation (m)
10	17847 Ergani	38.2670	39.7660	986
11	17874 Çermik	38.1371	39.4644	695
12	17910 Kahta	37.7918	38.6155	725
13	17912 Siverek	37.7522	39.3291	801
14	17968 Ceylanpınar TİGEM	36.8406	40.0307	360

3.2.2. ERA5-Land Climate Data

ERA5-Land has a native horizontal resolution of approximately 9 km and is distributed through the Copernicus Climate Data Store at hourly temporal resolution on a regular 0.1° × 0.1° latitude–longitude grid (Muñoz-Sabater et al., 2021). Hourly total precipitation, 2 m air temperature, 2 m dew point temperature, and surface pressure data were obtained for 1985–2014 over the domain bounded by 36°–40° N and 38°–42° E. Hourly precipitation was aggregated to daily totals, whereas air temperature, dew point temperature, and surface pressure were converted to daily means. Precipitation was converted to millimeters, air and dew point temperatures to degrees Celsius, and surface pressure to hectopascals. ERA5-Land variables were interpolated to station locations using inverse distance weighting (IDW; p = 2) applied to the four nearest grid cells, with distances calculated in the WGS84/UTM 37N coordinate system.

3.3. Methodology

The computational experiment used a common framework with controls against data leakage to compare direct substitution using ERA5-Land_EQM, spatial interpolation, and five machine learning scenarios. Of the station-day observations, 15% were reserved as an independent final test set. Model development, calibration, SHAP-based feature importance analysis, five-fold cross-validation, and parameter selection were restricted to the remaining 85% development pool.

ERA5-Land daily mean temperatures were calibrated against temperature observations from meteorological stations using empirical quantile mapping (EQM). The calibrated ERA5-Land_EQM temperatures were then used to estimate the masked observations in the independent 15% test set.

IDW and Ordinary Kriging were applied using observations from neighboring stations available on the target date. The IDW distance exponent, number of neighbors, and search radius, and the Kriging variogram model, number of neighbors, and search radius were selected according to the mean cross-validation RMSE. The selected IDW settings were p = 2.5, a maximum of eight neighbors, and a search radius of 150 km. The selected Kriging settings were a Gaussian variogram, a maximum of four neighbors, and a search radius of 200 km.

XGBoost and LightGBM were included as gradient boosting tree methods in the hybrid models (Chen & Guestrin, 2016; Ke et al., 2017). The other methods were random forest (RF), support vector regression (SVR) with a radial basis function kernel, and multilayer perceptron (MLP). LightGBM, XGBoost, MLP, SVR, and RF were trained using five-fold cross-validation on the 85% of the data outside the test set. In addition to the basic predictors, the models received estimates generated by Ordinary Kriging, ERA5-Land precipitation, surface pressure and dew point temperature, relative humidity derived from ERA5-Land variables, and calibrated ERA5-Land_EQM temperature. The models were trained with these inputs to predict the independent test observations. All models used the same 17 predictors: UTM x and y coordinates; elevation; the sine and cosine components of day of year; one- and two-day temperature lags; temperatures at the two nearest stations; the Kriging estimate; the distance and elevation difference relative to the nearest available station; and calibrated ERA5-Land temperature, precipitation, dew point temperature, relative humidity, and surface pressure.

The contributions of model inputs to predictions were examined using the SHAP (SHapley Additive exPlanations) framework of Lundberg and Lee (2017). In this study, SHAP values were calculated using an

auxiliary XGBoost model, and inputs were ranked according to their mean absolute SHAP values across samples. Rankings obtained across the cross-validation folds were combined, and all 17 inputs were retained in the final models.

The hyperparameter search evaluated ten combinations each for XGBoost and LightGBM, eight for RF, three for SVR, and four for MLP. The LightGBM configuration selected on the basis of the lowest mean cross-validation RMSE used 400 trees, 63 leaves, and a learning rate of 0.1. No maximum tree depth was imposed; the column subsampling ratio was 0.9, and reg_lambda was set to 1. All methods were evaluated on the same 15% test set using RMSE, MAE, Pearson's correlation coefficient (r), and Nash–Sutcliffe efficiency (NSE). RMSE and MAE are expressed in °C; r and NSE are dimensionless.

4. Results

The hybrid machine learning models achieved lower RMSE values on the independent test set than ERA5-Land_EQM and the spatial interpolation methods (Table 2). In ascending order of RMSE, the methods ranked as follows: LightGBM, XGBoost, MLP, SVR, RF, ERA5-Land_EQM, IDW, and Ordinary Kriging.

Table 2. Performance of the methods on the independent final test set.

Method	RMSE (°C)	MAE (°C)	r	NSE
LightGBM	0.99386	0.75061	0.99577	0.99156
XGBoost	1.00001	0.75530	0.99572	0.99146
MLP	1.00049	0.75008	0.99572	0.99145
SVR	1.00510	0.74724	0.99568	0.99137
RF	1.07247	0.81095	0.99508	0.99018
ERA5-Land_EQM	1.74747	1.26420	0.98701	0.97392
IDW	2.20699	1.71991	0.97900	0.95839
Ordinary Kriging	2.29152	1.76177	0.97743	0.95515

LightGBM, XGBoost, MLP, SVR, and RF are hybrid models supported by ERA5-Land and Kriging predictors. LightGBM achieved an RMSE of 0.99386 °C, an MAE of 0.75061 °C, an r of 0.99577, and an NSE of 0.99156. Its RMSE was 43.13% lower than that of ERA5-Land_EQM, 54.97% lower than that of IDW, and 56.63% lower than that of Ordinary Kriging. The RMSE differences between LightGBM and XGBoost and between LightGBM and MLP were approximately 0.00615 and 0.00663 °C, respectively. SVR achieved the lowest MAE (0.74724 °C), and MLP also produced a slightly lower MAE than LightGBM. Therefore, LightGBM's leading performance should be interpreted in terms of RMSE, r, and NSE.

In the auxiliary XGBoost model used for feature importance analysis, the two highest-ranked inputs were calibrated ERA5-Land temperature (mean absolute SHAP value = 5.86484) and the Kriging estimate (1.86720). These were followed by the seasonal cosine component (0.54845) and the one-day lag (0.40451). This ranking supports the combined use of reanalysis and spatial information.

5. Discussion and Conclusions

In this experiment, the direct use of ERA5-Land_EQM produced lower errors than IDW and Ordinary Kriging. The lowest RMSE was obtained with the hybrid LightGBM model, which jointly used ERA5-Land and Kriging inputs. This result indicates the benefit of considering reanalysis information together with other explanatory variables in the dataset examined.

Varotsos et al. (2023) reconstructed daily maximum and minimum temperatures at 15 European stations using Climatol and showed that ERA5-Land-supported series agreed more closely with observations than raw reanalysis outputs. The present study used a different target variable and experimental design; therefore, the

performance metrics cannot be considered directly equivalent. Nevertheless, both studies indicate the benefit of combining local observations with reanalysis information. The framework presented by Hengl et al. (2018) for jointly modeling spatial proximity and auxiliary variables also supports the conceptual basis of the hybrid architecture.

Using precipitation data from the same stations, Tektaş and Polat (2026) found that direct use of calibrated ERA5-Land precipitation performed less well than the spatial methods. In the present study, ERA5-Land_EQM outperformed IDW and Kriging for temperature, indicating that the ranking of methods for one variable cannot be assumed to apply to another. Both studies, however, found an advantage for hybrid models combining auxiliary reanalysis and spatial information. The more regular temporal and spatial structure of temperature provides a possible explanation for this difference.

In conclusion, hybrid models combining calibrated ERA5-Land data, Kriging estimates, and local observations produced lower errors in this dataset. The LightGBM RMSE of approximately 0.99 °C demonstrates the practical potential of the approach.

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FULL PAPER · S8.7 · ONLINE SESSION 8

Responsible Healthcare Procurement: A Structured Literature Review and Evidence Synthesis

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ABSTRACT

Healthcare procurement decisions increasingly carry responsibilities that extend beyond cost, quality, and availability to environmental impacts, social and labor conditions, supply resilience, transparency, and accountability. However, these responsibilities have developed across largely fragmented research streams, leaving limited understanding of what responsible healthcare procurement encompasses, where responsibility is exercised across the supply chain, and through which governance mechanisms it is operationalized. This study addresses this fragmentation by systematically mapping and synthesizing the literature on responsible healthcare procurement. A structured literature review and evidence synthesis was conducted using Web of Science. The search yielded 676 records; following screening and full-text assessment, 30 studies formed the core analytical corpus. Full texts were coded across four interrelated dimensions: responsibility domains, procurement and supply-chain lifecycle stages, governance mechanisms, and actor representation. The synthesis reveals that responsible healthcare procurement is multidimensional but unevenly developed. Broad economic, environmental, and social concerns are prominent, whereas their more specific dimensions, notably human and labor rights, circularity, and biodiversity, are less extensively examined; digital responsibility is also rarely made explicit. Responsibility is concentrated in selected stages, particularly distribution, purchasing, and monitoring, whereas needs assessment, contracting, and supplier development remain comparatively underexplored. At the governance level, the literature extends beyond procurement criteria and regulation toward transparency, risk management, collaboration, traceability, and digital capabilities, showing that transaction-oriented practices coexist with broader forms of continuing supply-chain governance. Nevertheless, responsibility remains predominantly organized around buyers and suppliers, with affected stakeholders and broader social and ecological boundaries less visible. Integrating these findings, the study identifies four interrelated gaps, boundary, lifecycle, integration, and evidence gaps, and develops an integrative perspective connecting institutional foundations, lifecycle decisions, network governance, enabling capabilities, responsibility domains, actors, and outcome feedback. The synthesis provides a basis for advancing healthcare procurement from fragmented sustainability practices toward lifecycle-oriented, accountable, and outcome-focused responsible supply-chain governance.

