

Green supply chain management framework for sustainable organizational performance and green management excellence

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Abstract — Environmental sustainability has become a central strategic priority for organizations seeking long-term competitiveness. Green Supply Chain Management (GSCM) has emerged as a core pillar of this transition, yet many firms still struggle to operationalize environmental practices, measure performance, and balance sustainability with economic growth. At the same time, rapid advancements in digital transformation technologies including IoT, cloud systems, big data analytics, and intelligent automation are reshaping the possibilities for supply chain visibility, resource efficiency, circular economy adoption, and green management. This manuscript integrates the foundational principles of GSCM with the transformative potential of digital technologies, supported by insights from industrial case evidence. The study expands the conceptual scope of traditional GSCM by incorporating digital transformation, green supply chain integration, absorptive capacity, and economic policy uncertainty as strategic variables influencing sustainable performance. The analysis highlights how digital transformation enhances environmental monitoring, supplier transparency, process optimization, and end-to-end circular flows. Findings reveal that organizations embracing green integration and digitalization achieve substantial reductions in emissions, waste, and water usage while gaining operational efficiency and competitive advantage. The manuscript proposes an integrated framework that unifies digital transformation and GSCM to accelerate sustainability outcomes and future-ready supply chain resilience.

Index Terms — digital transformation, green supply chain management absorptive capacity, circular economy, environmental sustainability

I. INTRODUCTION

Environmental sustainability has become an essential strategic priority as organizations face rising ecological risks, resource constraints, and increasing expectations from regulators, customers, and society. Green management and Green Supply Chain Management (GSCM) (Saleem et al., 2020), offer structured approaches to reduce waste, improve resource efficiency, and embed environmental responsibility across procurement, production, logistics, and product recovery activities. However, modern supply chains are highly complex, making it difficult to track environmental performance or coordinate sustainable practices using traditional systems. Digital transformation offers new opportunities to strengthen green initiatives through advanced tools such as real-time monitoring, automation, cloud platforms, and data analytics. These technologies enhance visibility, transparency, and process optimization, providing the foundation for more efficient and environmentally responsible supply chains. Integrating digital capabilities with green management principles represents a promising pathway for organizations seeking sustainability-driven operational excellence.

Despite the growing adoption of green management, many organizations continue to struggle with practical implementation. Environmental responsibilities are often fragmented, resulting in limited visibility across the supply chain. Traditional systems do not generate real-time environmental data, making it difficult to evaluate performance, monitor resource usage, or ensure consistent compliance with green standards. Supplier collaboration is also hindered by inconsistent information sharing and limited technological integration. Although digital tools could address these challenges, their integration into green supply chain practices is not yet fully understood. Organizations vary greatly in technological readiness and internal learning capabilities, creating uneven outcomes. External instability, such as economic or policy uncertainty, further complicates long-term planning and investment in environmental initiatives. This gap highlights the

need to examine how digital transformation influences green management outcomes and which organizational or environmental factors shape its effectiveness (El Amine & El Bouzaidi, 2025).

Recent literature emphasizes developing comprehensive frameworks that integrate green practices across supply chain activities to achieve sustainable organizational performance. Scholars highlight that effective GSCM frameworks must encompass green procurement, eco-design, sustainable manufacturing, reverse logistics, and waste management as interconnected components rather than isolated initiatives. Research demonstrates that organizations adopting holistic green management approaches achieve superior environmental and economic performance through reduced operational costs, enhanced brand reputation, and improved stakeholder relationships. Studies reveal that successful GSCM implementation requires alignment between top management commitment, employee engagement, and supplier collaboration to embed sustainability throughout organizational culture. Furthermore, literature identifies performance measurement systems as critical framework elements, enabling firms to track environmental metrics, assess green initiative effectiveness, and drive continuous improvement. However, researchers note persistent challenges in standardizing GSCM practices across industries, balancing short-term costs with long-term sustainability benefits, and achieving cross-functional coordination necessary for green management excellence.

The proposed study investigates how digital transformation strengthens green supply chain practices and overall green management performance. The primary objectives are to:

- Examine how digital technologies enhance green supply chain integration and support environmental practices.
- Assess how an organization's absorptive capacity influences the effectiveness of digital transformation in green initiatives.
- Analyze how economic policy uncertainty affects the relationship between green management practices and supply chain performance.
- Propose an integrated framework combining digital transformation and green management to guide sustainable operational strategy.

Beyond operational benefits, this research supports broader societal goals by promoting cleaner production, responsible resource use, and more sustainable industrial systems aligned with global environmental commitments. The distinct approach promotes more sustainable and resilient supply chain practices that contribute to mitigating global warming, reducing greenhouse gas emissions, and fostering the reuse, recycling, and other environmentally friendly processes central to circular economy models. In addition, it addresses the growing need for organizations to shift from traditional supply chain models to digitally enabled, environmentally responsible systems. Integrating digital transformation with green management can significantly improve environmental monitoring, reduce inefficiencies, support compliance, and strengthen sustainability-driven competitiveness. The study contributes theoretically by clarifying how digital capabilities, absorptive capacity, and policy conditions shape green supply chain outcomes. It also provides practical value by offering clear strategies for managers seeking to improve environmental performance through technology adoption, supplier collaboration, and structured green practices. Beyond operational benefits, this research supports broader societal goals by promoting cleaner production, responsible resource use, and more sustainable industrial systems. The findings help organizations build resilient, transparent, and future-ready supply chains aligned with modern sustainability expectations (Gao, et al., 2022).

The rest of the manuscript proceeds as: Section II examines research gaps in prior work, Section III outlines the Theoretical Foundation and Hypotheses Development, Section IV demonstrates the proposed model. Results are comprehensively discussed in section V. Section VI highlights the discussion over the results and finally study is concluded in the conclusion section.

