

Leveraging Green Intellectual Capital for Sustainability: The Strategic Role of Green Business Strategy and Green Technology Adoption

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Abstract

The growing environmental uncertainties, stakeholder pressures, regulatory complexities and continuous problems with greenwashing practices necessitate a transition from having sustainable intentions to demonstrating measurable performance in sustainability. This review article analyzes the use of Green Intellectual Capital (GIC) as an instrument that could help increase sustainability performance through mediation by Green Business Strategy (GBS) and enablership by Green Technology Adoption (GTA). By utilizing the theories of resource-based view, natural resource-based view, knowledge-based view, dynamic capabilities theory, institutional theory, stakeholder theory and configurations approach, the review presents the framework which shows the links between GIC green human, structural and relational capital and strategic environmental orientation and implementation through the means of technologies. It is important to note that GIC includes all necessary knowledge, skills, routines and stakeholder relationships that are needed in sensing environmental opportunities, codifying green actions, and implementing eco-innovations. However, GIC alone is not enough since it needs to be used in a coherent way within GBS which matches environmental goals and priorities of resource allocation, governance and operations. Further, the study highlights several boundary conditions that include industry features, size of the firms, geographic location, quality of institutions, regulation, digitalization and supply chain preparedness. In addition, the paper suggests a future research direction that focuses on causation, micro-foundations of green capabilities and green leadership, digital-green convergence, ecosystems level analysis, social sustainability, just transition and cross-national comparison. Finally, this review makes contributions to the body of sustainability management literature by explaining the impact of knowledge-based green resources, green strategy and green technology on performance.

1. Introduction

It is common to find that organizations set aggressive goals for the environment yet have difficulties in translating intentions into actual sustainability performance due to the existence of ambiguous signals and standard. The reason why environmental, social and governance ratings of the same organization differ from each other is that of differing scopes of coverage, measures and weightings which lead to confusion and poor internal accountability, there exists an evidence of large systematic discrepancy in the ratings offered by different major service providers and measurement is the greatest contributor to the inconsistency (Berg et al. 2022). The majority of emissions and impact happen at the upstream and downstream of the organization where transparency is least where boundary and control issues are most severe. Studies show that there has always been ambiguity about value chain boundaries and data quality and that organizations tend to lower the upstream targets after involving suppliers which indicates the bias in initial target setting (Vieira et al. 2025; Chauke and Raphulu 2024). Information gaps allow for decoupling and greenwashing, as disclosures precede operations. Reviews conducted since 2020 show how companies selectively disclose their progress or exaggerate their efforts with regard to the environment, creating the appearance-reality gap that hinders allocating resources for high-impact projects. Research and literature show the link between greenwashing tendency and high external visibility as well as lack of assurance (Luan 2024; Free and Jones 2024; Kathan et al. 2025). From the

enforcement and investigation cases since 2023–2024, one can see how the trend towards addressing misleading statements becomes a regulatory issue which confirms that credibility problems prevent companies from improving performance. Capability and execution gaps continue within the company. Turning targets into achievements requires dynamic capabilities in order to sense opportunities/threats, exploit by investments and reconfigurations and learn constantly. Recent research explores the micro-foundations (skill sets, routines, information systems) necessary to overcome adoption challenges. Without such micro-foundations, green initiatives remain at the level of pilots or do not scale in plants/departments/business units (Franco and Giannoccaro 2025). Misaligned incentives and short-termism further diminishes the translation from intentionality to action. Current managerial scorecards continue to favor short-term financial metrics over longer-term environmental KPIs and corporate change programs remain fragmented among different functional areas (procurement, operations, finance), lacking a guiding strategy. Syntheses by practitioners of lessons learned by organizations show that failures can take place due to lack of ownership, budgeting that prioritizes rapid wins over long-term de-carbonization and ineffective change management, even for organizations with net-zero pledges. From the perspective of technology and operations, organizations have adoption and integration challenges as there are different de-carbonization solutions according to abatement cost and level of development. Furthermore, the majority of these solutions rely on third parties such as suppliers, logistics and energy companies. Supply chain-focused best practices point out that meaningful reductions involve detailed baselining, supplier participation and monitoring, rather than mere procurement commitments which is more complicated in multi-tier supply chains lacking digitalization. For instance, the 2024 climate disclosure regulation in the United States does not require Scope-3 reporting, thus lowering comparability for investors and delaying value chain measurement practices, regulatory inconsistency and rating divergence reinforce each other to foster measurement without management. Reputation and market pressure may distort focus to tangible promise delivery instead of intangible system change. Selective disclosure research warns about how companies promote good indicators and underplay bad ones, moreover, sector-specific research (for instance, fashion industry) demonstrates how strong corporate narratives are possible in conjunction with increasing supply chain emissions due to fossil-based suppliers that remain untouched. Consequently, there is a performance plateau amidst increasing communication (Roszkowska-menkes and Aluchna 2024). The gap between intention and impact is not one problem but an accumulation of multiple (i) noisy metrics (rating divergence), (ii) measurement and controllability issues in the value chain (Scope-3), (iii) action-disclosure disconnect (greenwashing), (iv) lack of dynamic capabilities and incentive misalignment (execution), (v) dependence on technology and partners (operations) and (vi) inconsistent regulation (policy). Literature consistently suggests integrated solutions including third-party verifiable assurance, supplier-level data infrastructure, dynamic capability investment and strategy-oriented portfolio formation with environmental KPI-driven capital allocation (Luan 2024; Berg et al. 2022).

The green intellectual capital (GIC) as the intangible resource base. Under both knowledge-based and NRBV approach, the GIC is defined as the resource stock of green knowledge and routines, as well as human, structural and relational green capitals that serve as the foundation for firms' ability to sense

environmental problems, develop best practice knowledge (EMS and green IT) and collaborate within the supply chain. Current research works always include all these three dimensions of the GIC and correlate them with eco-innovation and performance making GIC the basis for further actions (Diab et al. 2024). The managerial logic of Green business strategy (GBS) as orchestration logic, Strategy converts that resource endowment into strategic direction through allocation of attention, budgeting, governance and motivation towards proactive environmental intentions, research indicates that proactive environmental intentions enhance the effectiveness of knowledge resource endowment and depend upon information and governance systems that facilitate cross-functionality (orchestration) in organizations, an argument which gets reinforced in light of NRBV/dynamic capability studies concerning the ways firms re-configure resources for environmental advantage. In short, GBS is the logic of managing the sequence of capabilities based on the GIC theory (Galbreath et al. 2023; Alkaraan et al. 2024; Liang et al. 2023). GTA as Enactment Mechanism-Adoption, this is where intent turns to operations through the selection, integration and scaling up of technological systems (cleaner production, circularity systems, energy/carbon systems). Research using TOE/DOI since 2020 recognizes that technology, organization and the environment interact to affect the scope and pace of adoption, critically, GTA acts as the mediator between GIC and performance through the generation of eco-innovations and environmental metrics. Therefore, GTA acts as the execution layer where the impact of GIC-based strategy on the firm's sustainability performance is materialized (Faiz et al. 2024; Liu et al. 2022a). Piecing things together (GIC→GBS→GTA→performance), new empirical and conceptual studies increasingly adopt GIC as the antecedent resource base that powers strategic orchestration (GBS) which in turn manages the selection, timing and extent of GTA with eco-innovation and environmental performance as the subsequent outcomes; the green dynamic capabilities (sensing-seizing-reconfiguring) often emerge as the micro-foundations that mediate the impacts of GIC and digital maturity, regulatory pressure and partner preparedness serve as moderators of the process. The hierarchical approach explains why companies with identical technology portfolios achieve different results, the absence of robust GIC and the orchestration of GBS makes GTA patchwork but their presence turns the adoption programmatic and scalable (Mulatsih 2025; Kumar et al. 2026; Correggi et al. 2024).

1.1 Integrative Review and Framework

Green intellectual capital (GIC) broadens the intellectual capital concept to the environmental sphere and encompasses the combination of green human, structural and relational capital into reusable knowledge within an organization towards sustainability. Researches reveal that companies with more GIC turn their environmental knowledge into routines (EMS database, eco-KPIs), collaboration with stakeholders and learning that positively impacts environmental performance and competitiveness (Diab et al. 2024; Asiaei et al. 2023; Alnaim et al. 2024). Through RBV/NRBV perspective, GIC serves as the capability base to be managed into a proactive GBS focused on preventing pollution, product stewardship and clean-technology positioning. Studies among SMEs and developing economies prove that environmental scanning and analysis result in a better environment-related strategy and performance provided that environmental knowledge and routines are well-developed. GBS will thus become the internal logic that reduces resistance and facilitates criteria clarification for adopting GTA from cleaner production

machines to digital carbon accounting systems. Current TOE research demonstrates how technological fit and advantages, organization readiness (top-management commitment, IT capability) and environmental pressure influence adoption, importantly, a consistent GBS enhances these TOE paths and accelerates the routine adoption of new green technologies (Chaudhuri et al. 2024; Li et al. 2025). Institutional pressures (coercive, normative and mimetic) remain strong stimuli for green innovation and adoption, however, organizations will obtain better results only if they have the absorptive and learning capabilities inherent in GIC. Various literature findings demonstrate how entrepreneurial orientation and digital business-model innovation transform external pressures into consistent green performance based on internal capabilities (Zhang et al. 2024; Liang et al. 2023). This is where the research on dynamic capabilities is useful: sensing of opportunities and threats in the environment, leveraging by making green investments and transforming operations form the mechanism that drives GIC to GBS and GTA. Reviews and empirical research show that such sustainable dynamic capabilities are positively associated with ESG strategy execution and performance thereby supporting the capabilities-strategy-adoption sequence (Liang et al. 2023; Correggi et al. 2024). In the manufacturing, logistics and service sectors, performance benefits are derived mostly from eco-innovations and supply chain integration, for example green process and product innovations according to the strategy. Recent research also points out the importance of measurement and IT complements such as EMA and IT capabilities that enhance the impact of strategy and adoption on both environmental and financial performance (Hanif et al. 2023; Alnaim et al. 2024). From the synthesis of this evidence, we develop a hierarchical model where (1) GIC (green human/structural/relational capital) provides the capability foundation, (2) managers integrate the foundation into GBS, (3) GBS facilitates GTA, subject to TOE and institutional environment, (4) eco-innovation and green supply-chain integration have impacts on environmental and financial performance and (5) IT capability and EMA positively moderate these relationships. This theoretical model is in line with the recent literature on GIC-innovation studies (Asiaei et al. 2023), TOE-institutional adoption research (Chaudhuri et al. 2024; Zhang et al. 2024) and dynamic capabilities perspectives (Liang et al. 2023; Correggi et al. 2024).

Figure 1 presents the conceptual model of Green Intellectual Capital (GIC), Green Business Strategy (GBS) and Green Technology Adoption (GTA) as the dynamic process aimed at reaching sustainable results. The starting point of the process is represented by GIC that consists of human, structural and relational capitals that generate the required knowledge and values for the green actions. The base of knowledge is used for creating a Green Business Strategy as the logic of orchestration. The green strategy is implemented through Green Technology Adoption and involves cleaner production, eco-innovation and resource efficiency. The sustainability results achieved in the environmental, economic and social aspects, become the input into GIC due to organizational learning and re-investments. The external forces represented by institutional pressures (regulations, societal pressure) serve as the external moderators of the model while internal factors related to firms' capabilities (level of digitalization, firm size and innovative capacity) are the moderators from within (Xiao et al. 2023; Wang et al. 2025).

1.2 Boundary Conditions (Industry, Firm Size, Geography, Regulation)

However, when boundaries are set based on the fact that the structural characteristics of the value chain and the level of pollution dictate the feasibility and benefits of green initiatives. The empirical evidence generated from recent meta- and cross-country studies reveals that regulation is more effective at stimulating green innovation among industries and sectors that are characterized by pollution intensity and asset-intensity compared to service industries, the effectiveness of circular economy (CE) policies and measures is also inconsistent among industries and sectors (Zhang et al. 2024; Elia et al. 2024; Gode and Aspelund 2024). Figure 2 illustrated that firm size was the next boundary influencing cost (disclosure, retooling) and benefit (reputation, financing) aspects of ESG/CE/green innovation strategy implementation. Larger companies generally have resources, capabilities and visibility to translate their ESG and eco-innovations into tangible performance, several recent conference panels and concept papers find that there exists a significant or non-linear link between ESG and performance or innovation for larger companies but small and medium-sized companies suffer from capability and financing barriers and get the benefit only from niche positioning or supply chain regulations. Size class coding (small vs. large firms, revenue or employee size groups) and where available, interact with ESG and innovation variables to prevent heterogeneity from being averaged out (Feng et al. 2025; Chen et al. 2021; Li et al. 2022). Geography and institutions form the third boundary since there is significant variation in policy credibility, policy enforcement, green finance development and technical infrastructure across countries and regions. Research on the impact of environmental policies in OECD economies shows stronger associations between policy stringency and green innovation. The effect of institutional voids such as weak standards and lack of monitoring and supporting institutions has been identified for emerging economies. Present findings by national income groups/regions and wherever possible by particular institutional characteristics such as enforcement quality, logistics or recycling infrastructure (Xie et al. 2023; Lee et al. 2025). Regulation and policy design create a fourth boundary. Multi-country meta-analysis confirms once again the Porter-type association at the aggregate level but reveals instrument-specific differences: command-and-control instruments lead to the most reliable reaction of innovation to regulation and voluntary instruments offer flexibility but lack reliability without credible enforcement mechanisms and market pressures, the degree of strictness and credibility plays a role and differs between developed and developing countries (Zhang et al. 2024; Benatti et al.; Tao et al. 2025).

2. Background on Green Intellectual Capital, Green Business Strategy and Green Technology Adoption

Increased attention paid to climate change and its broader implications for public health and economic well-being has forced firms to use sustainability-focused policies in order to prevent further environmental degradation (Melville 2016). However, the success of this process is not only about implementation of new policies but also about activation of existing internal knowledge-based resources known as green intellectual capital (GIC) which is the part of intellectual capital focused on environment. (Reed and Lubatkin 2006; Parthenope et al. 2025). GIC, in practice, is concerned with the skill level of employees in sustainable practices and innovation (Schiederig and Tietze 2012; Yong et al. 2019), environmentally-focused organizational culture and practices (Benevene et al. 2021) as well as

stakeholder relations characterized by environmental awareness (Delgado-verde et al. 2017). There is increasing research support for viewing GIC as a key enabler of SP facilitating the creation of strategies and innovations that reduce environmental impacts while enhancing competitiveness (Tjahjadi et al. 2025). Companies develop green knowledge resources with a view to achieving sustainability objectives and reducing emissions, waste, resource use and improving reputation, in addition to economic benefits such as cost reductions, differentiation and better financial performance (Asiaei et al. 2023; Zameer et al. 2020). Still, heterogeneity in the results occurs among organizations. While certain companies are able to achieve considerable sustainability success by using GIC (through significant reduction in carbon emission and waste leading to financial gains and competitive advantage (Asiaei et al. 2023; Tjahjadi et al. 2025), others experience either insignificant or even sporadic gains from applying the approach mainly because of poor alignment between GIC and strategy, lack of sponsorship from top management and inability to embed sustainability practices in regular business activities (Busch et al. 2024; Yousaf 2022). The heterogeneity of results implies that the relationship between GIC and sustainable performance is conditional and complex (Begum et al. 2023; Parthenope et al. 2025).

