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Research Article

Transformational Leadership and Supply Chain Sustainability in Emerging Economies: The Serial Mediating Roles of Digital Capability and Green Innovation

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Abstract

Purpose: This study explores how transformational leadership drives supply chain sustainability through the sequential mediators of digital capability and green innovation among manufacturing SMEs in an emerging economy. It introduces Digital Green Orchestration Capability as a meta capability linking digital transformation and environmental performance.

Design/Methodology: Using survey data from 332 manufacturing SMEs, the study employs Partial Least Squares Structural Equation Modeling (PLS-SEM) to test a serial mediation model grounded in Dynamic Capabilities Theory and Upper Echelons Theory.

Findings: TL exerts no direct influence on SCS but shows full serial mediation via DC and GI. DGOC effectively converts leadership vision into sustainability outcomes through digital enablement and green implementation.

Practical Implications: SME leaders should align digital transformation with sustainability strategies by investing in technological integration and eco-innovation routines.

Originality: This research pioneers DGOC as a behavioral–capability mechanism bridging leadership cognition, digital transformation, and environmental sustainability in emerging economies.

Introduction

The global manufacturing sector is undergoing rapid transformation as firms grapple simultaneously with the imperatives of digitalization and sustainability (Wagan & Sidra, 2024). In emerging economies, this dual challenge is intensified by resource scarcity, weak institutional support, and unpredictable regulatory frameworks, forcing organizations to rely heavily on leadership behavior to initiate and sustain change. Transformational leadership (TL) defined by inspirational motivation, intellectual stimulation, and individualized consideration has long been identified as a driver of adaptability, knowledge sharing, and innovation (Nurhayati, Musa, & Pusparini, 2022). However, despite abundant evidence linking TL to innovation and firm performance, scholars still lack a clear understanding of how leadership translates visionary intent into measurable sustainability outcomes, especially within small and medium-sized enterprises (SMEs) that dominate emerging economy supply chains. Most prior work has examined leadership–innovation or leadership–digitalization relationships in isolation (Pham, Pham, Truong Quang, & Dang, 2023; Yang, Dong, Guo, & Peng, 2025), treating environmental or digital outcomes as separate domains rather than interdependent processes.

This conceptual fragmentation has left open a critical question: how can leadership orchestrate digital and green transformation simultaneously to achieve supply chain sustainability (SCS)? To address this gap, the present study introduces the construct of Digital–Green Orchestration Capability (DGOC) a meta capability through which leaders synchronize digital transformation and environmental innovation to attain sustainability objectives. DGOC integrates the sensing–seizing–reconfiguring logic of Dynamic Capabilities Theory (DCT) (Kor & Mesko, 2013) with the cognitive orientation of Upper Echelons Theory (UET) (Achyar, 2024). From a DCT perspective, transformational leaders stimulate digital routines that sense environmental shifts and reconfigure processes for agility, while UET explains how the leader's digital and environmental mindset determines the direction and intensity of these routines.

This integration yields a coherent behavioral–capability framework that explains how leadership cognition is converted into operational sustainability results. Empirically, the study provides one of the first operationalizations of DGOC by testing a serial mediation model in which TL influences SCS through two sequential mediators' digital capability (DC) and green innovation (GI) representing technological enablement and environmental implementation, respectively. The model (Figure 1) captures the hierarchical process by which leadership vision triggers digital sensing and seizing (DC), which then facilitates eco-innovation (GI), culminating in sustainable supply chain outcomes (SCS). Manufacturing SMEs in emerging economies serve as an ideal empirical context for testing this model because they operate under tight resource constraints and institutional voids that magnify the influence of leadership vision (Mwansasu & Mwagike, 2025).

National programs such as the Smart Industry 2030 Roadmap and Green Manufacturing Initiative reinforce the dual pressures of digitalization and environmental performance, making this setting theoretically and practically significant. The study pursues three objectives: first, to examine how TL fosters DC and GI; second, to test whether DC and GI act as sequential mediators between TL and SCS; and third, to determine whether this mediation is full or partial, clarifying the extent to which sustainability outcomes depend on orchestrated capabilities rather than leadership alone. By addressing these aims, the research contributes to the literature in three ways. Theoretically, it extends DCT into the leadership domain by validating DGOC as a measurable mechanism linking cognition to dynamic routines. Methodologically, it applies Partial Least Squares Structural Equation Modeling (PLS SEM) to capture predictive, variance-based relationships appropriate for SME research (Hair & Alamer, 2022). Practically, it provides SME leaders with a blueprint for aligning digital transformation and environmental strategies under institutional constraints. The remainder of this paper develops the theoretical framework and hypotheses, outlines the methodology, presents the results, and discusses theoretical and managerial implications before concluding with declarations and references.

The theoretical foundation of this study integrates Dynamic Capabilities Theory (DCT) and Upper Echelons Theory (UET) to explain how leadership behavior shapes the digital and environmental transformation of organizations. DCT focuses on a firm's ability to sense, seize, and reconfigure resources in response to environmental turbulence (Ameer, 2018; Kor & Mesko, 2013). These dynamic capabilities allow organizations to sustain competitive advantage amid uncertainty. However, DCT pays limited attention to the cognitive sources of these capabilities the individuals who initiate and orchestrate them. UET fills this gap by arguing that organizational outcomes mirror managerial values, experiences, and cognitive orientations (Achyar, 2024). When combined, these perspectives yield a powerful framework: leadership acts as the behavioral micro foundation that mobilizes dynamic routines, while managerial cognition determines the direction of capability deployment. This integration is central to the proposed construct of Digital–Green Orchestration Capability (DGOC), defined here as a meta capability through which leaders coordinate digital transformation and environmental innovation to achieve sustainable supply chain outcomes.

