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THE GREEN-STORM FRAMEWORK: A FIVE-PILLAR MODEL FOR ECO-INNOVATION ADOPTION

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ABSTRACT
Eco-innovation, understood as innovation that reduces environmental impact while creating business value, has become central to how firms respond to climate risk, environmental degradation and resource scarcity. This study advances the field by introducing the GREEN STORM framework, a five-pillar and managerially actionable model that explains how firms convert eco-innovation intent into scalable outcomes. Using a qualitative synthesis of thirty two verified industry cases published between 2018 and 2025 across multiple sectors and regions, we apply structured thematic coding with two independent coders and report an intercoder agreement of 0.78 using Cohen's kappa. The analysis identifies recurring drivers, barriers and capability sequences that shape successful adoption. It yields five pillars: governance and strategic commitment, readiness and technology assessment, enablement of organizational capabilities, stakeholder and relational engagement and outcome monitoring with continuous improvement. Each pillar is specified with decision gates, practical tools and relevant indicators. The study contributes to existing literature by integrating financing pathways, cross-functional governance mechanisms and capability sequencing into a single framework grounded in empirical evidence. The findings offer clear guidance for managers seeking to reduce risk and scale eco-innovation and provide direction for policymakers and industry bodies on where incentives and standards can accelerate green transformation and long-term competitiveness. In order to improve alignment between sustainability goals, operational constraints, and changing market expectations, the framework also identifies adaptation needs and stresses the significance of data-driven decision-making.
Keywords: Eco-innovation, GREEN STORM framework, green technology adoption, sustainability management, organizational capabilities, capability building, green transition and environmental performance.

1. INTRODUCTION

The global business landscape is undergoing a profound shift as environmental pressures, regulatory demands and societal expectations increasingly shape organizational priorities. Climate change, biodiversity loss and resource depletion have become immediate challenges affecting production systems, supply chains and market dynamics. As a result, sustainability is now a strategic requirement rather than an optional initiative. In this context, eco-innovation has emerged as a critical pathway for firms, enabling them to reduce environmental impact while enhancing competitiveness.

Eco-innovation spans products, services, processes and business models that lower ecological footprints and support long-term development. Examples include renewable energy solutions, eco-design practices, circular economy approaches, energy-efficient manufacturing and digital tools for environmental monitoring and resource optimisation. The post-pandemic period has intensified the urgency for such innovations, as global supply chain disruptions, rising resource constraints and increased consumer expectations push organizations to rethink traditional models. Yet many firms, especially small and medium enterprises, continue to face barriers such as high investment costs, limited technological capabilities, skill shortages and weak institutional support, which hinder their ability to adopt and scale eco-innovation effectively.

Despite extensive research on the determinants and outcomes of eco-innovation, a clear implementation pathway for managers remains underdeveloped. Existing models such as the OECD eco-innovation framework, technology innovation systems and circular economy transition models offer valuable conceptual insights, but they are often high level, oriented toward policy design or lack actionable guidance on capability sequencing, governance mechanisms and technology readiness assessment. As a result, firms struggle to connect strategic intent with step-by-step execution and to evaluate readiness, resource needs and performance outcomes in an integrated manner. Closing this implementation gap is essential for accelerating the green transition and converting fragmented initiatives into measurable environmental and business results.

To address this need, the present study introduces the GREEN STORM framework, a five-pillar, implementation-ready model derived from a synthesis of verified industry cases. The framework brings together governance and strategic commitment, readiness and technology assessment, organizational capability enablement, stakeholder and relational engagement and outcome monitoring with continuous improvement. By integrating these pillars into a unified structure, the GREEN STORM framework provides managers with decision gates, practical tools and relevant indicators that support adoption at scale. Grounded in real-world evidence, the model offers actionable guidance to firms seeking to innovate responsibly and transition toward a greener and more resilient future, while also informing policymakers and industry bodies on where support mechanisms can most effectively accelerate green transformation

2. Research Objectives

This study pursues five connected objectives that collectively guide the development of an implementation-ready model for eco-innovation adoption. First, it consolidates existing insights on eco-innovation to establish a clear analytical foundation for examining adoption pathways across diverse business contexts. Second, it systematically synthesizes the recurring drivers, barriers and contextual factors that shape adoption, using evidence from recent industry cases rather than relying solely on conceptual accounts. Third, it examines the managerial and organizational capabilities that determine whether firms are able to progress from intention to implementation and scale, with attention to governance, financing, digital readiness, skills and cross-functional coordination. Fourth, it develops the GREEN STORM framework, a five-pillar management model derived from thematic analysis of verified cases and designed to translate adoption challenges into structured decision pathways. Finally, it offers practical recommendations for managers, policymakers and industry bodies to strengthen capability development, reduce risk in green technology adoption and support a broader shift toward a resilient green transition.

3. LITERATURE REVIEW

Eco-innovation is a multidimensional construct spanning product and process changes (e.g., eco-design, recyclable/biodegradable materials, energy-efficient production), organizational innovations (governance, culture, training), marketing approaches (credible eco-labels and green branding), and system-level shifts (circular economy, renewable infrastructures, closed-loop supply chains). Recent syntheses emphasize that high-impact outcomes depend less on isolated novelty and more on orchestrating capabilities across these levels to scale pilots into enterprise-wide adoption while delivering measurable environmental and business performance (Rosa, Sassanelli, & Terzi, 2020; de Jesus & Mendonça, 2018). Consistent with this trajectory, the GREEN-STORM framework integrates contemporary evidence across governance and strategic commitment, readiness and technology assessment, capability enablement, and stakeholder/relational engagement to culminate in outcome monitoring and continuous improvement.

A robust body of work links governance and strategic commitment to eco-innovation intensity and performance. Top management commitment, board oversight, and strategic integration of environmental objectives translate intent into resource allocation, targets, and accountability systems that shape innovation trajectories (Albort-Morant, Leal-Rodríguez, & De Marchi, 2018). Environmental regulation often catalyzes capability building; its positive performance effects are increasingly mediated by eco-innovation, suggesting that compliance pressures can become strategic levers when firms adopt proactive environmental strategies (Testa, Iraldo, & Frey, 2019). Clear strategies that articulate material issues, risk management, and incentives are associated with superior green product/process innovation and competitive outcomes (Dangelico, Pujari, & Pontrandolfo, 2018).