Previous research suggests that possession of GIC alone is not enough to achieve any significant sustainability benefits (Begum et al. 2023). Without proper utilization, the potential benefits of GIC cannot be realized and it all depends on how successfully it is incorporated into the overall strategic framework of the company. Identifying the organizational process involved in utilizing the GIC is important to identify weaknesses, improve its utilization and provide practical recommendations for firms operating in a highly competitive environment. One such process is that of green business strategy (GBS) which involves proactive inclusion of environmental aspects in strategy formulation and implementation (Begum et al. 2023; Mohd et al. 2023; Ullah 2022). In line with the research on proactive environmental strategies, GBS entails planned and preventative activities that exceed compliance in terms of integration of environmental concerns in core (Sharma et al. 2019; Aragón-Correa and Sharma 2003; Zhang et al. 2024). This perspective is premised on strategic leadership, environmental innovation and resource orchestration with particular emphasis on GIC. With well-articulated sustainability goals and implementation strategies, GBS ensures that the intellectual capital of an organization is oriented towards meeting its environmental concerns and hence achieving higher levels of sustainability performance and competitiveness (Leonidou et al. 2017; Wang 2021). In other words, GBS is the missing link that translates GIC to SP. Without this alignment, organizations will fail to utilize their intellectual capital to its maximum potential leading to fragmented approaches (Begum et al. 2023).

Within this context, the application of green technology (GT) functions as a moderator and facilitator in the GIC→GBS→SP sequence. Contrary to GBS, which is related to the prioritization and coordination of environmental and business objectives (Zhang et al. 2019), GT adoption focuses on the actual implementation of environment-friendly methods and technology (Ikram and Sadki 2024). Companies usually implement GTs in a proactive manner to deal with the environmental problems and obtain competitive advantages, often even before the implementation of a formalized green strategy (Guo et al. 2020; Ikram et al. 2021; Wang 2021). For instance, the introduction of renewable energy sources or clean production techniques could be a response to the existing pressure and market requirements prior to

being incorporated into the strategy (Tsoutsos and Stamboulis 2010; Khanra et al. 2022). Indeed, theoretically, the implementation of GT would provide the link between intent and execution, in the absence of appropriate technology infrastructure, the well-formulated plans for GBS based on GIC would still be insufficient in reality (Secundo et al. 2020). On the other hand, GT adoption makes the process of implementing a strategy more effective and thus leads to greater efficiency in the usage of intellectual and strategic resources, resulting in lower emissions and better environmental performance (Chen and Chen 2008). In such a way, one can see that GBS and GT adoption reinforce each other as technology can impede or facilitate strategy (Leonidou et al. 2017; Ben Arfi et al. 2018).

Extending theories such as the resource-based view (RBV) and natural resource-based view (NRBV) theory, we formulate a theoretical framework regarding the relationships among GIC, GBS and green technology adoption. The former theory proposes that value is created based on resources that are valuable, rare, inimitable and non-substitutable while the latter integrates environmental capability into the equation (Barney 1991; Hart and Dowell 2011). In the contemporary scenario, competitive advantage is not just about strategic resources but also includes the ability of the organization to respond to environmental threats and challenges using its knowledge, strategy and technology (Siddiqi et al. 2025). This is why we consider a moderated mediation where GIC improves SP through green business strategy and GTA further reinforces it by transforming the strategic intentions into action with the use of technology.

2.1 Green Intellectual Capital (GIC)

GIC is defined as the organization’s knowledge resources directed towards the environment and inherent in people, routines and relations in the organization (Chen and Chen 2008). From an analytical perspective, GIC acts as a strategic resource that is valuable, rare, non-substitutable and non-imitable but is clearly aligned towards environmental objectives. RBV and NRBV help us understand the reasons behind the sustained competitive advantage derived from these resources while IC explains how these resources are constructed and deployed in the organization. Practically speaking, GIC can be viewed through three interconnected components which include GHR, green structural capital and green relational capital as seen in Fig. 3 below. These form the basis for the firm’s ability to develop and utilize environmental knowledge for enhanced sustainability. Table 1 below captures the dimensions of GIC and its associated indicators.

Table 1
Scopes of Green Intellectual Capital.

GIC Scopes	Interpretation	Notable example	References
Green human capital	The knowledge, skills, experience, and attitudes of employees focused on environmental protection and green innovation	Employee training on eco-friendly practices and sustainability initiatives.	(Singh et al. 2020; Tjahjadi et al. 2025)
Green relational capital	An organization's relationship with stakeholders aiming to share knowledge and foster sustainable economic practices	Collaborations with suppliers to develop environmentally friendly supply chains.	(Yu et al. 2022)
Green structural capital	Organizational assets like culture, reward systems, and information management supporting sustainable growth and competitive advantage	Implementing a digital system to manage resources and reduce waste efficiently.	(Al-Omousha et al., 2024; Kusi-Sarpong et al. 2016)

Green Human Capital (GHC) is the set of knowledge, skills, competencies and values that employees of a firm possess to effectively respond to environmental issues and implement sustainable practices in the organization. It encompasses technical expertise such as renewable energy or waste management but also the commitment to sustainability of the employees and their capacity to innovate green solutions (Yong et al. 2019). This aspect of GIC is important, as it enables individuals within an organization to spearhead change and sway the adoption of green technologies and practices (Tjahjadi et al. 2025). In addition, GHC is considered as a major facilitator of ongoing environmental innovation which is critical for the maintenance of competitive advantage in the changing market (Parthenope et al. 2025). In this regard, organizations are increasingly investing in training and development programs to strengthen the green capabilities of their workforce (Siddiqi et al. 2025), because skilled human capital directly contributes to better sustainability performance.

Green Structural Capital (GSC) is defined as the organizational systems, processes, routines and structures which allow the firm to effectively manage and utilize its green knowledge. This comprises environmental management systems (EMS), sustainable manufacturing processes, eco-efficient technology infrastructure, and corporate policies to minimize environmental impact (Benevene et al. 2021). GSC allows the firm to increase the sustainability strategies by integrating green practices into the daily operations of the firm (Asiaei et al. 2023). There is also institutionalized environmental knowledge permeating the corporate culture, so that sustainability is not only a top-down directive but a core organizational value (Leonidou et al. 2017). Strong GSC firms are often better able to adopt and scale green innovations, integrate sustainability into supply chain management, and align business processes with long-term environmental objectives (Wang 2021).

Green Relational Capital (GRC) is the environmentally-oriented relationship of an organization with external stakeholders such as customers, suppliers, regulatory authorities and environmental NGOs. These relationships are based on trust, collaboration and a joint commitment to sustainable practices

(Delgado-verde et al. 2017). GRC is important for companies to access green technologies, know the market trends and meet with regulatory requirements. Furthermore, effective GRC can improve a company's reputation and brand image, drawing in environmentally conscious consumers and partners (Chen and Chen 2008). With sustainability becoming a key driver for business success, strong GRC will better position companies to innovate green products and services to improve their competitive positioning in the marketplace (Zameer et al. 2020). GRC also encourages collaborative efforts with suppliers and customers to enhance environmental performance across the value chain (Ikram and Sadki 2024).

2.2 Green Business Strategy (GBS)

GBS is the firm-level template that embeds environmental objectives into competitive decisions (markets, offerings, processes, partnerships) and aligns resources and routines accordingly. It brings to life the NRBV/RBV view by converting green resources (knowledge, skills, routines) into performance through proactive environmental choices beyond compliance, opportunity-seeking and often innovation-led. Empirical work shows positive links between proactive/green strategies and market, environmental and sometimes financial performance, often through mediators (reputation, CSR) and contingencies (competition, business model innovation) (Nguyen and Adomako 2021; Galbreath et al. 2023; Adomako et al. 2021).

The role of the firm has changed to not only concern itself with value creation but also with the pollution caused by the operations of the firm and wider responsibilities for social development (Ansoff 1977). At this stage, the Green Business Strategy (GBS) establishes the principles that merge the competitive goals of manufacturers with less harm to the environment. Such concerns have influenced managerial practice for decades and social and CSR considerations are now part of contemporary GBS objectives. The increasing sustainability goals also encourage manufacturers to act proactively, absorbing the environmental costs to reduce the effects and thereby improving the perceptions of stakeholders and reinforcing the corporate responsibility to society (Lyon and Maxwell 2011). The GBS integrates environmental issues into corporate strategy and operational management (Olayeni et al. 2021). GBS can reduce costs and access new markets improving profitability and access to finance relative to competitors by increasing resource efficiency and attracting environmentally sensitive customers (Porter et al. 1995; Ashton et al. 2017). Through CSR programs, firms' strategic internalization of social responsibilities redesigns business practices to complement GBS. CSR and GBS work together to achieve environmental, social and economic objectives. Empirical studies have shown that GBS can generate competitive advantages and improve firm performance (FP) (Olayeni et al. 2021) although not always positive across contexts (Lin et al. 2021; Tan et al. 2022). Similarly, CSR activities can result in economic benefits and improved stakeholder relations (Asad et al. 2023; Okafor et al. 2021), despite the mixed results obtained from some samples and designs (Velte 2022). Mapping concrete actions adopted by manufacturers is necessary to understand when and how GBS-CSR portfolios translate into sustained performance advantages.

(Carroll and Brown 2018) noted that present practices in firms are more focused on environmental stewardship and social initiatives, which pose challenges and opportunities to reposition towards new markets. Efforts on pollution control and recycling promotion in manufacturing directly shape CSR performance and visibility (Yang 2019). In this regard, it has been observed that inclusion of CSR is proposed as part of the sustainability-oriented business strategies. The implementation of the Green Business Strategy (GBS) allows for the prevention and reduction of pollution, which is prioritized by the stakeholders, and at the same time, it improves the firm's CSR reputation (Yang et al. 2019). Banerjee (2002) did not find any significant relationship between firms' environmental management and social dimension. This is further critiqued by (Banerjee 2008), who argues that the emphasis on social and environmental problems and claims of responsibility are only useful to manufacturing firms and provide little value to stakeholders. Similarly, Aagaard (2016) cautions that CSR is more of a marketing tool than an engine of sustainability, innovation or development in many large multinationals. Thus, one may legitimately question the wisdom of embedding CSR-promoting activities in GBS at the strategic level because the size and certainty of the benefits do not appear to be clear or independent of context

2.3 Green Technology Adoption (GTA)

GTA is the organizational choice and implementation of technologies that reduce environmental impact (energy efficiency, circularity, low-carbon processes) while maintaining or improving performance. Modern research uses combined frameworks to study GTA such as Technology-Organization-Environment (TOE), Diffusion of Innovation (DoI), Resource-Based View/Natural RBV (RBV/NRBV), Institutional Theory and Dynamic Capabilities, as the adoption is determined by technology attributes, firm resources/capabilities and external pressures/incentives at the same time (Naser et al. 2022). Green technology innovation (GTI) and clean energy are indispensable to carbon neutrality and the pressure to increase GTI is increasing under the dual constraints of resources and environment (Shan et al. 2021)(Lv et al. 2020). Developments in green and innovative technologies encourage more innovations in manufacturing which contributes to sustainable development. Organizations are embedding green innovation into strategy more and more to address the adverse effects of traditional growth models (Guo and Wang 2022). In this sense, Müller's political-economy approach stresses the crucial roles of innovation and nature for sustainable economic development, supported by organizations, institutions and policies where stricter environmental regulations improve firms' technical efficiency, stimulate environmental innovation and foster durable economic growth for long-term environmental, social and economic well-being (Meramveliotakis and Manioudis 2021). GTI is critical in achieving sustainable development goals with less impact on the natural environment than traditional development models (Guo et al. 2020; Wu et al. 2020). Its importance has been well acknowledged (Chang 2013; Qiu and Wang 2020) and is expected to be a key driver for sustainable economic growth in developing countries (Liu et al. 2023; Sun et al. 2023) with additional potential to alleviate environmental pollution (Liu et al. 2023). Yet the development of green technologies typically follows a long and exploratory process accompanied by many uncertainties and setbacks (Wicki and Hansen 2019). Thus, firms are often less incentivized to pursue green innovation (Ren et al., 2023). The technological complexity and asset specificity of green solutions and the immaturity of green markets increase costs,

market risk and payback periods for firms engaging in GTI activities (Money et al. 2018). Some managers also view environmental practices as a burden and respond passively (Yang 2019). Compared with traditional innovation, green innovation generally needs higher risk, more initial investment and slower returns (Adams et al. 2016). Thus, companies that want to integrate green technologies have to identify factors that improve social acceptance by stakeholders (Shahzad et al. 2022) and know how these factors influence economic performance, operations and intangible assets. Yet empirical evidence on drivers and consequences of green innovation in the service sector is still limited (Huang and Chen 2022).

The six pillars that summarize the main mutually reinforcing drivers of Green Technology Adoption (GTA) are illustrated in Fig. 4. First, there are external pressures and incentives that emanate from regulatory and policy frameworks such as standards, subsidies and international agreements. Second, economic and market drivers drive adoption through cost and energy savings, competitive differentiation and investor preferences for sustainable firms. Third, growing consumer and stakeholder expectations, such as supply-chain demands, encourage companies to protect brand reputation by adopting cleaner practices. Fourth, technology improvements lower adoption frictions by making greener options more efficient, cheaper and scalable. Fifth, using sustainable materials and green manufacturing moves strategy to action (e.g., switching from plastics to plant-based packaging) and directly reduces impacts. Finally, CSR and ethical commitments institutionalize GTA internally by aligning it with strategy, workforce values and reporting standards. The levers collectively move firms from compliance driven change to strategic capability based sustainability (Raj 2025).

2.4 Sustainability Performance

Sustainability performance (SP) is best measured using the triple bottom line: environmental (emissions, resource intensity), economic (profitability, productivity, risk) and social (employee well-being, community outcomes, equity). Both the scholarship and the practice are still predominantly TBL framing, which is more and more embedded in ESG measurement systems (Mishra and Pandey 2025). The Triple Bottom Line (TBL) framework has altered the way in which organizations and policy makers define and measure performance. It considers economic, social and environmental goals; taking a view beyond financial metrics to measure the long term impact of business decisions (Slaper 2021). TBL was born out of John Elkington's concept in the 1990s and has become a cornerstone of corporate sustainability and public policy, adding a clear ethical dimension by asserting organisational responsibility to stakeholders, society and the natural environment. TBL is currently a fundamental benchmark for sustainability and social responsibility for multinational corporations, local programs and governmental initiatives (Slaper 2021).. However, despite its widespread use, there are still concerns about inconsistent application as well as difficulties in measuring social and environmental outcomes (Macdonald 2016). The question then is whether TBL is mainly a strategy for branding or a real commitment to ethical responsibility.

2.4.1 Triple bottom line

The business concept Triple Bottom Line (TBL) is the idea that companies should find ways to measure their social and environmental impact, in addition to their financial performance. Instead of just focusing on profits, TBL looks at three areas. These three areas are profit, people and planet (see Fig. 5). It helps businesses understand their impact on the environment, create social value and achieve financial results. Companies that take these three factors into account do not simply aim for one result. The idea is to hold companies accountable in all areas not just in making money. TBL strives for a balanced approach to success, placing equal value on financial, social and environmental aspects. This approach motivates companies to be conscious of their contribution to society and the world. The end goal is for companies to positively impact all three areas, ensuring a sustainable and just future (Miller 2020).