To remove any ambiguity regarding the conceptual status of digital green orchestration capability, this study treats DGOC as a meta capability rather than an independently measured latent construct. DGOC refers to the orchestrating mechanism through which transformational leaders convert their cognitive orientation into coordinated digital and environmental routines. It is conceptually distinct from dynamic managerial capabilities, orchestration capability, and digital transformation capability because it emphasizes the simultaneous and integrated deployment of digital enablement and green innovation to achieve supply chain sustainability. Empirically, DGOC is represented through the sequential capability chain TL → DC → GI → SCS, which reflects how leadership vision is operationalized first through digital enablement and subsequently through environmental implementation. Developing DGOC as a measurable higher order construct is a theoretically promising direction and is recommended for future research but falls beyond the empirical scope of this study.

Literature Review

Transformational Leadership and Digital Capability

In SMEs where hierarchical layers are few and formal R&D units are scarce leadership behavior strongly determines how and when technology is adopted. Transformational leadership (TL) motivates employees through charisma, inspiration, and intellectual stimulation, thereby generating openness to technological change (Nurhayati et al., 2022). TL shapes an organization's Digital Capability (DC) by articulating a compelling digital vision, communicating its relevance to future competitiveness, and fostering a shared sense of purpose among employees. Digital capability refers to the firm's proficiency in deploying, integrating, and exploiting digital technologies such as enterprise resource planning systems, IoT, and analytics to improve efficiency, collaboration, and decision making (Majumdarr et al., 2025).

Transformational leaders cultivate DC through both strategic and cultural channels. Strategically, they allocate resources for digital projects, champion data driven decision processes, and prioritize system integration across functions (Eng et al., 2023; Hozhabri et al., 2014; Mobarakabadi et al., 2013). Culturally, they promote psychological safety, encouraging experimentation and tolerating early-stage errors conditions necessary for digital learning. Empirical studies demonstrate that leadership vision and communication are among the most decisive enablers of successful digital transformation (Yang et al., 2025). Within DCT, TL thus represents the sensing component that initiates capability building by recognizing technological opportunities. Hence, firms led by transformational leaders are more likely to develop stronger DC, leading to the following hypothesis:

H1: Transformational leadership positively affects digital capability.

Transformational Leadership and Green Innovation

Beyond technological transformation, transformational leaders also influence a firm's environmental orientation. Green Innovation (GI) involves creating or adapting products, processes, and technologies that minimize environmental impact while maintaining or enhancing competitiveness (Pham et al., 2023). In resource constrained SMEs, environmental initiatives often compete with short term financial objectives. TL mitigates this tension by redefining sustainability as a shared organizational value and source of differentiation rather than a cost burden (Martins & Pato, 2019). Through inspirational motivation, transformational leaders frame environmental responsibility as part of the firm's identity, while individualized consideration empowers employees to generate eco-friendly ideas (Cui et al., 2023).

From the DCT lens, GI is a higher order implementation capability that operationalizes learning and knowledge into tangible environmental performance (Korir & Tenai, 2020). Leaders who provide intellectual stimulation challenge employees to rethink resource use and production processes, thereby fostering continuous improvement and eco-efficiency. Empirical research shows that leadership commitment and employee empowerment are strong predictors of environmental innovation success in SMEs (Singh et al., 2020). Consequently, transformational leadership is expected to strengthen the firm's capacity for green innovation.

H2: Transformational leadership positively affects green innovation.

Digital Capability and Green Innovation

Digital capability acts as a bridge between technology adoption and environmental innovation. Firms that master data integration and analytics can identify inefficiencies, monitor emissions, and model the environmental impact of production processes (Del Giudice & Della Peruta, 2016). Such insight enables proactive eco-design, predictive maintenance, and circular economy initiatives. Advanced DC supports the collection and analysis of sustainability data across supply chain partners, allowing evidence-based decision making in materials sourcing, logistics, and waste management (Cheng et al., 2024).

Within the DCT hierarchy, DC functions as an enabling capability that underpins GI by providing the infrastructure for experimentation and collaboration. When digital platforms improve transparency and traceability, firms gain the information required to redesign processes for eco-efficiency. For instance, real time sensor data can reveal energy consumption peaks, while simulation tools evaluate alternative process configurations. By converting digital insights into environmental improvements, organizations with higher DC exhibit stronger innovation and sustainability performance (Khin & Ho, 2019). Therefore, digital capability is posited to have a direct, positive influence on green innovation.

Although prior studies acknowledge reciprocal or parallel relationships between digital transformation and environmental innovation, the sequential ordering DC and GI is more theoretically defensible in the SME context. Digital capability provides the foundational infrastructure such as real time data visibility, production analytics, sensor intelligence, and cross functional integration required to redesign products and processes for eco-efficiency. Without this digital groundwork, firms lack the information transparency and decision support systems necessary for identifying environmental hotspots and evaluating alternative green solutions. Thus, environmental innovation becomes a downstream capability that depends on digital enablement rather than a simultaneous or independent outcome. This logic aligns with DCT, which conceptualizes lower order technological capabilities as enablers of higher order implementation capabilities, supporting the strict sequential model adopted in this study.