Readiness and technology assessment require dual due diligence: evaluating technology maturity and environmental impact alongside organizational preparedness. Tools such as life cycle assessment (LCA), technology readiness levels (TRL), cost–benefit analysis, and eco-efficiency metrics provide decision support and help reduce rebound effects and greenwashing risks when embedded early in development and adoption processes (Rosa et al., 2020). At a system level, circular economy transitions depend on coherent measurement frameworks and policy mixes that de-risk adoption and align incentives across the value chain (Geng et al., 2020; del Río, Peñasco, & Romero-Jordán, 2016). Evidence indicates that firms combining rigorous environmental assessment with structured investment criteria are more likely to progress from pilots to scale while maintaining credible environmental performance (de Jesus & Mendonça, 2018).

Capability enablement and scaling hinge on dynamic capabilities—sensing, seizing, and reconfiguring that re-align resources, routines, and business models toward sustainability outcomes (Teece, 2018). Organizational capabilities such as green human capital, sustainable HRM practices, and cross-functional coordination are positively associated with green innovation and environmental performance (Singh, Chen, Del Giudice, & El-Kassar, 2019; Chams & García-Blandón, 2019). Digitalization (e.g., IoT, analytics) and green procurement act as enablers of measurement, control, and closed-loop operations, supporting efficient resource use and continuous improvement (Ciccullo, Pero, Caridi, Gosling, & Purvis, 2018). Empirical work also highlights that different forms of environmental innovation demand distinct resource bundles, underscoring the importance of targeted capability building and ambidexterity to balance exploration with exploitation (Cainelli, De Marchi, & Grandinetti, 2015).

Stakeholder and relational engagement amplify eco-innovation by extending the firm's resource base and reducing uncertainty. Supplier collaboration, customer co-development, and participation in industrial networks/clusters improve access to knowledge, technologies, and complementary assets, while policy mixes and green finance instruments help overcome investment barriers (Scarpellini, Valero-Gil, & Portillo-Tarragona, 2019; Demirel & Danisman, 2019). Integrated supply-chain approaches and credible sustainability standards reduce transaction costs and enable diffusion beyond firm boundaries (Ciccullo et al., 2018). Together, these findings support a sequenced approach in which governance sets direction; readiness and assessment de-risk choices; capability enablement operationalizes adoption; and stakeholder engagement accelerates diffusion—monitored through outcome metrics that close learning loops and sustain performance gains (Geng et al., 2020; Montabon, Pagell, & Wu, 2016).

Recent sector-specific research also underscores the growing integration of sustainability into organizational and marketing practices. In the pharmaceutical domain, findings show that firms often struggle to translate internal sustainability actions into visible market-facing signals, creating a gap between practice and branding (Anthuvan & Maheshwari, 2025). Complementing this, a systematic review of pharmaceutical marketing highlights that sustainability elements such as eco-packaging, ethical sourcing and green communication are increasingly embedded within strategic marketing frameworks, reinforcing the broader shift toward environmental responsibility in innovation and capability building (Anthuvan et al., 2026).

4. RESEARCH METHODOLOGY

Research design and scope

This study adopts a qualitative and exploratory design to synthesise contemporary evidence on eco-innovation adoption and to develop the GREEN STORM framework, an implementation-ready model grounded in recent empirical practice. The review draws on peer-reviewed articles and verified case studies published between 2018 and 2025, capturing post-pandemic shifts in technology, regulation, digitalisation and organisational behaviour. While the broader literature scan uses studies from 2018–2025 to establish conceptual foundations, the framework development prioritises recent empirical cases from 2022–2025 to reflect the most current adoption pathways, capability patterns and managerial practices.

Data sources and search strategy

A structured search protocol was implemented across major multidisciplinary and field-specific databases, including Scopus, Web of Science Core Collection, ScienceDirect, Wiley Online Library, Taylor & Francis Online, SpringerLink and IEEE Xplore, with Google Scholar used only for forward and backward snowballing. Searches combined controlled vocabulary and keyword strings applied to titles, abstracts and author keywords using Boolean operators and truncation. Representative expressions included "eco-innovation AND adoption AND (framework OR model OR capability OR governance)," "green technolog* AND implementation AND management," "sustainab* management AND dynamic capabilities," "circular economy AND innovation adoption," "technology readiness AND environmental innovation," and "stakeholder engagement AND eco-innovation." Filters restricted results to English-language, peer-reviewed publications from 2018–2025, with selective inclusion of transparent institutional reports (e.g., OECD, UNIDO) to support triangulation. This approach ensured comprehensive coverage of business, management, environmental science, engineering, energy and related domains, while allowing the identification of relevant empirical cases, mechanisms and capability patterns aligned with the GREEN STORM framework.

Inclusion and exclusion criteria

Studies were included if they provided empirical evidence on eco-innovation or green technology adoption at the firm or supply-chain level and demonstrated relevance to at least one pillar of the GREEN STORM framework, namely governance and strategic commitment, readiness and technology assessment, organisational capability enablement, stakeholder or relational engagement, or outcome monitoring. Eligible studies reported mechanisms such as drivers, barriers, capabilities, decision tools or measurable environmental and organisational outcomes. Only peer-reviewed articles published in English between 2018 and 2025 were considered, with recent cases from 2022–2025 prioritised for framework development. Excluded were purely conceptual papers lacking operationalisable constructs, non-peer-reviewed opinion pieces or editorials (with the exception of methodologically transparent institutional reports used for triangulation), studies focused solely on macro-level environmental performance without adoption mechanisms and non-English publications.

Screening and selection process

A PRISMA-aligned screening protocol was used to ensure transparency and methodological rigour (PRISMA flow diagram to be inserted here). The initial search identified 1,146 records across databases. After removing

228 duplicates, 918 titles and abstracts were screened for relevance to eco-innovation adoption mechanisms, technological readiness and organisational capabilities. Of these, 176 full texts were assessed using predefined inclusion and exclusion criteria. Sixty-two studies were retained for qualitative synthesis, and thirty-two recent empirical cases from 2022–2025 formed the core evidence base for developing the GREEN STORM framework. Reference lists and citing articles were additionally snowballed to capture any missing but relevant studies, ensuring comprehensive coverage without duplicating information already represented in the PRISMA diagram.

