INDUSTRY 4.0 TECHNOLOGIES AND SUSTAINABILITY PERFORMANCE: GREEN LOGISTICS MEDIATION AND GOVERNMENT SUPPORT MODERATION EFFECTS

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Abstract. This conceptual paper investigates the relationship between Industry 4.0 (I4.0) technologies, Green Logistics Practices (GLP), and sustainability performance, with government support as a moderating factor. In response to escalating sustainability challenges and the accelerated pace of digital transformation, the study addresses a key gap in understanding how the adoption of Industry 4.0 (I4.0) translates into sustainability outcomes. While prior work has considered the benefits of digitalization, the mediating role of GLP and the influence of institutional support have received limited scholarly attention. Drawing on a comprehensive review of recent literature (2020–2024), the paper proposes a conceptual framework grounded in the Resource-Based View (RBV) and Institutional Theory. RBV conceptualizes I4.0 as strategic resources and GLP as organizational capabilities, whereas Institutional Theory highlights how government policies shape adoption. The study advances theory by integrating internal and external perspectives to clarify the technology–sustainability nexus, and offers practical insights for firms aligning digital transformation with sustainability goals and for policymakers promoting green logistics.
Keywords: *industry 4.0 technologies, Green Logistics Practices (GLP), sustainability performance, government support, Resource-Based View (RBV), institutional theory*

Introduction

The global agenda has been profoundly reshaped by mounting sustainability challenges that continue to disrupt and redefine supply chains in recent years. Today's supply chains must operate within a complex and turbulent environment characterized by climate change, resource scarcity, regulatory pressures, and heightened stakeholder expectations for transparency and ethical sourcing (Shabur, 2024; Morella et al., 2023; Sun et al., 2021). The climate crisis, in particular, has intensified calls for reducing carbon footprints across industries, pushing firms to adopt greener practices. Simultaneously, the COVID-19 pandemic exposed the fragility of global networks and emphasized the urgent need to embed resilience and adaptability through sustainability-driven transformations (Tan et al., 2020). Collectively, these pressures underscore the necessity for innovative responses from supply chain stakeholders amid growing consumer demand for sustainable products.

In this context, Industry 4.0 (I4.0) technologies play a pivotal role in enabling the digital and green transformation of supply chains. Emerging technologies such as the Internet of Things (IoT), artificial intelligence (AI), blockchain, robotics, and big data analytics are reshaping supply chain operations to become more transparent, efficient, and sustainable (Nagy et al., 2023; Nureen et al., 2022; Agyabeng-Mensah et al., 2020). For instance, AI enables predictive analytics that reduce inefficiencies, while blockchain enhances transparency and material traceability, ensuring compliance with sustainability standards (Li et al., 2023; Uwamahoro et al., 2023; Ngisau and Ibrahim, 2020). When

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combined with Green Logistics Practices (GLP), these technologies offer significant potential for enhancing sustainability performance by reducing waste, optimizing resource utilization, and supporting circular economy initiatives (Korucuk et al., 2022; Yue et al., 2022).

Logistics, in particular, is central to sustainability given its significant contribution to carbon emissions and resource efficiency. Effective management of transportation, warehousing, and inventory flows can substantially reduce environmental impacts while ensuring operational continuity (Iwan et al., 2024; Habib et al., 2021). GLP, such as eco-friendly transportation, sustainable packaging, and reverse logistics, have been widely recognized for their role in reducing carbon footprints and fostering circular economy practices (Zhu et al., 2023; Okorokov et al., 2021; Savina et al., 2021; Zhang et al., 2020). As such, logistics is increasingly positioned at the forefront of sustainable supply chain initiatives, highlighting the importance of examining how GLP interacts with I4.0 technologies to drive sustainability outcomes. Taken together, these developments highlight the timeliness and relevance of exploring the intersection of I4.0, GLP, and sustainability performance. This study builds on these considerations to position digital transformation and green logistics as critical levers for addressing sustainability challenges in contemporary supply chains.

Research problem

Despite significant advancements in both digital and green supply chain practices, several critical gaps remain in the literature. First, existing studies offer limited insights into the direct mechanisms through which Industry 4.0 technologies influence sustainability outcomes (Asamoah et al., 2023; Guo and Xiang, 2023; Shahzad et al., 2024; Van and Nguyen, 2023). Although the transformative potential of digitalization has been widely acknowledged, the specific pathways linking Industry 4.0 adoption to measurable sustainability performance remain underexplored. Second, while GLP is increasingly recognized as a cornerstone of sustainable supply chain management, its mediating role in the relationship between I4.0 adoption and sustainability performance remains insufficiently investigated (Wahid et al., 2023; Umar et al., 2021; Agyabeng-Mensah et al., 2020). Clarifying this mediating role is critical, as GLP may serve as the mechanism that enables firms to convert technological adoption into tangible environmental and social outcomes.

Third, the moderating influence of government support has not received adequate attention in prior research, despite its decisive role in shaping organizational behaviours. Policies such as subsidies, incentives, and environmental regulations can either accelerate or hinder the adoption of I4.0 technologies and green practices (Korucuk et al., 2022; Olanipekun and Sutrisna, 2021; Ngisau and Ibrahim, 2020). A more nuanced understanding of this institutional factor is essential for contextualizing sustainability transformations across diverse regions and industries. Addressing these gaps is vital for advancing both theoretical and practical perspectives. From a theoretical standpoint, this study integrates the Resource-Based View (RBV) and Institutional Theory to examine how internal capabilities (I4.0 and GLP) interact with external institutional forces (government support) to shape sustainability performance. From a practical perspective, the study offers valuable insights for firms seeking to align digital transformation with their sustainability goals, as well as for policymakers aiming to promote the adoption of green logistics practices.