II. LITERATURE REVIEW

A widely investigation examined by Yang et al. (Yang et al., 2020), how the adoption of digital technologies transforms environmental performance by enhancing visibility, coordination, and control across supply chain activities. The objective was to determine whether digital tools such as analytics, automation, and sensor-based monitoring enhance green management capabilities across procurement, production, and distribution. The researchers employed a quantitative design, collecting survey data from manufacturing firms and analyzing the relationships through structural equation modeling. Results showed that digital technologies significantly improved waste reduction, energy efficiency, and accuracy in environmental reporting. Firms using advanced data systems demonstrated stronger green supply chain integration and better alignment between environmental goals and operational decisions. However, the study primarily evaluated large firms with advanced digital maturity, limiting its applicability to smaller organizations. It also did not consider how organizational capabilities might moderate the effectiveness of digital tools.

A significant empirical study by Brem et al. (Brem et al., 2020), examined how coordinated environmental practices within supply chains contribute to stronger operational sustainability outcomes. The objective was to assess whether supplier engagement, cross-functional communication, and customer-driven environmental coordination translate into measurable improvements in green management. A cross-sectional survey from multiple industries was analyzed using regression-based mediation techniques to evaluate how environmental collaboration influences outcomes. Results indicated that firms with higher integration achieved greater efficiency, reduced waste, and stronger environmental compliance. Environmental collaboration emerged as a key mediating factor, showing that integrated efforts amplify the impact of green initiatives. However, the study relied entirely on self-reported survey data, raising concerns about subjective bias. It also did not evaluate the role of digital technologies, missing an opportunity to understand how digital systems could accelerate integration.

The investigation evaluated by Vismara et al. (Vismara, 2019), how a firm's absorptive capacity shapes its ability to adopt sustainability-oriented innovations and improve environmental performance. The objective was to assess whether firms with stronger knowledge acquisition and learning capabilities are better positioned to implement green management practices. Using a multi-industry sample, the researchers applied hierarchical regression to analyze how knowledge assimilation, transformation, and application affect sustainability outcomes. Results showed that organizations with higher absorptive capacity more effectively adopt environmental technologies, integrate green practices, and achieve superior environmental performance. The study emphasized the importance of internal learning mechanisms in translating environmental initiatives into operational improvements. However, the study did not consider digital transformation as a source of external knowledge, limiting its practical relevance. It also overlooked how external environmental uncertainty influences learning and sustainability adoption.

III. THEORETICAL FOUNDATION AND HYPOTHESES DEVELOPMENT

The theoretical foundation integrates Resource-Based View, Data Empowerment Theory, and Contingency Theory to explain how digital transformation, absorptive capacity, and economic policy uncertainty influence green supply chain integration and performance toward green management.

A. *Theoretical foundation*

The proposed study draws on three complementary theoretical perspectives to develop its conceptual framework:

- **Resource-Based View (RBV):** The RBV is one of the most prominent managerial frameworks for identifying strategic resources organizations need for sustainable competitive advantage. This framework focuses on organizational internal resources like managerial ability, technological capabilities, brand reputation, and tacit knowledge. The RBV aids managers in understanding the needs of developing resources, allocating resources based on demand, enabling data-driven decision-making processes,

leveraging talent, and maximizing organizational performance. In this study, digital transformation capabilities and absorptive capacity represent strategic resources that can enhance green supply chain performance (Saleem, et al., 2022).

- **Data Empowerment Theory:** Data empowerment enhances green supply chain performance through data collection and analysis processes leading to efficient operations. Big data analytics, incorporating technology and organizational support, generates insights for improving supply chain efficiency. In the digital world, green supply chain performance management is transforming with innovative practices involving various emerging technologies that enable real-time environmental monitoring, predictive analytics for resource optimization, and transparent information flows supporting circular economy models (Shahzad, 2020).
- **Contingency Theory:** Contingency theory suggests that management success depends on specific firm circumstances, including economic policy uncertainty, which could impact organizational structure, effectiveness, and innovativeness. Organizations may experience various challenges, including resource constraints, requiring contingency planning. The contingency theory provides the foundation for understanding how absorptive capacity and economic policy uncertainty serve as contingent factors shaping the effectiveness of digital transformation and green supply chain integration initiatives (Afnan, 2020).

B. Hypotheses development

Digital Transformation and Green Supply Chain Performance: Digital transformation technologies can enhance GSCM performance through several mechanisms. First, advancements in supply chain management can enhance the efficiency of green supply chains by prioritizing innovations in green technologies, reducing transaction costs, and alleviating financial constraints that help achieve green management. For instance, big data analytics can optimize resource allocation and logistics planning, while AI can automate processes and minimize waste generation.

Second, digital transformation enables comprehensive environmental monitoring and reporting. IoT sensors provide real-time data on energy consumption, emissions, and resource usage across the supply chain. Cloud platforms facilitate information sharing among partners, while analytics transform raw data into actionable environmental insights. These capabilities enable organizations to identify environmental hotspots, optimize processes, reduce waste, and demonstrate compliance with sustainability standards (Rasheed et al., 2022).

Third, digital technologies support circular economy practices by enabling product tracking throughout lifecycles, facilitating reverse logistics for product recovery, and optimizing material reuse and recycling processes. Blockchain can create transparent records of materials and products, supporting verification of recycled content and enabling circular business models.

Based on previous literature demonstrating positive relationships between digital capabilities and environmental outcomes, this study hypothesizes:

Mediating Role of Green Supply Chain Integration: Green supply chain integration encompasses collaboration with environmentally responsible suppliers, cross-functional cooperation for environmental improvements, communication of environmental issues among departments, and accumulation and sharing of environmental knowledge across organizational boundaries. Extensive studies underline the favorable impact of green supply chain integration on both environmental and cost performance, showing that green customer integration promotes environmental performance improvements through green development innovation which could accelerate green management (Qasim, 2021).

Digital transformation enhances green supply chain integration by establishing secure data exchange networks that facilitate collaboration and knowledge transmission among supply chain partners. Technologies such as blockchain enable transparent information sharing about environmental practices, IoT provides real-time visibility into partner operations, and cloud platforms support collaborative

environmental planning and execution. This enhanced integration enables organizations to coordinate green practices more effectively across the supply network (Jameel et al., n.d.).