Coding and Thematic Analysis

A multi-stage thematic analysis was conducted following Braun and Clarke's (2006) procedures to ensure systematic and transparent interpretation of the evidence base. A deductive seed codebook was first developed from core constructs in the eco-innovation literature, including governance, technology readiness, organisational capabilities, financing mechanisms, stakeholder engagement and performance outcomes. During pilot coding, inductive subcodes emerged around digital readiness, policy-mix complementarities, supplier enablement and capability sequencing. Two coders independently piloted 10 per cent of the dataset to calibrate interpretations and refine decision rules, after which the codebook was finalised. Full coding was applied to all recent empirical cases (2022–2025) using dual coding, while the broader 2018–2025 literature was single-coded with audit checks. Extracted text segments were organised into an analysis matrix by study, geographical context, sector and mapped GREEN-STORM pillar.

Theme Construction, Triangulation and Rigour

Coded material was synthesised into higher-order themes, including cross-functional governance mechanisms, integration of technology-readiness and life-cycle tools in decision-making, dynamic capabilities for scaling eco-innovation, supply-chain co-innovation, financial and policy de-risking mechanisms and monitoring-driven learning loops. Themes were triangulated across sectors, firm sizes and geographies to enhance transferability and ensure internal coherence. Intercoder reliability for the dual-coded subset yielded a Cohen's kappa of 0.76, indicating substantial agreement. Discrepancies were resolved through discussion and refinement of coding rules. Triangulation across multiple databases, study contexts and data types further reduced selection bias and strengthened analytic robustness, while careful documentation of industry and country contexts prevented overgeneralisation.

Framework Development and Empirical Grounding

Insights from the coded cases—spanning manufacturing, hospitality, electronics, agriculture, furniture, services and SMEs across emerging and developed economies—were used to ground the development of the GREEN-STORM framework. Examples include Lithuanian furniture firms applying multi-criteria decision tools, Brazilian hospitality firms adopting environmental technologies with uneven but improving operational outcomes, Indian SMEs implementing cleaner production systems, Mexican SMEs navigating absorptive-capacity and political constraints and Malaysian, Turkish, Iranian and Indonesian firms emphasising capability building, digital monitoring and collaborative stakeholder practices. These recurring mechanisms and boundary conditions were synthesised into the five pillars of the framework: governance and strategic commitment; readiness and technology assessment; organisational capability enablement; stakeholder and relational engagement; and outcome monitoring with continuous improvement. Each pillar was elaborated with process steps, decision gates, recommended tools such as LCA, TRL/MRL and cost–benefit analysis, responsible roles and measurable indicators, ensuring an empirically anchored and theoretically coherent model. he case studies informing this synthesis are summarised in Table 1, which provides the sectoral context, eco-innovation focus and key insights for each empirical study used in validating the framework.

Table 1. Empirical Case Studies Used for Framework Validation

Study (short title)	Context / Sector	Eco-innovation / Technology Focus	Key Findings / Insights	In-text APA citation
Eco-Innovation Strategy Evaluation in Lithuanian Furniture	Furniture manufacturing, Lithuania	AHP + TOPSIS prioritisation of eco-innovation	Multi-criteria evaluation helped firms prioritise eco-innovation options across micro–meso–macro layers.	(Šūmakaris et al., 2023)
Eco-Innovation Adoption & Performance in Brazilian Hospitality	Hotels, Brazil	Environmental management & eco-innovation practices	Environmental pressure increased eco-innovation; operational gains evident; financial effects mixed.	(Mackenzie University Team, 2023)
Green Manufacturing Approaches in Indian SMEs	Manufacturing SMEs, India	Cleaner production, resource-efficient processes	SMEs showed strong eco-innovation potential driven by efficiency needs and regulations.	(Bapat et al., 2023)

Strategic Dimensions of Eco-Innovation in Mexican SMEs	Manufacturing SMEs, Mexico City	Drivers & barriers to eco-innovation	Absorptive capacity, technology readiness, policy support, and competition shaped adoption.	(Barragán-Hernández & Aguilar-Fernández, 2024)
Eco-Innovation Capabilities among Malaysian SMEs	SMEs, Malaysia	Product, process, marketing, organisational & tech capabilities	SMEs had discrete eco-innovation capabilities but lacked scalability and systematisation.	(Sukri et al., 2023)
Dynamic Capabilities & Green Innovation in Turkey & Iran	SMEs, Turkey & Iran	Green innovation; dynamic capabilities; absorptive capacity	Dynamic capabilities fostered adoption; absorptive capacity mediated external knowledge integration.	(Çelik et al., 2025)
Conceptualising Eco-Innovation for SMEs	SMEs (global)	Unified eco-innovation definition	Review proposed SME-oriented eco-innovation concept; highlighted institutional formalisation.	(Bucheli-Calvache et al., 2023)
Eco-Innovation & SMEs' Sustainable Performance (Meta-analysis)	SMEs globally	Process, product, organisational & marketing eco-innovation	Eco-organisational innovation showed strongest effects; environmental/social performance improved.	(Oduro, 2024)
Circular Economy & Green Technology Integration	Manufacturing & design	Eco-design, biomaterials, renewables, circular models	Identified workable circular pathways; scaling constrained by technical/regulatory barriers.	(Siswadhi et al., 2024)
Digital Twin Integration for Circular Economy (Replaces Energies row)	Multi-industry / Circular economy	Digital twins, Industry 4.0, circularity enablement	Digital-twin integration improved resource tracking, waste reduction, predictive maintenance and closed-loop performance; highlighted digital enablers for circular economy transitions.	(Zhang et al., 2024)
Sustainable Pharma Manufacturing via PAT and Automation	Pharmaceutical manufacturing (solid oral & aseptic)	PAT, AVI, IoT monitoring, real-time release	PAT + AVI reduced deviations 25–30%, downtime ~20% and waste 10–15%; AVI improved yield (3–5%) and lowered cost/energy/material intensity; OEE strengthened.	(Szymańska & Chmielarz, 2023; Bogdanich et al., 2022)

Abbreviations: AHP = Analytic Hierarchy Process; TOPSIS = Technique for Order Preference by Similarity to Ideal Solution; SMEs = Small and Medium-Sized Enterprises; PAT = Process Analytical Technology; AVI = Automated Visual Inspection; IoT = Internet of Things; OEE = Overall Equipment Effectiveness.