H3: Digital capability positively influences green innovation.

Green Innovation and Supply Chain Sustainability

Supply Chain Sustainability (SCS) involves integrating environmental, social, and economic goals into supply chain strategy and daily operations (Le et al., 2022). SCS reflects a firm's ability to maintain competitive performance while minimizing ecological harm and promoting social wellbeing (Korir & Tenai, 2020). Green innovation is central to this integration because it reshapes production and logistics processes toward lower carbon intensity, resource circularity, and stakeholder engagement. SMEs implementing GI practices such as eco-design, cleaner production, or waste recycling systems report improved environmental performance and stronger relationships with eco-conscious customers and suppliers (Cheng et al., 2024; Mwansasu & Mwagike, 2025; Singh et al., 2020).

From the dynamic capabilities' viewpoint, GI acts as the reconfiguration mechanism through which knowledge and resources are transformed into sustainable outcomes. It closes the loop between sensing (leadership vision) and seizing (digital capability) by operationalizing innovation that benefits both firm performance and ecological systems. Therefore, GI is expected to have a positive, direct effect on SCS.

H4: Green innovation positively affects supply chain sustainability.

Serial Mediation of Digital Capability and Green Innovation

Integrating the above relationships, this study proposes that digital capability and green innovation jointly form a serial mediation chain linking transformational leadership to supply chain sustainability (Ahmadimousaabad et al., 2013; Wagan & Sidra, 2024). TL initially fosters DC by shaping an organizational culture that embraces digitalization (Wagan & Sidra, 2024). As digital systems improve data visibility and coordination, they provide the technological foundation for environmental initiatives, enabling GI. Subsequently, GI drives operational and strategic improvements that culminate in sustainable supply chain outcomes. This sequential logic captures how leadership cognition is translated into measurable sustainability performance through layered capabilities.

The notion of serial mediation aligns with the hierarchical model of dynamic capabilities, where lower-level routines (e.g., digital integration) enable higher order implementation capabilities (e.g., green innovation) that, in turn, generate competitive advantage (Kor & Mesko, 2013; Permana et al., 2019). Previous studies have tested partial mediation effects of innovation in leadership–performance relationships, but few have empirically validated a dual sequential mechanism that links digital and green pathways. By demonstrating this connection, the study extends both leadership and sustainability research, illustrating that leadership alone does not directly yield sustainable outcomes it must operate through orchestrated capabilities. Therefore, the following hypotheses are advanced:

H5: Digital capability mediates the relationship between transformational leadership and supply chain sustainability.

H6: Green innovation mediates the relationship between transformational leadership and supply chain sustainability.

H7: Digital capability and green innovation jointly and sequentially mediate the relationship between transformational leadership and supply chain sustainability.

Conceptual Model

Figure 1 presents the proposed conceptual framework in which transformational leadership functions as the exogenous variable initiating the dynamic capability process, digital capability and green innovation serve as sequential mediators, and supply chain sustainability represents the outcome. This structure encapsulates the essence of Digital–Green Orchestration Capability (DGOC) a unifying construct describing how transformational leaders integrate digital and environmental transformations to generate sustainable performance in manufacturing SMEs.