Green supply chain integration, in turn, translates into improved environmental performance. Firms with robust integration can leverage coordinated efforts to implement environmental audits, set collective sustainability goals, share best practices, and optimize end-to-end environmental impact. The integration facilitates the seamless incorporation of digital technologies with current green supply chain processes, enhancing operational efficiency and environmental sustainability.

Moderating Role of Absorptive Capacity: Absorptive capacity, grounded in resource-based theory, highlights a firm's competitive advantage derived from its unique capability to acquire, assimilate, transform, and exploit external knowledge. Within supply chain management studies, absorptive capacity plays an essential role in achieving business excellence. Firms with high absorptive capacity exhibit the capability to integrate knowledge from external partners effectively, fostering innovation and enhancing performance.

The successful implementation of digital transformation initiatives requires specific organizational capabilities, among which absorptive capacity stands out prominently. Organizations with strong absorptive capacity are better positioned to understand emerging digital technologies, learn from implementation experiences, adapt technologies to their specific contexts, and integrate digital capabilities with existing green supply chain processes.

Despite the significant potential of digital transformation to enhance supply chain integration, firms often encounter challenges in supply chain transformation due to constraints in knowledge and capabilities. Organizations with low absorptive capacity may struggle to effectively utilize digital technologies for green purposes, failing to extract full value from digital investments. Conversely, firms with high absorptive capacity can more effectively leverage digital tools to enhance supplier collaboration, optimize environmental processes, and accelerate green innovation (Adnan et al., 2022).

Direct Effect of Green Supply Chain Integration on Performance: Green supply chain integration encompasses collaboration with suppliers to set environmental goals, implementation of environmental audits, cross-functional cooperation for environmental improvements, communication of environmental issues among departments, and accumulation and sharing of environmental knowledge. These integrated practices enable organizations to coordinate environmental initiatives across organizational boundaries, resulting in improved environmental outcomes (Ahmed, 2020).

Previous research has demonstrated positive contributions of green supply chain integration activities to sustainable performance across various industries. Integration facilitates the identification of environmental hotspots throughout the supply chain, enables coordinated improvement efforts, supports the diffusion of environmental innovations, and enhances overall environmental accountability. Firms with robust green supply chain integration can leverage digital technologies for improved monitoring, optimization, and reporting of environmental performance.

Moderating Role of Economic Policy Uncertainty: Economic policy uncertainty, grounded in contingency theory, represents a critical environmental contingency that organizations must navigate. EPU introduces ambiguity and risk into the business landscape through uncertainty in government support for green technologies, fluctuations in taxation policies, changes in trade policies, and ambiguity in environmental regulations. These uncertainties can affect organizational resource allocation decisions, strategic planning horizons, and willingness to invest in long-term environmental initiatives (Muhammad, 2024).

In the context of supply chain management, EPU forms a specific environment that can impact the efficacy of green supply chain integration practices. Firms with globalized supply chains are particularly susceptible to policy uncertainty and may adjust their supplier networks, investment strategies, and environmental initiatives in response to perceived policy risks. Disruptions in supply chains and resource availability due to economic policy uncertainty could hinder the translation of green supply chain integration efforts into performance improvements.

However, the precise nature of this moderating effect is theoretically ambiguous. On one hand, high EPU might weaken the integration-performance relationship by creating resource constraints, shortening

strategic planning horizons, and increasing the perceived risk of environmental investments. On the other hand, firms with strong green supply chain integration may have already developed robust, flexible practices that enable them to maintain performance despite external uncertainties. The resilience and adaptability of environmentally conscious businesses in response to external disruptions may buffer against EPU effects.

C. Conceptual Framework

The integrated conceptual framework positions digital transformation as a key antecedent to green supply chain performance, operating both directly and indirectly through green supply chain integration as a mediating mechanism illustrated in figure 1. Absorptive capacity moderates the effectiveness of digital transformation in achieving green supply chain integration, while economic policy uncertainty serves as an environmental contingency potentially affecting the translation of integration into performance outcomes. This framework integrates insights from resource-based theory (absorptive capacity as a strategic capability), data empowerment theory (digital transformation enabling environmental optimization), and contingency theory (economic policy uncertainty as an environmental contingency). Control Variables (Firm Age, Size, and Type) are connected to the core constructs to account for their potential influence. The entire framework is grounded in Theoretical Foundations, including the Resource-Based View and Contingency Theory.

IV. PROPOSED TOPOLOGICAL MODEL

The study employs a quantitative research design utilizing cross-sectional survey data to examine the relationships among digital transformation, green supply chain integration, absorptive capacity, economic policy uncertainty, and green supply chain performance. The quantitative approach is appropriate for testing the hypothesized relationships in the conceptual framework and enables statistical generalization of findings.

A. Sampling and data collection

The study gathers empirical data through a survey from key stakeholders and IT professionals in India, a context characterized by both rapid digital transformation and growing environmental consciousness. Convenience sampling was adopted due to its simplicity, lower cost, and rapidity. While convenience sampling is a non-probabilistic method with limitations regarding generalizability, it is appropriate for this preliminary research examining emerging phenomena where comprehensive sampling frames are unavailable.