And businesses can integrate sustainability into every aspect of their business, from their supply chain and partnerships to their energy use. This allows them to do some good for the environment and society. And at the same time it allows them to stay profitable. Companies can achieve both social and environmental benefits as they expand their bottom line (Miller 2020).

Profit

In a capitalist economy the key indicator of a company's success is its financial performance and the profits it makes for shareholders. Businesses are inclined to focus on strategies that aim to increase profits, reduce costs and manage risks. In the past, many companies only cared about economic growth. But today's leaders are learning that they can use their businesses to make positive social or environmental change, without hurting profits. In reality, implementing sustainability initiatives generally leads to improved business performance. More and more companies are finding out that good for the world can be good for business. Success can be attained through sustainable practices that are beneficial to the company and society (Miller 2020).

People

The second element of the triple bottom line concerns a company's impact on society or its commitment to people. It is important to distinguish between shareholders and stakeholders. Companies have focused on increasing the value of their shares in the past which are owned by the owners of the company. However, as businesses start to embrace sustainability practices they are now starting to look for ways to benefit all stakeholders including customers, employees and community. A company can do good by having fair hiring practices and encouraging its employees to volunteer. They can also partner with non-profit organizations to have a greater impact on society, particularly when they have the same mission (Miller 2020).

The Planet

The third element of the triple bottom line is about helping the environment. Big companies have polluted a lot since the Industrial Revolution. And that has helped climate change. For example, the International Energy Agency estimated that the global energy sector released 135 million tonnes of

methane into the atmosphere in 2022 (IEA, 2023). Businesses are a huge part of the climate problem but they can also be a huge part of the solution. Many business leaders are realizing now that they have a responsibility to help. The biggest companies aren't the only ones who can make a difference to reduce their carbon footprint, every business can. This can all help things like using eco-friendly materials, reducing energy use and improving shipping methods. And these measures matter for long-run sustainability (Miller 2020).

3. Theoretical Lenses and Integrative Logic

In this section, five complementary theoretical lenses are synthesized Natural Resource-Based View, Knowledge-Based View, Dynamic Capabilities, Institutional/Stakeholder theories and Configuration/Complexity thinking to build an integrative logic that explains how Green Innovation Capability (GIC) translates into Green Business Strategy (GBS) and Green Technological Adoption (GTA) and ultimately firm outcomes. Each lens highlights different mechanisms and boundary conditions and collectively provides a multidimensional basis for theory building and hypothesis formulation.

3.1 Natural Resource-Based View (NRBV): environmental capabilities as strategic resources

The NRBV builds on the conventional resource-based view by highlighting firm resources and capabilities resulting from environmental practices as possible sources of sustained competitive advantage. From this viewpoint, GIC is seen as a strategic and inimitable capability that emerges from investments in resource-efficient processes, pollution-prevention technologies and routines for environmental management. NRBV offers two complementary mechanisms: (a) value creation through cost savings, product differentiation or access to green markets and (b) appropriability through firm-specific routines and complementarities (supplier networks, eco-design practices) that are difficult to be imitated by rivals. Empirical recent work has supported the application of NRBV to green innovation by showing that green innovation can function as a strategic resource and contribute to differentiation and firm performance (Khanra et al. 2022; Andersons 2010). NRBV posits that firms with strong GIC are more likely to integrate green priorities into their strategic planning (GBS) and invest in GTA because such investments improve strategic advantages. NRBV informs predictions for hypothesis building such as 1. GIC positively predicts the adoption of firm-level green strategies and selective uptake of green technologies, 2. The GIC→performance effect is mediated by GBS and moderated by resource complementarity (green suppliers) (Khanra et al. 2022).

3.2 Knowledge-Based View (KBV): GIC as knowledge assets and routines

The KBV perceives the firm as a knowledge reservoir; innovation results are dependent on knowledge stocks and knowledge management processes. From this point of view, GIC is essentially a configuration of knowledge assets technical know-how, environmental R&D, tacit skills and

organizational learning routines that facilitates the discovery, implementation and scaling of green solutions. Recent empirical and review papers indicate the importance of green intellectual capital (human, structural, relational) and knowledge management practices in the promotion of green innovation and diffusion (Liu et al. 2022a). Based on the KBV, mechanisms of GIC conversion into GBS and GTA are proposed: knowledge codification and sharing to facilitate strategy design (GBS) and absorptive capacity and learning to allow the firm to evaluate and adopt GTA effectively. This lens also proposes measurement approaches (proxies for green human capital, patents, training intensity, knowledge sharing indices). Hypotheses derived from KBV are: green knowledge stocks strengthen the effect of GIC on GTA, knowledge transfer mechanisms mediate the GIC-GBS relationship (Liu et al. 2022a)..

3.3 Dynamic Capabilities: Sensing, Seizing and Reconfiguring for Green Opportunities

The theory of dynamic capabilities explains how firms detect opportunities/threats in the environment, exploit opportunities by deploying resources and reconfigure bundles of resources to compete in evolving contexts. When applied to sustainability, the focus is on green dynamic capabilities the firm's ability to sense regulatory, market or technological signals related to sustainability, mobilize resources for green projects and realign routines and structures toward low-carbon pathways. Contemporary reviews synthesize typologies of dynamic capabilities designed to promote sustainability and stress the nexus between strategic intent and operational change (Ortiz-avram et al. 2024). Dynamic capabilities provide the process perspective that links GIC (resource/knowledge base) to concrete outcomes: sensing explains the role of GIC in sensing technology opportunities (GTA), seizing and reconfiguring explains how GIC leads to firmwide strategy (GBS) and organizational change. Empirically, dynamic capabilities are plausible mediators/moderators: they mediate the GIC→GBS→performance path and they moderate the effectiveness of adopting GTA in fast-changing regulatory or market environments (Almeida et al. 2024).

3.4 Institutional Theory and Stakeholder Theory: external pressures as boundary conditions

Institutional and stakeholder perspectives emphasize the role of regulatory regimes, normative expectations and stakeholder pressures (customers, suppliers, investors, NGOs) in shaping the adoption and the results of green strategies and technologies. Institutional theory explains isomorphic pressures (coercive, mimetic, normative) that push firms toward compliance or symbolic adoption. Stakeholder theory explains variation in strategic responses based on stakeholder salience and firm stakeholder management practices. The recent literature suggests that institutional pressures play a dual role in encouraging firms to invest in GIC and shaping how this capability is strategically utilized (encouraging more visible GBS when legitimacy is a concern) (Benvenuto et al. 2023; Risi et al. 2023). These views provide explanations of boundary conditions. They predict contingent effects such as: the GIC→GBS relation is stronger in institutional environments where environmental regulation is strict, stakeholder

engagement moderates whether GIC investments are directed to substantive technology adoption (GTA) or symbolic compliance. For empirical strategy include measures of regulatory stringency, stakeholder pressure and disclosure/legitimacy outcomes (Benvenuto et al. 2023; Risi et al. 2023).

3.5 Configuration and Complexity: Equifinality and Multiple Pathways (GIC-GBS-GTA)

Configuration theory and complexity approaches reject single-path causal models and suggest that there are multiple distinct configurations of capabilities, strategies and contextual factors that can lead to similar sustainability outcomes (equifinality). In the green innovation domain, this implies that some firms may achieve environmental and business goals through a knowledge-intensive path (strong GIC + collaboration + selective GTA) whereas other firms may achieve the same performance through a resource reallocation path (heavy capital investment in GTA + operational GBS). Various studies on green innovation ecosystems and systems perspectives highlight such emergent, non-linear dynamics (Zhou 2024; Qin et al. 2026). Configuration logic has methodological implications go beyond single-equation causal models and use configurational methods (fsQCA, cluster analysis, set-theoretic approaches) or structural models rich in interactions that show multiple effective pathways. Hypotheses in this stream are often configurational rather than linear, different combinations of high/low GIC, strong/weak dynamic capabilities and institutional pressures will map onto different but equally effective GBS-GTA pathways to performance (Zhou 2024).

4. Micro-foundations of GIC

Absorptive capacity is the ability of a firm to recognize the value of new external knowledge, assimilate it, transform it and apply it to commercial ends. This fourfold process is based on Cohen and Levinthal and was re-conceptualized into potential and realized absorptive capacity by Zahra and George. Consider human, structural and relational green capitals as antecedents that enhance the firm's potential and realized green absorptive capacity (Cohen and Daniel 1990; Zahra 2002).

4.1 Human Capital (Green Skills, Training and Incentives)

Green skills and targeted training build upon employees' existing related knowledge and cognitive structures, enabling them to recognize and appreciate new environmental knowledge. Incentive systems stimulate employees to search for external green knowledge and to share it internally. Taken together, these actions improve the acquisition and assimilation steps of absorptive capacity, making organizations receptive to best practices, cleaner technologies and regulatory knowledge. Empirical studies have indicated that green knowledge sharing and training strongly predict absorptive capacity and downstream green innovation (Javeed et al. 2023). Human capital is a core determinant for developing absorptive capacity for sustainability as it influences how individuals identify, assimilate and use external environmental knowledge. Formal training, on-the-job learning, certification workshops, green HRM practices, incentive systems and leadership experience operate through different but

complementary pathways. The literature since 2020 best examines their effects using coding of evidence across three outcomes, namely knowledge acquisition, knowledge assimilation and innovation adoption. Formal training programs are mainly knowledge-acquisition enhancing. Training in environmental management, cleaner production, life-cycle assessment, or decarbonization provides employees with baseline conceptual frameworks to identify and value external sustainability knowledge. Empirical evidence suggests that firms that invest in continuous environmental training have higher scanning intensity for regulatory updates, emerging technologies and sustainability standards. Training also creates a common technical language that shortens the cognitive distance between internal teams and external sources of knowledge. The proxies used to operationalize evidence are training intensity, training hours per employee or environmental training breadth which are generally associated with higher levels of potential absorptive capacity. On-the-job learning is a more powerful mechanism for knowledge assimilation. Experiential learning enables the employees to link the knowledge from outside environment to the firm's own processes instead of formal training. Sustainability knowledge can be interpreted, adapted and embedded into daily operations through learning-by-doing, cross-functional project teams and problem-solving routines. The literature shows that companies with an experiential learning orientation have higher internal knowledge sharing and faster internalization of environmental practices. The results of assimilation are often measured by indicators of the quality of internal communication, collaboration between departments or the degree to which green practices have become a routine. Certification workshops and professional credentials such as training to be an ISO 14001 auditor or to earn energy management certifications bridge acquisition and assimilation. Such mechanisms expose employees not only to global best practices codified in standards, but also educate them on translating standards into operational routines. Studies indicate that learning through certification-oriented training increases the interpretative capacity of employees, consequently reducing ambiguity in environmental decision-making. In the literature, outcome coding links certifications to augmented procedural knowledge, expedited EMS adoption, and diminished resistance to organizational change, which in turn promote greater realized absorptive capacity. The systematic execution of green HRM practices has been observed in all stages of absorptive capacity. Recruitment policies focusing on environmental competencies foster initial knowledge acquisition and performance appraisal systems with environmental measures ease assimilation and application. Training, appraisal and reward systems aligned to sustainability goals encourage behavioral consistency and reinforce learning loops. Empirical studies reveal that green HRM facilitates the transformation of environmental knowledge into green process and product innovations. In review coding, green HRM variables are often associated with greater adoption rates of innovation, especially when absorptive capacity is a mediating mechanism. Monetary and non-monetary incentives are important for the conversion of assimilated knowledge into innovation adoption. Employees are motivated to try new sustainability practices and take short-term risks for green innovation through financial incentives, promotions, recognition programs and symbolic incentives. There is evidence that incentives lead to more exploitation by stimulating proactive behavior, sharing knowledge and the adoption of externally developed solutions. Studies usually measure the outcomes in terms of the number of green innovations adopted, improvements in eco-efficiency or speed of diffusion of technology within the firm. Board and leadership green experience is a cross-

cutting influence on absorptive capacity through strategic attention and organizational priorities. Experienced leaders in environmental management, sustainability reporting or green innovation are more capable of recognizing good external knowledge and allocating resources to obtain and implement it. Several research indicates that leadership green experience enhances the effect of training and incentive systems, thereby promoting innovation adoption. Empirical coding links leadership variables to strategic absorptive capacity, long-term investment in sustainability and successful scaling of green innovations (Song et al. 2020).

4.2 Structural Capital: Routines, ISO 14001 / EMS and Green IT infrastructure

Codified routines and management systems provide stable channels for the internal flow of knowledge as well as for embedding external knowledge into processes. Mature EMS and ISO 14001 institutionalize scanning, documentation and continuous improvement processes that translate external environmental information into standardized operating procedures. Green IT and digital infrastructure help us capture, analyze and share information, allowing knowledge to be absorbed and put into practice more quickly and effectively. Researches show that both the adoption of EMS and the digital transformation improve firms' capability to convert environmental information into actionable green innovations (Wang et al. 2022).

Literatures since 2020 converge on evidence that ISO 14001-based environmental management systems (EMS) play a significant role in reshaping internal routines and improving environmental performance, although the magnitude of these effects varies across contexts. Empirical and meta-analytical studies have shown that the implementation of ISO 14001 is usually associated with improved environmental performance including emissions reduction, resource efficiency, regulatory compliance and green innovation. But more and more scholars are emphasizing that these outcomes are not automatic. Instead, ISO 14001 is an enabling framework whose effectiveness depends on its depth of implementation, managerial commitment and complementarities with other organizational resources. Studies accounting for self-selection and firm heterogeneity show clearer causal links between EMS adoption and performance suggesting that ISO 14001 contributes to sustainability primarily when it is internalized rather than symbolic certification (Barinaga-rementeria 2024).

At the organizational level, ISO 14001 impacts environmental performance by institutionalizing routines that directly support the transformation stage of absorptive capacity. The standard mandates environmental scanning, documentation, internal audits and corrective actions which translate external environmental knowledge such as regulations, stakeholder expectations and best practices to codified internal procedures. Through the Plan-Do-Check-Act cycle, continuous improvement mechanisms allow firms to experiment with new environmental practices, measure the results and improve the practices over time. ISO 14001 clarifies roles, responsibilities and reporting structures and reduces ambiguity and co-ordination costs to make possible the systematic transformation of assimilated knowledge into operational know-how embedded in daily routines (Zhang et al. 2024).

Besides transformation, ISO 14001 also supports the exploitation phase of absorptive capacity by providing governance structures that facilitate the scaling and routinisation of green innovations. Accountability mechanisms such as internal audits, management reviews and certification requirements help firms institutionalize successful environmental practices across departments and sites. Several studies since 2020 demonstrate that EMS-certified firms are more likely to commercialize green products, adopt cleaner production technologies and achieve sustained eco-efficiency gains. But the literature also points to important contingencies: the exploitation benefits of ISO 14001 are higher in larger firms, in pollution-intensive sectors and where EMS is combined with employee training, digital monitoring tools and leadership commitment to sustainability (Oyelakin 2022).