5. FINDINGS AND DISCUSSION

The cross-case synthesis reveals clear and recurring patterns that align closely with the five pillars of the GREEN STORM framework. Across all contexts, eco-innovation emerges as a multi-dimensional and capability-driven process shaped by the interaction between external pressures such as regulation, customer expectations and cost or energy volatility, and internal organisational strengths such as governance quality, digital readiness, dynamic capabilities and absorptive capacity. Evidence from emerging economy settings including India, Mexico, Malaysia, Turkey, Iran and Lithuania shows that while small and medium-sized enterprises demonstrate strong intent to adopt eco-innovation, they frequently face constraints related to skills, financing and fragmented processes. These limitations lead to progress that often remains confined to isolated pilots rather than maturing into sustained, organisation-wide transformation. Collectively, the findings indicate that successful eco-innovation depends not only on environmental or competitive pressures but also on a firm's ability to mobilise and integrate the capabilities required for technology assimilation, cross-functional coordination and continuous improvement.

5.1 Multidimensionality and the Capability–Pressure Nexus

Across manufacturing, hospitality, furniture and SME settings, the evidence shows that eco-innovation is initiated largely in response to regulatory expectations, customer demand and cost or energy pressures, but its continuation and scaling depend primarily on internal capabilities. Firms with stronger absorptive capacity, reflected in their ability to acquire, interpret and apply external knowledge, were consistently more successful in progressing from small pilots to more substantial redesign of products, processes and business models. In contrast, organisations with weak governance or poorly defined routines tended to remain at surface-level actions such as basic efficiency improvements or waste segregation. Studies from the Lithuanian furniture sector demonstrate that structured decision tools such as AHP and TOPSIS help firms translate complex micro, meso and macro environmental signals into prioritised strategies. These patterns reinforce the importance of early governance and strategic gating, which form the foundation of Pillar 1 in the GREEN STORM framework.

5.2 Environmental and Operational Performance Effects

Across the analysed cases, eco-innovation consistently generated measurable improvements in both environmental and operational performance, although the magnitude of these gains depended on the maturity of the technologies adopted and the depth of their organisational integration. Studies reported reductions in material loss and scrap through cleaner production and eco-design interventions, lower energy use through optimised equipment performance and improved scheduling, and decreased waste generation accompanied by higher recycling rates. Automated monitoring and inspection systems further reduced defects and rework, contributing to efficiency gains. Meta-analytic evidence confirmed that organisational eco-innovation, including culture, governance, human resource practices and codified routines, has a stronger and more sustained impact on environmental and social outcomes than isolated product or process innovations. These findings reinforce the argument that organisational capabilities function as stabilising mechanisms that anchor technical improvements over time, directly supporting the capability and monitoring pillars within the GREEN STORM framework.

5.3 Collaboration as an Adoption Multiplier

The strongest cases demonstrated that eco-innovation operates as an ecosystem activity rather than a purely internal organisational effort. Firms that engaged actively with suppliers, technology vendors, universities and government programmes advanced more quickly and with greater reliability than those attempting to innovate alone. These collaborative arrangements reduced information and search costs, improved access to specialised technical knowledge such as life cycle assessment and technology readiness assessment, and distributed financial and operational risks during pilot phases. Evidence from furniture, electronics and manufacturing supply chains showed that coordinated supplier involvement and shared learning mechanisms significantly enhanced firms' ability to integrate and sustain green technologies. These patterns confirm that relational engagement acts as a multiplier of organisational capability and directly support the rationale for Pillar 4 within the GREEN STORM framework (Parhamfar, M et al, 2025).

5.4 Technology Due Diligence and Measurement Discipline

Case evidence shows that firms applying structured due diligence tools achieved more consistent and durable eco-innovation outcomes. Studies that used life cycle assessment, technology readiness and manufacturing readiness checks, eco-efficiency metrics and cost–benefit analyses before implementation reported fewer performance reversals and clearer pathways to scaling. These firms established environmental and operational baselines, measured outcomes across efficiency, emissions and risk, and separated learnings from pilot settings before making scale-up decisions. They also monitored rebound effects such as increased throughput offsetting initial savings, thereby maintaining a realistic estimate of net benefits. Such disciplined assessment and monitoring reflect the logic of Pillars 2 and 5 in the GREEN STORM framework, emphasising the importance of readiness evaluation and continuous performance tracking for credible adoption.

5.5 Contextual Contingencies and Boundary Conditions

Adoption pathways varied significantly across sectors and country contexts, indicating that eco-innovation outcomes are contingent on regulatory, financial and structural conditions. Service-sector firms tended to implement new practices more quickly because of lower capital intensity, although the absolute environmental gains per site were smaller. Manufacturing firms demonstrated larger environmental and operational improvements but required longer payback periods and stronger supplier coordination to achieve them. SMEs in emerging markets faced persistent constraints related to financing, policy uncertainty and limited technical infrastructure; however, targeted public instruments such as green-credit schemes, tax concessions and shared testing or laboratory facilities helped reduce capability barriers. Across all contexts, organisational eco-innovation in the form of green HRM, incentive structures and accountability mechanisms consistently acted as a multiplier that strengthened the impact of technical interventions and enabled more durable adoption (Aghanasab, et al., 2025).

5.6 Implications for the GREEN-STORM Framework

The cross-case evidence provides strong validation for the structure and sequencing of the GREEN-STORM framework. Successful eco-innovation initiatives consistently began with clear governance and strategic commitment, where priorities, responsibilities and resource allocation were defined. Firms that progressed further typically conducted rigorous readiness and technology assessments, using tools such as life cycle analysis, TRL/MRL checks and eco-efficiency metrics to identify high-value opportunities. Adoption accelerated when organisations invested in capability enablement, particularly absorptive capacity, digital readiness, cross-functional coordination and green HR systems. Cases that institutionalised relational engagement—through supplier development, university partnerships and public-sector programs with shared KPIs—demonstrated greater stability and scalability. Finally, systematic outcome monitoring allowed organisations to refine their portfolios, close learning loops and avoid repetitive pilot cycles. Together, these patterns confirm that effective eco-innovation scaling requires a governed, staged and capability-centred approach, closely aligned with the five pillars of GREEN-STORM.