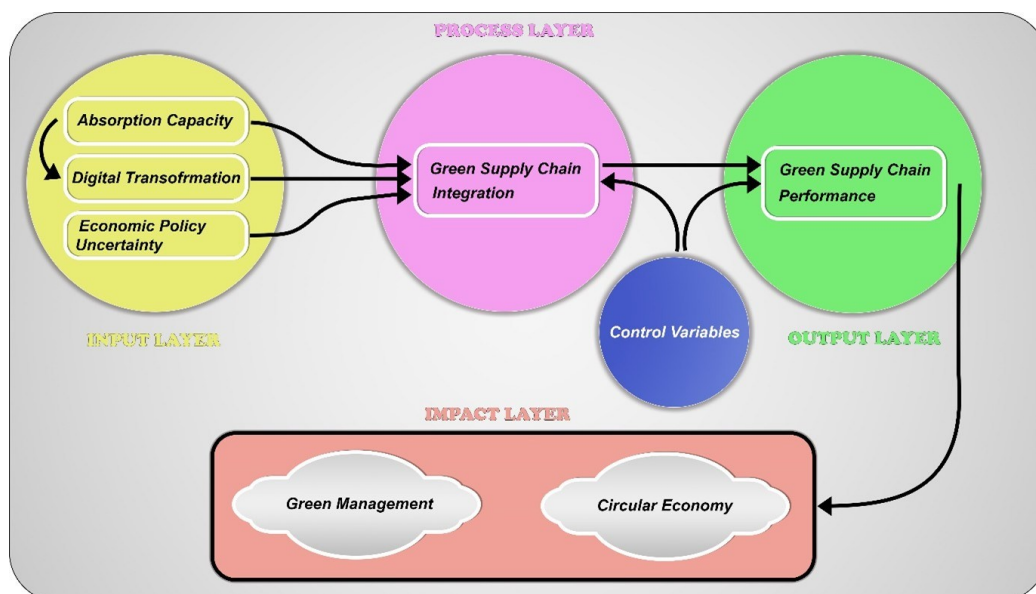


Figure 1: Topological interaction model linking digital transformation to green supply chain capabilities

To address common method bias concerns, the data collection process was conducted in two stages. Initially, managers were asked to share responses about their firms' involvement in digital transformation in green supply chains and provided demographic information. One month later, the same participants were surveyed about absorptive capacity and economic policy uncertainty. Both phases were conducted through online questionnaires to ensure confidentiality and improve response reliability.

The survey was conducted from January 15 to March 25, 2024. A total of 350 participants from Indian IT firms participated in the survey. After reviewing for missing data and outliers, 310 valid questionnaires were analyzed. The remaining 40 responses were excluded due to being completely vacant or containing multiple responses to single items.

B. Demographic profile

The demographic profile of the 310 respondents reveals:

- Gender: 63% male (195), 37% female (115)
- Education: 56% graduate degree (175), 34% post-graduate degree (105), 10% doctorate (30)
- Age: 43% under 30 years (133), 47% between 30-45 years (147), 10% over 45 years (30)
- Organizational Hierarchy: 29% senior managers (89), 58% managers (180), 13% business development officers (41)

This distribution indicates good representation across organizational levels, with managers forming the core respondent group, and balanced representation across age categories, ensuring diverse perspectives on digital transformation and green supply chain practices.

C. Measurement instruments

The questionnaire was constructed to ensure language accuracy and demographic relevance. All scale items were evaluated using a five-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree). A five-point Likert scale was chosen for its simplicity and because it provides respondents with a neutral option (neither disagree nor agree). The items were specifically designed based on established literature, with the complete set of questions provided in the Appendix.

- Digital Transformation was measured through five items adapted from (Zuhair et al., 2023), and. The survey items focused on integration and adoption of digital technologies within the organization, including: driving new business processes built on digital technologies (big data, analytics, cloud, mobile, social media), integrating digital technologies to drive change, shifting business operations toward digital technologies, pursuing IT for real-time tracking, and pursuing continuous innovation in core global supply chain processes.
- Absorptive Capacity was measured using five scale items adapted from (Kashi et al., 2025). The items focused on: capturing information from suppliers, capturing customer information, development of knowledge management programs, using ICT to improve knowledge flows, and ability to use and exploit new knowledge.
- Economic Policy Uncertainty was assessed through five scale items inspired by (Nasir et al., 2024). These items included statements about: variation in government support for green technologies over time, impact of fluctuations in taxation policies on green supply chain management, effects of economic policy changes on green supply chain operations, complications from trade policy uncertainty for green supply chain strategies, and effects of ambiguity in environmental policies on green supply chain planning.
- Green Supply Chain Integration was measured using five scale items adapted from (Ashraf & Aslam, 2023). These items focused on: collaborating with suppliers to set up environmental goals, implementing environmental audits for suppliers' internal management, cross-functional cooperation for

environmental improvements, communication of environmental issues among departments, and accumulation and sharing of environmental knowledge across departments.

- Green Supply Chain Performance was assessed through five scale items taken from (A. Arfeen, A. Khan, & Ahmed, 2020). These items included statements about: efforts to reduce raw material costs aligned with environmental sustainability goals, minimizing the carbon footprint of products, implementing measures to reduce defects and waste, designing supply chain operations to be flexible and adaptable to environmental changes, and organizational commitment to achieving cost savings while promoting environmental sustainability in supply chain management practices.

D. *Analytical approach*

The study utilized Partial Least Squares Structural Equation Modeling (PLS-SEM) (Tahir, et al., 2020), to evaluate the measurement instruments and test the theoretical framework. PLS-SEM is well-suited for analyzing relationships among latent variables and offers enhanced predictive outcomes compared to covariance-based methods. It facilitates examination of complex cause-and-effect models, reduces bias in parameter estimation, and supports mediation-moderation analyses.

The analysis proceeded in two stages. First, the measurement model was evaluated to assess reliability and validity of the constructs. Second, the structural model was examined to test the hypothesized relationships. Model fit was assessed using multiple criteria including R^2 values, Normed Fit Index (NFI) (Ahmed, 2020), and Standardized Root Mean Residual (SRMR) (Shahzad & Tauqeer, 2020).

V. RESULTS

To address common method bias (CMB) (Afnan, et al., 2020), concerns inherent in single-source survey research, multiple procedural and statistical remedies were implemented. Procedurally, the data collection employed temporal separation, with digital transformation and demographic variables measured in the initial wave (January 2024) and absorptive capacity and economic policy uncertainty measured one month later (February 2024). Respondent anonymity was assured throughout to reduce evaluation apprehension and social desirability biases.

Statistically, Harman's Single Factor Test revealed that no single factor accounted for the majority of variance (largest factor = 34.7% of total variance), well below the 50% threshold indicating problematic CMB. Additionally, the marker variable technique following Lindell and Whitney (2001) showed correlations between substantive variables remained significant after adjusting for the marker variable, confirming that CMB does not substantially threaten result validity.