Keywords: responsible healthcare procurement; sustainable procurement; responsible supply chain; healthcare supply chain; evidence synthesis

1. Introduction

Healthcare procurement connects clinical service delivery with the environmental, social, and operational conditions under which medicines, devices, consumables, and other supplies are produced and used. Consequences arise before purchasing, through manufacturing and labour practices, and afterwards, through distribution, maintenance, recovery, and disposal. They may also affect people outside the purchasing organization. Responsible healthcare procurement consequently involves more than price, quality, and compliant supplier selection: it requires specifying relevant obligations, identifying where decisions can influence them, and determining whose interests and outcomes are considered.

Public procurement studies examine institutional constraints, sustainability criteria, and supplier relationships in healthcare. Evidence from French hospitals, comparative British Italian public healthcare, and Australian purchasing identifies distinct managerial and regulatory challenges (Rico & Oruezabala, 2012; Oruezabala & Rico, 2012; Ahsan & Rahman, 2017; Chiarini et al., 2017). Policy and barrier analyses further clarify implementation conditions (Ahmed et al., 2021; Zaidi et al., 2021). Yet these studies primarily examine procurement institutions rather than connected decisions across the product lifecycle.

A complementary stream formalizes supplier and supply-chain decisions through multicriteria evaluation, replenishment coordination, and sustainability assessment (Nematollahi et al., 2018; Yazdani et al., 2020; Kamruzzaman et al., 2025; Chen & Zhang, 2026). Such models clarify objectives and trade-offs but cannot, without corresponding outcome evidence, establish improvements in working conditions, environmental burdens, or health-service performance.

Other studies examine harms concealed by aggregate sustainability measures. Research on healthcare supply-chain inequities, product-origin labour risks, glove manufacturing, modern-slavery disclosures, and pharmaceutical reporting offers different perspectives on social responsibility (Demir & Min, 2019; Trueba et al., 2021; Abbott et al., 2024; Brown et al., 2024; Tan et al., 2026). Environmental contributions address carbon reduction, protective equipment, circular medical-device management, and biodiversity (Lavoie et al., 2024; Torkki et al., 2024; Lopes et al., 2026; Butt & Arshi, 2026). Their coexistence does not establish that these concerns are governed together.

Digital studies add traceability, information governance, and access-related questions to this fragmented picture. Vaccine initiatives, ethical assessments of connected systems, pharmaceutical blockchain applications, and reproductive-health distribution each address different capabilities or risks (Radanliev et al., 2021; Pagliusi et al., 2023; Hajizadeh et al., 2025; Hao & Zhao, 2026). Digital visibility alone does not establish responsible outcomes.

Across these streams, responsibility is defined at different levels and investigated through different decisions, mechanisms, actors, and forms of evidence. A supplier criterion, corporate disclosure, operational model, and worker account can each inform procurement but answer different questions. An integrated evidence synthesis is therefore needed to identify what responsible healthcare procurement encompasses and where existing research leaves important connections unresolved. The review addresses four research questions:

RQ1. Which broad and specific responsibility domains are represented in responsible healthcare procurement research, and how do their conceptual boundaries differ?

RQ2. Which procurement and supply-chain lifecycle stages receive attention, and which connections between decision stages are comparatively underexamined?

RQ3. Which governance mechanisms are examined in connection with particular responsibility domains, and what does their joint representation suggest about the scope of existing governance research?

RQ4. Which actors are represented in this literature, and how do different forms of empirical, analytical, and conceptual evidence shape what can be concluded about responsible procurement?

The review distinguishes broad responsibilities from specific obligations, maps their intersections with lifecycle stages and governance mechanisms, and compares actor representation and evidentiary claims. These analyses identify four linked research gaps, boundary, lifecycle, integration, and evidence, and inform an integrative framework connecting obligations, decision points, governance arrangements, stakeholders, and outcomes.

2. Methodology

A structured literature review and mixed descriptive–qualitative evidence synthesis was used to map responsible healthcare procurement across heterogeneous empirical, analytical, and conceptual studies. Four dimensions corresponding to RQ1-RQ4 guided classification and comparison; category coverage was distinguished from evidence of organizational effectiveness.

Web of Science was searched in September 2026 using the following three-block Boolean query: (healthcare OR "health care" OR hospital OR hospitals OR "health system*" OR pharmaceutical* OR "medical device*" OR "medical suppl*") AND ("supply chain*" OR procurement OR sourcing OR purchasing OR supplier*) AND ("responsible supply chain*" OR "responsible sourcing" OR "responsible procurement" OR "responsible purchasing" OR "ethical supply chain*" OR "ethical sourcing" OR "ethical procurement" OR "sustainable procurement" OR "sustainable sourcing" OR "supplier responsibility" OR "supply chain transparency" OR "supply chain traceability" OR "supply chain accountability" OR "supply chain due diligence" OR "human rights" OR "modern slavery" OR "labour rights" OR "labor rights" OR "supplier code*" OR "supplier audit*")

The search returned 676 records. Screening retained studies substantively examining responsible or sustainable healthcare procurement, supplier relationships, or related supply-chain decisions involving health systems, pharmaceuticals, medical devices, consumables, food, or dental supplies. Purely clinical or technical studies without a relevant procurement or supply-chain responsibility dimension were excluded. Full-text assessment yielded 30 publications (2012-2026). Diverse research designs were eligible because the objective was evidence mapping rather than pooled effect estimation.

Thirty-five non-exclusive indicators were organized into four dimensions: nine responsibility domains, twelve lifecycle stages, eight governance mechanisms, and six actor groups. Broad economic, environmental, and social domains were distinguished from more specific concerns: climate/carbon, circularity, and biodiversity under environmental responsibility, and human/labour rights under social responsibility. Resilience and digital responsibility captured supply continuity and normative digital concerns, respectively. Lifecycle stages ranged from needs assessment, specifications, and supplier selection through contracting, purchasing, inventory, distribution, monitoring, supplier development, use/maintenance, reverse flows, and end-of-life. Governance covered criteria, standards, transparency, risk management, collaboration, traceability, technology, and lifecycle arrangements; actors comprised buyers, suppliers, regulators, patients, workers, and communities/ecosystems.

Categories were assigned when substantively addressed in a study's aims, analysis, findings, or argument; multiple codes per publication were permitted. Specific indicators were not inferred automatically from general labels: environmental discussion did not necessarily imply carbon or circularity, and social sustainability did not necessarily imply labour rights. Likewise, digital capability was distinguished from responsibility for its ethical governance. Actor representation referred to substantive consideration of interests or roles, not necessarily direct participation.

The synthesis combined publication-level frequencies (n and % of 30), responsibility-domain × lifecycle and responsibility-domain × governance cross-tabulations, and qualitative comparison of research designs and claims. Cross-tabulation cells represent within-publication co-occurrence; proportions within each responsibility domain were also examined to avoid overemphasizing common categories. Co-occurrence does not demonstrate implementation or effectiveness. Comparative interpretation distinguished theoretical and decision-model outputs, organizational evidence, risk indicators, reported commitments, and observations of affected groups. Together these analyses informed the four research gaps and conceptual framework.

3. Results and Evidence Synthesis

The 30 studies span public procurement, pharmaceutical and medical-device supply chains, labour governance, resilience, climate-related purchasing, and digital traceability. Results are organized by RQ1–RQ4, combining coded coverage with differences in what individual studies can establish.

RQ1 identifies a disparity between broad responsibilities and specific obligations (Table 1). Economic considerations appear in all 30 publications (100.0%), environmental responsibility in 27 (90.0%), social responsibility in 20 (66.7%), and resilience in 18 (60.0%). More specific concerns appear less frequently: climate/carbon in 15 (50.0%), human/labour rights in nine (30.0%), circularity in six (20.0%), digital responsibility in four (13.3%), and biodiversity in one (3.3%). These indicators overlap: climate, circularity, and biodiversity are included in environmental coverage, and human/labour rights within social coverage. The ubiquitous economic code reflects its broad definition, including costs, resources, and service trade-offs, not universal evidence of economic performance.

Table 1. Representation of responsibility domains in the reviewed studies

Responsibility domain	Count (n)	Percentage (%)
Economic	30	100.0
Environmental	27	90.0
Social	20	66.7
Resilience	18	60.0
Climate / carbon	15	50.0
Human rights / labour	9	30.0
Circularity	6	20.0
Digital responsibility	4	13.3
Biodiversity	1	3.3

Note. N = 30 publications. The indicators are non-exclusive. Climate/carbon, circularity, and biodiversity are specific environmental concerns; human/labour rights are a specific social concern. Percentages use the full corpus as denominator and do not sum to 100%.