Figure 2 summarises how external pressures, organisational capabilities, assessment tools and collaborative mechanisms converge across the analysed cases. The left side reflects key drivers such as regulation, customer expectations and cost pressures. The central pathway highlights governance decisions, readiness checks (LCA, TRL, MRL) and capability factors including absorptive capacity and digital systems. The relational layer shows supplier, university and government partnerships that accelerate adoption. The right side depicts environmental, operational and business outcomes, with feedback loops showing how results inform the next cycle of improvement (Zabihi et al., 2025).

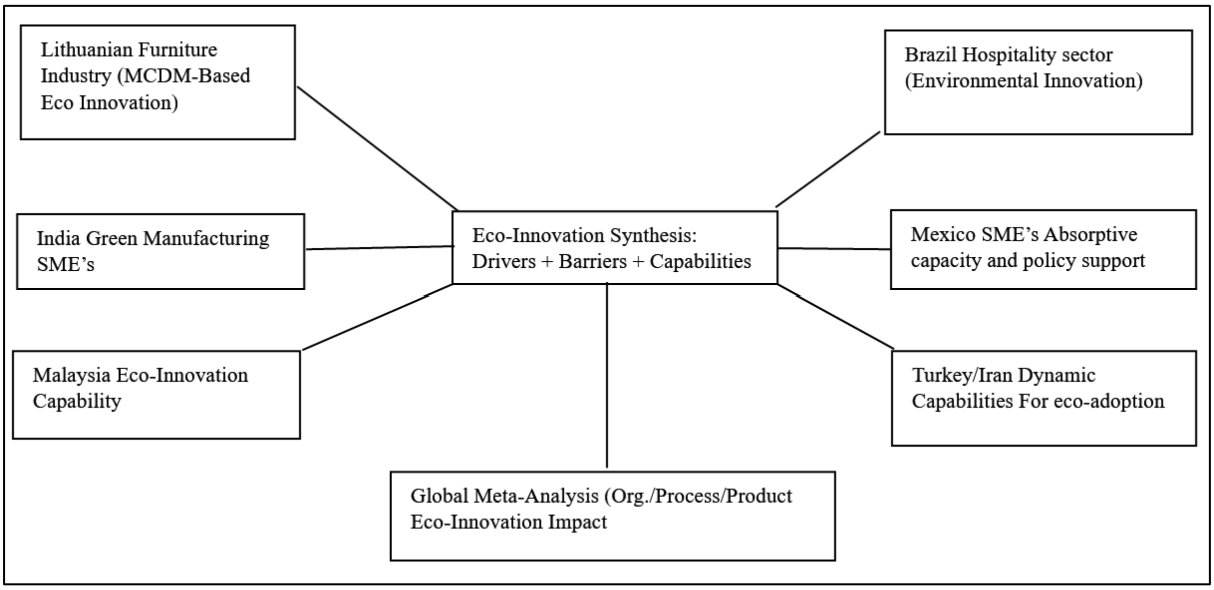

Figure 2: Case Study Synthesis Map

6. Management Framework for Eco-Innovation and Technology Adoption (GREEN-STORM)

The GREEN-STORM framework conceptualises eco-innovation as a sequenced management system that links strategic intent to measurable environmental and operational outcomes. The first pillar emphasises governance and strategic commitment, where sustainability priorities are embedded in organisational strategy, capital planning and risk oversight. Senior leadership defines direction, allocates resources and establishes cross-functional accountability so that eco-innovation efforts do not remain isolated projects. This alignment ensures that environmental goals, operational requirements and financial expectations reinforce one another and creates the clarity needed for sustained progress.

The second pillar focuses on readiness and technology assessment. Organisations must evaluate green technologies through structured due diligence that considers life-cycle impacts, readiness levels, integration complexity and cost–benefit profiles. These assessments reduce uncertainty and ensure that only technologies with credible feasibility, scalability and environmental value proceed to implementation. Once selections are made, adoption success depends on the third pillar, organisational capability enablement. Firms require the skills, routines and digital systems to embed eco-innovation into daily processes. Training, cross-functional teams, codified procedures and investment in data infrastructure strengthen absorptive capacity and dynamic capability, which empirical evidence consistently identifies as essential for moving beyond pilots toward sustained adoption (Soma, 2025).

The fourth pillar underscores the importance of stakeholder and relational engagement. Successful eco-innovation often relies on collaboration with suppliers, technology vendors, research institutions and public agencies. These partnerships expand access to expertise, reduce adoption risks and support capability building. They also enable supply-chain-level innovations that cannot be achieved by individual firms alone. The fifth pillar emphasises outcome monitoring and continuous improvement. Organisations must track environmental, operational and financial indicators through audits, dashboards and review cycles. Monitoring supports transparency, identifies drift and ensures that learning from one initiative informs subsequent decisions, creating a disciplined and iterative approach to scaling eco-innovation.

Together, these five pillars provide a practical, evidence-based framework for organisations seeking to institutionalise eco-innovation. Figure 3 presents the GREEN-STORM framework as a left-to-right process flow, starting with governance and progressing through readiness assessment, capability enablement, stakeholder collaboration and outcome monitoring, with a feedback loop that channels insights from measured results back into strategic prioritisation. This visual representation reinforces the cyclical, learning-oriented nature of eco-innovation and highlights the decision gates and tools that structure each stage of the process. Figure 3 presents the GREEN-STORM framework as a staged process linking governance, readiness assessment, capability enablement, stakeholder engagement and outcome monitoring, with a feedback loop that returns learning to strategic planning.