Collinearity diagnostics using Variance Inflation Factor (VIF) (Raza , 2019), analysis showed all values ranged from 1.21 to 2.84, substantially below the conservative threshold of 3.3, indicating absence of multicollinearity that could inflate standard errors or bias coefficient estimates.

A. *Descriptive statistics and preliminary correlations*

As shown in Table 1, the correlation matrix reveals expected positive associations among key constructs. Digital transformation correlates significantly with both green supply chain integration ($r = .256$, $p < .01$) and performance ($r = .485$, $p < .01$), providing preliminary support for hypothesized relationships. Green supply chain integration shows strong positive correlation with performance ($r = .419$, $p < .01$), suggesting potential mediation pathways. Mean scores ranging from 3.62 to 3.88 on five-point scales indicate moderate-to-high levels of construct presence across the sample.

Table 1: Descriptive statistics and correlation matrix (N=310)

Variable	M	SD	1	2	3	4	5
Digital Transformation (DT)	3.62	0.74	-				
Green Supply Chain Integration (GSCI)	3.81	0.67	0.256	-			
Green Supply Chain Performance (GSCP)	3.79	0.71	0.485	0.419	-		
Absorptive Capacity (AC)	3.88	0.76	0.168	0.227	0.334	-	
Economic Policy Uncertainty (EPU)	3.74	0.69	0.253	0.288	0.371	0.284	-

B. Measurement model assessment

Table 2, presents the reliability and convergent validity assessment results. All constructs demonstrate excellent reliability, with Cronbach's alpha values exceeding 0.88 and composite reliability values surpassing 0.91, both well above the 0.70 threshold. Average Variance Extracted (AVE) (Naeem, et al., 2020), values range from 0.678 to 0.738, all exceeding the 0.50 criterion, confirming adequate convergent validity. Individual item factor loadings range from 0.789 to 0.892, all exceeding the 0.70 benchmark for established scales.

Table 2: Reliability and convergent validity assessment

Construct	Items	Cronbach's α	Composite Reliability (CR)	Average Variance Extracted (AVE)	Factor Loadings Range
Digital Transformation	5	0.912	0.934	0.738	0.821 - 0.889
Green Supply Chain Integration	5	0.886	0.916	0.687	0.798 - 0.862
Green Supply Chain Performance	5	0.893	0.921	0.699	0.807 - 0.871
Absorptive Capacity	5	0.907	0.931	0.729	0.816 - 0.892
Economic Policy Uncertainty	5	0.881	0.913	0.678	0.789 - 0.856

Discriminant validity assessment using the Heterotrait-Monotrait (HTMT) ratio (Muhammad, et al., 2020), is presented in Table 3. All HTMT values fall below 0.85, with the highest being 0.542 (DT-GSCP), confirming that constructs are empirically distinct. This ensures that each construct captures unique variance rather than overlapping with other constructs.

Table 3: Discriminant validity assessment (heterotrait-monotrait ratio)

	DT	GSCI	GSCP	AC	EPU
DT	-				
GSCI	0.284	-			
GSCP	0.542	0.479	-		
AC	0.186	0.257	0.371	-	
EPU	0.287	0.326	0.421	0.318	-

C. Structural model results

The structural model was assessed using PLS-SEM with bootstrapping (5,000 resamples, 95% bias-corrected confidence intervals) to test hypothesized relationships. Table 4 presents the complete structural path analysis results, including direct effects, mediation effects, and moderation effects. As shown in Table

4, the model quality indices demonstrate acceptable to excellent fit. The structural model explains 12.7% of variance in green supply chain integration and 39.6% of variance in green supply chain performance. Positive Stone-Geisser Q^2 values (GSCI: 0.079; GSCP: 0.264) confirm predictive relevance beyond sample-specific explanation. Overall model fit indices SRMR (0.049) and NFI (0.853) indicate acceptable-to-excellent fit, validating that the theoretical model adequately represents empirical relationships.

Table 4: Structural path analysis results

Hypothesis	Path	β	SE	t-value	p-value	95% CI	Decision
H1	DT $\rightarrow$ GSCP	0.3870.048		8.063	<.001	[0.293, 0.481]	Supported
H2 (Mediation)	DT $\rightarrow$ GSCI $\rightarrow$ GSCP	0.0640.021		3.048	.002	[0.023, 0.105]	Supported
H3 (Moderation)	AC $\times$ DT $\rightarrow$ GSCI	0.1240.055		2.255	.024	[0.016, 0.232]	Supported
H4	GSCI $\rightarrow$ GSCP	0.2810.052		5.404	<.001	[0.179, 0.383]	Supported
H5 (Moderation)	EPU $\times$ GSCI $\rightarrow$ GSCP	0.0080.051		0.157	.875	[-0.108, 0.092]	Not Supported

Supporting Paths:

Path	β	p-value
DT $\rightarrow$ GSCI	0.239	<.001
AC $\rightarrow$ GSCI	0.204	.001
EPU $\rightarrow$ GSCP	0.192	<.001

Model Quality Indices:

Metric	GSCI	GSCP	Benchmark
R^2	0.127	0.396	Acceptable
Adjusted R^2	0.113	0.382	Acceptable
Q^2 (Stone-Geisser)	0.079	0.264	Predictive relevance confirmed
SRMR	-	0.049	<0.08 (Excellent)
NFI	-	0.853	>0.80 (Acceptable)

D. Hypothesis testing outcomes

H1: Digital Transformation $\rightarrow$ Green Supply Chain Performance ($\beta = 0.387$, $p < .001$)

As indicated in Table 4, the analysis strongly supports H1, revealing that digital transformation exerts substantial positive influence on green supply chain performance. The large effect size and narrow confidence interval [0.293, 0.481] indicate a robust relationship. This finding demonstrates that organizations investing in digital technologies IoT monitoring, big data analytics, cloud platforms, and AI automation achieve significant environmental performance improvements including waste reduction, energy efficiency, emissions minimization, and enhanced regulatory compliance. These results validate digital transformation as a critical enabler of green management practices.