The distinction between broad and specific responsibilities is especially visible in studies of public purchasing and supplier decisions. Ahsan and Rahman (2017) prioritize barriers to green procurement in Australian healthcare; Chiarini et al. (2017) compare sustainability practices and evaluation criteria in British and Italian public healthcare; Ahmed et al. (2021) develop a policy-oriented account of sustainable procurement implementation; and Zaidi et al. (2021) examine the structure of barriers affecting public health procurement. Although these contributions share an interest in changing procurement institutions, their analytical objects differ from a supplier-evaluation exercise such as Yazdani et al. (2020), which structures the selection of alternatives in a Spanish hospital. Rico and Oruezabala (2012) and Oruezabala and Rico (2012) further show why sustainability expectations can affect supplier relationships as well as formal purchasing procedures. Taken together, these studies support a broad definition of responsible procurement as organizational and relational; they do not, however, establish a common measure of environmental or social improvement across institutions.

The sharper substantive boundary concerns labour conditions and the distribution of harm. Trueba et al. (2021) argue that procurement of healthcare goods can produce global inequalities when the conditions under which goods are made are overlooked. Abbott et al. (2024) assess potential labour-rights risks through medical-product country-of-origin information and associated risk measures. Brown et al. (2024) examine forced labour in medical-glove supply chains using worker-grounded and value-chain evidence, while Tan et al. (2026) assess modern-slavery transparency through organizational reporting. Demir and Min (2019) investigate the consistency of corporate social-responsibility reporting in the pharmaceutical industry. These contributions should not be combined as if they measured the same outcome: a risk proxy identifies exposure, a worker

account provides evidence about lived conditions, and a disclosure study describes what organizations report. Their convergence is conceptual rather than methodological: an ethical commitment to responsible purchasing is incomplete unless it can be linked to conditions in the supply chain and to evidence beyond general policy statements.

Environmental responsibility contains similar internal heterogeneity. Lavoie et al. (2024) frame healthcare procurement as a potential lever in the move toward net-zero emissions, while Torkki et al. (2024) identify practical tensions in incorporating sustainability into public procurement of personal protective equipment. Duane et al. (2019) consider the purchase and use of products within dental settings, where environmental consequences intersect with professional routines. At the same time, circularity-oriented studies address a different decision sequence: sustainable health-system food purchasing (Thottathil, 2022), pharmaceutical blockchain and resource-loop applications (Hajizadeh et al., 2025), resilient and circular health supply chains (Alfina et al., 2025), the procurement and underutilization of medical devices in lower-resource settings (Di Virgilio et al., 2025), and the management of durable devices across acquisition, maintenance, and end-of-life (Lopes et al., 2026). Chen and Zhang (2026) add an integrated evaluation perspective in biopharmaceutical supply chains. Biodiversity is represented by Butt and Arshi (2026), whose socioecological perspective widens the scope beyond emissions and waste. The low counts for these more specific domains are a finding about this selected research corpus, not a claim about their intrinsic importance or their actual prevalence in healthcare practice.

Within environmental coverage (n = 27), climate/carbon appears in 15 publications (55.6%), circularity in six (22.2%), and biodiversity in one (3.7%). Human/labour rights occur in nine of the 20 social-responsibility studies (45.0%). These nested proportions show why broad category coverage cannot stand in for specific obligations. Environmental criteria for PPE and recovery of durable devices, for example, require different interventions and evidence (Torkki et al., 2024; Lopes et al., 2026); the same is true of social disclosures versus worker-grounded evidence (Demir & Min, 2019; Brown et al., 2024).

Resilience represents a further point of conceptual intersection rather than a substitute for sustainability. The pharmaceutical coordination model of Nematollahi et al. (2018) connects periodic replenishment decisions to supply-chain and service considerations; supply disruptions and organizational constraints appear in work on public healthcare purchasing and personal protective equipment (Torkki et al., 2024). Alfina et al. (2025) more explicitly seek connections between healthcare supply-chain resilience and circular strategies. These examples illustrate why continuity of essential health services can be a responsibility in its own right, but also why it should be differentiated from environmental efficiency. A supply chain that minimizes immediate purchase costs or material use without accounting for service disruption may not achieve the same objectives as one designed for availability, recovery, and equitable access.

RQ2 concerns the distribution of attention across procurement and supply-chain activities. Distribution is the most frequently represented stage (23 studies, 76.7%), followed by purchasing (20, 66.7%) and monitoring/audit (17, 56.7%). End-of-life (12, 40.0%) and reverse flows/reuse (11, 36.7%) are also addressed, but use/maintenance is comparatively limited (eight, 26.7%). Early and relationship-building decisions attract less explicit attention: needs assessment occurs in one publication (3.3%), specification/criteria in six (20.0%), supplier selection in seven (23.3%), contracting in four (13.3%), and supplier development in five (16.7%). Because monitoring may extend over several stages and a paper can address multiple decisions, these values are best interpreted as coverage of relevant activities rather than frequencies of successive steps in a standardized procurement process.

Figure 1 demonstrates why simple category frequencies must be complemented by within-domain readings. Environmental responsibility occurs with purchasing in 19 of its 27 publications (70.4%) and with distribution in

20 (74.1%), but with needs assessment in only one (3.7%) and contracting in three (11.1%). The corresponding profile for climate/carbon shows purchasing in 13 of 15 studies (86.7%) and no joint treatment with contracting. Circularity displays a more concentrated later-stage profile: five of its six studies (83.3%) also examine end-of-life, and four (66.7%) address reverse flows or reuse. This is substantively different from simply counting all 12 publications with an end-of-life code as circular-economy research. Together, these contrasts indicate that the specific definition of responsibility matters for the decision stages that become visible in literature.



Figure 1. Co-occurrence between responsibility domains and procurement/supply-chain lifecycle stages

Note. Cells are numbers of publications jointly addressing a responsibility domain and lifecycle stage (N = 30). Larger cells may reflect more common marginal categories; interpretation also considers within-domain shares. Co-occurrence does not establish that stages are operationally connected in practice.

The limited coverage of needs assessment warrants particular attention because it precedes many of the decisions that later become difficult to reverse. It is possible to purchase a formally compliant product whose infrastructure requirements, consumables, operator training, or maintenance demands are incompatible with a facility's capabilities. A systems perspective on unused medical devices illustrates how this mismatch may emerge before the tender and persist through the asset lifecycle (Di Virgilio et al., 2025). The reverse case also matters: ongoing replenishment coordination can enhance medicine availability even when the research focus is not tender design (Nematollahi et al., 2018). Viewed together, these studies imply that responsible procurement needs to be examined as connected decisions rather than as an isolated act of acquiring a product. The evidence base contains pertinent examples of such connections, but the low cross-stage representation of needs definition and contracting shows that they are not a consistently developed object of inquiry.

Downstream cases expose another set of gaps between transactions and realized performance. Pagliusi et al. (2023) discuss vaccine traceability pilots and the operational requirements of following products across supply-chain stages. Lopes et al. (2026) examine fragmented durable-medical-device management and propose a digitally enabled circular operations framework that links asset information, maintenance, and end-of-life considerations. Duane et al. (2019) emphasize the contribution of dental purchasing and everyday product-use practices, whereas Thottathil (2022) reflects on sustainable food procurement across a health system and the organizational work required to maintain such commitments. These studies suggest that the procurement event itself is often an insufficient boundary for evaluating responsibility: the relevant evidence may concern

utilization, product condition, recovery, maintenance, worker exposure, or service delivery long after the contract has been signed.

RQ3 examines eight governance mechanisms and their co-occurrence with responsibility domains, as illustrated in Figure 2. Transparency/accountability appears in 23 studies (76.7%), collaboration in 20 (66.7%), regulation/standards in 18 (60.0%), digital technology in 14 (46.7%), lifecycle governance in 12 (40.0%), risk management in 11 (36.7%), traceability in seven (23.3%), and procurement criteria in four (13.3%). These are different governance functions: standards establish expectations; purchasing criteria structure selection; disclosures communicate practices; traceability links information to products; and monitoring may support verification. Their co-occurrence does not establish a coordinated governance system. The narrowly defined criteria code concerns substantive criterion design or application.



Figure 2. Co-occurrence between responsibility domains and governance mechanisms

Note. Cells indicate publications jointly examining a responsibility domain and governance mechanism (N = 30). Raw overlaps are interpreted relative to the coverage of each category; the matrix does not estimate mechanism effectiveness.

The largest governance intersections are strongly influenced by the prevalence of the broad environmental category. Environmental responsibility overlaps with transparency/accountability in 21 of 27 studies (77.8%), collaboration in 18 (66.7%), and regulation/standards in 17 (63.0%), but with traceability in only five (18.5%). Because transparency/accountability itself appears in 23 of 30 studies (76.7%), the raw overlap of 21 cannot, on its own, be interpreted as evidence of an especially strong relationship. What distinguishes the studies is the nature of the governance activity: work on procurement barriers and health-system policy identifies institutional constraints (Ahsan & Rahman, 2017; Ahmed et al., 2021; Opoku-Mensah et al., 2026), while the pharmaceutical regulation case of Nassè et al. (2026) addresses compliance within a different decision setting. By contrast, work on vaccine traceability concerns the practical conditions under which information follows product movements (Pagliusi et al., 2023). These forms of governance can be complementary, but the existing studies do not collectively demonstrate a standardized or universally effective combination.