Consistent with the EMS literature, studies on green information technologies since 2020 highlight their increasing significance for enhancing both transformation and exploitation stages of absorptive capacity. Sensors and Internet of Things (IoT) technologies allow for real-time, high-resolution monitoring of emissions, energy use, effluents and process conditions. Such technologies greatly reduce the uncertainty and latency of information allowing firms to translate abstract environmental objectives into quantifiable operational parameters. Studies show that sensor-based monitoring influences the process of transforming environmental data into actionable insights, especially when combined with existing management routines. However, in the absence of such integration, sensor data are often underutilized, thereby limiting their contribution to absorptive capacity.

Cloud analytics, machine learning tools and digital lifecycle assessment platforms further expand the role of green IT in transformation by translating large volumes of environmental data into contextual knowledge. With analytics platforms, firms can combine internal operational data with external datasets such as regulatory benchmarks, supplier footprints and lifecycle databases to identify patterns, predict environmental impacts and assess alternative interventions. Empirical research shows that firms that use advanced analytics are better able to reinterpret knowledge from the external environment and adapt it to firm-specific contexts thereby strengthening the transformation component of absorptive capacity (Rup and Bajic 2024).

Enterprise systems, digital twins and integrated ERP and sustainability reporting platforms also play a crucial role in the exploitation stage of Green IT. These systems can embed transformed knowledge into workflows, procurement rules, performance dashboards and decision-support tools allowing green practices to be implemented and scaled consistently. Post-2020 studies show that firms that adopt enterprise level digital systems experience faster diffusion of environmental innovations across organizational units and supply chains. Importantly, these exploitation effects are most pronounced when digital tools are aligned with EMS routines, governance structures and employee capabilities, highlighting the complementarities between ISO 14001 and green IT (Charfeddine and Umlai 2023).

4.3 Building Sustainability-Oriented Absorptive Capacity through Human, Structural, and Relational Green Capital

Absorptive capacity (AC) which refers to the firm's ability to acquire, assimilate, transform and exploit external knowledge, is a key dynamic capability for achieving sustainability outcomes (green innovation, operational resource efficiency, and improved compliance) (Soetanto et al. 2024).

By providing human capital (knowledge and motivation), green skills, targeted training programs and incentive systems, employees are prepared to recognize and interpret environmental knowledge from markets, regulators, research institutions and suppliers. The investments mainly aid the acquisition and assimilation stages of AC by enhancing the scanning capabilities, absorptive attention and the interpretive schemes required to internalize green knowledge. Empirical work has linked workforce skills and targeted training with improved green absorptive outcomes and green innovation (Demirel 2025; Levis et al. 2017; Du and Wang 2022).

Processes and technology i.e. structural capital, formal routines, Environmental Management Systems and green IT/digital infrastructures convert individual knowledge into organizational memory and processes. Standardized EMS routines codify procedures and establish audit-feedback loops that facilitate the integration and transformation of environmental knowledge into operational practices. Green IT and analytics enhance sensing capabilities and internal knowledge flows, enabling quicker recombination and utilization of green knowledge. Research (Research). Adoption of ISO 14001/EMS and organizational routines improve the governance and constitute the basis for green capability development (Abid et al. 2021).

Relational capital (external linkages), stakeholder partnerships (regulators, NGOs, universities), supplier integration along green supply-chain practices and customer collaboration supply diverse external knowledge and legitimacy. These external links increase the firm's exposure to new environmental solutions and co-creation opportunities, fueling acquisition and enabling richer transformation when combined with internal capabilities. Recent evidence suggests that stakeholder engagement and green supply chain integration enable green process innovation with absorptive capacity as a mediator (Appiah 2023; Yang et al. 2019)

4.4 Mechanism: How the three capitals produce Absorptive capacity (AC)

Acquire: Relational capital (suppliers, research partners, regulators) and proactive human capital (trained employees, green-skills) enrich environmental scanning and inflow of relevant knowledge. Structural supports (green IT, routines) enhance the reach and fidelity of captured knowledge (Appiah 2023).

Assimilate

Trained people plus codified EMS procedures interpret and translate external signals into internal representations (reports, KPIs, playbooks). ISO 14001 routines formalize interpretation through audits, risk registers and management review cycles (Abid et al. 2021).

Transform

Cross-functional teams, enabled by green IT (data analytics, digital platforms) and management incentives, recombine the absorbed knowledge into new processes or product designs (circular-material pilots, low-energy process redesign) (Du and Wang 2022).

Exploit

It routinizes innovations (standard operating procedures, supplier contracts with sustainability clauses) to realize measurable environmental and business outcomes, energy/waste reduction, regulatory compliance and enhanced stakeholder trust. Evidence finds that AC mediates the relationship between external pressure and relational integration with green innovation outcomes (Appiah 2023).

5 From Green Innovation Capacity (GIC) to Green Business Strategy (GBS)

In the face of increasing climate change issues, regulatory pressures and stakeholder demands, Green Industrialization and Green Innovation Capability (GIC) have become vital enabling factors for firms to achieve a dual goal of economic performance and environmental sustainability. The GIC gauges a company's ability to develop and deploy environmentally-friendly products, processes and technologies which reduce environmental impacts while enhancing competitiveness. However, the translation of GIC into long term organizational value is largely dependent on its integration into a coherent green business strategy that embeds sustainability into core decision making, resource allocation and value creation processes. Green business strategy goes beyond compliance by proactively using environmental initiatives to achieve cost efficiencies, market differentiation, innovation leadership and improved corporate reputation. Research shows that firms that align GIC strategically with green business strategies are better able to achieve sustainable competitive advantage, resilience, and superior financial and environmental performance, particularly in resource intensive and environmentally-sensitive industries (Salonen and Camilleri 2021; Hart and Dowell 2011; Khalifa 2024; Kumar et al. 2025).

5.1 Mechanisms Enabling Organizational Adaptation and Sustainability

Organizations in complex and uncertain environments depend on a set of interrelated mechanisms to support strategic decision-making, adaptability and long-term sustainability. Strategic sensemaking, environmental scanning, cross-functional integration and governance mechanisms are key to align organizational capabilities to external dynamics. All these mechanisms together enable the organization to read environmental signals, align its internal resources and respond effectively to new challenges.

Strategic Sensemaking

Strategic sense-making is the process by which organizations interpret ambiguous, complex and changing environmental information to construct shared meanings that guide strategic actions. This is especially important in uncertain environments such as technological disruption, regulatory change and

transitions to sustainability. Sense-making helps decision makers to move from disconnected information to coherent stories that drive strategic choices and organizational priorities. Various literature emphasizes that strategic sense-making is not a pure cognitive activity but a socially constructed process shaped by organizational culture, leadership and power relations. Managers make sense of problems by framing them, by choosing cues from their environment and by legitimizing such choices through communication and discourse. We argue that this collective sense-making process influences how organizations perceive the risks and opportunities of sustainability, innovation, and market changes (Maitlis 2014). In sustainability settings, strategic sense-making helps embed environmental and social considerations in core business strategies. Sense-making-oriented organizations are better able to align sustainability objectives with operational and financial goals thereby enhancing strategic coherence and long-term resilience (Wiley and Gioia 2011). Digital technologies and data analytics are also playing an ever-increasing role in sense-making processes through real-time interpretation of complex environmental data (Bhimani 2020).

Environmental Scanning

Environmental scanning is the systematic gathering, analysis and interpretation of information from the external environment to identify emerging trends, uncertainties and potential disruptions. It is about following technological innovations, regulatory changes, market trends and socio-environmental forces that might affect the performance of the organization.

More recent studies highlight the role of environmental scanning as a dynamic capability for organizational agility and strategic renewal. By enabling organizations to anticipate change rather than simply react to it, effective scanning reduces strategic blind spots and improves decision quality (Teece 2014). Advanced digital tools, like big data analytics and artificial intelligence have emerged and enhanced the scope and accuracy of environmental scanning, allowing organizations to analyze large volumes of structured and unstructured data (Sivarajah et al. 2024). As regards sustainability, environmental scanning is important to identify environmental risks and expectations of stakeholders, and to understand the development of policy frameworks on climate change and resource efficiency. Sustainability-oriented scanning within strategic planning is associated with a higher propensity to adopt proactive environmental strategies and to conform to the increasing stringency of regulations (Harris and Brooker 2025; George and Schillebeeckx 2022). But environmental scanning will only work if there are organizational learning mechanisms that can turn external information into actionable insights.

Cross-Functional Integration

Cross-functional integration is the cooperation and collaboration of the functional units of an organization, i.e., operations, finance, marketing, research and development, and sustainability management. This mechanism is critical to breaking down organizational silos and ensuring that strategic priorities are consistently executed across functions. The past literatures have indicated that cross-functional integration is beneficial for knowledge sharing, innovation and strategic alignment, especially in complex initiatives such as sustainability transitions and digital transformation. Integrated

teams facilitate the exchange of different types of knowledge and opinions and are therefore more-able to solve multidimensional problems that cannot be solved in a single functional area (Poberschnigg and Pimenta, 2026). In sustainability oriented strategies cross-functional integration facilitates the alignment of environmental goals with operational efficiency and financial performance. Environmental management integrated with production and supply chain functions can enhance resource efficiency and reduce environmental impacts (Yong et al. 2019). In addition, leadership support, common performance metrics and integrative communication platforms are identified as essential enablers of successful cross-functional collaboration (Akuffo 2020).

Governance Mechanisms

Governance mechanisms refer to structural and institutional arrangements for decision making, accountability and control in organizations. These mechanisms include formal policies, board oversight, managerial incentives and stakeholder engagement structures which shape strategic behavior and ensure alignment with organizational objectives. Various work highlights the growing importance of governance in addressing sustainability and environmental issues. Strong governance structures increase transparency, decrease information asymmetry and help to incorporate environmental, social and governance (ESG) considerations into strategic decision-making (Naciti et al. 2022). Having a board with sustainability expertise and diverse representation is associated with improved environmental performance and long-term value creation (Menicucci and Paolucci 2025). In addition, governance mechanisms are crucial in coordinating the other adaptive mechanisms discussed above. Effective governance allows for cross-functional integration to translate the insights from environmental scanning and strategic sensemaking into coherent strategies and implementation. In this context, adaptive and participatory models of governance are increasingly mentioned as key to address complexity and uncertainty in sustainable development pathways (Massuga et al. 2024).

5.2 Proactive Green Business Strategy as a Driver of Green Technology Adoption

A proactive green business strategy (GBS) does not consider green technology adoption (GTA) as a mere compliance activity but rather transforms environmental responsibility into a strategic decision-making logic that defines the selection of technologies to be adopted, the degree of their embedding in the firm, and the timing of adoption. In this sense, GBS is an organizing mechanism for firms to identify green opportunities, allocate resources, manage transition risks and institutionalize environmental change across business functions. Past studies have indicated that green competitive advantage and sustainable performance are closely related to green strategy, green dynamic capabilities, green innovation adoption and green technology adoption (Bhatia 2021; Yu et al. 2022; Chen et al. 2021; Nawab 2024). First, proactive GBS influences the “what” of GTA by impacting the firm’s green technology portfolio. Companies that adopt a reactive approach tend to use stand-alone technologies that meet regulatory requirements, such as pollution-control equipment, energy-saving devices, or waste-treatment systems. However, proactive companies tend to build up a diversified portfolio of cleaner production

technologies, renewable energy systems, circular economy technologies, digital monitoring tools, green supply chain platforms and product redesign technologies. Such firms consider technologies not only on payback period but also on their contribution to carbon reduction, resource productivity, stakeholder legitimacy and long-term competitive positioning. The logic of this portfolio is supported by research evidence that corporate green strategy can support green assets, green technology, green performance and green competitive advantage (Chen et al. 2021). Likewise, the adoption of green technology has been associated with green dynamic capabilities and green product innovation, implying that the selection of technologies should be consistent with the firm's capability building trajectory, rather than being treated as a one-time investment (Bhatia 2021).

Second, the depth of integration defines the "how" of GTA in which proactive GBS drives the process. On the surface, GTA may be about installing individual green technologies with no change in routines, supplier relationships, employee behaviour or performance metrics of the firm. But a forward-looking GBS encourages companies to go further with greater integration of green technologies into production planning, procurement, logistics, product development, data systems, human-resource practices and strategic control systems. GTA in this deeper form is a component of organizational learning and dynamic capability development (Wasiq and Kamal 2023). Bhatia (2021) found that proactive environmental strategy is a precursor of green process innovation, and that technological capabilities and organizational learning mediate the relationship between green process innovation and operational performance. Yu et al. (2022) further emphasized that green dynamic capability supports green innovation adoption especially when supported by analytical capability. Thus, the "how" of GTA depends on whether the firm simply acquires technology or also develops the organizational routines to use, improve and scale it. Third, GBS influences the "when" of GTA by influencing adoption timing through proactive GBS. Reactive firms are likely to delay adoption until external pressures become unavoidable such as increasing regulation, customer demands, investor pressure or rising energy costs. On the other hand, firms that are forward-looking may adopt early in order to gain first mover advantages, learn ahead of their competitors, reduce future compliance costs and build legitimacy with regulators, customers and financiers. Early adoption is particularly important in areas where the learning curve for technologies, infrastructure development, supplier preparedness and employee capability building takes time. But timing should not be interpreted as the sooner the better. For firms, there is a trade-off between the benefits of early adoption of proactive GBS and the costs of technological uncertainty, capital intensity, transition risk and implementation readiness. Thus, the timing of adoption seems to be a strategic decision taken by the firm based on its environmental scanning, risk assessment, regulatory anticipation and absorptive capacity.

Budget allocation is a central mechanism of translating proactive GBS into GTA. Green technologies have initial CAPEX, training, digital infrastructure, certification fees, supplier development and monitoring systems. GBS-mature companies are more likely to have dedicated sustainability budgets, green capital-expenditure criteria, lifecycle-costing approaches, internal carbon pricing and sustainability-linked investment priorities. Proactive companies view projects not just through the prism of short-term financial returns, but also long-term savings, avoided regulatory penalties, reputational benefits, security

of resources and access to green finance. The transition-finance literature further stresses the role of credible transition plans, transparent taxonomies and climate-related disclosure in directing capital to low-carbon investments (OECD, 2021; NGFS, 2022; SSE, 2025). The budget allocation thus becomes a financial and strategic signal of whether the firm's green strategy is rhetorical or grounded in actual investment decisions. The risk tolerance also plays a mediating role between GBS and GTA. There are a number of risks involved in investing in green technologies such as technological failure, uncertain payback, dependence on suppliers, regulatory change, employee resistance, market acceptance and possible disruption to existing operations. Such firms are typically reactive, low risk tolerant and favor proven incremental technologies. Forward-looking companies are more willing to accept a greater calculated risk if the technology offers long-term strategic value, potential for emission reduction, learning advantage or future market access. But proactive risk tolerance is not risk blindness. This comprises scenario analysis, pilot testing, phased scaling, supplier evaluation, digital monitoring and governance mechanisms to mitigate uncertainty. Various work on green dynamic capabilities suggests that firms need the ability to sense environmental opportunities, to seize green technologies and to reconfigure resources in response to changing environmental and market conditions (Yu et al. 2022; Kalyar et al. 2024).