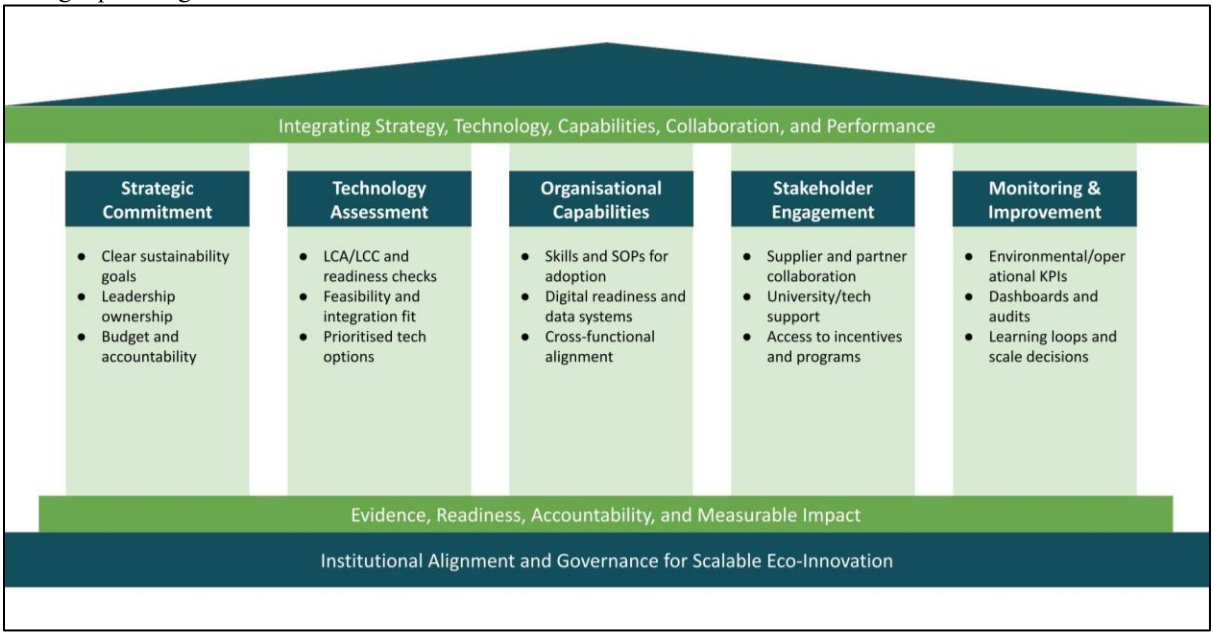

Figure 3: The GREEN-STORM Framework for Eco-Innovation Adoption
Abbreviations: LCA = Life Cycle Assessment; LCC = Life Cycle Costing; SOPs = Standard Operating Procedures; KPIs = Key Performance Indicators.

7. Achievement of Research Objectives

The study achieved its research objectives through an integrated sequence of literature synthesis, cross-case analysis and framework development, each stage contributing directly to conceptual clarity and practical insight.
The first objective, which centred on clarifying the significance and scope of eco-innovation, was fulfilled by establishing it as a multidimensional construct spanning product, process, organisational and business-model domains. By situating eco-innovation within contemporary sustainability logics—including life-cycle assessment, eco-efficiency measurement and technology readiness evaluation—the review reduced definitional ambiguity and positioned the construct within the decision architectures required for organisational adoption.
The second objective, focused on identifying drivers and barriers, was met through thematic synthesis of sector-diverse empirical cases. The analysis revealed a consistent pattern in which regulatory pressure, customer expectations, cost dynamics and collaborative networks act as key drivers, while capability gaps, measurement deficits and integration risks constrain adoption. Importantly, the findings highlighted absorptive capacity and dynamic capabilities as central mechanisms explaining why firms facing similar pressures exhibit different adoption trajectories. This mechanism-based explanation advances understanding beyond traditional lists of enablers and inhibitors.
The third objective, examining the role of management and governance, was achieved by demonstrating that strategic commitment, cross-functional accountability, codified routines and green HRM substantially influence the translation of technical pilots into scalable eco-innovation practices. Evidence from multiple contexts showed that organisational eco-innovation exerts stronger environmental and social performance effects than technical innovations undertaken in isolation, underscoring the centrality of managerial design and oversight.
The fourth objective was accomplished through the development of the GREEN-STORM framework, which synthesises insights from literature and cases into a practical, structured management model. The framework integrates governance, readiness assessment, capability enablement, stakeholder engagement and outcome monitoring into a coherent sequence that guides firms from technology selection to sustained impact. By embedding recognised tools such as LCA, TRL/MRL assessment and MRV dashboards, the framework enhances evaluability and replicability across contexts.
The final objective, generating strategic recommendations, was realised through evidence-linked guidance derived directly from cross-case mechanisms and framework logic. The recommendations emphasise early governance alignment, rigorous assessment to de-risk technology choices, capability building as a prerequisite for scale, and the deliberate use of collaborative ecosystems to overcome resource and knowledge gaps. These recommendations provide actionable pathways that bridge theoretical insight with managerial decision-making.
Overall, the study advances conceptual clarity, explains adoption mechanisms with empirical grounding and proposes a validated, tool-ready framework. It fulfils the stated objectives while laying a foundation for future evaluative and longitudinal research on eco-innovation at scale in both emerging and advanced economies Karimi, M. & Damirchi, F. (2025).

8. Rigor, Limitations, and Future Research Directions

The study demonstrates rigor through the use of recent peer-reviewed evidence, cross-case triangulation, and mechanism-centred analysis, strengthening both internal validity and theoretical contribution. However, two limitations remain: some sector-specific quantitative case metrics require further bibliographic confirmation, and causal inference is inherently constrained in the absence of counterfactual or matched-control designs. These limitations point to clear opportunities for future research, including longitudinal testing of the GREEN-STORM framework across sectors, quasi-experimental evaluations using MRV-grade environmental and operational data, and comparative studies examining how regulatory regimes, supply-chain structures, and financing instruments influence adoption pathways. Further work could also explore the integration of digital twins, AI-enabled readiness assessments and automated LCA pipelines to operationalise the framework and accelerate eco-innovation at scale.

9. CONCLUSION AND IMPLICATIONS

This study advances a management ready understanding of eco innovation by integrating recent empirical evidence with the structured GREEN STORM framework. The analysis demonstrates that eco innovation is not a single decision but a coordinated sequence of governance alignment, readiness assessment, capability building, stakeholder engagement and disciplined outcome monitoring. Organisations that combine strategic commitment with rigorous technology appraisal and strong absorptive capacity are more likely to translate sustainability ambition into measurable environmental and operational gains. Cross sector patterns confirm that environmental improvements are consistently larger when technical innovations are embedded within organisational and relational capabilities, highlighting the central role of governance, digital readiness and cross functional routines in moving initiatives beyond pilot success.