H2: Mediation Effect (Indirect effect $\beta = 0.064$, $p = .002$)

Table 4 shows that the mediation analysis confirms green supply chain integration partially mediates the digital transformation-performance relationship. The significant indirect effect (95% CI [0.023, 0.105] excludes zero) demonstrates that digital transformation enhances performance not only directly but also through strengthened supply chain collaboration. The total effect of digital transformation on performance is 0.451 (0.387 direct + 0.064 indirect), with approximately 14.2% operating through the integration pathway. This partial mediation indicates that digital transformation operates through dual mechanisms: direct process optimization and integration-enabled collaboration, both essential for comprehensive green management.

H3: Absorptive Capacity Moderation ($\beta = 0.124$, $p = .024$)

As presented in Table 4, Hypothesis 3 receives empirical support. Absorptive capacity significantly strengthens the relationship between digital transformation and green supply chain integration, with a confidence interval [0.016, 0.232] that excludes zero. Simple slope analysis reveals that at high absorptive capacity levels (+1SD), the DT-GSCI relationship ($\beta = 0.332$) is substantially stronger than at low absorptive capacity levels (-1SD, $\beta = 0.146$), representing a 127% difference. Organizations with superior knowledge acquisition, assimilation, and exploitation capabilities extract significantly greater supply chain integration benefits from digital investments. This moderation highlights that technology effectiveness depends critically on organizational learning capabilities, which are fundamental for successful green management implementation.

H4: Green Supply Chain Integration $\rightarrow$ Performance ($\beta = 0.281$, $p < .001$)

Table 4 demonstrates strong support for H4. Green supply chain integration encompassing supplier collaboration, environmental auditing, cross-functional coordination, and knowledge sharing significantly enhances environmental performance with a confidence interval [0.179, 0.383]. Organizations implementing comprehensive integration practices achieve superior outcomes in emissions reduction, waste minimization, resource efficiency, and sustainability goal attainment. The medium-to-large effect size underscores integration's strategic importance for environmental outcomes and effective green management across supply chain networks.

H5: Economic Policy Uncertainty Moderation ($\beta = -0.008$, $p = .875$)

Contrary to contingency theory predictions, Table 4 shows that H5 is not supported. Economic policy uncertainty does not moderate the integration-performance relationship, with a confidence interval [-0.108, 0.092] that includes zero. Simple slope analysis confirms nearly identical GSCI-GSCP relationships across low ($\beta = 0.287$), medium ($\beta = 0.281$), and high ($\beta = 0.275$) EPU levels. While EPU shows significant main effects on performance ($\beta = 0.192$, $p < .001$), as indicated in the supporting paths section of Table 4, it does not condition how effectively integration translates into outcomes. This suggests that well-designed green supply chain integration maintains effectiveness despite external policy volatility, challenging assumptions about environmental contingencies weakening practice effectiveness in green management initiatives.

E. Model explanatory power and fit

As displayed in the model quality indices section of Table 4, the structural model explains 12.7% of variance in green supply chain integration ($R^2 = 0.127$) and 39.6% of variance in green supply chain performance ($R^2 = 0.396$). While GSCI's R^2 appears modest, it represents reasonable explanation given that integration depends on numerous factors beyond the model's scope organizational culture, industry norms, regulatory pressures, and competitive dynamics. The GSCP R^2 of 0.396 indicates substantial explanatory power, with the model accounting for nearly 40% of performance variation.

Positive Stone-Geisser Q^2 values (GSCI: 0.079; GSCP: 0.264) confirm predictive relevance beyond sample-specific explanation. The model demonstrates not only explanatory fit but also predictive validity for new observations. Overall model fit indices SRMR (0.049) and NFI (0.853) indicate acceptable-to-excellent fit, validating that the theoretical model adequately represents empirical relationships. Table 5, provides a comprehensive summary of all hypothesis testing results, consolidating the findings and facilitating interpretation of the overall model performance.

Table 5: Summary of hypothesis testing

Hypothesis	Prediction	Result	Effect Interpretation
H1	DT $\rightarrow$ GSCP (+)	Supported ($\beta=.387$)	Strong direct effect
H2	DT $\rightarrow$ GSCI $\rightarrow$ GSCP	Supported ($\beta=.064$)	Partial mediation
H3	AC moderates DT $\rightarrow$ GSCI	Supported ($\beta=.124$)	Positive moderation
H4	GSCI $\rightarrow$ GSCP (+)	Supported ($\beta=.281$)	Strong effect

Table 5: Summary of hypothesis testing

Hypothesis	Prediction	Result	Effect Interpretation
H5	EPU moderates GSCI → GSCP	Not Supported ($\beta = -.008ns$)	No moderation

VI. DISCUSSION

A. *Digital transformation as environmental performance driver*

The substantial direct effect shown in Table 4 ($\beta = 0.387$, $p < .001$) positions digital transformation as a fundamental enabler of environmental sustainability rather than a peripheral enhancement. This finding advances prior research by demonstrating that digital technologies create transformative capabilities for green management through three primary mechanisms.

First, visibility creation through IoT sensors and cloud monitoring systems provides unprecedented real-time transparency into environmental impacts across complex supply networks. This enables precise identification of resource inefficiencies, emissions hotspots, and waste generation points that traditional systems cannot capture. Organizations can now monitor energy consumption patterns, track water usage across facilities, measure emissions at granular levels, and identify circular economy opportunities with data-driven precision fundamental requirements for effective green management.

Second, optimization intelligence through big data analytics and artificial intelligence transforms vast environmental datasets into actionable insights. Predictive algorithms optimize logistics routes to minimize fuel consumption, forecast demand patterns to reduce overproduction waste, schedule operations to leverage renewable energy availability, and identify material reuse opportunities that were previously uneconomical. These optimization capabilities enable organizations to systematically improve environmental performance while maintaining operational efficiency a critical balance in green management.