The last condition that decides whether GTA produces meaningful transformation is change management. Even if firms choose the right green technologies and allocate the right budgets, adoption may not take place if there is a lack of employee training, lack of middle management alignment, lack of supplier involvement and no change in performance indicators. Thus, proactive GBS is communication of environmental objectives, cross-functional integration, employee involvement, green training, commitment by leadership and continuous measurement of environmental results. Organizational commitment also strengthened the relationship between green competitive advantage and sustainable development in the context of GTA and dynamic capabilities (Nawab 2024). Hence, through change management, green technology becomes an organizational capability rather than a physical asset. Generally, pro-active GBS affects GTA in three strategic dimensions: the portfolio of adopted technologies, the depth of organizational integration and the timing of adoption. It also drives the management conditions that enable adoption such as budget allocation, risk tolerance, change management, etc. The previous literature shows that GTA should not be considered solely as a technological or operational decision. Instead, it should be seen as a strategic transformation process where firms combine green intent, financial commitment, dynamic capability and organizational change to achieve sustainable competitive advantage.

5.3 Mediating and Moderating Mechanisms in the Relationship between Sustainability-Oriented Capabilities and Firm Outcomes

The relationship between sustainability-oriented strategic actions and firm performance is often not straightforward. A growing number of recent literature shows that environmental strategy, circular economy adoption, green innovation, and low-carbon transformation affect organizational outcomes by

internal capability-building mechanisms and some boundary conditions. Mediators such as green dynamic capabilities, absorptive capacity and cultural readiness explain how sustainability initiatives are translated into environmental, social, operational and financial outcomes while moderators such as regulatory stringency, market turbulence, digital maturity, supply-chain pressure, firm size and age, industry carbon intensity and ownership/governance explain when and for whom these relationships become more or less potent.

The key mediating mechanisms include green dynamic capabilities that allow companies to sense environmental opportunities and risks, to seize green business opportunities and to reconfigure resources into sustainable products, processes and business models. In this context, sustainability initiatives such as green supply chain management, circular economy practices, digital green innovation and environmental management systems may not improve performance automatically unless firms have the capability to integrate these practices into routines, technologies, employee behavior and strategic decision-making. Dynamic capabilities are critical resources for environmental sustainability, economic sustainability and corporate social responsibility (Franco and Giannoccaro 2025). Green dynamic capability may help facilitate environmental and social innovation behavior, as shown by (Li et al. 2023). Thus, green dynamic capabilities mediate the relationship between external sustainability pressure and internal organizational transformation. Another important mediator is the absorptive capacity, because firms need to recognize, acquire, assimilate and exploit external sustainability-related knowledge. In the green transformation useful knowledge can be obtained from customers, suppliers, universities, competitors, regulators, consultants, industry associations or digital platforms. Companies with a high absorptive capacity are more able to translate environmental regulation, stakeholder expectations, technological development, and market signals into green innovation and sustainability performance. For example, knowledge on cleaner production, renewable energy, eco-design, waste valorization, life-cycle assessment and carbon accounting is of no use unless the firm is able to internalise it and translate it into products, processes and managerial routines. Thus, absorptive capacity contributes to the transformation of sustainability inputs to green innovation outputs and long-term competitive advantage.

Cultural readiness is also a mediator, because sustainability transformation is not only about adopting technology or compliance. It depends on common values, employee engagement, leadership support, collaboration across departments, willingness to experiment, openness to change. Companies can implement digital tools, systems for a circular economy or cleaner technologies but these investments can be symbolic or underutilized if there is not a supporting culture. Cultural readiness makes employees and managers accept sustainability goals, engage in eco-innovation, share knowledge and adapt daily practices to environmental objectives. It thus mediates the relationship between sustainability strategy and actual implementation outcomes by translating formal policies into behavioural change. Various moderating variables moderate the strength of these mediating mechanisms. Regulatory stringency is an important external moderator. Green capabilities can be further enhanced and have more positive impacts on innovation and performance when combined with strict environmental regulations, carbon disclosure requirements, extended producer responsibility rules, emission standards and waste

management laws. The strong regulatory pressure is likely to make the green transformation of the firms a strategic necessity instead of a voluntary activity. For example, Nazir et al. (2024) pointed out the moderating role of institutional pressure in the link between green manufacturing and sustainability performance. But if regulation is too rigid or unpredictable, it can increase the costs of compliance, particularly for small firms with limited resources.

Another important moderator is market turbulence. In highly turbulent markets, changing customer preferences, technological uncertainty, price volatility and competitive pressure may be both incentives and constraints for green innovation. Turbulent market conditions can be a moderating factor in the eco-innovation-sustainable business performance relationship, as posited by Larbi-siaw et al. (2022). In such settings, green product innovation may enable firms to differentiate and capture emerging demand while green process innovation may reduce cost and resource dependence. But market turbulence can undermine sustainability results if firms are more focused on short term survival than long term environmental investment. Digital maturity strengthens the relationship between sustainability capabilities and performance as digitally mature firms are able to use data analytics, artificial intelligence, blockchain, Internet of Things, cloud platforms and digital twins to enhance resource efficiency, monitor emissions, trace supply chains and optimize circular flows. Xie et al. (2023) argued that digital and sustainability orientations can jointly drive digital green innovation through capability reconfiguration. Similarly, previous work on circular economy and digitalization highlights that digital technologies allow for data-driven decision making, lifecycle transparency, recycling, reverse logistics and resource optimization. Therefore, digital maturity can positively moderate the speed, accuracy and scalability of green transformation.

Sustainability outcomes are also hurt by supply-chain pressure. Firms may adopt green procurement, eco-design, cleaner production, carbon reporting and circular supply-chain practices under pressure from large buyers, multinational corporations, suppliers, logistics partners and downstream customers. Firms embedded in supply chains demanding sustainability may benefit more from green dynamic capabilities and absorptive capacity, as external partners provide knowledge, standards, monitoring systems and market incentives. Conversely, firms with fragmented or lightly regulated supply chains may not see the necessary pressure or support to convert sustainability capabilities into performance improvements. Organizational moderators such as firm size and age are important. Larger and older firms are likely to possess greater financial resources, managerial expertise, formal systems and stakeholder visibility which may strengthen the effect of sustainability capabilities on performance. They may, however, also have the drawbacks of bureaucracy and path dependence that may slow transformation. Smaller and younger firms may be more flexible and entrepreneurial but they often lack capital, technical expertise and regulatory knowledge. So the moderating effect of size and age can be nonlinear: large firms might be better at scaling green transformation but small firms might be better at experimenting with disruptive green innovation (Liu et al. 2025).

The capability–performance relationship also depends on the carbon intensity of the industry. Firms in carbon-intensive industries such as cement, steel, chemicals, energy, mining, aviation and heavy

manufacturing face increased regulatory scrutiny, stakeholder pressure and transition risk. In such industries, green capabilities could have a stronger effect on environmental performance because emission reduction opportunities are more visible and greater. But the costs of de-carbonization may be higher and that could hurt short-term financial performance. Studies on corporate governance and carbon emissions show that governance mechanisms and carbon intensity are interacting factors in determining emissions performance, indicating that sustainability outcomes are largely dependent on industrial context. Finally, the relationship between sustainability capabilities and outcomes is moderated by ownership and governance. Governance characteristics such as board independence, board diversity, ESG committees, duality of CEO, family ownership, institutional ownership and ESG-linked compensation, influence the extent to which sustainability strategies are prioritized, monitored and executed. Good governance can help to avoid greenwashing, align managers' incentives with long-term environmental goals and ensure accountability for carbon reduction and circular economy goals (UNIDO/GACERE, 2025). (Oyewo 2023) finds governance mechanisms to be associated with carbon-emission performance but the effects may differ between carbon and non-carbon intensive industries. Ownership and governance, therefore, decide if green capabilities are seen as strategic assets or symbolic compliance devices.

5.4 Evidence on Environmental, Economic and Social Outcomes: Short-Term Cost, Long-Term Advantage, Rebound Risks and Disclosure-Performance Gaps

The sustainability performance of circular economy, resource-efficiency and low-carbon transition strategies cannot be assessed only on the basis of the presence of "green" practices or sustainability reporting. A full assessment requires evidence across three interlinked dimensions environmental outcomes, economic outcomes and social outcomes. Several literatures have shown that circular and sustainability-oriented strategies can reduce material extraction, waste generation, energy demand and greenhouse-gas emissions by substituting virgin resource use, extending product lifetimes, improving recovery efficiency and reducing production losses (Khanna and Gusmerotti 2022; Tan et al. 2022). But environmental benefits do not just happen. They depend on system boundaries, efficiency of technology, quality of recovered materials, energy sources used in processing, transport distances and whether circular outputs displace primary production or simply add to new consumption. From an environmental point of view the strongest evidence is when life cycle assessment, material flow analysis and carbon accounting are used together. Such integrated approaches also help to avoid shifting burdens like recycling reduces landfill disposal but increases electricity use or chemical consumption. The circular transition has to be evaluated in a multidimensional and multi-criteria way, as the environmental gains can change depending on scale, sector and geography. In a similar vein, Khanna and Gusmerotti (2022) reported that the circular economy is very relevant for climate-change mitigation but the literature still mostly focuses on mitigation rather than adaptation and social transformation. Hence, the environmental performance must be reported as measurable indicators such as avoided virgin material demand, emission intensity, waste diversion rate, water footprint, energy intensity and toxicity reduction and not only in qualitative claims.

The economic outcomes are more complex as sustainability transitions are often associated with high short-term costs but may generate long-term strategic advantages. Firms may have upfront costs of new infrastructure, redesign of products, reverse logistics, digital traceability, certification, employees training, supplier coordination and environmental standards compliance. In the short term, these costs could make circular or sustainability-oriented models less attractive, especially for small and medium enterprises or sectors with low margins. However, long-term benefits may be gained from reduced dependence on resources, exposure to volatile raw material prices, improved regulatory preparedness, ability to innovate, market differentiation, access to green finance and increased stakeholder confidence. Tan et al. (2022) argue that an ongoing reliance on a linear 'take-make-waste' model places companies at risk of resource scarcity, price volatility and supply chain disruptions. The economic case for sustainability should therefore not be based solely on immediate payback but also on resilience, risk reduction and future competitiveness. Compared to environmental and economic outcomes, the literature on social outcomes is relatively less mature. Social aspects in circular economy research are still measured inconsistently, although they are essential for a just transition (Padilla-rivera et al. 2020). Relevant social indicators include employment generation, quality of work, worker safety, skill development, affordability for consumers, community participation, inclusion of informal workers, distribution of benefits and impacts on vulnerable groups. A circular or low-carbon transition may create new jobs in repair, remanufacturing, recycling, logistics and digital monitoring, but may also displace workers from conventional production systems if reskilling and social protection are not planned. Studies should therefore not assume that environmental improvement leads automatically to social benefit. Social life-cycle assessment, stakeholder mapping and justice-oriented indicators are needed to understand who wins, who loses and who pays transition costs.

A key tension in the evidence is the contrast of short-term cost and long-term benefit. In the short term, companies often face capital expenditures, operational disruptions, technological uncertainty and administrative burden. Performance measurement systems may also place too much emphasis on current costs and revenues, which may discourage long-term circular investments (Vegter et al. 2021). But in the longer term, companies may benefit from resource efficiency, innovation, brand legitimacy, lower compliance risk and better relationships with regulators, investors and consumers. So sustainability strategies should be evaluated with a temporal perspective: short-term financial costs should be weighed against long-term environmental savings, avoided liabilities, market access and resilience. This short-term accounting approach may underestimate the real value of sustainability transitions. Another important risk is the risk of rebound effects. Strategies of circular economy and efficiency can lead to unintended consequences of higher total consumption if cost savings, cheaper secondary materials or higher efficiency induce higher demand. For example, recycling or remanufacturing may reduce the cost of product but if consumers buy more products as a result, the net environmental benefit may be reduced or even cancelled. (Castro et al. (2023) define circular rebound as a mechanism that delays or weakens the intended benefits of circular strategies. Lowe et al. (2024) also showed that econometric techniques, macroeconomic models, life-cycle assessment, material-flow analysis and hybrid methods can be used to estimate rebound effects. Rebound should therefore be

taken into account in review papers not as a marginal issue but as a core condition for assessing real sustainability performance. Policies such as absolute resource caps, carbon pricing, eco-design standards, product longevity standards and demand-side measures may be required to ensure efficiency gains translate into absolute reductions in environmental pressure.

Another big problem is the gap between disclosure and actual performance. Sustainability reporting, ESG disclosure and corporate environmental claims can enhance transparency but disclosure does not necessarily mean environmental improvement.

Christensen and Leuz (2021) argue that mandatory CSR and sustainability reporting can generate capital-market, stakeholder and behavioural effects but the results are highly dependent on implementation, enforcement and reporting standards. Haji et al., (2022) also documented that CSR reporting regulation have a frequently increased disclosure volume but whether reporting quality and real performance always improve is still unclear. This is important as firms may be engaging in symbolic reporting, selective disclosure or greenwashing where positive actions are publicized and negative impacts are hidden. The empirical evidence on the disclosure-performance links is mixed. In some studies, mandatory disclosure leads to real environmental gains. Yang et al. (2019) examine the U.S. Greenhouse Gas Reporting Program and offer evidence on the real effects of mandatory emissions disclosure. There is also evidence that the EU CSR reporting mandate had real effects on firms (Fiechter and Lehmann 2022), suggesting that disclosure can change corporate behaviour under certain conditions. But other studies suggest that disclosure without verification, comparable metrics and enforcement may remain ceremonial. Ratti (2025) showed that firms that actually invest in environmental initiatives are different from firms that only report environmental performance or claim carbon-neutrality goals, raising concerns about greenwashing. Further, Ma and Han (2026) suggested that false-disclosure greenwashing may result in short-term benefits but degrades long-term financial sustainability by increasing constraints, weakening green innovation and creating environmental uncertainty.

6. Proposed GIC-GBS-GTA Sustainability Performance Framework

In recent literature on sustainability and strategic management, there is a growing argument that firms do not achieve superior sustainability performance merely through possession of environmental knowledge or green resources. Rather, such resources need to be configured strategically, deployed operationally and continuously renewed through organization capabilities. In this context, the current review proposes an integrated pathway where Green Intellectual Capital (GIC) is the antecedent resource base, Green Business Strategy (GBS) is the strategic orchestration and positioning mechanism, Green Technology Adoption (GTA) is the execution mechanism and Sustainability Performance is the ultimate multi-dimensional outcome. The framework is based on natural resource-based view, dynamic capabilities theory, absorptive capacity theory and institutional theory. The green intellectual capital of a firm is a stock of environmental knowledge, skills, routines, relationships, databases, patents, environmental culture and stakeholder oriented green expertise. Often it is reflected in green human

capital, green structural capital and green relational capital. Green human capital is the environmental knowledge, technical skills, eco-design competence and awareness of sustainability requirements that employees have. Environmental management systems, green patents, databases, sustainability reporting routines, eco-design procedures and green knowledge repositories are part of green structural capital. Green relational capital is related to the relationships with regulators, suppliers, customers, universities, industry associations and environmental stakeholders. Previous studies such as (Begum et al. 2023; Alkaf et al. 2023; Tariq et al. 2026) suggested that GIC provides the knowledge infrastructure from which green strategies and sustainability-oriented innovations emerge.