The nine human/labour-rights publications provide a more focused test of this distinction. Seven address transparency/accountability (77.8%), seven regulation/standards (77.8%), and just one traceability (11.1%). The pattern suggests that labour conditions are often addressed in terms of duties, reporting, and institutional

regulation, while product-linked verification is less visible as an explicit research focus. Yet the underlying evidence is not interchangeable. Abbott et al. (2024) estimate exposure to labour-rights risk using product-country-of-origin data; Brown et al. (2024) investigate forced labour in a Malaysia-Nepal-UK glove value chain through worker survey and interviews; and Tan et al. (2026) examine how Australian healthcare buying organizations disclose and operationalize modern-slavery responses. Product-level exposure, accounts from workers and chain actors, and buyers' disclosures each illuminate part of the same governance problem. An integrated approach would need to connect these sources to contract incentives, supplier monitoring, corrective action, and independently assessed outcomes; their mere joint presence in a publication does not establish such a chain.

Digitalization further distinguishes a governance capability from a substantive responsibility. All four publications coded for digital responsibility also address digital technology, but only four of the 14 technology-coded contributions (28.6%) explicitly engage the normative dimensions classified as digital responsibility. The comparison does not imply that the other ten studies ignore ethics altogether; it indicates that ethical or accountability issues are not a substantive focus under this definition. Radanliev et al. (2021) discuss shared ethical and cyber risks in connected vaccine-supply infrastructures, whereas Pagliusi et al. (2023) investigate identification and traceability in vaccine supply chains. Hao and Zhao (2026) use a blockchain-accountability setting to examine reproductive-health supply chains, while Hajizadeh et al. (2025) consider human-centric blockchain applications for circular pharmaceutical supply chains. These contributions address different analytical objects, risk, information infrastructure, governance relationships, and circularity, so the presence of a common technology label cannot establish comparable effects or equivalent responsibility safeguards.

A further methodological contrast emerges between governance models and actual intervention evidence. The multicriteria evaluation of Yazdani et al. (2020), the structural analysis of procurement challenges by Zaidi et al. (2021), and Chen and Zhang's (2026) biopharmaceutical evaluation approach can inform how decision criteria are organized. Conversely, organizational interviews, reporting analyses, and implementation cases illuminate how instruments are applied or constrained (Rico & Oruezabala, 2012; Demir & Min, 2019; Tan et al., 2026). The first type of contribution can identify preferred alternatives or structural relationships under its assumptions; the second can reveal implementation frictions or observed processes. Neither should be represented as definitive evidence of reduced environmental harm, better labour conditions, or improved patient outcomes without relevant outcome data.

RQ4 addresses two linked but distinct issues: whose interests the literature represents and what its evidence can substantiate. Suppliers/manufacturers appear in 27 publications (90.0%), buyers or focal purchasing organizations in 21 (70.0%), and regulators or policy actors in 18 (60.0%). Patients/service users and workers each appear in 11 (36.7%), while communities/ecosystems are represented in ten (33.3%). These are counts of substantive analytical representation, not counts of participants interviewed or decision-makers with formal authority. Table 2 therefore reports the actor groups independently rather than mechanically pairing actors with the nine responsibility categories.

Table 2. Representation of actor groups in responsible healthcare procurement research

Actor group	Count (n)	Percentage (%)
Supplier / manufacturer	27	90.0
Buyer / focal procuring organisation	21	70.0
Regulator / policy actor	18	60.0
Patient / service user	11	36.7
Worker / labour	11	36.7
Community / ecosystem	10	33.3

Note. N = 30 publications. Actor categories are non-exclusive. Representation means substantive consideration of a group's role or interest; it does not necessarily indicate direct involvement in data collection or procurement decisions.

The relative visibility of different actor groups is significant, but it is not a simple measure of participation. Workers are represented in eight of the nine human/labour-rights studies (88.9%), although this includes risk assessment as well as worker-grounded research. Abbott et al. (2024) assess potential labour abuse through product-origin data, while Brown et al. (2024) draw on survey and interview evidence to investigate forced labour and the roles of states and other value-chain actors. Their difference is methodological: an external risk proxy can prioritize scrutiny, but it cannot on its own identify the working conditions experienced by particular people. Likewise, patient representation in research on pharmaceutical service levels (Nematollahi et al., 2018), safe-medicine access (Loomba, 2024), or reproductive-health supply chains (Hao & Zhao, 2026) is not equivalent to direct evidence from patients. In medical-device procurement, Di Virgilio et al. (2025) show why the capability to install, maintain, and use equipment matters to the value of the purchase, even when patient or clinical-user participation is not the study's primary empirical unit.

The inferential consequences can be organized into four broad types of evidence. Conceptual and policy analyses clarify responsibilities and plausible mechanisms, while mathematical and multicriteria models formalize trade-offs under specified assumptions. Organizational interviews, surveys, and reporting studies provide empirical material about perceptions, governance practices, and disclosed commitments, but vary in their access to upstream conditions. Product-risk analyses, operational pilots, and case-based process mapping provide more direct evidence about particular exposures or activities without necessarily establishing longitudinal impacts on patients, workers, or ecological systems. These types are not mutually exclusive methodological classes, and Table 3 offers a comparative synthesis rather than a second numerical classification of the 30 publications. The distinction matters because a modelled supplier score, a modern-slavery statement, a traceability demonstration, and verified improvement in working conditions are different evidentiary claims. They should not be combined under a single, undifferentiated assertion of responsible procurement performance.

Table 3. Principal evidence configurations and their implications for responsible procurement

Evidence setting and representative studies	What the evidence contributes	What it cannot establish alone
Hospital procurement implementation: Rico & Oruezabala (2012); Oruezabala & Rico (2012); Ahsan & Rahman (2017); Opoku-Mensah et al. (2026)	Explains institutional constraints, purchasing routines, supplier relationships, and implementation conditions.	Interview or organizational accounts do not by themselves verify downstream environmental, labour, or clinical effects.
Decision and coordination models: Nematollahi et al. (2018); Yazdani et al. (2020); Chen & Zhang (2026)	Specifies objectives, constraints, coordination mechanisms, and decision trade-offs for supplier or supply-chain choices.	Predicted or ranked alternatives depend on assumptions; realized outcomes require implementation evidence.
Labour risk, field evidence, and disclosure: Abbott et al. (2024); Brown et al. (2024); Tan et al. (2026)	Contrasts product-origin risk proxies, worker and value-chain testimony, and buyers' modern-slavery reporting.	A risk proxy, observed account, and corporate disclosure cannot be treated as equivalent proof of labour conditions.
Digital accountability and traceability: Radanliev et al. (2021); Pagliusi et al. (2023); Hao & Zhao (2026)	Examines ethical risk, technical visibility, product identification, and governance of information flows.	Improved information visibility does not automatically demonstrate ethical safeguards, equitable access, or improved health.
Lifecycle and circular operations: Thottathil (2022); Alfina et al. (2025); Di Virgilio et al. (2025); Lopes et al. (2026)	Links purchasing to service context, resource loops, device usability, maintenance, and recovery decisions.	Frameworks and case-based observations do not establish generalizable lifecycle effects without follow-up indicators.

Note. Representative studies illustrate distinct evidence claims; the groupings are not mutually exclusive and are not a frequency distribution or a ranking of methodological quality.

A stronger evidence chain can be illustrated in several product contexts. In medical gloves, origin-based risk indicators can signal priorities for further enquiry, worker and supplier accounts can identify mechanisms of

harm, and buyer contracts or audit records can reveal whether those concerns reach purchasing governance (Abbott et al., 2024; Brown et al., 2024; Tan et al., 2026). In vaccines, traceability may establish whether products can be identified and followed, but evidence of equitable access and service continuity requires additional outcomes (Pagliusi et al., 2023; Radanliev et al., 2021). In durable medical devices, a proposed digital circularity framework becomes a testable intervention only when asset utilization, maintenance requirements, recovery pathways, and clinical suitability are measured over time (Di Virgilio et al., 2025; Lopes et al., 2026). These examples demonstrate that responsibility cannot be inferred from the availability of an instrument alone; a substantive claim must specify the harm, the point of intervention, the actors who bear or mitigate the risk, and the observations that would indicate whether conditions changed.

4. Discussion and Research Agenda

The four research questions expose a common problem: studies identify responsibility concerns, decision stages, governance tools, and actors more readily than they demonstrate how these elements jointly affect outcomes. An environmental criterion does not necessarily yield circular use; a labour policy does not verify factory conditions; and traceability does not by itself establish equity. A defensible responsibility claim should therefore connect an identified obligation to an actionable lifecycle decision, governance instruments, affected stakeholders, and evidence of consequences. The four gaps below describe where such connections remain insufficiently developed.

The boundary gap concerns what is recognized as a procurement responsibility (RQ1). Broad environmental (27 studies) and social (20) classifications encompass more specific yet less visible issues, including climate/carbon (15), circularity (6), biodiversity (1), and human/labour rights (9). Carbon reduction, device recovery, ecological risk, and labour conditions concern different harms and exposed groups (Lavoie et al., 2024; Lopes et al., 2026; Butt & Arshi, 2026; Brown et al., 2024). Future research should explicitly define the obligation, product and geographical boundaries, affected parties, and outcome indicators before aggregating performance into a general sustainability score.