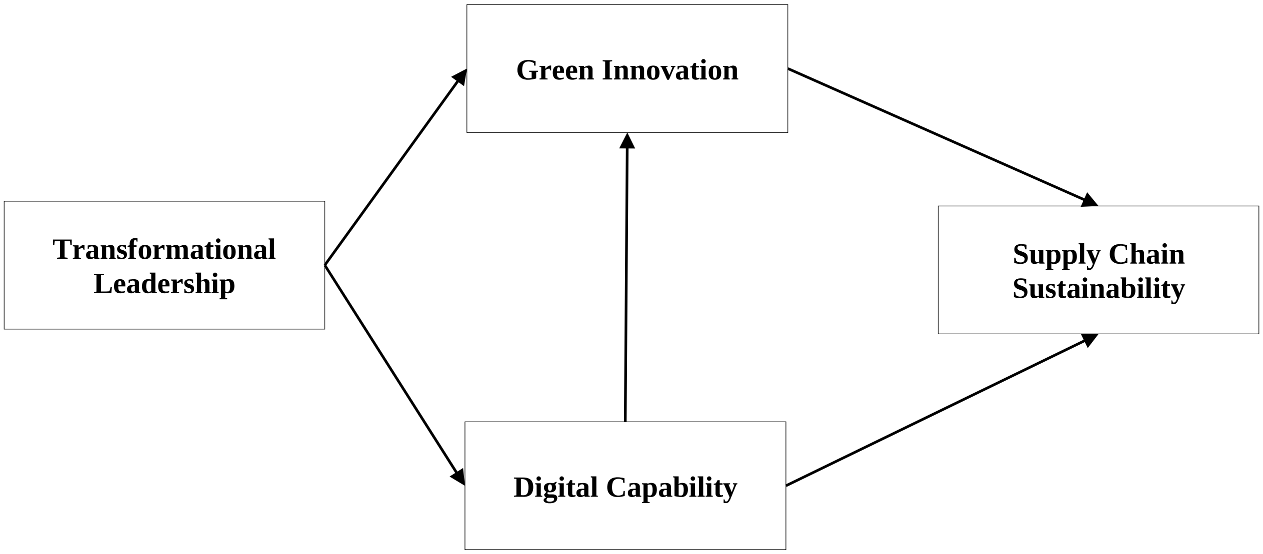

Figure 1. Conceptual Model

Research Methodology

Research Design

This study employed a quantitative, cross sectional survey design suitable for examining complex mediation relationships among latent constructs. Because the model includes multiple sequential mediators and the research objective is predictive rather than purely confirmatory, Partial Least Squares Structural Equation Modeling (PLS-SEM) was chosen over covariance-based SEM (Hair & Alamer, 2022). PLS-SEM is particularly appropriate when the theoretical model is relatively new, the sample size is moderate, and the data distribution may deviate from normality conditions typical of SME survey research. The approach also allows simultaneous assessment of measurement reliability and structural path significance through bootstrapping.

To reduce common method bias (CMB), several procedural and statistical safeguards were adopted. Procedurally, the questionnaire randomized item order, separated predictor and criterion constructs into distinct sections, and assured anonymity to limit social desirability effects. Respondents were informed that there were no right, or wrong answers and that data would be aggregated solely for academic purposes. Statistically, full collinearity variance inflation factors (VIFs) were later tested; all values fell below 3.3, indicating negligible CMB.

Population, Sampling, and Context

The population consisted of manufacturing SMEs operating in Iran, selected because they face simultaneous digitalization and sustainability pressures. National initiatives such as the Smart Industry 2030 Roadmap and the Green Manufacturing Program encourage SMEs to integrate advanced technologies while complying with new environmental standards. This dual pressure environment makes Iran a theoretically rich context for exploring the digital–green orchestration mechanism.

Iranian SMEs offer a particularly rich setting for studying DGOC because they operate in an environment where institutional voids, fragmented regulatory enforcement, and resource dependency intensify the role of leadership in strategic transformation. Unlike developed economies where sustainability initiatives are driven by market incentives and clear compliance frameworks, Iranian manufacturers face inconsistent environmental monitoring, financial constraints, and limited access to advanced digital infrastructure. These conditions force

SME leaders to personally mobilize both digital adoption and environmental practices, making leadership-driven orchestration far more influential than structural or policy-based drivers. Additionally, recent industrial reforms have heightened sustainability expectations without providing proportional governmental support, amplifying the need for internally coordinated digital–green capability development. This contextual configuration positions Iranian SMEs as an ideal empirical domain for examining DGOC as a leadership dependent mechanism.

Sampling frames were obtained from regional industrial development directories and chambers of commerce. A stratified random sampling procedure ensured proportional representation across subsectors (automotive parts, electronics, machinery, food, and chemicals). Of the 600 survey invitations distributed, 352 responses were received, and 332 were retained after eliminating incomplete or inconsistent questionnaires a 55 percent usable response rate, considered robust for SME research. Key informants included owner managers, production managers, and supply chain heads with at least three years of tenure, ensuring familiarity with both leadership practices and operational systems.

The industrial directories listed a total of 4,912 manufacturing SMEs, of which 1,186 operated in automotive and metal parts, 972 in electronics, 843 in machinery, 1,004 in food processing, and 907 in chemicals. Proportional allocation was calculated based on the share of SMEs in each subsector, ensuring equal chance of representation across industries. Within each stratum, firms were selected using a computerized randomization process. Where multiple contacts were listed for a firm, the highest-ranking individual with operational responsibility (CEO, production manager, or supply chain manager) was contacted first to reduce within firm heterogeneity.

Demographically, 58 percent of respondents held middle or senior management positions, 24 percent were owners or CEOs, and 18 percent were operational supervisors. Average firm age was 12 years, and average employment size was 148 workers, confirming SME classification. These attributes align with the population profile of emerging economy manufacturers.

Measurement Development

All constructs were operationalized as reflective latent variables using multi-item Likert scales (1 = strongly disagree, 5 = strongly agree). Items were adapted from established sources and contextualized to SME manufacturing (Table 1). Transformational Leadership (TL) was measured with five items from Nurhayati et al. (2022) capturing inspirational motivation, intellectual stimulation, and individualized consideration (e.g., “My leader communicates a clear and positive vision of the future”). Digital Capability (DC) employed five items adapted from Majumdarr et al. (2025) and Yang et al. (2025) reflecting the firm’s ability to integrate and exploit digital technologies (e.g., “We use digital analytics to support operational decisions”). Green Innovation (GI) used five items based on Pham et al. (2023) describing eco-design and cleaner production (e.g., “We design products that minimize environmental impact”).

Supply Chain Sustainability (SCS) comprised five items adapted from (Le et al., 2022) emphasizing environmental and social integration in supplier relationships (e.g., “We collaborate with suppliers to reduce carbon emissions”). A panel of three academic experts and two SME managers reviewed the draft survey to ensure content validity and language clarity. A pilot test with 30 firms confirmed reliability (Cronbach’s $\alpha > 0.80$ for all constructs) and item comprehension.