But GIC ownership alone is not sufficient to generate sustainability outcomes. Firms are forced to convert their green knowledge base into a coherent strategic posture. Therefore, this review considers Green Business Strategy (GBS) as the first significant mediator between GIC and sustainability performance. GBS measures the degree to which environmental goals are incorporated into corporate strategy, competitive positioning, investment decisions, production planning, supply-chain coordination, marketing, stakeholder engagement and performance evaluation systems. In this sense, GBS is a strategic orchestration mechanism that converts dispersed green knowledge into coordinated managerial priorities. Empirically, Begum et al. (2023) found that GIC positively impacts on GBS and green absorptive capacity plays a significant role in the improvement of this conversion. Likewise, Tariq et al. (2026) found that GIC improves sustainable performance when strategically embedded through GBS. These studies indicate that GBS is not merely a declaration of environmental policy, but a strategic connector of green knowledge and organizational direction. GTA is the subsequent step within the framework. GBS is the strategic intent and positioning, GTA is the execution. GTA uses cleaner production technologies, renewable energy systems, waste-reduction technologies, energy-efficient machinery, water recycling systems, environmental monitoring systems, eco-design tools, green digital technologies, artificial intelligence, Internet of Things, big data analytics, blockchain-enabled traceability, and Industry 4.0-enabled resource optimization systems. So, GTA is seen as the vehicle for translating a firm's green strategic commitments into operational changes. But, the integration of technology adoption, digital transformation, and green innovation with strategic and organizational capabilities has been found to improve environmental, operational, and ESG outcomes (Zhang et al. 2024; Bag et al. 2021; Kumar et al. 2023; Liu et al. 2023).

The proposed pathway is therefore: GIC → GBS → GTA → Sustainability Performance. The logic is as follows: firms accumulate green knowledge resources, then strategically orchestrate those resources through GBS, then implement them through GTA and finally improve sustainability performance. Sustainability performance is a multidimensional construct including environmental, economic and social outcomes. The environmental performance includes reduction in emissions, waste and resource use, reduction in energy use, cleaner production and increased good environmental compliance. Economic performance means savings on costs, improved productivity, green market advantage, returns from innovation and long-term competitiveness. Social performance includes employee safety, community legitimacy, stakeholder trust, customer satisfaction and improved corporate reputation.

6.1 Dynamic Capabilities as Micro-Foundations

The internal process logic explaining how the proposed pathway works is provided by dynamic capabilities. These include the firm's ability to sense environmental opportunities and threats, seize sustainability-oriented opportunities and reconfigure resources to respond to changing environmental, regulatory and market conditions. In the proposed framework, dynamic capabilities are the micro-foundations for firms to mobilize GIC, formulate GBS and implement GTA. The sensing capability allows firms to detect shifts in environmental regulation, customer demand, stakeholder expectations, technological trends and competitor behaviour. Firms with strong GIC have better environmental knowledge and stakeholder-related intelligence to interpret these signals. The seizing capability enables firms to convert these signals into strategic choices, investment decisions and green business models. This is where GBS comes into play as it decides if the company will go for pollution prevention, eco-efficiency, circular economy practices, green product differentiation or compliance-oriented approaches. The reconfiguring capability enables companies to redesign processes, acquire new technologies, retrain employees and build new partnerships and restructure supply chains. This capability directly supports GTA, because the adoption of technology often involves changes in routines, skills, production systems and inter-organizational coordination. Recent studies (Amaranti et al. 2024; Asiedu et al. 2025) have demonstrated that green dynamic capabilities play an important role in transforming green knowledge and technology investments into green innovation, competitive advantage and sustainability performance. Dynamic capabilities are therefore not an outcome in themselves, but the internal capability architecture that enables the GIC–GBS–GTA pathway to work effectively.

6.2 Absorptive Capacity as a Micro-Foundation

Another significant micro-foundation in the framework proposed is absorptive capacity. It refers to a firm's ability to acquire, assimilate, transform and exploit external knowledge. This can be termed as green absorptive capacity in sustainability contexts, as firms need to gain knowledge from regulators, suppliers, customers, universities, consultants, environmental agencies, competitors and technology providers. Green absorptive capacity enables firms to understand new environmental standards, select suitable green technologies, learn from best practices and integrate external knowledge into internal processes. Absorptive capacity has a dual role in the GIC–GBS–GTA pathway. First, it increases conversion of GIC to GBS. Even if firms have internal green knowledge, they need to acquire external knowledge to update and validate their strategic priorities. Second, it increases the conversion of GBS to GTA because the successful adoption of green technologies requires firms to understand technical specifications, supplier capabilities, implementation risks, employee training needs and process redesign requirements. Begum et al. (2023) demonstrated that green absorptive capacity mediates and moderates the relationship between GIC and GBS. Furthermore, Amaranti et al. (2024) suggested that absorptive capacity is most effective when combined with green dynamic capabilities and green manufacturing practices. Absorptive capacity thus explains the learning, adaptation and exploitation of environmental knowledge in the process of strategy formulation and technology implementation.

6.3 Moderating Role of Institutional Pressures

Institutional pressures are likely to moderate the proposed pathway. These pressures include coercive pressures from laws, environmental regulations, carbon policies, disclosure rules and compliance requirements; normative pressures from industry associations, professional bodies, certification systems and sustainability standards and mimetic pressures from competitors and industry leaders. Environmental pressures on institutions can strengthen the GIC-GBS link, as firms facing stringent environmental expectations are more prone to formalize green knowledge into strategy. They may also strengthen the GBS-GTA relationship as regulatory and stakeholder pressures may encourage firms to move from symbolic environmental commitments to actual technology adoption. But institutional pressure might have a different effect. Non-compliance is expensive, so institutional pressure can speed up GTA in highly regulated industries. In weak institutional environments, companies may symbolically use GBS without actual technology adoption. Institutional pressures can influence green innovation, digital business model innovation and green (Zhang and Chen 2024; Liang et al. 2023). Thus, we propose institutional pressure as a contextual moderator of the relationship between green knowledge and strategy and actual sustainability actions.

6.4 Moderating Role of Digital Readiness

Digital readiness is another important moderator. The digital readiness index is defined as the readiness of digital infrastructure, data systems, digital skills, analytics capability, IT-business alignment, cybersecurity readiness and managerial commitment to digital transformation. Digitally mature companies are better positioned to implement advanced green technologies, including smart energy systems, real-time emissions tracking, predictive maintenance, blockchain for traceability, AI for optimizing resource use and IoT for waste management. Thus, digital readiness is expected to enhance the GBS-GTA link and the GTA sustainability performance link. The role of digital readiness is very important, as many green technologies are now enabled digitally. A firm may have a strong green strategy but without the digital infrastructure and digital skills it can struggle to implement advanced GTA. Studies such as Bag et al. (2021), Kumar et al. (2026), Liang et al. (2023) and Liu et al. (2022) have recently shown that digital transformation, Industry 4.0 adoption, and digital business model innovation can lead to improved sustainability outcomes if supported by organizational capabilities. Hence digital readiness is an enabler for GTA, determining the depth, speed and effectiveness of it.

6.5 Moderating Role of Industry Context

The proposed pathway is also moderated by industry context. The relative importance of GIC, GBS and GTA may differ across the manufacturing, energy, construction, services, food processing, textiles, electronics and high pollution sectors. In pollution-intensive industries, environmental regulation and stakeholder scrutiny are more intense, making the GIC-GBS-GTA pathway more urgent and visible. GTA may be more effective in technology-intensive sectors, subject to digital readiness and innovation capability. The move from GBS to GTA might face hurdles due to resource limitations in SMEs even when managers are dedicated to environmental issues. Sustainability performance in service industries may rely more on green relational capital, green service innovation, energy-efficient operations and stakeholder engagement rather than heavy technological investment. Thus the strength of each of the

relationships in the model is influenced by the industry context. For example, in manufacturing companies, green structural capital and cleaner production technologies might be more important. In hospitality firms, green relational capital, customers' expectations and energy-saving technologies could be more relevant. Digital readiness could be the deciding factor in high-tech sectors. In emerging economies, institutional gaps, financing constraints and availability of technology may shape feasibility of GTA. Thus, future empirical work should test the model across different industries, rather than assuming uniform effects (Kumar et al. 2026).

6.6 Testable Propositions and Hypotheses

The proposed framework posits that green intellectual capital (GIC) has a positive effect on green business strategy (GBS) as firms with higher green human, structural and relational capital are more likely to formulate proactive environmental strategies. Further, GBS is hypothesized to mediate the relationship between GIC and sustainability performance, implying that green knowledge resources will result in stronger sustainability outcomes when they are strategically embedded into business planning and competitive positioning. GBS is also suggested to have a positive impact on green technology adoption (GTA), as companies with a strong green strategic orientation are more likely to invest in clean production, energy-efficient systems, circular economy and digital green technologies (Li et al. 2022). GTA is expected to improve sustainability performance through reduced emissions and waste generation, improved resource efficiency and operational cost savings, thus improving environmental, economic and social outcomes. We suggest that GTA moderates the relationship between GBS and sustainability performance, implying that green strategies can lead to better sustainability outcomes when translated into specific technological actions. Together, GBS and GTA should sequentially mediate the relationship between GIC and sustainability performance, suggesting that the effect of GIC first passes through strategic orchestration and then technological execution. Moreover, green dynamic capabilities are proposed to strengthen the GIC–GBS and GBS–GTA links by enabling firms to sense environmental opportunities, seize green strategic options and reconfigure resources for technology implementation. In the same way, green absorptive capacity should reinforce the GIC–GBS relationship by assisting firms to acquire, assimilate, transform and exploit external environmental knowledge. Finally, the framework proposes that institutional pressures, digital readiness and industry context moderate the overall GIC-GBS-GTA sustainability performance pathway, such that the relationships are stronger under higher coercive, normative and mimetic pressures, stronger digital infrastructure and analytics capability and in environmentally sensitive, technology-intensive and highly regulated industries (Liu et al. 2022b).

6.7 Research Implications

The proposed framework makes three contributions to the sustainability literature. It first clarifies the role of GIC as a prior resource base rather than a direct and automatic predictor of sustainability performance. Second, it positions GBS as a strategic mechanism for orchestration that translates green knowledge into managerial priorities and competitive positioning. Third, it conceptualizes GTA as the operational mechanism through which green strategy becomes operational reality. The framework

describes how firms sense opportunities, absorb external knowledge, seize green opportunities and reconfigure resources by adding dynamic capabilities and absorptive capacity as micro-foundations. The model incorporates institutional pressures, digital readiness and industry context as moderators, recognizing that sustainability transformation is dependent on external pressure, technological readiness and sector-specific conditions. Future empirical research using structural equation modelling, moderated mediation analysis or longitudinal panel designs can test this model. Researchers can operationalise GIC through green human, structural and relational capital, GBS through environmental strategic orientation and integration, GTA through cleaner production technologies, digital green technologies and circular technology adoption, and sustainability performance through environmental, economic and social indicators. Such testing would help to explain why some firms are able to turn green knowledge into tangible sustainability results, while others stay at the level of symbolic environmental commitment (Alkaf et al. 2023).

7. Methodological Concerns and Future Research Directions in GIC-GBS/GTA Research

The construct validity is a key methodological issue in the studies linking green intellectual capital (GIC) with green brand satisfaction (GBS), green trust/attitude (GTA) and associated green performance outcomes. The majority of the empirical literature considers GIC as a reflective higher-order construct implying that green human capital, green structural capital and green relational capital are interchangeable manifestations of a single underlying latent variable. However, this assumption is often questionable because these dimensions may be instead causal components that jointly form GIC. For example, a company may have a strong green relational capital with suppliers and stakeholders but a weak green structural capital like databases, routines or environmental management systems. In such cases the dimensions are not necessarily highly correlated and should not be forced into a purely reflective structure. Hence, in future research, the justification should be explicitly stated if GIC is conceptualized as a reflective, formative or higher-order composite construct and the appropriate validity tests such as convergent validity, discriminant validity, indicator weights, multi-collinearity and redundancy analysis should be reported depending on the measurement specification (Hair and Alamer 2022; Hair et al. 2024). Various studies on GIC have used structural equation modeling to test the relationship between GIC, green absorptive capacity, green business strategy, green innovation and environmental performance. But many of them have provided limited theoretical justification about the direction of measurement between indicators and latent constructs (Begum et al. 2023; Asiaei et al. 2023).

A second concern is the measurement of GBS and GTA. Green brand satisfaction, green trust and green attitude are psychologically rich constructs which normally require multi-item measurement to capture affective, cognitive and evaluative dimensions. Single-item measures reduce respondent fatigue but preclude reliability assessment, reduce construct coverage and may be especially problematic if the construct is abstract or multidimensional. For example, “green trust” may involve trust in environmental

claims, product safety, brand credibility and long-term ethical commitment. Similarly, green brand satisfaction may include post-purchase evaluation, perceived environmental value, emotional approval and expectations comparison. Therefore, single-item measurement of GBS/GTA should be avoided unless the construct is very concrete, the item is theoretically rich, and predictive validity has been demonstrated separately. Various work comparing single-item and multi-item trust scales confirms that when trust acts as a substantive explanatory mechanism rather than as a simple descriptive variable, it is best treated with careful scale validation (Castro et al. 2023; Allen et al. 2022).

An additional limitation in this stream of research is endogeneity, in particular common method bias, reverse causality, omitted variable bias and simultaneity. A lot of studies collect self-reported data from a single respondent at one-time point and then infer causal paths such as GIC → green trust → purchase intention or GIC → green innovation → green business strategy. These designs are vulnerable because the observed associations might be partly due to respondents' general pro-environmental orientation, social desirability, consistency motives, or firm reputation effects, rather than to a true causal influence. Post hoc tests such as Harman's single-factor test are not a panacea for common method bias. Stronger remedies for common method bias include temporal separation, psychological separation of predictor and outcome measures, marker variables, use of multiple informants, objective secondary indicators and latent method-factor approaches (Behavior et al. 2024). For GIC–GBS/GTA research, researchers could collect GIC data from managers, brand trust/satisfaction data from customers and environmental performance indicators from firm records or third-party databases.

Greater attention needs to be paid to reverse causality. More likely, firms with higher levels of green brand satisfaction and customer trust will invest more in GIC, rather than GIC alone leading to better brand outcomes. High environmental performance can also assist in the creation of green relational capital by attracting environmentally sensitive partners. Future research should go beyond cross-sectional SEM and use instrumental variables, panel data, lagged models, difference-in-difference and natural experiments to address this. Good instrumental variables should affect the development of GIC or green capability and should not directly impact brand satisfaction or trust except through the focal mechanism. Natural experiments can be regulatory shocks, green certification requirements, policy incentives, rules of environmental disclosure or abrupt changes in sustainability standards. Such designs are instrumental in identifying exogenous variation and enhancing causal claims in green marketing and green management research (Wu et al. 2024).