The lifecycle gap concerns links between the original need, product acquisition, use, and subsequent consequences (RQ2). Distribution (23 studies) and purchasing (20) receive more attention than needs assessment (1), contracting (4), or supplier development (5). This imbalance does not prove these functions are neglected in practice; it indicates limited study of their connections. Device underutilization highlights the importance of pre-purchase suitability (Di Virgilio et al., 2025), replenishment modelling addresses service continuity (Nematollahi et al., 2018), and digital device management and vaccine traceability extend attention downstream (Lopes et al., 2026; Pagliusi et al., 2023). Longitudinal product- or contract-level studies could test how early decisions affect later utilization, corrective action, and end-of-life outcomes.

The integration gap asks whether multiple governance mechanisms address a specified risk in a connected manner (RQ3). Transparency (23 studies), collaboration (20), and standards (18) appear frequently, but their joint presence does not establish enforcement. For labour rights, supplier disclosure, product-origin screening, worker evidence, contract incentives, and remediation offer distinct but potentially complementary functions (Abbott et al., 2024; Brown et al., 2024; Tan et al., 2026). Similarly, identification systems may enable verification without resolving ethical risks (Radanliev et al., 2021; Pagliusi et al., 2023). Future comparative research should examine which combinations of standards, contracting, monitoring, traceability, and corrective action operationalize particular duties in specific healthcare settings.

The evidence gap concerns whether organizational claims correspond to conditions experienced by affected groups (RQ4). Suppliers (27 studies) and buyers (21) appear more often than patients and workers (11 each) or communities (10). Analytical models, reports, risk indicators, and observed interventions cannot support

equivalent effectiveness claims. Future studies should combine procurement and contract records with independently relevant evidence, such as shortages and continuity, device utilization, emissions and recovery, or worker conditions, selected according to the responsibility being assessed. Table 4 summarizes research directions arising from these four gaps.

Together, the gaps form an analytical sequence: specify the obligation (boundary), locate the decision (lifecycle), establish the governing relationship (integration), and assess consequences (evidence). Weakness at one link limits interpretation of the others. This sequence underpins Figure 3.

Table 4. Research priorities derived from the four-dimensional evidence synthesis

Research gap and synthesis finding	Research question arising from the evidence	Suggested design and outcome indicators
Boundary (RQ1): broad environmental 27/30 vs circularity 6/30, biodiversity 1/30; broad social 20/30 vs labour rights 9/30.	How does defining a specific risk change the procurement criteria, boundaries, and stakeholders considered?	Compare product categories using explicit carbon, material recovery, labour-risk, and ecological indicators; document trade-offs rather than merging all duties into one score.
Lifecycle (RQ2): distribution 23/30 and purchasing 20/30; needs assessment 1/30 and contracting 4/30.	At which pre-purchase and post-purchase transitions do responsibility obligations become effective or fail?	Follow device, medicine, or PPE procurement cohorts from need and contract to supply, utilization, corrective action, and recovery; measure shortages, usability, maintenance, and waste.
Integration (RQ3): transparency 23/30 and traceability 7/30; labour rights × traceability only 1/9.	Which configurations of standards, buyer requirements, monitoring, and data capabilities verify a defined responsibility risk?	Comparative multi-actor implementations combining contract clauses, supplier data, independent audits, traceability, and documented remediation.
Evidence and actors (RQ4): suppliers 27/30, buyers 21/30; patients 11/30, workers 11/30, communities 10/30.	What additional evidence would distinguish policy intention and modeled performance from realized outcomes for affected groups?	Mixed-method and longitudinal designs linking procurement records to worker, patient, community, clinical-continuity, and environmental outcome evidence.

Note. Counts refer to study-level representation in the 30-publication corpus; proposed designs and indicators are future research directions.

Figure 3 links the four gaps in an integrative framework. Institutional mandates and health-service priorities shape the setting; a responsibility obligation is defined for a particular product and stakeholder boundary; and the relevant intervention point is located across needs assessment, contracting, purchasing, use, or recovery. Criteria, regulation, collaboration, monitoring, traceability, and corrective action form possible governance arrangements. Actor-specific indicators then test whether these arrangements are associated with changes in service continuity, social conditions, or environmental outcomes. The framework describes research relationships to be examined, not estimated causal effects.

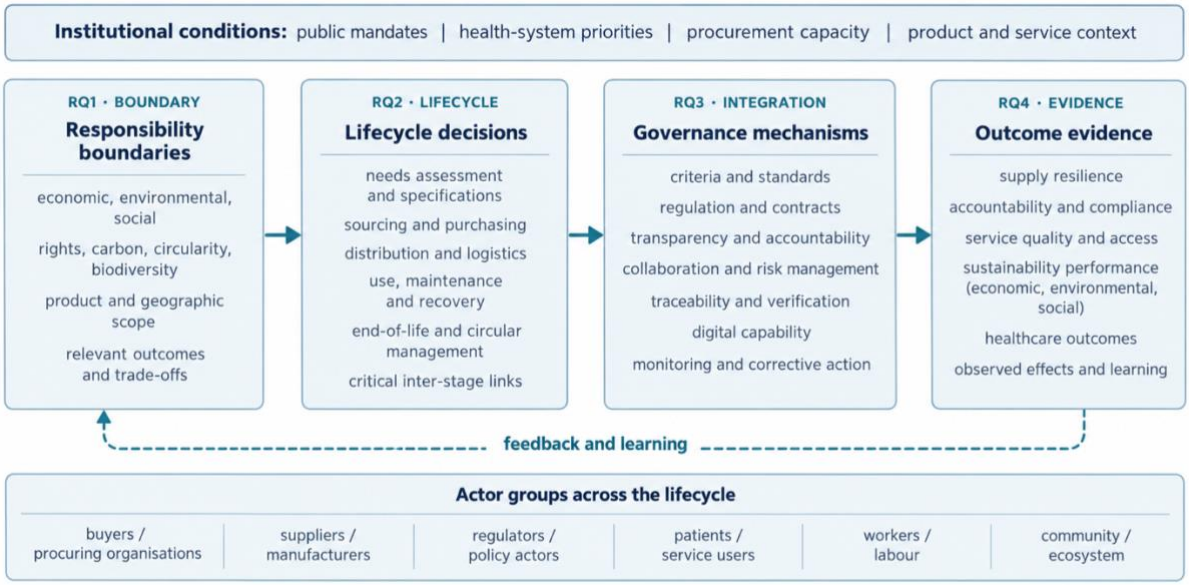


Figure 3. Integrative research framework linking responsibility boundaries, lifecycle decisions, governance, and outcome evidence

Note. The four blocks correspond to the boundary, lifecycle, integration, and evidence gaps identified in the synthesis. Relationships are proposed analytical links; they are not empirically estimated effects.

The framework accommodates product-specific responsibilities. PPE links emergency availability with environmental requirements and production labour conditions (Torkki et al., 2024; Brown et al., 2024); medicines and vaccines foreground supply continuity, traceability, and access (Nematollahi et al., 2018; Pagliusi et al., 2023; Loomba, 2024); durable devices raise suitability, maintenance, utilization, and recovery questions (Di Virgilio et al., 2025; Lopes et al., 2026). Food and dental purchasing entail different organizational and use-phase practices (Thottathil, 2022; Duane et al., 2019). Thus, common analytical questions need not impose a single universal performance indicator.

Several limitations qualify these findings. The heterogeneous, selected 30-study corpus is not representative of procurement practices across healthcare organizations. Binary publication-level coding measures substantive coverage, not depth, quality, or effectiveness. Broad and specific responsibility indicators overlap; co-occurrence identifies joint treatment within articles, not operational integration or causation. Rico and Oruezabala (2012) and Oruezabala and Rico (2012) also concern closely related French public-hospital settings, so publication counts should not be interpreted as independent organizational observations. Differences in research designs preclude pooled effect estimation. The contribution is a structured evidence map and integrative research agenda.

5. Conclusion

The review synthesizes 30 publications across responsibility domains, lifecycle stages, governance mechanisms, and actor/evidence representation. Economic, environmental, and social concerns appear widely, while more specific obligations, human/labour rights, circularity, digital responsibility, and biodiversity, are less visible. Distribution, purchasing, and monitoring receive greater attention than needs assessment, contracting, and supplier development. Transparency, collaboration, and standards are common governance subjects, but their links to independently verified effects are less developed. Buyers and suppliers dominate actor representation, while evidence ranges from decision models and organizational reports to risk indicators and direct accounts.

The proposed framework connects defined obligations to lifecycle intervention points, governance relationships, affected actors, and observable outcomes. Boundary, lifecycle, integration, and evidence gaps

therefore offer a cumulative research agenda: establish what responsibility means, where procurement can influence it, how it is governed, and whether meaningful improvement can be demonstrated. This shifts attention from sustainability labels to verifiable consequences for health services, people, and environments.