Accordingly, the research is guided by the following central question: “How do Industry 4.0 technologies contribute to sustainability performance through Green Logistics Practices (GLP), and how does government support moderating this relationship?” To address this question, the study is guided by the following objectives: (1) To examine how the adoption of Industry 4.0 (I4.0) technologies enables and supports the implementation of Green Logistics Practices (GLP); (2) To evaluate the extent to which GLP functions as a mediating mechanism linking I4.0 adoption with sustainability performance; (3) To analyse how government support moderates and strengthens the relationship between I4.0, GLP, and sustainability performance across different institutional contexts.

Literature review

This section reviews the literature relevant to the intersection of Industry 4.0 technologies, Green Logistics Practices (GLP), sustainability performance, and government support. The aim is to identify how prior research has conceptualized the role of digital transformation in advancing sustainable supply chains, while also highlighting the mechanisms and contextual factors that remain underexplored. The review is structured into five parts. First, it examines the core Industry 4.0 technologies that are transforming supply chain and logistics operations. Second, it discusses Green Logistics Practices as operational pathways that link digital adoption with sustainability outcomes. Third, it evaluates the concept of sustainability performance as the outcome variable in this study. Fourth, it examines the role of government support as an institutional moderator that shapes the adoption of technology and sustainability. Finally, the review outlines the theoretical foundations, drawing on the Resource-Based View (RBV) and Institutional Theory, that provide the conceptual grounding for this paper.

Industry 4.0 technologies

Industry 4.0 refers to the fourth industrial revolution, defined by the integration of cyber-physical systems, IoT, big data analytics, AI, robotics, blockchain, and additive manufacturing into supply chain and logistics operations (Shahzad et al., 2024; Guo and Xiang, 2023). These technologies collectively enable real-time data sharing, advanced decision-making, and automation that enhance efficiency and sustainability performance (Letunovska et al., 2023). Recent studies highlight IoT and AI as drivers of “smart logistics,” improving visibility and optimizing routes, while blockchain provides transparency and traceability to ensure compliance with environmental standards (Asamoah et al., 2023; Agyabeng-Mensah et al., 2020). Big data analytics further strengthens these capabilities by processing large datasets, generating insights for demand forecasting and operational optimization (Yue et al., 2022). Robotics and additive manufacturing also reduce waste and energy use, supporting localized and efficient production systems (Zhu et al., 2023; Umar et al., 2021). As illustrated in *Figure 1*, these six technologies collectively form the backbone of Industry 4.0 in logistics and supply chains.

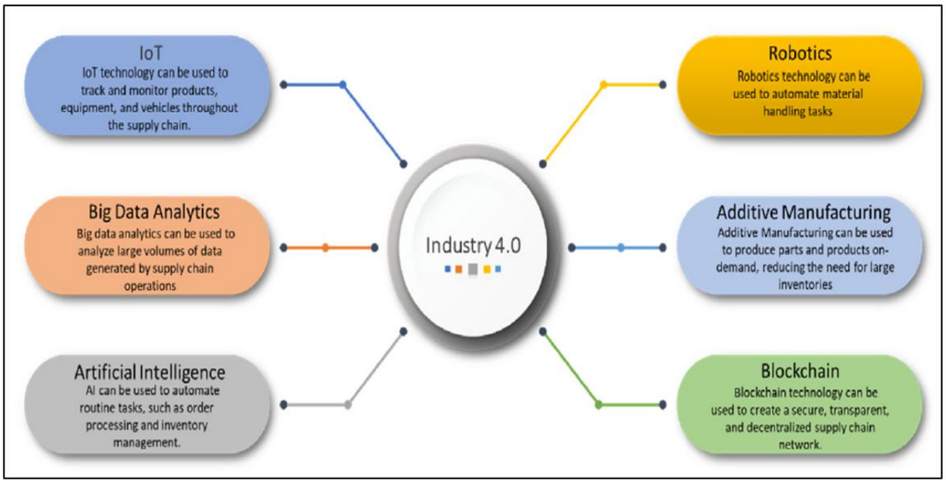

Figure 1. *Applications of industry 4.0 technologies in supply chains.*
Source: Sharma et al. (2022).