Several promising methods are underused. First, longitudinal designs are needed because GIC, green trust and green satisfaction are not static. Green knowledge assets are accumulated slowly and consumer trust may not react quickly to repeated brand actions. A longitudinal design can test whether changes in GIC result in changes in GBS/GTA and whether the effect gets stronger or weaker over time. Second, fsQCA can complement SEM by identifying alternative causal configurations. For instance, high green purchase intention may be driven by one configuration with strong GIC, high green perceived value and strong green trust and another with moderate GIC, but with strong green brand positioning and

customer environmental concern. This is important because green branding outcomes are potentially equifinal rather than being generated by one universal linear pathway (Meuer and Fiss 2020).

Third, necessary condition analysis (NCA) can determine whether a minimum level of a condition is necessary for an outcome. In GIC–GBS/GTA research, NCA could be used to test if a threshold level of green trust, green absorptive capacity or green human capital leads to high green brand satisfaction or green innovation performance. This would move the field beyond “net effect” reasoning and clarify bottleneck conditions firms need to fulfil before other resources become useful (Dul et al. 2023). Fourth, field and survey experiments could explore how consumers respond to verified versus vague green claims, how green certifications affect trust or how employee green training affects sustainability communication with customers. Such designs are very useful to separate genuine trust-building effects from appearances of greenwashing. Finally, multi-level modeling is important because GIC is multi-level. Individuals have green knowledge, teams develop green routines and collaboration norms and firms institutionalize green strategy and brand identity. Thus, multi-level models can link individual-level green behavior, team-level green climate and firm-level GIC/brand performance, avoiding the ecological fallacy of equating individual and organizational mechanisms. Research on green leadership and green innovation more and more show the benefits of matched employee-team or employee-firm data and future GIC–GBS/GTA research should follow similar research designs.

In general, future work should move beyond simple cross-sectional, single-source SEM models and instead adopt more rigorous designs that integrate measurement logic, causal identification, and analytical method with theory. GIC should be modeled according to its conceptual nature, GBS/GTA should be measured with validated multi-item scales whenever possible and causal claims should be supported with longitudinal, experimental, panel or quasi-experimental evidence. The integration of SEM with fsQCA, NCA and multi-level modeling would allow the field to capture both linear effects and complex configurational pathways, thereby increasing the theoretical and practical robustness of green branding and green intellectual capital research.

8. Contextual Heterogeneity in Firm-Level Sustainability and Digital Transformation: Size, Sector, Economy Type, Ecosystems and Disclosure Regimes

Digital transformation and sustainability-oriented innovation have differential effects across firms. Firm size, sector characteristics, national institutional environments, ecosystem position and disclosure pressure are key determinants. Thus, review studies should not treat firms as homogenous units and should take into consideration how contextual conditions moderate the effects of adoption, implementation and performance.

8.1 SMEs Versus Large Firms.

SMEs often face greater constraints than large firms in adopting digital, sustainability and ESG-oriented practices due to generally lower financial resources, weaker internal digital capabilities, fewer specialised employees and lower bargaining power in supply chains. These constraints force the

adoption of technology to be more incremental and externally dependent. Research on SMEs suggests that the lack of funding, limited digital capability, human-resource shortages and technical barriers are the key obstacles to digital transformation, especially for small service businesses (Chen et al. 2021). Similarly, systematic reviews of technological transformation in SMEs suggest that digital technologies have the potential to enable business model innovation but still many SMEs operate at a low level of transformation because they are unable to combine technology assimilation with strategic renewal (Silva et al. 2024). Large firms, on the other hand, tend to have higher absorptive capacity, formal R&D systems, dedicated sustainability teams and better access to capital. This allows them to invest in advanced tools including artificial intelligence, blockchain, IoT, traceability systems and ESG data platforms. Large firms also face more organisational inertia, legacy systems and complex stakeholder scrutiny that may slow implementation. Thus, while SMEs may be more agile, they may be resource constrained, and large firms may be resource-rich but structurally rigid.

8.2 Manufacturing Versus Services.

Sectoral differences also determine the direction and intensity of the digital and sustainability transformation. In manufacturing firms digital transformation is often associated with Industry 4.0 technologies, process automation, energy efficiency, predictive maintenance, circular production, cleaner supply chains and product-life-cycle traceability. Sustainability gains are often measured in terms of operational efficiency, material savings, waste minimization, emissions monitoring and cleaner production. However, in service firms, digital transformation is more associated with customer experience, platform-based service delivery, digital payment systems, data analytics, remote interaction and service personalisation. The key drivers of digital transformation of small service businesses are to improve customer engagement, service accessibility and business growth, while the priority areas of transformation are determined by the sectoral characteristics (Chen et al. 2021). Review papers should therefore distinguish between manufacturing-oriented sustainability outcomes such as resource efficiency and cleaner production, and service-oriented outcomes such as access, responsiveness, dematerialisation and customer value creation.

8.3 Developed Versus Emerging Economies.

Another layer of heterogeneity comes from developed and emerging economies with different institutional and infrastructural backgrounds. Companies in developed economies tend to benefit from a mature digital infrastructure, stronger regulatory enforcement, advanced innovation ecosystems, established ESG norms and greater availability of finance. Such circumstances tend to favor a more systematic adoption of sustainability reporting, green innovation and digital traceability. Emerging economy firms suffer from poorer infrastructure, more severe financing constraints, lack of skills and fragmented institutional support. But they may also have leapfrogging opportunities through mobile technologies, platform-based services and frugal innovation. Studies on the adoption of ICT in SMEs in developing countries show that digital technologies can increase competitiveness and internationalisation but the adoption is heavily dependent on overcoming internal and external barriers (Yuwono et al. 2024). The effect of the same technology is therefore likely to be different in firms

operating in the developed and the emerging economy. A review paper should thus analyse if sustainability and digital transformation studies control for country-level factors, including regulatory quality, digital infrastructure, access to finance, innovation policy and ESG maturity.

8.4 Supply-Chain Ecosystems and Platform Effects

Transformation at the firm level increasingly takes place within supply-chain and platform ecosystems, not just within individual firms. Large buyers, multinational lead firms and digital platforms can convey sustainability expectations to suppliers through demands for emissions data, traceability, responsible sourcing, quality certification and ESG disclosure. This provides opportunities and pressures for SMEs. On the one side, participation in platform ecosystems can improve market access, data visibility, collaboration and innovation. On the other hand, it may increase compliance costs and technological dependence, especially for smaller suppliers. Digital platform ecosystems have been conceptualised as meta-organisational structures that can enable sustainable innovation by coordinating multiple actors around shared data, standards and value-creation mechanisms (Calabrese et al. 2021). Digital tools such as blockchain, cloud platforms, IoT and supplier portals can increase transparency, reduce information asymmetry and enable sustainability monitoring in supply chains. But platform effects are not an automatic positive. Benefits depend on governance, rules for data-sharing, interoperability, trust and distribution of fair value among ecosystem actors.

8.5 Collaboration with Universities and Start-ups.

External collaboration is especially important where firms are deficient in internal knowledge or R&D capability. Cooperation between universities and industry can provide companies with access to scientific knowledge, laboratories, skilled graduates, technical expertise and innovation networks. Such collaboration can be a substitute for small and medium-sized enterprises for lack of internal R&D capacities and can support innovation without large permanent research departments. The importance of compatibility of goals, selection of partners, trust, absorptive capacity and clear benefit sharing mechanisms are emphasized in recent studies on university-industry collaboration (Ćudić et al. 2022). Literature reviews on MSME-higher education cooperation further suggest that collaboration models should be designed to be based on practical problem solving, joint projects, training, knowledge like clean technology, ESG analytics, circular design and digital platforms. But working with start-ups requires governance structures to handle intellectual property, scaling risk, transfer and long-term ecosystem building (Access 2024). There's also a growing importance of working with startups, as they can bring specialized technologies, agile experimentation and niche solutions in areas cultural differences and imbalances in bargaining power. Therefore, university-startup collaborations should be considered as enablers at the ecosystem level rather than fringe activities.

8.6 ESG Disclosure Regimes and Regulatory Pressure.

ESG disclosure regimes are a major institutional driver of firm behavior. The development of standards such as IFRS S1 and IFRS S2, the European Sustainability Reporting Standards under the Corporate Sustainability Reporting Directive and climate-related disclosure rules in major markets has driven

demand for consistent, comparable and auditable sustainability information. These regimes apply not only to the firms that are directly regulated, but also to suppliers that are required to provide Scope 3 emissions data, labour-practice information, material traceability and environmental-risk evidence. This has a knock-on effect through supply chains. Large listed firms may have more capacity to comply with ESG disclosure requirements whereas SMEs may face indirect reporting burdens through buyer requirements (Tandon 2021). Meanwhile, ESG disclosure can encourage companies to formalise sustainability strategy, improve data systems and embed environmental and social indicators into decision-making. Therefore, review papers should look at ESG disclosure not only as a reporting practice but also as a governance mechanism which restructures inter-firm relationships, supplier selection, platform participation and innovation incentives (Free and Jones 2024).

Finally, the literature suggests the importance of a multi-level contingency perspective in the study of digital and sustainability transformation. The size of a firm influences its resources and agility; the sector influences the type of sustainability value it creates, the national context influences institutional support and constraints; supply-chain and platform ecosystems influence interdependence; university and start-up collaboration influences access to knowledge and ESG disclosure regimes influence transparency, legitimacy and compliance pressure. Hence, future reviews should make comparisons of studies across SMEs and large firms, manufacturing and services, developed and emerging economies and ecosystem-based versus firm-centric settings. This could help identify where digital and sustainability practices drive real performance gains where they create compliance burdens and under what conditions they create long-term environmental, social and economic value.

9. Strategic and Policy Pathways for Building Green Innovation Capability and Accelerating Green Technology Adoption

The shift towards sustainable industrial systems demands firms to embrace green technologies and build green innovation capability (GIC) which is defined as the organizational ability to create, absorb, integrate and exploit environmental knowledge for green products, processes and business models. In this context, GIC is to be understood as a dynamic capability that allows firms to sense environmental opportunities, develop internal competencies, collaborate with external actors and constantly reconfigure resources for sustainability-oriented innovation. Studies of green knowledge management, green learning orientation and green dynamic capability indicate that firms with stronger systems for sharing environmental knowledge and stronger learning routines are better able to improve green product and process innovation performance (Baquero 2024; Wang et al. 2022; Asiedu et al. 2025).

A first strategic requirement is the building of targeted green training systems. Green training should not be limited to general awareness about the environment but rather should be targeted towards technology-specific skills such as energy auditing, waste minimization, cleaner production, analysis of circular material flow, carbon accounting, environmental life-cycle thinking and digital monitoring of resource use. This kind of training helps employees to spot environmental inefficiencies and convert them into innovation opportunities. The knowledge management and green innovation literature

hypothesizes that green learning orientation enhances firms' ability to transform environmental knowledge into new products and cleaner processes. Therefore, firms need to institutionalize green training through a structured module, certification-based skill development and continuous learning programs for managers, engineers, production workers and supply-chain personnel (Ogiemwonyi et al. 2023).

Second, organizations should develop green knowledge repositories to collect and disseminate environmental knowledge in the organization. Such repositories may contain databases of best available green technologies, material substitution options, process energy benchmarks, environmental regulations, emission factors, waste valorization avenues, supplier sustainability data and lessons learned from pilot projects. These repositories reduce duplication of effort and support evidence-based decision making during AGT. Knowledge repositories are particularly important because green innovation often requires the integration of technical, regulatory, market and environmental information. Research on the ability of knowledge management shows that systematic knowledge creation, sharing and utilization are highly associated with green innovation results, especially when firms combine internal knowledge with external environmental intelligence (Costa and Matias 2020).

Third, cross functional routines are required to transform green knowledge into implementable technologies. Green innovation should not be confined to R&D department but should be coordinated among production, procurement, finance, marketing, quality control, environmental management and top management. Cross functional green teams can assess the technical feasibility, cost implications, environmental benefits, regulatory compliance and market acceptance of proposed green technologies. Such routines matter because many green technologies fail at the adoption stage because of lack of coordination between technical and managerial functions. Therefore, firms should have green innovation committees, joint problem-solving workshops, eco-design review meetings and stage-gate systems with environmental performance indicators (Mubarak and Petraite 2021).

Fourth, partner ecosystems are critical to strengthening GIC. Green innovation increasingly demands collaboration with universities and research institutions, technology suppliers, governments, financial institutions, start-ups, industry associations and customers. The open innovation and Industry 4.0 literature confirms that collaboration with external partners improves access to new technologies, sustainability knowledge and digital tools necessary for green innovation. Partner ecosystems are especially helpful to small and medium-sized companies that often lack the internal resources to experiment with new technology or environmental R&D. Partnerships allow firms to access pilot facilities, testing laboratories, technical consultancy, green finance and shared data platforms, thus reducing the uncertainty associated with GTA (IEA 2025).

Strategically, firms need clear playbooks as to how to sequence green technology adoption. A useful sequence is capability building, pilot test, scale-up. During the capability-building phase, firms should identify environmental hotspots, train employees, identify available green technologies, create repositories of knowledge and form cross-functional teams. The pilot phase should focus on a limited

number of green technologies to assess technical performance, cost savings, emission reductions, reliability and operational risks. In the scale-up phase, successful pilots should be integrated into mainstream production systems, with clear investment plans, supplier contracts, standard operating procedures and performance monitoring systems. This phased approach reduces the risk of adoption, and helps firms avoid premature large-scale investment in unproven technologies (Raj 2025).

Organizational ambidexterity should also be part of the green strategy playbooks. Firms have to balance exploration and exploitation. Exploitation involves improving current processes, energy efficiency, waste reduction, cleaner fuels, recycling and process optimisation. Exploration is about trying out new materials, renewable energy systems, circular business models, digital platforms and AI-enabled monitoring and advanced low-carbon technologies. Ambidexterity is important. Firms that only do incremental improvement may miss the disruptive green opportunities, while firms that do radical innovation may suffer from high uncertainty and implementation failure. Research on green innovation and ambidexterity suggests that both exploitative and exploratory capabilities are important for green innovation and sustainability performance (Theoharakis 2025).

strategy implementation requires governance and incentives Senior management must set measurable targets for green innovation, designate specific departments to be responsible for it and tie environmental performance to managerial appraisal. Rewards for energy-saving ideas, recognition for waste-reduction projects, innovation grants to develop green prototypes and performance bonuses tied to carbon or resource-efficiency targets could be part of the incentive systems. Governance mechanisms should also comprise environmental key performance indicators, periodic audits, transparent reporting and accountability structures. Without governance and incentives, green innovation can be symbolic (Naser et al. 2022).

Technology roadmaps are yet another practical tool to accelerate GTA. The criteria for selecting green technologies for companies should be environmental impact, technical feasibility, cost-effectiveness, payback period, regulatory urgency and scalability. Focus on high-impact, quick-win technologies that offer early environmental and financial benefits and build organizational confidence. Examples include energy efficient motors, heat recovery, water recycling, process automation, digital energy monitoring, segregation of wastes, material recovery, and cleaner production practices. Medium- or long-term roadmaps may include more complex technologies such as carbon capture, green hydrogen, advanced biorefineries, AI-enabled optimization or circular supply-chain platforms, depending on sectoral readiness and investment capacity (Nawab 2024).