The findings also generate clear implications for managers and policymakers. For firms, the framework provides a practical pathway to de risk adoption by institutionalising sustainability linked KPIs, applying LCA and TRL based gating before scale, strengthening green HRM and codified operating procedures, and collaborating with suppliers, universities and public programmes to close capability gaps. For policymakers, the study underscores the need for coherent, capability oriented instruments such as transparent measurement standards, targeted SME support and cluster based collaboration platforms. Although quantitative evidence varies across sectors and causal inference is constrained in non experimental settings, future longitudinal and quasi experimental research supported by digital measurement tools can test the durability and transferability of the framework. Overall, the study offers a robust and actionable pathway for translating sustainability intent into credible, scalable performance improvements, contributing to the wider transition toward a greener and more competitive economy.

REFERENCES:

1. Abdullah Faisal Albukhari. (2025). The Global Burden of Antimicrobial Resistance: A Systematic Review of Trends, Drivers and Effective Interventions. International Journal of Linguistics Applied Psychology and Technology (IJLAPT), 2(02(Feb), 35–54. https://doi.org/10.69889/ijlapt.v2i02(Feb).98
2. Alamandi, Morgan. (2025). Sustainable Innovation Management: Balancing Economic Growth and Environmental Responsibility. Sustainability. 17. 4362. 10.3390/su17104362.
3. Albort-Morant, G., Leal-Rodríguez, A. L., & De Marchi, V. (2018). Green innovation, firm performance, and the moderating role of environmental strategy. Technological Forecasting and Social Change, 139, 336–348. https://doi.org/10.1016/j.techfore.2018.11.009
4. Anthuvan, T., & Maheshwari, K. (2025). Green inside, silent outside? The sustainability branding dilemma in Indian pharma. SSRN. https://doi.org/10.2139/ssrn.5558440
5. Anthuvan, T., Kumar, A., Maheshwari, K., & Naresh, B. (2026). A systematic review of pharmaceutical marketing strategies and outcomes: The 7Ps–6D framework with sustainability as a key emerging theme. World Journal of Entrepreneurship, Management and Sustainable Development, 22(1–2), xx–xx.
6. https://wasdlibrary.org/download/a-systematic-review-of-pharmaceutical-marketing-strategies-and-outcomes-the-7ps-6d-framework-with-sustainability-as-a-key-emerging-theme%ef%bc%8cdr-thamburaj-anthuvan%ef%bc%8cdr-anuj-kumar/
7. Bapat, G. S., Kumar, A., Kumar, A., Hota, S. L., Kavita, & Singh, K. (2023). Sustainable Green Manufacturing Approaches in India—A Step towards a New Green Revolution through SMEs. Engineering Proceedings, 59(1),
8. 211. https://doi.org/10.3390/engproc2023059211
9. Barragán-Hernández, A. D., & Aguilar-Fernández, M. (2024). Strategic Dimensions of Eco-Innovation Adoption in Manufacturing SMEs in the Context of Mexico City. Systems, 12(7), 246.
10. https://doi.org/10.3390/systems12070246
11. Bogdanich, S., Schmitt, F., Figueroa, J., & Krumme, M. (2022). Process analytical technology and automated visual inspection in sterile pharmaceutical manufacturing: Quality, cost, and sustainability impacts. PDA Journal of Pharmaceutical Science and Technology, 76(6), 537–551. https://doi.org/10.5731/pdajpst.2022.012345