Empirical evidence from 2020 to 2024 suggests that adopting I4.0 technologies enhances operational efficiency, reduces costs, and lowers carbon emissions (Cuevas-Pichardo et al., 2024; Korucuk et al., 2022). IoT supports real-time monitoring and inventory accuracy, reducing fuel consumption and overproduction (Wahid et al., 2023; Ngisau and Ibrahim, 2020). AI enables predictive analytics that optimize logistics planning and reduce unnecessary transportation and storage (Iwan et al., 2024). Big data analytics complements these capabilities by uncovering hidden patterns in large datasets, improving demand forecasting, and supporting strategic decision-making (Yue et al., 2022; Ngisau and Ibrahim, 2020). Blockchain ensures immutable transaction records, enhancing accountability and reducing fraud in sustainable sourcing (Srivastava et al., 2022). Robotics streamlines warehouse operations, cutting energy consumption (Kim et al., 2024), while additive manufacturing enables localized, low-waste production aligned with sustainability goals (Hajiheydari et al., 2022; Martins, 2022). Despite these advances, three significant gaps remain. First, most studies examine isolated technologies, such as IoT, AI, or big data analytics, without considering their synergistic effects (Omotayo and Melan, 2022; Farradia et al., 2021). Second, longitudinal evidence on the long-term sustainability impacts of I4.0 adoption is scarce (Karia, 2022). Third, there is limited theorization on the mechanisms through which I4.0 translates into measurable sustainability outcomes, particularly in relation to mediating practices such as GLP (Yue et al., 2022; Sun et al., 2021). Addressing these gaps is critical to understanding how I4.0 can be strategically leveraged to enhance sustainability performance within supply chains.

Industry 4.0 technologies (as illustrated in *Figure 1*) provide the digital backbone for achieving greater efficiency, transparency, and responsiveness in supply chains. However, their contribution to sustainability performance is not automatic; it depends mainly on how these technologies are translated into operational practices. Green Logistics Practices (GLP) represents a critical pathway through which I4.0 capabilities can be operationalized to reduce emissions, optimize resource utilization, and enable circular economy initiatives. Therefore, the following section reviews the role of GLP in bridging technological innovation and sustainable supply chain outcomes.

Green logistics practices

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Green Logistics Practices (GLP) are defined as a set of strategies and methods aimed at reducing the environmental footprint of logistics activities, particularly in transportation, warehousing, and distribution operations. They integrate principles of sustainability into logistics processes by focusing on minimizing carbon emissions, reducing waste, and optimizing resource utilization across the supply chain (Savina et al., 2021). Beyond meeting regulatory requirements, GLP is increasingly recognized as a strategic lever for improving both environmental and organizational performance in a highly competitive and sustainability-driven global market (Okorokov et al., 2021). The literature generally identifies three main dimensions of GLP. First, green transportation emphasizes route optimization, the use of eco-friendly vehicles, and the utilization of alternative fuels to reduce emissions and fuel consumption (Guo and Xiang, 2023). Second, green packaging involves reducing packaging volume, employing recyclable or biodegradable materials, and designing efficient packaging systems that improve load utilization while minimizing waste (Letunovska et al., 2023). Third, reverse logistics focuses on recovering, recycling, and remanufacturing products after consumption, thereby promoting circular economy initiatives and reducing reliance on virgin raw materials (Zhu et al., 2023).

Scholars distinguish GLP from the broader field of Green Supply Chain Management (GSCM). While GSCM encompasses sustainability considerations across the entire supply chain: including sourcing, production, and supplier engagement; GLP concentrates more narrowly on logistics operations such as transportation, packaging, and distribution. For example, whereas GSCM may involve eco-design and supplier selection, GLP emphasizes operational aspects of moving, storing, and returning goods within environmentally responsible frameworks (Van and Nguyen, 2023; Umar et al., 2021). GLP has been shown to improve both environmental efficiency and overall sustainability performance significantly. Green transportation methods, such as AI- and GPS-enabled route optimization, reduce unnecessary mileage and congestion, thereby cutting fuel use and lowering CO_2 emissions. Studies report that firms adopting green transportation strategies can reduce emissions by up to 30% (Asamoah et al., 2023; Wahid et al., 2023; Agyabeng-Mensah et al., 2020).

Green packaging similarly reduces environmental impact by minimizing material waste and enhancing transport efficiency. Companies that adopt biodegradable materials and compact packaging designs minimize the volume of waste sent to landfills, while also optimizing container space to lower transport-related emissions (Iwan et al., 2024; Alraja et al., 2022; Anwar et al., 2020). Reverse logistics reinforces sustainability outcomes by enabling recycling, refurbishing, and remanufacturing processes. These practices minimize waste disposal, reduce demand for virgin resources, and align with the principles of a circular economy. Empirical studies confirm that reverse logistics contributes directly to both environmental and financial sustainability performance, supporting resource efficiency and profitability (Shahzad et al., 2024; Farradia et al., 2021; Gupta and Singh, 2020). Empirical evidence from 2020 to 2024 highlights that logistics firms implementing GLP report not only reduced emissions and improved recycling rates but also enhanced financial outcomes, demonstrating that environmental responsibility and profitability can be mutually reinforcing (Ma et al., 2023; Olanipekun and Sutrisna, 2021).

The integration of Industry 4.0 (I4.0) technologies has proven to be a significant enabler of GLP adoption and effectiveness. IoT devices enable the real-time tracking of goods and resources, thereby facilitating greater transparency and efficiency in logistics operations (Omotayo and Melan, 2022). Artificial intelligence enhances demand forecasting and logistics planning, minimizing waste and reducing inefficiencies (Kim et al., 2024). Blockchain technologies support sustainable practices by providing immutable records, ensuring traceability, and verifying suppliers' environmental credentials (Kolev and Otsetova, 2022). Robotics and automation contribute by streamlining warehouse processes and enabling automated waste sorting, leading to higher recycling rates and reduced environmental impact (Habib et al., 2021; Ngisau and Ibrahim, 2020). These examples underscore the complementary relationship between digital transformation and sustainability. By enabling more precise, efficient, and transparent logistics operations, I4.0 technologies reinforce the capacity of GLP to deliver tangible sustainability outcomes.