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ABSTRACT PAPER · IP1.3 · IN-PERSON SESSION I

Operational Risks in Green Logistics: Challenges and Implications for Sustainable Entrepreneurship and Green Innovation

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ABSTRACT

Green logistics has become an increasingly important strategic approach for organizations seeking to respond to stricter environmental regulations, resource scarcity, climate-related pressures, and growing stakeholder expectations for sustainable value creation. Although green logistics practices can contribute to environmental performance, operational efficiency, and competitive advantage, their implementation also creates and intensifies a range of operational risks that may undermine the successful transition toward sustainable logistics systems. Despite the growing literature on green logistics, sustainability, and green innovation, the operational risks associated with green logistics have received limited systematic attention, particularly from the perspective of entrepreneurship and organizational innovation. This paper addresses this gap by developing an integrative conceptual framework that systematically identifies, classifies, and explains the potential implications of operational risks in green logistics for sustainable entrepreneurship and green innovation. The paper conceptualizes operational risk in green logistics as a multidimensional phenomenon comprising six interrelated categories: technological and infrastructural risks, regulatory and compliance risks, supply and demand risks, financial risks, human-capital and organizational risks, and reputational and stakeholder-related risks. The framework is theoretically grounded in the Natural-Resource-Based View of the Firm (NRBV), Entrepreneurial Orientation (EO) theory, and the Sustainable Supply Chain Management (SSCM) literature. By integrating these perspectives, the study proposes that operational risk should not be viewed solely as a constraint or threat. Instead, its organizational consequences may vary according to firms' entrepreneurial orientation, organizational capabilities, resource availability, technological readiness, and capacity to recognize, absorb, and respond to uncertainty. From this perspective, operational risks may negatively affect green innovation by increasing implementation costs, disrupting logistics operations, reducing investment capacity, creating technological and infrastructural constraints, increasing regulatory uncertainty, and generating employee or organizational resistance to change. At the same time, exposure to operational risks may create pressure and incentives for firms to engage in entrepreneurial experimentation, reconfigure resources, adopt cleaner and more efficient technologies, redesign logistics processes, develop new sustainable business solutions, and strengthen organizational capabilities for environmental innovation. The framework therefore positions entrepreneurial orientation and organizational capabilities as important conditions shaping whether operational risk becomes an obstacle to, or a catalyst for, sustainable entrepreneurship and green innovation.

Keywords: Green Logistics; Operational Risk; Sustainable Entrepreneurship; Green Innovation; Green Supply Chain Management; Risk Management

ABSTRACT PAPER · S1.1 · ONLINE SESSION 1

Green Entrepreneurship as a Driver of Sustainable Economic Development

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ABSTRACT

Green Entrepreneurship is considered as a significant mechanism for integrating economic value with environmental sustainability. It involves identifying and utilising entrepreneurial opportunities through green products, technologies, services etc that reduce negative environmental impacts (OECD, 2022). The Purpose of the study is to examine how green entrepreneurship contributes to economic growth, resource efficiency, innovation, employment generation while encouraging the transition towards sustainable business models. It adopts the conceptual and exploratory approach based on the review and analysis of existing literature on green entrepreneurship, sustainable development etc which draws upon peer reviewed and institutional research to identify major avenues through which green entrepreneurship can influence major impact sustainable economic development. The review is global in scope and considers evidence across economies and sectors, focussing specially on how green entrepreneurship drives sustainable development. Existing literature indicates that increasing levels of green entrepreneurial activities are positively associated with economic and social development (Neumann, 2022). Research also shows that systematic reviews highlight the growing but fragmented nature of research on green and ecological entrepreneurship (Gast et al., 2017). The review further situates green entrepreneurship within the United Nations Sustainable Development Goals (SDGs), particularly SDG-8: Decent work and Economic Growth, SDG-12: Responsible Consumption and Production and SDG-13: Climate Action (United Nations, 2015). However, the literature remains relatively disintegrated, emphasizing the need for a more fragmented understanding of the relationship between green entrepreneurship and sustainable development (Gast et al., 2017; Benavides-Sánchez et al., 2025). The Study is expected to establish that green entrepreneurship can act as a stimulus for sustainable economic development by boosting innovation, efficient resource utilisation, generating green employment and adopting the environmental friendly business models. However, restrictions such as regulatory barriers, limited access to finance, technological challenges and market uncertainty (OECD, 2022). The study also contributes to the existing literature by providing a comprehensive perspective on the economic and sustainable dimensions of green entrepreneurship and accentuating the importance of supportive policies, green financing, entrepreneurial education in accelerating sustainable economic development.

Keywords: Sustainable Economic Development, Sustainable Business Models, Environmental Sustainability

ABSTRACT PAPER · S1.4 · ONLINE SESSION 1

Beyond Business Models: Teaching Systems Thinking for Sustainable Entrepreneurship

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ABSTRACT

Sustainable entrepreneurship requires students to engage with complex societal and environmental challenges characterised by interdependence, uncertainty, and competing stakeholder perspectives. Yet entrepreneurship education continues to be frequently organised around venture creation, business modelling, validation, and execution. This study examines what happens when entrepreneurship education instead seeks to develop systems-oriented reasoning: the capacity to interrogate complex problem spaces, recognise stakeholder interdependencies, iteratively reframe problems, and construct value propositions in response to systemic rather than predetermined constraints. The study draws on a qualitative analysis of multiple iterations of an undergraduate entrepreneurship course within a School of Economics and Business at a European public university, where a systems-oriented pedagogical framework was implemented across successive cohorts. The analysis is informed by observations from a smaller elective entrepreneurship course in biotechnology and environmental sciences, which provides a contrasting educational context. Data collected across course iterations include instructor field notes, student project artefacts, presentations, reflective submissions, and recurring patterns of participation and coordination. Findings indicate that exposure to systems-oriented concepts and tools does not itself change how students approach complex entrepreneurial problems. Students may master the language of systems thinking while continuing to rely on linear reasoning and fragmented task division. Meaningful change becomes observable when teams develop shared problem frames, integrate diverse perspectives, and engage in sustained recursive reframing. These collaborative processes, however, are fragile: their development is sensitive to class size, opportunities for sustained interaction, instructor monitoring capacity, time constraints, motivational heterogeneity, and assessment structures. The study argues that sustainability-oriented entrepreneurship education requires more than adding sustainability content to conventional business-model pedagogies. Addressing complex sustainability challenges requires systems thinking to be developed as a way of reasoning rather than taught simply as a set of analytical tools. Educational structures must therefore provide the conditions for the sustained collaborative reasoning through which systems thinking develops.

Keywords: Sustainable entrepreneurship education, Systems thinking, Transformative pedagogy, Collaborative learning, Institutional constraints

ABSTRACT PAPER · S2.1 · ONLINE SESSION 2

Exchange Rate Volatility and Sustainable Entrepreneurship in Nigeria: Evidence from Economic Indicator

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ABSTRACT

This paper examines the effect of exchange rate volatility on the economic dimension of sustainable entrepreneurship in Nigeria, using gross fixed capital formation (GFCF) as the proxy for the economic pillar of the Triple Bottom Line framework. Anchored on the Resource-Based View, the study argues that firms undertaking capital intensive investment are disproportionately exposed to currency driven cost uncertainty because a large share of machinery and capital goods used in Nigeria is imported and priced in foreign currency. Quarterly data spanning 1990Q1 to 2025/2026Q1 were sourced from the Central Bank of Nigeria, the World Bank's World Development Indicators, and the National Bureau of Statistics. Exchange rate volatility was first modelled using a GARCH(1,1) specification applied to the real effective exchange rate (REER), and the resulting relationship between REER and gross fixed capital formation was estimated using the Autoregressive Distributed Lag (ARDL) bounds testing approach, alongside an Error Correction Model (ECM) and Wald tests of short-run joint significance. The ARDL bounds test confirmed a long-run relationship among gross fixed capital formation, exchange rate volatility, domestic credit to SMEs, trade openness, and inflation ($F = 4.799$, exceeding the 1% upper bound of 4.370). Exchange rate volatility exerted a statistically significant negative long-run effect on gross fixed capital formation ($\beta = -0.0128$, $p = 0.0087$), and its short-run coefficients were jointly significant under a Wald test ($F = 2.927$, $p = 0.0365$) even though no individual short-run coefficient reached significance. About 20.8% of any disequilibrium in gross fixed capital formation is corrected each quarter. These findings, benchmarked against a parallel non-oil GDP model in which no such relationship could be confirmed, indicate that exchange rate volatility transmits to the economic pillar of sustainable entrepreneurship through a narrow, investment-specific channel rather than through broad output. The paper recommends exchange rate stability targeting and the development of hedging instruments for capital-intensive enterprises as a means of protecting long-run investment and, by extension, sustainable entrepreneurship in Nigeria.