Third, collaboration enablement through digital platforms reduces transaction costs of coordinating environmental initiatives across organizational boundaries. Blockchain creates transparent, immutable environmental records building trust among partners. Cloud systems enable real-time data sharing supporting joint decision-making. Collaborative planning platforms facilitate coordinated environmental goal-setting and progress monitoring. These digital infrastructure investments fundamentally enable the integrated green management approaches that deliver superior environmental outcomes.

The magnitude of this effect, as evidenced in Tables 4 and 5, challenges perspectives viewing digital transformation and environmental sustainability as separate strategic initiatives. Instead, findings suggest these represent increasingly inseparable elements of contemporary competitive strategy. Organizations pursuing environmental leadership without digital capabilities, or digital transformation without green management focus, forego significant synergistic opportunities. This convergence carries particular implications for achieving ambitious environmental goals including emissions reduction, circular economy adoption, and comprehensive sustainability performance across supply chains.

B. *Integration as strategic mediation mechanism*

The significant mediation effect documented in Table 4 ($\beta = 0.064$, $p = .002$, representing 14.2% of total effects) illuminates a previously underexplored mechanism: digital transformation enhances environmental performance partially by strengthening collaborative green management practices across organizational boundaries. This finding addresses a critical gap by clarifying the "black box" between digital inputs and environmental outputs.

Previous research acknowledged digital technologies' potential for green management improvement but often treated relationships as direct or mechanistically simple. The mediation finding revealed in Table 4 demonstrates more nuanced processes wherein digital technologies first enable enhanced collaboration, coordination, and knowledge sharing across supply chain partners ($DT \rightarrow GSCI$, $\beta = 0.239$, $p < .001$), which

subsequently translates into superior environmental outcomes ($GSCI \rightarrow GSCP$, $\beta = 0.281$, $p < .001$). Organizations deploying digital technologies create information infrastructures that facilitate supplier environmental data sharing, coordinate joint sustainability initiatives, enable distributed environmental knowledge management, and support collaborative green innovation all essential components of effective green management systems.

The partial mediation pattern shown in Table 5 where both direct (86%) and mediated (14%) pathways achieve significance indicates that digital transformation operates through complementary mechanisms simultaneously. Direct effects capture process-level efficiencies and resource optimizations enabled by technology within organizational boundaries. Mediated effects through integration capture collaborative and systemic improvements emerging from cross-organizational coordination. This multiplicity suggests comprehensive digital transformation strategies for green management should address both internal optimization and external integration dimensions.

While integration-mediated effects represent a smaller proportion of total impact as shown in the correlation analysis in Table 1, they may constitute harder-to-imitate capabilities providing more sustainable competitive advantages. Competitors can potentially replicate internal process optimizations through technology adoption, but collaborative relationships, shared knowledge systems, and coordinated capabilities embedded in supply chain integration represent relationship-specific investments that are inherently difficult to duplicate. These integration capabilities may provide more durable foundations for green management excellence.

C. *Absorptive capacity as critical contingency*

The significant positive moderation by absorptive capacity presented in Table 4 ($\beta = 0.124$, $p = .024$) empirically validates capability-based theories of digital transformation effectiveness for green management. This finding challenges technology-deterministic perspectives assuming uniform benefits regardless of organizational context, instead demonstrating that organizational learning capabilities critically shape technology outcomes. The simple slopes analysis reveals that high absorptive capacity organizations experience effects more than twice as strong as low absorptive capacity organizations (0.332 vs. 0.146), illuminating substantial heterogeneity in digital transformation outcomes for green management. This explains why organizations making similar digital investments achieve dramatically different environmental results variation stems not from technology differences but from organizational capacity to effectively leverage technologies for green management purposes.

As indicated by the supporting paths in Table 4, organizations with strong absorptive capacity more effectively identify and acquire knowledge about emerging digital technologies and green management practices ($AC \rightarrow GSCI$, $\beta = 0.204$, $p = .001$), understand how technologies address specific environmental challenges within their contexts, adapt generic technologies to particular green management applications, and continuously refine implementations based on experience. These capabilities enable organizations to extract maximum environmental value from digital investments, translating technological potential into actual green management improvements.

The main effect of absorptive capacity on integration documented in Table 4 ($\beta = 0.204$) reinforces that learning capabilities directly contribute to environmental collaboration beyond their moderating role. As shown in the correlation matrix in Table 1, absorptive capacity demonstrates significant positive associations with all other constructs (r ranging from .168 to .334), suggesting organizations with strong absorptive capacity appear predisposed toward collaborative green management approaches, viewing external partners as valuable knowledge sources and actively seeking integration opportunities that enhance collective environmental performance.

This finding carries critical implications for green management implementation strategies. Technology acquisition represents necessary but insufficient conditions for success, as demonstrated by the moderation effect in Table 5. Organizations must simultaneously invest in developing absorptive capacity through employee training in both digital and environmental domains, knowledge management systems capturing

and diffusing learning, cross-functional teams integrating diverse expertise, cultures valuing experimentation and learning, and external partnerships providing access to cutting-edge green management knowledge.

D. *Robustness despite policy uncertainty*

The null moderation effect of economic policy uncertainty shown in Table 4 ($\beta = -0.008$, $p = .875$) represents an unexpected but theoretically important finding challenging straightforward contingency theory applications to green management. While EPU demonstrates significant main effects on environmental performance documented in the supporting paths of Table 4 ($\beta = 0.192$, $p < .001$) indicating policy volatility directly affects outcomes it does not moderate how effectively green supply chain integration translates into performance, as evidenced by the wide confidence interval $[-0.108, 0.092]$ that includes zero.

This pattern, clearly illustrated in Table 5 where H5 is marked as not supported, suggests well-designed green supply chain integration practices embedding collaboration, flexibility, knowledge sharing, and mutual adaptation may inherently possess resilience against environmental uncertainties. The correlation analysis in Table 1 shows that while EPU correlates significantly with performance ($r = .371$, $p < .01$), this relationship operates independently of the integration mechanism rather than conditioning it.