Despite the demonstrated potential of GLP, several research gaps remain. Many existing studies are limited to case-based or region-specific analyses, which constrains the generalizability of findings across industries and countries (Labaran and Masood, 2023; Moroza and Jurgelāne-Kaldava, 2020). Additionally, few studies provide integrative models that capture the multidimensional and interdependent nature of GLP. Another significant gap concerns the mediating role of GLP in the relationship between I4.0 adoption and sustainability performance. While prior research often highlights the benefits of technology and sustainability separately, limited work examines how GLP specifically operationalizes the potential of digital technologies to achieve sustainable outcomes (Singh et al., 2020). The literature disproportionately focuses on developed economies, leaving limited insights into GLP implementation in developing contexts. Given the environmental pressures of rapid industrialization in emerging economies, this gap constrains both theoretical development and policy design (Ismayil and Karagulle, 2023; Jayarathna et al., 2022).

GLP functions as a critical pathway through which Industry 4.0 technologies can be translated into sustainability performance. By integrating green transportation, packaging, and reverse logistics, firms can achieve measurable environmental and economic benefits. The following section, therefore, examines sustainability performance as the outcome variable of interest in this conceptual framework.

Sustainability performance

Sustainability performance in supply chain and logistics refers to an organization's capacity to align operational efficiency with environmental, economic, and social objectives. It is a multidimensional construct that emphasizes responsible resource utilization, the reduction of adverse ecological impacts, profitability improvements, and contributions to social welfare (Okorokov et al., 2021; Savina et al., 2021). Within this context, sustainability performance extends beyond traditional operational metrics to encompass long-term resilience, stakeholder satisfaction, and compliance with global sustainability standards. The literature typically distinguishes three main dimensions of sustainability performance. First, environmental performance concerns reducing greenhouse gas emissions, energy consumption, and waste generation, often measured through indicators such as carbon footprint or recycling rates (Joensuu-Salo and Matalamäki, 2023; Zhu et al., 2023). Second, economic performance addresses the financial implications of sustainable practices, including profitability, operational cost savings, and return on investment (Asamoah et al., 2023; Guo and Xiang, 2023). Third, social performance evaluates organizational practices in terms of employee well-being, community engagement, and ethical responsibility (Wahid et al., 2023; Olanipekun and

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Sutrisna, 2021). Unlike corporate social responsibility (CSR), which often emphasizes social and moral factors, sustainability performance offers a broader, integrated framework that balances environmental, economic, and social imperatives (Agyabeng-Mensah et al., 2020; Ngisau and Ibrahim, 2020).

Sustainability performance has emerged as a critical strategic priority for firms in global supply chains. Climate change introduces risks to supply chain stability, prompting urgent adoption of sustainable practices to ensure resilience (Smith et al., 2021). Stricter environmental regulations worldwide demand measurable evidence of sustainability, making compliance an operational necessity (Iwan et al., 2024). Moreover, evolving stakeholder expectations, particularly from consumers and investors, have shifted market dynamics toward sustainability as a source of legitimacy and competitive advantage (Anwar et al., 2020). Firms demonstrating strong sustainability performance not only comply with regulations but also enjoy improved brand reputation, customer loyalty, and greater access to responsible investment capital (Nagy et al., 2023; Gupta and Singh, 2020). Empirical evidence highlights cost savings and efficiency gains resulting from sustainable operations, reinforcing sustainability as both a compliance requirement and a profitability driver (Moroza and Jurgelāne-Kaldava, 2020; Singh et al., 2020).

Recent research underscores the growing interconnection between Industry 4.0 adoption, Green Logistics Practices (GLP), and sustainability performance. The adoption of IoT, AI, and blockchain technologies enables firms to measure sustainability metrics with greater precision, optimize energy and resource utilization, and reduce emissions through more intelligent decision-making (Issa et al., 2024; Endang et al., 2022; Mohsen, 2022). Logistics, particularly when guided by GLP, enhances sustainability outcomes through eco-friendly transport, sustainable packaging, and reverse logistics practices that align with circular economy principles (Ma et al., 2023; Zhang et al., 2020). Cross-country studies further demonstrate how regional contexts shape sustainability outcomes. For instance, EU logistics firms have integrated GLP more extensively compared to logistics firms in emerging markets, reflecting disparities in institutional support and regulatory frameworks (Zuhri et al., 2024; Yue et al., 2022). Such findings highlight both the progress and uneven adoption of sustainability practices across different economic environments (Cuevas-Pichardo et al., 2024; Ahmad et al., 2022).