Keywords: Exchange rate volatility; sustainable entrepreneurship; gross fixed capital formation

ABSTRACT PAPER · S2.5 · ONLINE SESSION 2

Investor Benefits from Green Finance and Impact Investment in Sustainable Firms: Insights from an Emerging Economy

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ABSTRACT

This study aims to investigate the connectedness between investments in sustainable firms and key financial asset classes, namely equities, bonds, crude oil, gold, and cryptocurrencies. In addition, it examines whether the inclusion of sustainable firms in multi-asset portfolios offers diversification benefits and enhances portfolio efficiency. The findings are expected to provide valuable insights into the role of sustainable firms in improving portfolio resilience and optimizing investors' risk-adjusted returns. As a prerequisite, the study first examines the connectedness among the selected asset classes using the extended Time-Varying Parameter Vector Autoregression (TVP-VAR) Joint Connectedness framework. Subsequently, the portfolio diversification benefits are evaluated using three widely adopted portfolio optimization strategies: the Minimum Variance Portfolio (MVP), the Equally Weighted Portfolio (EWP) and the Maximum Sharpe Portfolio (MSP). Portfolio performance is assessed by comparing the risk-return characteristics of portfolios with and without the inclusion of investments in sustainable firms, thereby evaluating their effectiveness in enhancing diversification and improving investors' risk-adjusted returns. The results of the TVP-VAR extended Joint connectedness indicates lower connectedness (22.69%) among the Green Finance-Impact Investment and other assets, namely Equity, Bond, Crude oil, Gold and Cryptocurrency. This indicates the portfolio diversification opportunity of Green Finance-Impact Investment for other assets. A portfolio without the Green Finance-Impact Investment assets reveals the Sharpe ratio of 0.12, 0.17 and 0.22, for MVP, EWP and MSP strategies, respectively. However, A portfolio without the Green Finance-Impact Investment assets reveals the Sharpe ratio of 0.13, 0.22 and 0.26 for MVP, EWP and MSP strategies, respectively. This indicates the Utility on investing on Green Finance-Impact Investment assets.

Keywords: Green Finance, Impact Investment, Sustainable Firms, Investor benefits

ABSTRACT PAPER · S4.6 · ONLINE SESSION 4

AI-Enabled Future Skills for Sustainable Entrepreneurship: A Competency-Based Framework for University Students

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ABSTRACT

The rapid integration of artificial intelligence (AI) into entrepreneurial and professional environments is transforming the competencies required by future graduates. However, higher education institutions often emphasise AI tool adoption without sufficiently addressing how AI-related competencies can contribute to sustainable entrepreneurship, employability and responsible value creation. This conceptual study proposes a competency-based framework for developing AI-enabled future skills that can prepare university students to identify opportunities, solve sustainability-related problems and create responsible entrepreneurial value. The framework integrates four dimensions: AI and digital literacy, entrepreneurial problem-solving, sustainability-oriented decision-making, and evidence-based application. Rather than treating AI proficiency as an isolated technical skill, the proposed model positions AI as an enabler of opportunity recognition, innovation, resource optimisation, market analysis and sustainability-oriented decision-making. The framework further introduces an evidence component through which students demonstrate the practical application and impact of acquired competencies through projects, entrepreneurial challenges and real-world problem solving. The study is conceptual and draws on the intersection of literature on AI-enabled entrepreneurship, future skills, entrepreneurship education and sustainability. Its expected contribution is a structured framework that universities can use to design experiential learning and competency-development initiatives aligned with the emerging green and digital economy. The framework also provides a basis for assessing not merely student participation in entrepreneurial or technology-related activities, but the competencies demonstrated and the value created through those experiences. The proposed approach contributes to sustainable entrepreneurship by linking AI capability with responsible innovation, employability and sustainability-oriented entrepreneurial action. It offers implications for universities, educators and entrepreneurship-support ecosystems seeking to prepare students for increasingly AI-enabled and sustainability-conscious labour markets.

Keywords: Artificial Intelligence; Sustainable Entrepreneurship; Future Skills; Entrepreneurial Competencies; Sustainability

ABSTRACT PAPER · S5.1 · ONLINE SESSION 5

Educating Students for the Bioeconomy: A Pathway to Sustainable Innovation

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ABSTRACT

As global challenges such as climate change, resource depletion, and environmental degradation intensify, the transition toward sustainable development has become imperative. The bioeconomy, grounded in the use of renewable biological resources for producing food, energy, and bio based materials, represents a transformative approach to achieving environmental resilience and economic growth. Yet, the success of this paradigm depends on cultivating a workforce equipped with interdisciplinary expertise that bridges biology, technology, economics, and ecological ethics. Integrating bioeconomy education into academic curricula enables students to understand the circular use of resources, life cycle thinking, and innovation in bioprocesses. It fosters competencies in biotechnology, environmental management, and sustainable entrepreneurship, skills essential for addressing complex global problems. Universities play a pivotal role by embedding experiential learning, industry collaboration, and policy awareness into teaching frameworks. Through project based learning and cross disciplinary research, students can translate theoretical knowledge into practical solutions that support low carbon production systems and green innovation. Ultimately, bioeconomy education nurtures a generation of professionals capable of designing regenerative systems that balance economic viability with ecological integrity. By aligning educational strategies with sustainability goals, higher education institutions become catalysts for a sustainable bioeconomy workforce, driving innovation that benefits both society and the planet.

Keywords: Global sustainability, bio-based products, educational curriculum, bioeconomy careers, circular economy, biotechnology education

ABSTRACT PAPER · S5.2 · ONLINE SESSION 5

Promoting Green Skills in Future Distribution and Logistics Managers through Gamification

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ABSTRACT

As globalization expands, distribution and logistics have emerged as crucial drivers of the modern economy, yet they also stand among the most significant contributors to environmental pollution. Addressing this challenge requires future managers who are not only aware of these ecological impacts but are also equipped with strategies to mitigate them within complex, multi-stakeholder environments. This paper presents an innovative pedagogical approach designed to foster green skills among tomorrow's supply chain leaders through an interactive computer simulation game. Played by two competing teams of Master level university students, each comprising four distinct roles, the simulation challenges participants to make supply chain and logistics decisions that balance commercial objectives with environmental sustainability. To evaluate the effectiveness of this educational intervention, a survey was administered to participating students. The empirical findings demonstrate that gamification exerts a strongly positive influence on both intrinsic and extrinsic student motivation, while simultaneously enhancing overall learning satisfaction. These heightened motivational dynamics facilitate a deeper learning process, directly contributing to the acquisition of vital competencies required for sustainable supply chain management. By focusing on higher education, this study highlights the pivotal role that young professionals play in driving the broader transition toward a sustainable economic transformation and adapting to evolving labor market demands. Ultimately, this paper is expected to serve the SEFGEN 2026 Conference as a valuable case study of best practices in postgraduate education, offering actionable insights and inspiration for university lecturers, curriculum designers, and academic decision-makers aiming to embed green competencies into distribution, supply chain, and logistics management programs.

Keywords: Green skills; distribution and logistics managers; gamification; interuniversity collaboration

ABSTRACT PAPER · S6.3 · ONLINE SESSION 6

Mentorship Models for Women Entrepreneurs in Türkiye: Comparison of Cases

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ABSTRACT

Entrepreneurship is considered vital to countries' economies, creating employment, innovation, growth, and societal welfare (Van Praag & Versloot, 2008). In this conventional framework, women's entrepreneurship plays a more prominent role in economic growth, providing multi-layered benefits to society, including individual, resource, and network development (Hechevarría et al., 2019). However, compared to male entrepreneurs, women entrepreneurs encounter systematic challenges in acquiring knowledge, financial resources, and support systems (Amrutha et al.,2022). In this regard, mentorship programmes function as an intervention tool that helps overcome disadvantages faced by women entrepreneurs. This research investigates mentorship programmes for women entrepreneurs in Turkiye through the lens of an analytical framework in the mentorship literature, which includes goals and vision, matching, training and preparation, communication frequency, structural support, and evaluation. The study adopts qualitative document analysis through reviewing multiple cases that operate mentorship programmes using publicly available corporate resources such as activity reports, sustainability reports, and social impact analyses. The programmes are ÜNLÜ & Co Women Technology Entrepreneurs Academy, TÜRKONFED Women's Power in Entrepreneurship Project, Profilo–Habitat Association Women's Business Entrepreneurship Project, and Young Women Building Their Future. The results reveal that Turkish mentorship programs are relatively transparent regarding their “Goals and Vision,” “Training and Preparation,” and “Structural Support” components; conversely, the “Matching” and “Frequency of Communication” components are not publicly reported by most programs. In terms of transparency, the “Evaluation” component shows significant differences among institutions: corporate companies provide substantial data, whilst NGO-led programs disclose minimal data. By examining Turkish mentorship programs for women entrepreneurs alongside comparable examples from international literature (Spain, Serbia, France, South Africa), the study indicates that hybrid delivery models and systematic monitoring and evaluation (M&E) mechanisms might be practical in Turkiye. The results suggest that policymakers should focus on raising transparency and impact-measurement standards in mentorship programs and on monitoring mentees' development.

Keywords: Mentorship models, women entrepreneurship, comparison analysis

ABSTRACT PAPER · S6.4 · ONLINE SESSION 6

Women's Leadership Contribution to Carbon Reduction in Entrepreneurial Firms

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ABSTRACT

Women's leadership roles in corporate carbon reduction in entrepreneurial firms have not been examined from multiple theoretical perspectives. Motivated by this gap, this study collects data from Chinese manufacturing firms to investigate the contributions of women's leadership to corporate carbon performance. This study employs ordinary least squares regression models, evolutionary game theory, and propensity score matching with difference-in-differences to investigate the research question. It reveals that the effect of women's leadership on carbon reduction is a double-edged sword. It suggests that women managers, who account for at least 10% of the total, with an upper limit around 30%, play a significant role in corporate carbon reduction. Otherwise, this linear relationship becomes U-shaped, reflecting a bottleneck in carbon reduction related to women's leadership. According to resource dependence theory, connecting with external resources and religious beliefs can enhance this contribution; however, family background cannot. This contribution is attributed to the more diligent agency commitment to the environmental performance of female leaders compared with their male counterparts. It initially argues that board gender diversity has no significant association with firm carbon performance, once the female leadership is not over the critical mass value. The findings broaden the existing theoretical framework for corporate governance and social responsibility in manufacturing-dominated economies.