The interaction of the GTA with digital technologies is gaining ever more importance. Sensors, Internet of Things platforms, artificial intelligence, digital twins and data analytics are able to improve the measurement, verification and optimisation of green technologies. Digital systems enable companies to monitor real-time energy consumption, emissions, water use, material losses, equipment efficiency and waste generation. AI tools can be used for the detection of inefficiencies, prediction of equipment failures, optimization of process parameters and supporting decision making for low carbon operations.

But digitalisation itself needs to be managed responsibly, as AI data infrastructure can increase electricity demand. Therefore, companies should utilize digital tools that enhance net environmental performance and energy efficiency criteria in the selection of digital technology (Vrontis et al. 2022).

Policy levers are needed to address financial, technical and institutional risks of GtA. Green finance can help to overcome the capital barrier through concessional loans, green bonds, credit guarantees, sustainability linked loans and subsidies and tax incentives for environmentally beneficial technologies. Standards and certification systems boost investor confidence, improve comparability and reduce uncertainty by setting out what counts as a green technology and by setting performance benchmarks. Data infrastructure also matters because companies and investors need reliable data on emissions, energy use, technology performance and environmental outcomes. Public databases, digital reporting systems, taxonomy-based disclosure and sectoral benchmarking platforms can help reduce information asymmetry and facilitate more credible green investment decisions (Luan 2024).

The success of GTA ultimately depends on the interaction of firm-level capability building, strategic sequencing, technology road mapping, digital integration and supporting policy frameworks. Firms need to shift from individual green projects towards systematic green innovation systems. This means skilled human resources, codified knowledge, cross-functional routines, collaborative ecosystems, clear governance and policy support. The alignment of these elements transforms the adoption of green technology from an environmental compliance activity into a pathway to competitiveness, operational efficiency, resource security and long-term sustainable industrial transformation (Does et al. 2023).

10. Future Research Agenda

While the growing body of literature has recognized GIC as an essential organizational resource for achieving green innovation, environmental performance and green supply chain effects, there are still some areas that have been overlooked. In particular, future research needs to go beyond cross-sectional association research design and advance more robust causal, micro, digital, multi-actor, social and cross-national explanation of how GIC enables GTA (Javeed et al. 2023).

First, future research should focus on the causalities among constructs. Most of the research on GIC and GTA have adopted surveys using structural equation modeling techniques which are very effective in terms of theoretical development but they have been found to lack validity in terms of causalities. Future research should thus use quasi-experiments, natural experiments, policy shocks and difference in differences models. For instance, one can use policy measures including environmental regulation, green credit policies, carbon pricing reform, renewable energy mandate or green industrial policy of countries as policy shocks to check whether organizations having green human, relational and structural capital are able to adopt green technologies following the policy shock. Research conducted using policy shocks and difference in differences approach has been found to be very useful in the area of green innovation research (Liu et al. 2023) and such a design can be used in GIC and GTA literature as well.

Second, more focus is required on the micro-foundation of GIC. Current literature conceptualizes GIC at the organization level but the construction of green knowledge, green routines and green relationship is done by individual employee, managers and leaders. Research in future needs to explore how green competency, environmental awareness, green creativity, eco-literacy and environmentally responsible motivation of individual are converted into green human capital of organizations. Attention must be paid to the leadership style too. Green transformational leadership, environmental leadership, ethical leadership and servant leadership can play role in developing green skill and knowledge of individuals and help them develop GTA. The green transformational leadership and green creativity literature shows that leadership plays an important role in green thinking, organizational identity and innovative behavior of individuals (Al-ghazali and Gelaidan, 2022; Majali et al. 2022). Thus, future literature must explore the linkage between individual green competency and GIC.

Thirdly, research needs to explore digital-green convergence. The application of green technology is becoming more influenced by digital technologies such as artificial intelligence, Internet of Things, digital twin, big data analytics, blockchain and cloud computing. Digital technologies can serve as complements to GIC through enhancing environmental monitoring, resource management, predictive maintenance, life cycle management and decision making in real time. Big data analytics, for example, has been found to moderate the relationship between GIC and green supply chain performance (Al-khatib 2022) indicating that digital capability may help convert green knowledge into tangible results. In addition, existing studies on Green AI and Green Internet of Things show how digital technology helps achieve energy efficiency, environmental monitoring and sustainable decision making (Thilakarathne et al., 2020; Verdecchia and Sallou 2020). It would be interesting for future research to explore how AI, IoT and digital twin serve as complements, moderators and mediators in the context of GIC and GTA.

Fourth, it is important to consider broadening the scope of analysis from firm-level to a broader approach encompassing supply chain and ecosystem views. GTA relies not just on internal capabilities but on factors such as the suppliers, customers, regulatory agencies, universities, technology companies, banks and industry associations. In this respect, green relational capital becomes very relevant since it measures the quality of relationships with external organizations from an environmental perspective. Existing research has found that GIC helps in the process of green supply chain integration, green innovation and green supply chain performance (Liu et al. 2023; Buhaya et al. 2024). Yet, most studies continue to utilize data from a single respondent or firm.

Finally, future studies need to incorporate aspects of social sustainability and just transition. In the literature related to GIC and GTA, there has been an emphasis on environmental and economic outcomes, including green innovation, environmental performance, competitive advantage and supply chain efficiency. Yet, green technology adoption can influence not only the natural environment and the economy but also people, society, skills, working conditions, inclusion, health and safety at work and fairness. Following the just transition approach, researchers will have to investigate whether the GIC that contributes to GTA leads to decent work, employee involvement, decreases social inequality and protects vulnerable groups impacted by transformations in technology and the environment. It is

especially relevant due to the fact that green transformation can generate not only benefits for the firm but also some negative consequences such as emissions reduction combined with changes in the employment structure and requirements (Sova and Rožman 2024).

Lastly, future research should focus on cross-country comparative analysis and the issue of cultural contingency. The majority of the existing empirical research on GIC and green innovation is done either for specific emerging economies or in single-country contexts. Yet, the impact of GIC on the development of GTA could be quite contingent upon institutional environment, regulatory regime, national innovation system and cultural value. Thus, the collectivistic culture could foster collective learning regarding environmental issues while individualistic culture could stimulate the emergence of entrepreneurship-driven green innovation. Empirical evidences indicate that the role of cultural orientation and institutional quality matters in the performance of green innovation (Sova and Rožman 2024).

11. Conclusions

Concluding from the literature, it can be stated that Green Intellectual Capital (GIC) is an indispensable intangible capacity for realizing sustainable performance provided that it is strategically aligned with Green Business Strategy (GBS) and implemented through the adoption of Green Technology (GTA). The green human, structural and relational components of GIC offer companies the competencies, skills, processes and stakeholder networks required for identifying environmental problems and creating sustainability-driven solutions. Nevertheless, even GIC on its own does not suffice since its value depends upon the extent to which it is transformed into a consistent GBS involving the integration of environmental considerations into corporate goals, management, resource allocation, innovation and supply chains. In such a manner, GBS becomes a strategic orchestration mechanism capable of transforming green knowledge resources into purposeful sustainability activities. At the same time, GTA is the implementation tool that facilitates cleaner production, energy efficiency, circular economy practices, digital monitoring and low-carbon innovations, thus turning the strategy into sustainable results.

The review also demonstrates that the relationship between GIC, GBS, GTA and sustainability depends on theoretical and contextual preconditions. The Natural Resource-Based View, Knowledge-Based View, Dynamic Capabilities, Institutional Theory, Stakeholder Theory and Configuration theories provide comprehensive insights into the ways in which organizations create, exploit and redeploy green capabilities under pressure from regulators, markets and stakeholders. On the other hand, industry type, firm size, geographical location, regulation, institutional quality, level of digital maturity and readiness of the supply chain have an effect on the efficiency of green strategies and technologies deployment. Future research thus requires the development of longitudinal, causal, multilevel and cross-country studies with more attention being paid to micro-foundations such as green capabilities, leadership style, staff training, integration of digital and green management, ecosystem collaborations, social sustainability and just transitions.

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Authors' contribution:

NG led the conceptualisation, research design, data collection, analysis, and preparation of the original draft. MAT and AT supervised the study and contributed to theoretical refinement. All co-authors (MAT,AT, PK contributed to methodology support, AT supported data interpretation, PK contributed to critical review, and manuscript editing. All authors approved the final version of the manuscript and accept responsibility for its content and integrity.

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Figures

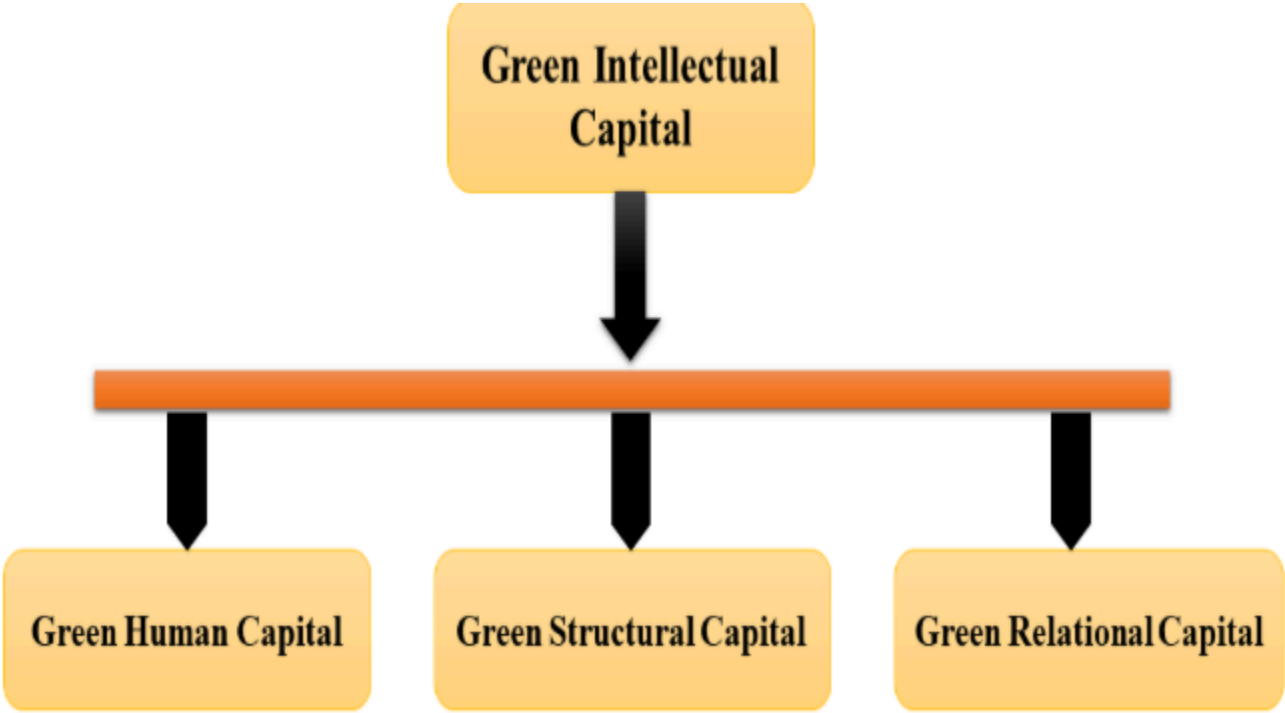


Figure 3

Components of Green Intellectual Capital

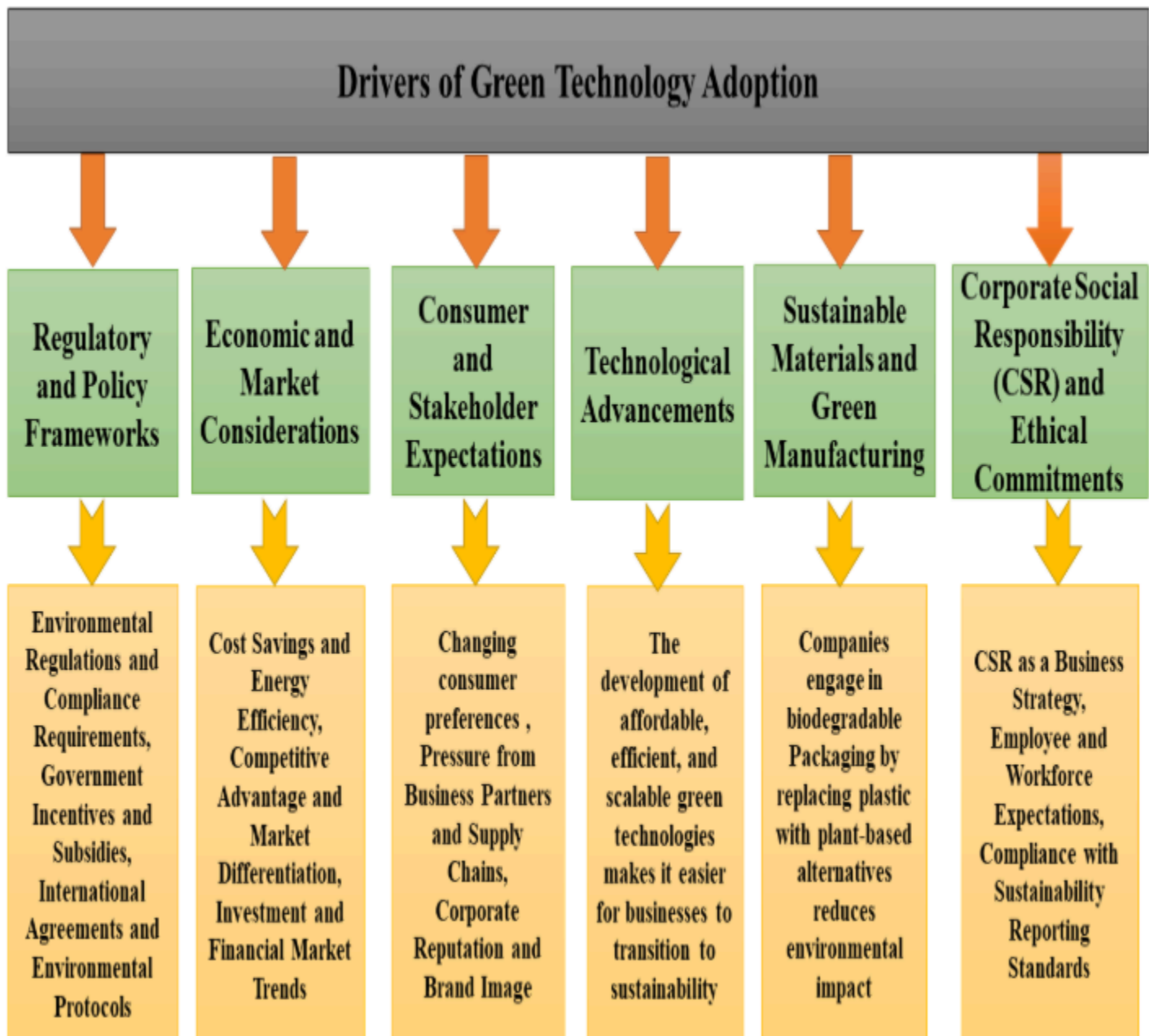


Figure 4

Main Drivers of Green Technology Adoption.



Figure 5

The 3 P's of the Triple Bottom Line.



Figure 6

Organizational Adaptation and Sustainability.