Additionally, green supply chain integration may represent strategic commitments reflecting long-term competitive positioning rather than tactical responses to immediate policy environments. Organizations increasingly view environmental sustainability as non-discretionary due to multiple stakeholder pressures investors demanding ESG performance, customers expecting sustainable products, employees seeking purposeful organizations, and communities monitoring environmental impacts. These diverse pressures maintain commitment to green management practices even when specific policies fluctuate, reducing policy dependence.

The significant main effect alongside null moderation, as documented across Tables 4 and 5, suggests policy volatility affects all organizations' environmental performance similarly creating resource constraints, risk perceptions, or planning difficulties but does not differentially affect how effectively integrated practices translate into green management results. This indicates policy uncertainty operates as an independent challenge rather than a conditional factor shaping practice-performance relationships.

E. *Implications for Green Management Practice*

These findings, comprehensively summarized in Table 5 with four of five hypotheses supported, carry several important implications for organizations pursuing comprehensive green management:

- **Strategic Integration Imperative:** The substantial direct effects documented in Table 4 ($\beta = 0.387$) demonstrate that digital and green management strategies should not be managed separately but as integrated strategic initiatives. The high correlation between digital transformation and performance shown in Table 1 ($r = .485$) further reinforces this integration imperative. Organizations should establish unified governance structures, align investment decisions across digital and environmental domains, develop integrated performance metrics, and communicate synergies clearly to stakeholders.
- **Capability Development Priority:** The absorptive capacity moderation revealed in Tables 4 and 5 ($\beta = 0.124$) emphasizes that technology alone is insufficient. The measurement model in Table 2 shows absorptive capacity demonstrates excellent internal consistency ($\alpha = 0.907$, $CR = 0.931$), confirming it as a reliable construct requiring systematic development. Organizations must invest in learning capabilities through training programs, knowledge management systems, cross-functional collaboration mechanisms, and cultures valuing continuous improvement to extract maximum green management benefits from digital investments.
- **Collaboration Emphasis:** The significant mediation through integration shown in Table 4 ($\beta = 0.064$) indicates that maximizing green management outcomes requires leveraging digital technologies to deepen supplier collaboration. The discriminant validity results in Table 3 confirm that green supply chain

integration represents a distinct construct from digital transformation (HTMT = 0.284), suggesting collaboration represents a separate strategic dimension requiring explicit attention.

- Long-term Commitment: The null EPU moderation documented in Tables 4 and 5 suggests organizations should maintain strategic commitment to green management despite policy uncertainties, viewing environmental sustainability as fundamental competitive positioning rather than policy-contingent tactics. Building flexible, collaborative practices enables resilience against policy volatility while delivering sustained environmental improvements.

These integrated implications, supported by the comprehensive empirical evidence across Tables 1-5, suggest that effective green management in the digital age requires simultaneous attention to technological infrastructure, organizational capabilities, collaborative relationships, and strategic commitment a holistic approach transcending traditional functional boundaries and short-term tactical thinking.

CONCLUSION

Based on the findings of this study, it is concluded that digital transformation acts as a pivotal driver for enhancing green supply chain management (GSCM) and environmental performance by enabling direct process optimizations and fostering greater supply chain integration, which in turn mediates this relationship. The effectiveness of this digital transformation is significantly amplified by an organization's absorptive capacity, highlighting that technological investments must be coupled with strong internal learning capabilities to yield maximum benefits. While economic policy uncertainty directly impacts performance, it does not weaken the critical link between integration and outcomes, suggesting that robust, collaborative green practices possess inherent resilience to external volatility. For future research, it is recommended to validate these relationships across diverse industrial and national contexts, employ longitudinal designs to capture dynamic effects, and investigate the specific roles of individual technologies like AI and blockchain. Further exploration of other potential moderators, such as organizational culture, leadership styles, and supply network structures, would also provide a more nuanced understanding of the contingencies influencing sustainable performance in the digital era.

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Okvir za zeleno upravljanje dobavne verige za trajnostno delovanje organizacij in odličnost na področju zelenega upravljanja

Izvleček – Okoljska trajnost je postala osrednja strateška prednostna naloga za organizacije, ki si prizadevajo za dolgoročno konkurenčnost. Zeleno upravljanje oskrbovalne verige (GSCM) se je uveljavilo kot ključni steber tega prehoda, vendar se številna podjetja še vedno spopadajo z izzivi pri uvajanju okoljskih praks, merjenju uspešnosti ter usklajevanju trajnosti z gospodarsko rastjo. Hkrati pa hitri napredek v tehnologijah digitalne transformacije, vključno z internetom stvari (IoT), oblračnimi sistemi, analitiko velikih podatkov in inteligentno avtomatizacijo, preoblikuje možnosti za preglednost oskrbovalne verige, učinkovitost virov, sprejemanje krožnega gospodarstva in zeleno upravljanje. Ta članek združuje temeljna načela GSCM s transformativnim potencialom digitalnih tehnologij, podprtimi z ugotovitvami iz primerov iz industrije. Študija razširja konceptualni obseg tradicionalnega zelenega upravljanja oskrbovalne verige (GSCM) z vključitvijo digitalne transformacije, integracije zelene dobavne verige, absorpcijske zmogljivosti in negotovosti gospodarske politike kot strateških spremenljivk, ki vplivajo na trajnostno uspešnost. Analiza poudarja, kako digitalna transformacija izboljšuje spremljanje okolja, preglednost dobaviteljev, optimizacijo procesov in celovite krožne tokove. Ugotovitve kažejo, da organizacije, ki sprejemajo zeleno integracijo in digitalizacijo, dosegajo znatno zmanjšanje emisij, odpadkov in porabe vode, hkrati pa pridobivajo operativno učinkovitost in konkurenčno prednost. Članek predlaga integriran okvir, ki združuje digitalno transformacijo in GSCM za pospešitev trajnostnih rezultatov in odpornosti oskrbovalne verige, pripravljene na prihodnost.

Ključne besede – digitalna transformacija, upravljanje zelene dobavne verige, absorpcijska zmogljivost, krožno gospodarstvo, okoljska trajnost