Table 1. Constructs, Definitions, and Measurement Sources

Construct	Definition	Sample Items	Key Sources
Transformational Leadership	The extent to which leaders inspire, intellectually stimulate, and provide individualized consideration to employees to achieve shared goals and organizational change.	"My leader communicates a clear and positive vision of the future." "My leader encourages new ways of looking at problems." "My leader inspires me to accomplish more than I expected."	(Nurhayati et al., 2022)
Digital Capability	The firm's ability to deploy, integrate, and reconfigure digital technologies such as analytics, IoT, and cloud systems to enhance agility, decision quality, and performance.	"We use data analytics to improve operational decisions." "Our digital systems are integrated across functions." "Employees are encouraged to experiment with digital tools."	(Eng et al., 2023; Majumdarr et al., 2025; Yang et al., 2025)
Green Innovation	The development or adoption of eco-friendly products, processes, and technologies that reduce environmental impact while maintaining competitiveness.	"We design products with minimal environmental impact." "We employ technologies that reduce waste and emissions." "Our firm continuously evaluates the environmental performance of new products."	(Cui et al., 2023; Pham et al., 2023; Singh et al., 2020)
Supply Chain Sustainability	The integration of environmental and social objectives into supply chain management to enhance long-term economic, ecological, and social performance.	"We collaborate with suppliers to reduce carbon emissions." "Our firm monitors energy and resource usage throughout the supply chain." "We evaluate suppliers based on environmental standards."	(Martins & Pato, 2019)

Data Analysis and Control Variables

After screening in SPSS 28 for missing data, outliers, and normality, the final dataset was analyzed using SmartPLS 4.0. The measurement and structural models were estimated following the two-step approach recommended by Hair and Alamer (2022). Convergent validity was assessed via factor loadings (> 0.70), composite reliability (CR > 0.70), and average variance extracted (AVE > 0.50). Discriminant validity was confirmed through the Heterotrait–Monotrait (HTMT) ratio (< 0.85) and the Fornell–Larcker criterion.

Three control variables firm size, firm age, and industry type were included to rule out contextual bias. None exhibited significant effects on SCS ($p > 0.10$), indicating the robustness of hypothesized relationships. In addition, to ensure model identification and avoid redundancy, item loadings with cross loadings > 0.40 were examined; no problematic overlap occurred.

Measurement Reliability and Validity

Results of reliability and validity testing are summarized in Table 2. Cronbach's α values ranged 0.88–0.91, CR values 0.91–0.94, and AVE values 0.66–0.73, confirming high internal consistency. All item loadings were significant ($p < 0.001$). HTMT ratios between constructs remained below 0.85, satisfying discriminant validity requirements. The Standardized Root Mean Square Residual (SRMR) of 0.064 indicated acceptable model fit (Barney, 1991).

Table 2. Reliability and Validity Statistics

Construct	Items	α	CR	AVE	HTMT Range
TL	5	0.91	0.93	0.71	< 0.80
DC	5	0.88	0.91	0.68	< 0.84
GI	5	0.89	0.92	0.70	< 0.85
SCS	5	0.90	0.93	0.69	< 0.82

Assessment of Bias and Robustness

To ensure data integrity, multiple bias tests were performed. Full collinearity VIFs ranged 1.72–2.81 (< 3.3), confirming the absence of multicollinearity and CMB. Harman's single factor test showed that no single factor explained more than 36 percent of total variance, indicating that CMB was not a serious threat. To evaluate non-response bias, early and late respondents were compared on all key variables; independent sample t-tests revealed no significant differences (Armstrong & Overton, 1977). Because the industrial directories contained basic observable attributes (size and subsector), the responding vs. non-responding firms were compared on these variables. Independent sample t-tests showed no significant differences for firm size ($p = 0.42$) or subsector distribution ($p = 0.37$), suggesting that non-response bias was minimal.

For robustness, exploratory multi-group analyses (automotive vs. non-automotive, small vs. medium firms) revealed consistent path coefficients ($\Delta\beta < 0.05$). Additional regression analyses including control variables produced no substantive changes to the main results. Finally, a two-stage endogeneity check using the Gaussian copula approach indicated no biasing effects, supporting internal validity. Although each firm was represented by a single key informant, this approach is widely accepted in SME leadership and capability research because top decision-makers typically possess exclusive knowledge of both leadership practices and operational systems. To mitigate single informant bias, all respondents had at least three years of tenure and held strategic or operational decision-making authority.

Ethical Considerations

Ethical principles guided all stages of data collection and reporting. Participation was voluntary; respondents could withdraw at any time. All participants provided informed consent before completing the questionnaire. Data were collected anonymously and stored securely. Because the study relied on managerial perceptions rather than personal or sensitive information, formal Institutional Review Board (IRB) approval was not required under national research ethics guidelines. The research adhered to the ethical principles of the Declaration of Helsinki and the Committee on Publication Ethics (COPE) framework for responsible research.

Results

Descriptive Statistics and Sample Profile

Descriptive analysis was first conducted to understand the distribution of the sample and to ensure adequate representation across industries. Table 3 presents the demographic profile of the 332 valid responses used for analysis. Respondents were drawn from diverse managerial levels: 58 percent were middle or senior level managers, 24 percent were owner managers or chief executives, and 18 percent were production or supply chain supervisors. Nearly half of the SMEs (43 percent) belonged to the automotive and metal manufacturing sector, 27 percent to electronics, 16 percent to food processing, and 14 percent to chemicals. The mean firm size was 148 employees ($SD = 49.2$) and the mean firm age was 12.4 years ($SD = 5.9$). These characteristics correspond closely to the structure of manufacturing SMEs in emerging economies.