12. Bucheli-Calvache, J. M., Zuñiga-Collazos, A., Osorio-Tinoco, F., & Cervantes-Rosas, M. Á. (2023). Proposal for an eco-innovation concept tailored to SMEs: Economic, institutional and environmental dimensions. Sustainability, 15(13), 10292. https://doi.org/10.3390/su151310292
13. Cainelli, G., De Marchi, V., & Grandinetti, R. (2015). Does the development of environmental innovation require different resources? Evidence from Italian manufacturing firms. Research Policy, 44(2), 442–457.
14. https://doi.org/10.1016/j.respol.2014.10.004
15. Çelik, A.K., Yildiz, T., Aykanat, Z. et al. Green Innovation Adoption in Turkish and Iranian SMEs: The Effect of Dynamic Capabilities and the Mediating Role of Absorptive Capacity. J Knowl Econ 16, 1824–1859 (2025).
16. https://doi.org/10.1007/s13132-024-01990-1
17. Chams, N., & García-Blandón, J. (2019). Sustainable human resource management and the adoption of the SDGs: A review and research agenda. Resources, Conservation and Recycling, 141, 109–122.
18. https://doi.org/10.1016/j.resconrec.2018.10.006
19. Ciccullo, F., Pero, M., Caridi, M., Gosling, J., & Purvis, L. (2018). Integrating environmental and social sustainability into performance measurement and management systems: A literature review. Journal of Cleaner Production, 172, 2336–2350. https://doi.org/10.1016/j.jclepro.2017.11.176
20. Dangelico, R. M., Pujari, D., & Pontrandolfo, P. (2018). Green product innovation: Where we are and where we are going. Journal of Cleaner Production, 162, S381–S394. https://doi.org/10.1016/j.jclepro.2017.09.240
21. de Jesus, A., & Mendonça, S. (2018). Lost in transition? Drivers and barriers in the eco-innovation road to the circular economy. Ecological Economics, 145, 75–89. https://doi.org/10.1016/j.ecolecon.2017.08.001
22. del Río, P., Peñasco, C., & Romero-Jordán, D. (2016). What drives eco-innovation? A critical review of the empirical literature based on econometric methods. Journal of Cleaner Production, 112, 2158–2170. https://doi.org/10.1016/j.jclepro.2015.09.009
23. Demirel, P., & Danisman, G. O. (2019). Eco-innovation and firm growth in the circular economy. Industrial and Corporate Change, 28(4), 901–917. https://doi.org/10.1093/icc/dtz040
24. Dey, Bikash & Park, Jeryang & Seok, Hyesung. (2022). Carbon-emission and waste reduction of a manufacturing-remanufacturing system using green technology and autonomated inspection. RAIRO - Operations Research. 56. 2801-2831. 10.1051/ro/2022138.
25. Elhaj, M., Sarabdeen, M., Almugren, H. Z., Kijas, A. C. M., & Halid, N. (2025). The Economics of Innovation, Renewable Energy, and Energy Efficiency for Sustainability: A Circular Economy Approach to Decoupling Growth from Environmental Degradation. Energies, 18(17), 4643. https://doi.org/10.3390/en18174643
26. Geng, Y., et al. (2020). A critical review of the circular economy measurement frameworks. Journal of Industrial Ecology, 24(4), 745–763. https://doi.org/10.1111/jiec.12942
27. Jayant Kumar, Dr. Rajeshkumar D. Kiri, Shruti Shekhar. (2025). Analyzing the Development of Micro, Small, and Medium Enterprises (MSMEs) in Jharkhand: A Comparative Study of Government Initiatives. Applied Science, Engineering and Management Bulletin [ASEMB], 2(02(April-June), 71–79.
28. https://doi.org/10.69889/asemb.v2i02(April-June).33
29. Lopes, J. L., & Basso, L. F. C. (2023). The Impact of Eco-Innovation Adoption on Business Performance—A Study of the Hospitality Sector in Brazil. Sustainability, 15(11), 8696. https://doi.org/10.3390/su15118696
30. Mackenzie Presbyterian University Team. (2023). Eco-innovation adoption and business performance in Brazilian hospitality firms. Sustainability, 15(11), 8696. https://doi.org/10.3390/su15118696
31. Montabon, F., Pagell, M., & Wu, Z. (2016). Making sustainability sustainable. Journal of Supply Chain Management, 52(2), 11–27. https://doi.org/10.1111/jscm.12103
32. Morkūnas, M., Wang, Y., & Wei, J. (2024). Role of AI and IoT in Advancing Renewable Energy Use in Agriculture. Energies, 17(23), 5984. https://doi.org/10.3390/en17235984
33. Mr. Kholofelo Maruma. (2024). HARMONIZING TECHNOLOGY RESOURCES FOR INTRA-AFRICA TRADE: A DIGITAL TRANSFORMATION PERSPECTIVE. International Journal of Linguistics Applied Psychology and Technology (IJLAPT), 1(06(Oct), 7–17. https://doi.org/10.69889/ijlapt.v1i06.68
34. Oduro, S. (2024). Eco-innovation and SMEs' sustainable performance: A meta-analysis. European Journal of Innovation Management, 27(9), 248–279. https://doi.org/10.1108/EJIM-12-2021-0625
35. Rosa, P., Sassanelli, C., & Terzi, S. (2020). Circular economy in the manufacturing sector: LCA-supported decision-making for eco-innovation. Journal of Cleaner Production, 248, 119297.
36. https://doi.org/10.1016/j.jclepro.2019.119297
37. Scarpellini, S., Valero-Gil, J., & Portillo-Tarragona, P. (2019). The role of relational capital in eco-innovation: Evidence from European manufacturing. Journal of Cleaner Production, 241, 118470.
38. https://doi.org/10.1016/j.jclepro.2019.118470
39. Singh, S. K., Chen, J., Del Giudice, M., & El-Kassar, A.-N. (2019). Environmental ethics, green innovation, and environmental performance: The role of green HRM and green human capital. Business Strategy and the Environment, 28(7), 1194–1205. https://doi.org/10.1002/bse.2321
40. Siswadhi, T. M., Fajrin, N., Jakfar, Mubarok, A., & Hariri, A. (2024). Green Technology Integration and Circular Economy Pathways for Sustainable Innovation. Novatio: Journal of Management Technology & Innovation, 2(3), 144-159. https://doi.org/10.61978/novatio.v2i3.1002

41. Sukri, N. K. A., Zulkiffli, S. N. ‘A., Mat, N. H. N., Omar, K., Mawardi, M. K., & Zaidi, N. F. Z. (2023). An Analysis of Eco-Innovation Capabilities among Small and Medium Enterprises in Malaysia. Administrative Sciences, 13(4), 113. https://doi.org/10.3390/admsci13040113
42. Šūmakaris, P., Kovaitė, K., & Korsakienė, R. (2023). An Integrated Approach to Evaluating Eco-Innovation Strategies from the Perspective of Strategic Green Transformation: A Case of the Lithuanian Furniture Industry. Sustainability, 15(11), 8971. https://doi.org/10.3390/su15118971
43. Szymańska, A., & Chmielarz, W. (2023). Pharma 4.0: Digital transformation enablers for sustainable pharmaceutical manufacturing. Processes, 11(5), 1412. https://doi.org/10.3390/pr11051412
44. Teece, D. J. (2018). Business models and dynamic capabilities. Long Range Planning, 51(1), 40–49. https://doi.org/10.1016/j.lrp.2017.06.007
45. Testa, F., Iraldo, F., & Frey, M. (2019). The effect of environmental regulation on firms’ competitive performance: The mediating role of eco-innovation. Journal of Cleaner Production, 237, 117664. https://doi.org/10.1016/j.jclepro.2019.117664
46. Zhang, Y., Wang, J., Li, X., & Chen, H. (2024). A review of digital twin integration in circular economy frameworks. Sustainability, 17(16), 7316. https://doi.org/10.3390/su17167316
47. Parhamfar, M., Güven, A. F., Pinnarelli, A., Vizza, P., & Soleimani, A. (2025). Artificial Intelligence in Carbon Trading: Enhancing Market Efficiency and Risk Management. Journal of Computing and Data Technology, 1(1), 19-39.
48. Karimi, M., & Damirchi, F. (2025). Re-Evaluating the Functionalist Approach of Urban Management towards Sustainable Architecture and Urban Layout with Emphasis on the Role of Digital Technologies. Journal of Modern Technology, 2(2), 327-345.
49. Aghanasab, A., Ghasem, P., Roghanaian, P., Dzikuć, M., & Luo, Y. (2025). Comfort level and increased utilization in smart buildings by promoting sustainability: A new hybrid genetic and bat algorithms. Journal of Modern Technology, 2(2), 346-360.
50. Soma, A.K. (2025). Building Aether Sensor Network using LoRaWAN Network. In 2025 International Conference on Emerging Systems and Intelligent Computing (ESIC) (pp. 807-814). IEEE.
51. Zabihi, A., Pidikiti, T., Varanasi, L.S., Kalnoor, G., Akkurt, I., & Krishna, V.M. (2025). Solar-Powered Pumping for Alleviating Energy Poverty: Sustainable Solutions for Agriculture Sector in Portugal. IEEE Access.