Within the proposed framework, sustainability performance represents the outcome variable that integrates operational, environmental, and social dimensions. By conceptualizing Industry 4.0 technologies as strategic resources and GLP as enabling capabilities, sustainability performance is positioned as both a measure of regulatory compliance and a driver of competitive advantage (Nureen et al., 2022; Wahyuni et al., 2020). This dual function emphasizes the importance of achieving sustainability not only to meet institutional requirements but also to capture long-term market opportunities (Barbosa, 2024; Korucuk et al., 2022). Despite growing scholarly attention, essential gaps persist. Measurement approaches often lack standardized indicators, limiting comparability across industries and regions (He and Xu, 2024; Otache and Usang, 2021). Furthermore, many studies treat Industry 4.0 adoption, GLP, and sustainability performance in isolation rather than examining their combined and interactive effects (Thai et al., 2024; Alraja et al., 2022). Sectoral gaps are also evident, as most research focuses on developed economies, leaving limited insights into how sustainability performance unfolds in SMEs, developing markets, or logistics-intensive industries (Shabur, 2024; Miao and Zhao, 2023). Addressing these gaps will be essential for advancing both theory and practice in the field.

Sustainability performance encapsulates the environmental, economic, and social benefits of aligning supply chain operations with sustainable objectives. While Industry 4.0 technologies and GLP provide pathways to achieving these outcomes, their effectiveness often depends on external institutional enablers. The following section, therefore, explores the role of government support as a moderating force in strengthening the relationship between technology adoption, green logistics, and sustainability performance.

Government support

Government support in the context of supply chain sustainability refers to the policies, regulations, incentives, and institutional pressures that governments introduce to foster the adoption of environmentally responsible practices and advanced technologies. It acts as an enabling external force that shapes organizational behaviors and accelerates the transition toward green and sustainable logistics. This support is especially critical in driving firms to integrate Industry 4.0 (I4.0) technologies with sustainability initiatives, creating an ecosystem where innovation and environmental stewardship can coexist (Korucuk et al., 2022; Ngisau and Ibrahim, 2020). Government support manifests in several interrelated forms. Regulatory frameworks constitute one of the most influential mechanisms, as they establish binding requirements such as carbon emission limits, environmental reporting obligations, and compliance with international standards (Olanipekun and Sutrisna, 2021). These regulatory measures not only enforce sustainability practices but also level the competitive playing field by compelling all firms to adopt green practices.

In addition to regulations, financial incentives play a pivotal role. Subsidies, tax reliefs, low-interest loans, and grants are widely recognized tools that reduce the economic burden of adopting advanced technologies and green logistics practices. These incentives are significant for small and medium-sized enterprises (SMEs) and firms operating in emerging economies, where capital constraints often limit investment in sustainability initiatives (Ngisau and Ibrahim, 2020). Beyond these formal mechanisms, governments exert institutional pressures by embedding sustainability into national strategies and promoting industry-wide sustainability norms. Examples include the encouragement of certifications such as ISO 14001, the provision of technical support and knowledge-sharing platforms, and partnerships with industry associations that foster collective learning and capacity-building. These institutional forces shape organizational culture, legitimize sustainable practices, and create long-term momentum for green transformation (Iwan et al., 2024; Korucuk et al., 2022). The influence of government support extends directly to the adoption of Industry 4.0 technologies and the implementation of Green Logistics Practices (GLP). Supportive regulatory and financial environments enable firms to overcome barriers related to high implementation costs, technological uncertainty, and resistance to change (Yue et al., 2022). For instance, subsidies for renewable energy integration in logistics operations or tax incentives for adopting digital monitoring systems provide immediate and tangible benefits that accelerate the transition to sustainable practices. In turn, these measures facilitate the deployment of intelligent logistics solutions, enhance transparency through blockchain adoption, and promote the use of eco-friendly transportation systems.

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Evidence from recent studies indicates that government support acts as a critical catalyst in aligning organizational incentives with sustainability goals. Companies operating in regions with proactive government policies demonstrate higher rates of technology adoption and more advanced implementation of GLPs compared to firms in areas with weaker policy frameworks (Zhu et al., 2023; Savina et al., 2021). This underscores the importance of supportive governance structures as moderators that strengthen the link between I4.0 adoption and sustainability performance. Despite its recognized importance, the moderating role of government support in the relationship between I4.0 technologies, GLPs, and sustainability performance remains underexplored. Much of the existing literature has examined government support in isolation, focusing either on regulatory compliance or financial incentives, without offering comprehensive frameworks that integrate these mechanisms into the broader technology–sustainability nexus (Ma et al., 2023). Moreover, studies tend to concentrate on developed economies, leaving limited insights into how government support operates in developing contexts where institutional and resource constraints are more pronounced (Ismayil and Karagulle, 2023). Future research should therefore investigate cross-country variations, sectoral differences, and longitudinal effects of government support to provide a more nuanced understanding of its role in driving sustainable logistics and supply chain transformation.

Government support is not merely an external backdrop but a decisive moderating force that shapes how firms leverage Industry 4.0 technologies and Green Logistics Practices to achieve sustainability performance. By combining regulatory enforcement, financial incentives, and institutional pressures, governments create the enabling conditions that transform technological potential into measurable environmental, economic, and social outcomes. This central role underscores why government support must be explicitly integrated into conceptual frameworks examining the nexus between digital transformation and sustainability.