Table 3. Sample Characteristics

Variable	Category	Frequency	Percentage (%)
Respondent position	Owner / CEO	79	23.8
	Middle/Senior Manager	192	57.8
	Production/Supply chain Supervisor	61	18.4
Industry type	Automotive & Metal	143	43.1
	Electronics	89	26.8
	Food Processing	53	15.9
	Chemical / Other	47	14.2
Firm size (employees)	< 100	113	34.0
	100–199	153	46.1
	200–249	66	19.9
Firm age (years)	< 10	130	39.2
	10–19	137	41.3
	≥ 20	65	19.5

Measurement Model Evaluation

The reliability and validity of all reflective constructs were evaluated prior to hypothesis testing following Hair and Alamer (2022). Table 4 reports Cronbach's α, composite reliability (CR), average variance extracted (AVE), and standardized loadings. All loadings exceeded 0.70 ($p < 0.001$). Cronbach's α values ranged 0.88–0.91 and CR values 0.91–0.94, demonstrating high internal consistency. AVE values ranged 0.66–0.73, confirming convergent validity.

Table 4. Reliability and Convergent Validity

Construct	Items	Loading Range	Cronbach's α	CR	AVE
Transformational Leadership (TL)	TL1–TL5	0.73–0.90	0.91	0.93	0.71
Digital Capability (DC)	DC1–DC5	0.74–0.89	0.88	0.91	0.68
Green Innovation (GI)	GI1–GI5	0.77–0.88	0.89	0.92	0.70
Supply chain Sustainability (SCS)	SCS1–SCS5	0.72–0.90	0.90	0.93	0.69

Discriminant validity was verified using both the Fornell–Larcker criterion and the Heterotrait–Monotrait (HTMT) ratio. Table 5 shows that each construct's square root of AVE exceeded its inter construct correlations and that all HTMT ratios were < 0.85, confirming discriminant validity. Variance inflation factors (VIF < 3.3) indicated an absence of collinearity.

Table 5. Fornell–Larcker and HTMT Matrix

Construct	TL	DC	GI	SCS
Fornell–Larcker (diagonal = √AVE)	0.84			
DC	0.68	0.82		
GI	0.61	0.66	0.84	
SCS	0.52	0.60	0.64	0.83

HTMT range = 0.61 – 0.82 (< 0.85) → Discriminant validity established. Model fit index: SRMR = 0.063 < 0.08 (Hu & Bentler, 1999).

Structural Model Assessment

The hypothesized relationships were tested using bootstrapping with 5 000 resamples. Path coefficients (β), t-values, p-values, and effect sizes (f^2) are displayed in Table 6. Coefficients of determination (R^2) and predictive relevance (Q^2) were also calculated to assess explanatory power and out of sample prediction.

Table 6. Structural Model Results

Hypothesis	Path	β	t-value	p-value	f²	Decision
H1	TL → DC	0.68	13.22	< 0.001	0.46	Supported
H2	TL → GI	0.21	3.74	< 0.001	0.11	Supported
H3	DC → GI	0.52	9.06	< 0.001	0.36	Supported
H4	GI → SCS	0.63	12.45	< 0.001	0.41	Supported
—	TL → SCS (direct)	0.08	1.14	0.254	0.02	Not Supported

R^2: DC = 0.46 GI = 0.54 SCS = 0.59.
Q^2: DC = 0.31 GI = 0.37 SCS = 0.41.
These values indicate strong explanatory and predictive power (Cohen, 1988).

Mediation Analysis

Mediation effects were tested using the bias corrected bootstrapping method (Preacher & Hayes, 2008) with 5 000 samples. Table 7 reports specific and serial indirect effects together with 95 percent confidence intervals (CIs).

Table 7. Bootstrapped Mediation Effects

Mediation Path	Indirect β	95% CI (Lower, Upper)	t-value	p-value	Mediation Type
TL → DC → SCS	0.18	(0.09, 0.27)	4.57	< 0.001	Partial (H5)
TL → GI → SCS	0.13	(0.06, 0.22)	3.89	< 0.001	Partial (H6)
TL → DC → GI → SCS	0.22	(0.13, 0.32)	6.31	< 0.001	Full Serial (H7)

Because the direct TL → SCS path was insignificant ($\beta = 0.08$, $p > 0.05$) when mediators were included, the overall pattern supports full serial mediation, confirming that TL affects SCS entirely through DC and GI.

Model Fit and Predictive Assessment

Model fit indices confirmed adequacy of the overall structure. The Standardized Root Mean Square Residual (SRMR) = 0.063 (< 0.08) and Normed Fit Index (NFI) = 0.91 (> 0.90) indicate satisfactory fit. To test predictive accuracy, a PLSpredict procedure compared the PLS-SEM model with a linear regression benchmark. For all indicators, root mean square error (RMSE) values for the PLS model were lower, demonstrating superior predictive relevance. Additionally, Importance–Performance Map Analysis (IPMA) identified Green Innovation as the most influential construct (importance = 0.64; performance = 81 percent), followed by Digital Capability (importance = 0.59; performance = 78 percent). This pattern underscores that strengthening environmental innovation yields the largest gain in supply chain sustainability among the studied SMEs.

Robustness and Additional Analyses

To assess the stability and generalizability of the findings, multiple robustness checks were conducted.