Keywords: Women leadership, Corporate decarbonization, Gender diversity, Corporate governance

ABSTRACT PAPER · S6.6 · ONLINE SESSION 6

Every Click Leaves a Trace: Digital Footprint Awareness, Curriculum Integration and Sustainable Digital Education in the Pre-University Schools

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ABSTRACT

The rapid digitalisation of education has increased the online presence of students and teachers, making digital technologies an increasingly integral part of contemporary educational, social, and professional life. Online activities generate persistent digital footprints that can influence individuals' digital identities, privacy, security, and future opportunities. Consequently, understanding digital footprints and their environmental impact has become a key component of digital competence, responsible digital citizenship, online safety, and sustainable digital behaviour. Our study is part of an Erasmus+ project conducted by research teams from four European countries (Germany, Portugal, Romania, and Turkey); it focuses on the situation in Romania, investigating the extent to which teachers and students understand the long-term implications of their online activities and feel prepared to manage their online behaviour responsibly and sustainably. The research combined a qualitative analysis of the national education framework (legislation, curricula, relevant policy documents) and key stakeholders - conducted using the Textoscopia app - with a questionnaire-based survey involving teachers and students regarding digital footprints and digital carbon footprints. Our analysis revealed that, although current curricula address topics such as responsible internet use, cybersecurity, digital literacy, and sustainability, explicit learning objectives regarding digital footprints and digital carbon footprints are largely absent. While various related concepts exist, they are distributed across different subject areas and educational levels, resulting in fragmented learning experiences. Consequently, the ability of teachers and students to understand how digital traces are created and managed - and to recognise the social, ethical, security, and environmental implications of digital activities - is limited. Instead of proposing the introduction of a separate school subject, the study recommends integrating education on digital footprints and digital carbon footprints into existing curricula through interdisciplinary and age-appropriate approaches. Strengthening teachers' professional development and students' digital skills can foster more responsible and sustainable online behaviour, enabling young people to participate safely, ethically, and effectively in contemporary digital society.

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Keywords: Digital footprint, digital carbon footprint, pre-university sustainable education, curriculum development

ABSTRACT PAPER · S7.1 · ONLINE SESSION 7

Sustainability Strategies and Internationalization of SMEs: Literature Review, Managerial Implications, and Academic Perspectives

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ABSTRACT

The circular economy (CE) offers a new perspective for firms to balance growth, environmental issues, resource scarcity, and social constraints (Geissdoerfer et al., 2017). It challenges linear production models, promoting resource efficiency, waste reduction, product longevity, reuse, recycling, and innovative business models. CE also gains importance in international business (IB), where cross-border activities can enhance economies of scale, resource efficiency, and sustainable practices (Chabowski et al., 2023; Kansheba et al., 2024). International firms show limited adoption of activities contributing to the SDGs, and circular models haven't yet reversed emissions and waste trends. A key reason may be the limited understanding of how CE principles are adopted by globally active SMEs. This gap is important. SMEs drive economic growth, innovation, and sustainability (Audretsch & Guenther, 2023; Hockerts & Wüstenhagen, 2010). Through international expansion, they spread new standards, practices, and responsible value-creation across borders (Dimitropoulos et al., 2023; Sinkovics et al., 2021). Research on the circular economy and IB mainly focuses on multinationals (Chabowski et al., 2023; Di Stefano et al., 2023; Kansheba et al., 2024), while integrating sustainability, CSR, and circularity into SME internationalization remains fragmented (Csibi, 2026; Denicolai et al., 2023). Consequently, little is known about how circular principles influence SMEs' international paths, strategies, and tensions. This research adopts a two-stage design. First, through a CE lens, we review 29 articles at the intersection of sustainability and SME internationalization, tracing how the field has developed since 2018 and covering principles, methods, and theories. Identifying three insights: sustainable practices depend on managerial values, capabilities, and stakeholder pressures; internationalization can drive circular transformation through exposure to new standards and partnerships; and the adoption of circularity is gradual, based on experimentation and learning. These form an initial framework. Second, the study compares three SME cases, Eco-Fashion, Cleaning tech, and Agri-tech, using interviews with founders, managers, specialists, and academics, as well as secondary data from websites and articles. This allows examining how circularity is interpreted, implemented, and justified across industries and settings. Our study advances knowledge on SMEs' circular internationalization, showing how it shapes business model transformation, strategies, and stakeholder management beyond economic factors. It illustrates circularity as an evolving process with trade-offs among growth, resources, and openness, offering insights into how international SMEs build responsible, circular trajectories across contexts. Accordingly, we ask: What circular practices are adopted by sustainability-focused SMEs during international expansion, and what challenges do they encounter?

Keywords: Sustainability strategies; Corporate social responsibility (CSR); Sustainable development; Internationalization strategy; International performance

ABSTRACT PAPER · S7.2 · ONLINE SESSION 7

Exploring the Drivers of Ecological Footprint in OECD Countries: Effects and Transmission Channels

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ABSTRACT

Our study aims to analyze the determinants of Ecological Footprint on environmental quality in OECD countries with a particular focus on assessing whether institutional quality of governance measured by an index, improves environmental quality to support sustainable development.In this context, we used the Method of Moments Quantile Regression (MMQR) for 30 OECD countries over the 1990/2022 period.We show that renewable energy exerts a negative and significant influence on the ecological footprint across the entire distribution. Similarly technological innovation affect negatively and significantly the ecological footprint across all quantiles. Whereas natural resource rents are positively associated with the ecological footprint. Urbanization exerts a negative and statistically significant effect on the ecological footprint. Human capital exhibits a positive and statistically significant relationship with the ecological footprint across all quantiles, indicating that its accumulation tends to heighten environmental pressures. We show also a validity of the inverted U-shaped Environmental Kuznets Curve (EKC) pattern observed among OECD nations. The findings carry important practical implications for policymakers, businesses, and other stakeholders. Governments should accelerate investment incentives and tax exemptions for renewable energy projects. Expanding renewable infrastructure especially in wind, solar, and bioenergy can deliver immediate reductions in ecological footprint. To foster technological innovation, policymakers must adopt a long-term strategies should emphasize research and development in low-carbon technologies, circular-economy solutions, and energy-efficient systems. To enhance governance effectiveness, institutional reforms should focus on enforcing environmental regulations, increasing transparency in resource management, and combating regulatory capture.

Keywords: Ecological Footprint, Renewable energy, Technological innovation

ABSTRACT PAPER · S7.5 · ONLINE SESSION 7

An Analysis of the European Agri-Food Sector from a Sustainability Perspective. Food Safety or a Healthy Environment? Can We Choose?

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ABSTRACT

Expanding agri-food output remains essential for global food security, yet this pursuit is inherently restricted by the ecological footprint of agricultural practices. This study investigates the complex ways in which agricultural, demographic, and sustainability factors drive agri-food production and environmental degradation across the European Union. Utilizing a panel dataset for the EU27 spanning 2011–2022, the research employs robust econometric frameworks, including Structural Equation Modeling (SEM) and a system Generalized Method of Moments (GMM), alongside predictive Vector Autoregression (VAR) models to forecast trends up to 2027.The empirical insights indicate that agri-food yields are the product of intricate interactions among land utilization, demographic shifts, and environmental frameworks. While arable land enhances agricultural output, it simultaneously compromises environmental integrity through the intensive application of agrochemicals. This detrimental impact of food cultivation and land use on environmental quality compounded by indirect demographic pressures is further validated by the GMM estimations. Although the European agricultural sector exhibits a progressive transition toward green practices, the empirical evidence underscores an urgent need to accelerate these initiatives. Furthermore, the VAR projections indicate a decoupling trend, where overall emissions are expected to decrease despite a projected rise in sector-specific agricultural emissions. Ultimately, this paper outlines critical policy interventions centered on technological innovation, resource efficiency, and sustainable governance. Moreover, the results show that, in the short and medium term, the European Union should prioritize food security, as there is no alternative in the food security - environmental sustainability relationship.

Keywords: Agriculture, sustainability, food production, greenhouse gas emissions

ABSTRACT PAPER · S8.4 · ONLINE SESSION 8

Green Digitalization, Urban Smartness, and Institutional Quality: Determinants of the Load Capacity Factor in G20 Economies

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ABSTRACT

This study investigates the drivers of ecological resilience in G20 economies by utilizing the Load Capacity Factor (LCF) as a comprehensive environmental benchmark. Employing a Method of Moments Quantile Regression (MMQR), the research demonstrates that green innovation, green digitalization, smart city development, and institutional quality serve as the primary catalysts for ecological restoration. The results also validate the Environmental Kuznets Curve (EKC) hypothesis, revealing a non-linear relationship between economic expansion and environmental quality. Notably governance quality acts as a critical moderator, significantly amplifying the positive impacts of green technological innovation and green digital investments on ecological outcomes. The findings highlight the importance of coordinated policies integrating technological innovation, digital transformation, renewable energy deployment, and strong governance frameworks to enhance ecological resilience and sustainability.

Keywords: Ecological Footprint, Renewable energy, Technological innovation, Institutional quality of governance, Method of Moments Quantile Regression

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