Theoretical foundations

The Resource-Based View (RBV) is a well-established theoretical framework that posits that a firm’s competitive advantage and performance stem from the unique resources and capabilities it controls (Letunovska et al., 2023). These resources can be tangible or intangible, ranging from financial and physical assets to knowledge, human capital, and technological infrastructure. According to RBV, resources that are valuable, rare, inimitable, and non-substitutable (VRIN) form the basis for sustained competitive advantage (Okorokov et al., 2021). Within the context of supply chain and logistics management, RBV emphasizes the importance of effectively deploying resources for organizational resilience and sustainability. From this perspective, Industry 4.0 technologies, such as IoT, AI, and blockchain, can be conceptualized as strategic resources. IoT provides real-time data visibility across logistics networks, AI enables predictive analytics for optimizing decision-making, and blockchain ensures secure and transparent records that enhance trust in supplier relationships (Savina et al., 2021). These technologies represent distinctive capabilities that firms can leverage to drive both operational efficiency and environmental responsibility, aligning competitive advantage with sustainability goals (Joensuu-Salo and Matalamäki, 2023). Moreover, Green Logistics Practices (GLP) can be interpreted through the RBV lens as organizational capabilities that transform resources into sustainability outcomes. Practices such as eco-friendly transportation, recyclable packaging, and reverse logistics

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enable firms to comply with environmental regulations while also improving economic performance and reputation (Shahzad et al., 2024; Zhu et al., 2023). Empirical research between 2020 and 2024 reinforces this view, showing that firms that integrate green capabilities with advanced technologies achieve superior sustainability results (Umar et al., 2021; Agyabeng-Mensah et al., 2020).

While RBV offers insights into internal strengths, Institutional Theory provides a complementary perspective by emphasizing the role of external pressures—regulative, normative, and coercive—in shaping organizational strategies (Asamoah et al., 2023). Regulative pressures derive from formal laws, environmental standards, and government regulations; normative pressures reflect the influence of societal expectations and industry norms; while coercive pressures arise from demands imposed by dominant actors such as governments, multinational buyers, or large customers (Wahid et al., 2023). Within this framework, government support becomes a critical institutional force, offering financial incentives, regulatory guidelines, and policy interventions that encourage firms to adopt Industry 4.0 technologies and GLP (Olanipekun and Sutrisna, 2021; Ngisau and Ibrahim, 2020). Examples include subsidies for eco-innovations, tax incentives for adopting green technologies, and environmental certifications that signal compliance with international standards (Jedynak et al., 2021). Empirical research highlights how such institutional pressures act as catalysts for digital transformation and sustainability transitions across logistics sectors (Alraja et al., 2022; Hajiheydari et al., 2022; Anwar et al., 2020). Taken together, RBV and Institutional Theory offer a complementary dual lens. RBV emphasizes the internal deployment of technological resources and green logistics capabilities, while Institutional Theory situates these within the broader external environment shaped by policy, norms, and stakeholder expectations (Gupta and Singh, 2020). By integrating these perspectives, this study provides a richer understanding of how Industry 4.0 adoption and GLP can jointly enhance sustainability performance under varying institutional contexts (Kolev and Otsetova, 2022).

This study deliberately focuses on the Resource-Based View (RBV) and Institutional Theory as its theoretical foundations. RBV provides the internal perspective necessary to conceptualize Industry 4.0 technologies as strategic resources and GLP as organizational capabilities that drive sustainability. Institutional Theory complements this by explaining how external institutional pressures, particularly government support, shape organizational adoption and diffusion of these practices. Although the Dynamic Capabilities View (DCV) has been employed in related studies, it essentially extends the RBV perspective and risks redundancy in this context. By contrast, combining RBV and Institutional Theory offers a more balanced and parsimonious framework, capturing both the internal mechanisms of resource deployment and the external institutional forces influencing sustainable supply chain transformation. This integration ensures a robust theoretical grounding for examining how Industry 4.0 and GLP jointly contribute to sustainability performance under the moderating role of government support.

Conceptual framework and hypotheses development

Conceptual framework

Based on the literature review, this study proposes a conceptual framework that integrates the adoption of Industry 4.0, Green Logistics Practices (GLP), sustainability performance, and government support. Drawing on the Resource-Based View (RBV), Industry 4.0 technologies are conceptualized as strategic resources, while GLP represents organizational capabilities that transform these resources into sustainability outcomes (Letunovska et al., 2023; Zhu et al., 2023; Okorokov et al., 2021). Complementing this internal perspective, Institutional Theory underscores the role of external pressures, particularly government support, as catalysts that shape the adoption and diffusion of digital and green practices (Asamoah et al., 2023; Wahid et al., 2023). As shown in *Figure 2*, the framework posits that Industry 4.0 adoption enables the implementation of GLP, which subsequently enhances sustainability performance across environmental, economic, and social dimensions. Furthermore, government support moderates the relationship between I4.0 adoption and GLP by lowering financial barriers, incentivizing eco-innovation, and reinforcing compliance with sustainability standards (Olanipekun and Sutrisna, 2021; Jedynak et al., 2021).