1. Alternative Model Test: A parallel mediation model (TL → DC & GI → SCS) was estimated; both R^2 (0.52) and Q^2 (0.33) were lower than in the sequential model, supporting the superiority of the proposed serial mediation structure.

2. Multi group Analysis (MGA): The dataset was divided by firm size (< 150 employees vs. ≥ 150) and by industry (automotive vs. non-automotive). Differences in path coefficients were statistically insignificant ($\Delta\beta < 0.05$, $p > 0.10$), confirming model invariance.
3. Control Variable Stability: Inclusion of firm age, size, and industry dummies as controls did not materially alter path strengths; all hypothesized effects remained significant.
4. Endogeneity Check: A two-stage Gaussian copula procedure detected no significant copula term ($p > 0.10$), suggesting absence of endogeneity bias.
5. Residual Diagnostics: No heteroscedasticity or influential outliers were detected; Cook's distance values were all < 1.

Collectively, these analyses verify that the structural relationships are robust, stable across sub-samples, and free from estimation bias.

Discussion

Theoretical Discussion

This study aimed to uncover how transformational leadership (TL) influences supply chain sustainability (SCS) through the dual and sequential mechanisms of digital capability (DC) and green innovation (GI) in manufacturing SMEs. The findings confirm that TL has no direct impact on SCS once mediating effects are included but exerts a full serial mediation through DC and GI. This outcome supports the idea that leadership primarily affects sustainability indirectly by creating conditions for digital and environmental capability development rather than by imposing sustainability goals from the top.

The finding of no significant direct TL and SCS path contrasts with prior studies conducted in emerging markets where transformational leadership demonstrated a positive direct influence on sustainability outcomes, particularly under strong regulatory pressure or when environmental certification is mandated. In such contexts, external enforcement substitutes for capability building, enabling leadership to convert sustainability vision directly into performance gains without requiring intermediate digital or environmental routines. The full mediation observed in this study therefore reflects the distinctive institutional environment of Iranian SMEs, where policy incentives are inconsistent and sustainability enforcement remains fragmented, making capability development not top-down pressure the primary pathway through which leadership influences sustainability outcomes.

The results advance theory in several ways. First, the study extends Dynamic Capabilities Theory (DCT) by demonstrating how behavioral and cognitive attributes of leaders activate dynamic routines. TL stimulates the sensing of technological opportunities, the seizing of digital initiatives, and the reconfiguring of organizational processes that together form DC (Ameer, 2018; Kor & Mesko, 2013). DC then serves as an operational foundation enabling firms to design and implement green innovations that lead to sustainability outcomes. In this way, the research clarifies the behavioral micro foundations of dynamic capabilities, connecting leadership style to capability orchestration.

Second, integrating DCT with Upper Echelons Theory (UET) provides a more comprehensive understanding of leadership influence. UET posits that managerial cognition and values shape organizational outcomes (Achyar, 2024). The present findings support this argument by showing that leaders with digital vision and pro-environmental orientation embed their cognition into organizational routines that materialize as measurable performance improvements. This synthesis offers a bridge between psychological and operational theories of organizational change.

Third, the evidence validates the concept of Digital–Green Orchestration Capability (DGOC), introduced in this study as a meta-capability that integrates digital transformation and environmental innovation. The DGOC concept transcends traditional resource-based perspectives by emphasizing the interaction between digital and green capabilities. Rather than treating digitalization and sustainability as parallel initiatives, the results reveal that their synergy driven by leadership produces superior sustainability outcomes. DGOC thus represents an emerging theoretical lens for examining how firms balance technological and ecological priorities in Industry 4.0 environments.

Contextual Insights and Boundary Conditions

The results also highlight the contextual dependency of leadership effectiveness. In emerging economies, where institutional infrastructure and regulatory enforcement are weak, leaders often compensate for systemic deficiencies through personal initiative and vision. TL's influence on DC and GI is therefore magnified under institutional voids because leaders become the primary agents of strategic change. Conversely, in highly regulated or resource rich settings, external incentives or policy mandates may substitute for leadership influence. Future research should test whether the magnitude of the TL and DC link diminishes as institutional maturity increases.

Another boundary condition concerns resource availability. While TL can inspire employees and attract investment in digital tools, the translation of vision into action depends on financial and technical resources. In resource poor SMEs, even strong leadership may not achieve large scale digital transformation without external support. Hence, capability development should be viewed as both leaderships driven and resource bounded. Policymakers could reinforce leadership initiatives by providing targeted funding or technology adoption programs.

DGOC is likely to be less effective in settings where sustainability requirements are externally mandated and monitored, such as highly regulated pharmaceutical, energy, or aviation industries. In such industries, legislation and certification standards directly shape firm behavior, and sustainability is compliance driven rather than capability driven. Similarly, DGOC may weaken in extremely resource constrained micro enterprises where investment in digital infrastructure is impractical regardless of leadership orientation. In both cases, sustainability outcomes are determined more by regulatory or resource structures than by orchestrated digital–green leadership mechanisms.

Reverse Causality and Future Dynamics

An important theoretical nuance emerging from this study is potential bidirectionality between leadership and capability formation. While this model assumes that TL precedes DC and GI, it is plausible that digital transformation itself reshapes leadership behavior. Exposure to digital technologies can encourage leaders to adopt data driven decision making and evidence-based management practices. Future longitudinal studies could explore these reciprocal dynamics, enriching understanding of how digitalization transforms leadership cognition over time.