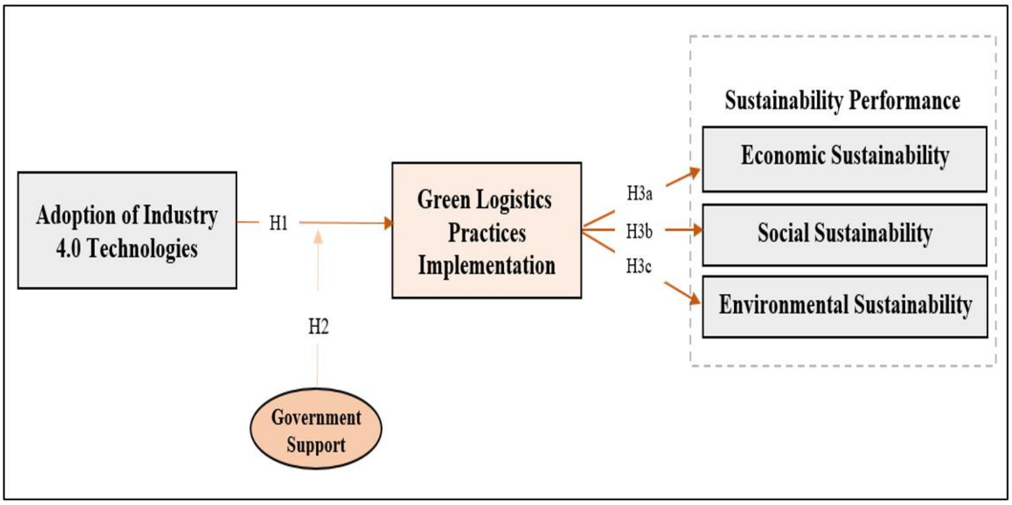

Figure 2. *Proposed conceptual framework.*

Hypotheses development

Industry 4.0 adoption and GLP implementation

Industry 4.0 technologies enhance firms' capabilities in data visibility, predictive analytics, and traceability, creating opportunities to optimize logistics operations and reduce environmental impacts (Joensuu-Salo and Matalamäki, 2023; Savina et al., 2021). Empirical studies demonstrate that the adoption of IoT, AI, and blockchain facilitates eco-friendly transportation, sustainable packaging, and reverse logistics (Umar et al., 2021; Ngisau and Ibrahim, 2020). Accordingly: (H1): The adoption of Industry 4.0 technologies positively influences the implementation of Green Logistics Practices.

Moderating role of government support

Institutional Theory highlights how regulative, normative, and coercive pressures shape organizational practices (Shahzad et al., 2024). Among these, government support—through subsidies, tax incentives, environmental regulations, and certification schemes—plays a decisive role in enabling digital and green transitions. Firms receiving stronger governmental backing are more likely to integrate Industry 4.0 technologies into logistics operations and align them with GLP (Van and Nguyen, 2023; Anwar et

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al., 2020). Thus: (H2) Government support positively moderates the relationship between Industry 4.0 adoption and the implementation of Green Logistics Practices.

GLP and sustainability performance

GLP enhances sustainability performance by reducing environmental impacts, improving economic efficiency, and strengthening social responsibility. Green transportation and packaging lower costs and emissions, while reverse logistics fosters resource recovery and stakeholder engagement (Hajiheydari et al., 2022; Gupta and Singh, 2020). Empirical studies confirm positive impacts across the three sustainability dimensions (Ma et al., 2023). Accordingly: (H3a): The implementation of Green Logistics Practices positively influences economic sustainability performance; (H3b): The implementation of Green Logistics Practices positively influences social sustainability performance; (H3c): The implementation of Green Logistics Practices positively influences environmental sustainability performance.

Summary of hypothesized relationships

Taken together, the hypotheses illustrate how Industry 4.0 adoption functions as a strategic resource, GLP serves as a mediating capability, and government support provides the institutional conditions that strengthen these dynamics. By integrating RBV and Institutional Theory, the framework offers a comprehensive explanation of how digital transformation and green practices jointly enhance sustainability performance in supply chains (Kim et al., 2024; Moroza and Jurgelāne-Kaldava, 2020). This dual-theory perspective not only advances scholarly understanding but also provides actionable insights for managers and policymakers seeking to align digital transformation with sustainability objectives.

Materials and Methods

This study employs a conceptual research design, emphasizing theoretical integration rather than empirical data collection. In rapidly evolving fields such as Industry 4.0 and green logistics, conceptual research is particularly valuable as it frames emerging issues, clarifies relationships, and identifies gaps that guide subsequent empirical investigations (Okorokov et al., 2021; Savina et al., 2021). The framework developed in this paper is grounded in the Resource-Based View (RBV) and Institutional Theory, providing a dual perspective that captures both internal resource capabilities and external institutional pressures. RBV conceptualizes Industry 4.0 technologies as strategic resources and GLP as organizational capabilities, while Institutional Theory emphasizes the role of government support and other institutional forces in shaping adoption. By systematically reviewing and synthesizing studies published between 2020 and 2024, the paper formulates hypotheses that connect Industry 4.0 adoption, GLP, and sustainability performance, with government support as a moderating factor (Letunovska et al., 2023; Van and Nguyen, 2023; Zhu et al., 2023).

The value of this conceptual approach lies in its ability to consolidate fragmented findings, integrate complementary theoretical perspectives, and propose a coherent framework that advances the explanation of the technology–sustainability nexus. In doing so, the study contributes to theory building by clarifying the mechanisms linking digital transformation with sustainability, and to practice by offering a structured agenda for future empirical testing and policy formulation. Ultimately, this methodology strengthens both academic and managerial understanding of how Industry 4.0 and GLP can jointly enhance sustainability performance (Guo and Xiang, 2023; Ma et al., 2023).

Results and Discussion

This study provides multiple contributions at the theoretical, practical, and policy levels. From a theoretical perspective, it enriches the Resource-Based View (RBV) by demonstrating how Industry 4.0 technologies, such as IoT, AI, and blockchain, function as strategic resources that enable firms to develop Green Logistics Practices (GLP). When effectively deployed, these technologies enhance operational efficiency and sustainability outcomes, aligning with RBV's notion of valuable, rare, inimitable, and non-substitutable (VRIN) resources (Okorokov et al., 2021). At the same time, the study extends Institutional Theory by highlighting the moderating role of government support in accelerating the adoption of I4.0 and GLP. Incentives and regulations reduce uncertainty and risks, encouraging firms to align strategies with sustainability mandates (Letunovska et al., 2023). This integrated perspective contributes to the growing body of research applying RBV and Institutional Theory together, while also opening avenues for empirical testing across different sectors and institutional contexts.

Beyond its theoretical contributions, the study offers significant managerial implications. For managers, adopting I4.0 in tandem with GLP generates tangible benefits, including cost savings, reduced emissions, and increased operational agility. For instance, IoT-enabled monitoring can optimize routing and reduce fuel consumption, while AI-driven analytics identify inefficiencies and minimize waste (Iwan et al., 2024; Anwar et al., 2020). The framework also guides the balancing of internal capabilities with external pressures, enabling firms to comply with regulatory demands while simultaneously strengthening their competitive advantage (Alraja et al., 2022). In addition to enhancing efficiency and compliance, GLP adoption also improves brand reputation and customer loyalty, ultimately leading to financial performance gains (Nagy et al., 2023; Jedynak et al., 2021). Achieving these benefits, however, requires not only technological investment but also organizational commitment and cultural change toward sustainability.

The study also highlights important policy implications. Governments play a decisive role in creating enabling conditions for sustainable logistics. Supportive policies, such as tax incentives, subsidies for eco-innovations, and environmental certification schemes, lower adoption barriers and foster institutional environments conducive to sustainability (Zhu et al., 2023; Savina et al., 2021). Successful cases in Scandinavia, Germany, and the Netherlands demonstrate how combining financial incentives with robust regulatory frameworks can reduce emissions and accelerate the integration of digital and green practices in logistics (Shahzad et al., 2024; Olanipekun and Sutrisna, 2021). These examples provide transferable lessons for governments worldwide, particularly in emerging economies where institutional support is less developed. This study bridges RBV and Institutional Theory to explain how Industry 4.0 adoption and GLP jointly improve sustainability performance under the moderating influence of government support. The proposed framework not only advances theoretical understanding but also provides actionable insights for managers and policymakers, underscoring the importance of integrated approaches in developing sustainable supply chains.

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Conclusion

This study integrates the Resource-Based View (RBV) and Institutional Theory to explain how Industry 4.0 technologies and Green Logistics Practices (GLP) jointly shape sustainability performance. From the RBV perspective, advanced technologies such as IoT, AI, and blockchain can be understood as strategic resources that enable firms to build unique capabilities for implementing GLP, thereby enhancing operational efficiency and environmental responsibility (Shahzad et al., 2024; Okorokov et al., 2021). At the same time, Institutional Theory emphasizes the significance of external forces, particularly government support, in mitigating adoption barriers and facilitating transitions toward sustainability (Letunovska et al., 2023; Savina et al., 2021). By linking these two perspectives, the paper provides a comprehensive framework that situates the internal deployment of resources within the broader institutional environment, thereby advancing the theoretical understanding of the technology–sustainability nexus.

Beyond theory, the framework provides clear practical and policy implications. For firms, the convergence of I4.0 and GLP delivers measurable benefits in terms of cost reduction, operational agility, and corporate reputation, while also meeting regulatory and stakeholder expectations (Ma et al., 2023; Anwar et al., 2020). For policymakers, the findings underscore the need for proactive institutional support, through subsidies, tax incentives, and regulatory schemes, to accelerate digital–green transitions in logistics and supply chains (Joensuu-Salo and Matalamäki, 2023; Agyabeng-Mensah et al., 2020). Conceptually, the paper also demonstrates the methodological value of conceptual studies in synthesizing fragmented knowledge, providing an integrative framework, and laying the groundwork for empirical validation (Umar et al., 2021).

Looking ahead, several avenues for future research emerge. Empirical investigations are needed to validate the hypothesized relationships using surveys, case studies, or structural equation modeling, and to capture how mediating and moderating mechanisms operate across different industries and institutional contexts (Guo and Xiang, 2023; Alraja et al., 2022). Comparative studies between developed and emerging economies, as well as focused research on small and medium enterprises, would enrich the applicability of the framework (Ma et al., 2023; Smith et al., 2021). Future research could also extend the model by incorporating dynamic capabilities or stakeholder pressures to deepen understanding of how firms adapt to evolving sustainability demands (Nagy et al., 2023). Finally, longitudinal designs are particularly valuable to trace the long-term sustainability outcomes of I4.0 and GLP adoption, providing more substantial evidence of causality beyond cross-sectional insights (Olanipekun and Sutrisna, 2021). This study not only advances theory by integrating RBV and Institutional Theory but also offers actionable insights for managers and policymakers. By bridging digital transformation with green practices, supported by government initiatives, the framework contributes to both the scholarly understanding and practical advancement of sustainable supply chains.

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Conflict of interest

The authors confirm that there is no conflict of interest among any parties involved in this research study.

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