Theoretical Implications

Overall, these findings make four core theoretical contributions.

1. They validate that leadership's effect on sustainability is indirect and capability mediated, reinforcing the view that outcomes arise from orchestrated routines rather than individual charisma.

2. They provide empirical support for DGOC as a dual transformation mechanism that connects behavioral leadership theory with digital sustainability literature.
3. They extend DCT's scope by embedding leadership cognition (from UET) into the dynamic capabilities' hierarchy.
4. They position SMEs as fertile contexts for examining micro-foundations of sustainability, since leadership influence is amplified in resource constrained firms.

Managerial Implications

This study offers several actionable insights for managers, policymakers, and consultants involved in SME transformation. First, leadership must translate vision into capability. Inspirational speeches and sustainability slogans have limited impact unless backed by investments in digital infrastructure, analytics platforms, and employee upskilling. SME leaders should create small "digital cells" that pilot technologies such as IoT or process monitoring systems before scaling firm wide. These initiatives simultaneously build DC and demonstrate early sustainability benefits, reinforcing employee confidence.

Second, digital capability is the foundation for environmental innovation. The results show that DC strongly predicts GI, suggesting that data visibility and process automation are prerequisites for meaningful environmental improvement. Managers should treat digitalization not merely as an efficiency exercise but as an enabler of eco-innovation using analytics to identify waste hotspots, forecast material demand, and simulate carbon reduction scenarios.

Third, green innovation must be institutionalized as a core routine, not a one-off project. The high importance–performance score of GI in the IPMA analysis underscores its centrality. SME managers should embed environmental metrics within performance dashboards and link supplier contracts to sustainability criteria. Examples include joint supplier audits, shared data on emissions, and circular economy design collaborations.

Fourth, training and culture matter. Leaders should promote a digital green culture by rewarding experimentation and knowledge sharing. Cross functional "green labs" or "digital sustainability hackathons" can stimulate creative solutions and break departmental silos. By recognizing both technological and ecological contributions, leaders reinforce the DGOC mindset across the firm.

Finally, policy makers and development agencies can enhance the success of such initiatives by coupling technology adoption incentives with environmental performance targets. Grants or tax reductions for digital transformation should be conditional on measurable sustainability outcomes, thereby institutionalizing the DGOC framework at a national level.

The IPMA results give leaders clear priorities for resource allocation. Because green innovation exhibits the highest importance–performance impact on SCS (importance = 0.64; performance = 81%), managers should prioritize investment in eco-design, cleaner production technologies, energy monitoring systems, and supplier environmental collaboration before increasing spending on new digital tools. Digital capability remains essential but acts as an enabler rather than the end objective; thus, resources should first strengthen the digital systems that directly support environmental initiatives (e.g., analytics for emissions tracking, IoT for machine energy efficiency). This prioritization ensures that limited resources are deployed toward the capability with the strongest sustainability payoff, converting DGOC from a conceptual leadership approach into an actionable transformation roadmap for SMEs.

Limitations and Future Research Directions

Despite rigorous design and robust statistical validation, this study has several limitations that offer avenues for future research.

1. Cross sectional design. The use of single time data prevents causal inference. Although bootstrapping and endogeneity tests mitigate this concern, longitudinal or experimental designs could capture dynamic feedback between leadership and capability development (Podsakoff et al., 2012). Although procedural remedies (anonymity, randomization of items) and statistical tests (full collinearity VIFs and Harman's single factor test) suggest that CMV is unlikely to distort the results, perceptual and self-report data inherently carry some risk of CMB. Therefore, the possibility of residual CMV cannot be entirely ruled out.

2. Single respondent data. Responses were obtained from one key informant per firm. Future research should incorporate multi-informant or dyadic data (e.g., buyer–supplier pairs) to reduce subjectivity. Future studies should incorporate multi-informant or dyadic data from multiple organizational levels or across buyer–supplier pairs to triangulate leadership behavior, capability development, and sustainability outcomes. A multi-source approach would further reduce perceptual bias and allow for a more granular mapping of the DGOC mechanism across supply chain tiers.

3. Geographical scope. The study focused on Iranian SMEs; cultural and institutional variations may limit generalizability. Comparative studies across multiple emerging economies such as Malaysia, India, and Turkey could reveal contextual moderators.

4. Potential omitted variables. Environmental turbulence, resource slack, or digital maturity might moderate the TL → DC → GI chain. Integrating Institutional Theory or Contingency Theory could clarify under what external conditions leadership is most effective.

5. Construct measurement. While validated scales were used, DGOC as a higher order construct remains conceptual. Future work should develop and validate a dedicated DGOC measurement instrument to capture the orchestration of digital and green dimensions empirically.

Conclusion

This study empirically validates a serial mediation model explaining how transformational leadership drives supply chain sustainability through digital and green capabilities. By integrating DCT and UET, the research shows that sustainable performance in SMEs emerges not from direct leadership influence but from orchestrated capability development. The results confirm that TL stimulates digital capability (the sensing–seizing routine) which then enables green innovation (the implementation routine), together producing sustainable supply chain outcomes. The introduction of Digital–Green Orchestration Capability (DGOC) thus offers a comprehensive explanation for how organizations in emerging economies can simultaneously pursue digital transformation and environmental responsibility. For practitioners, the study highlights that leadership success depends on the ability to operationalize vision through measurable technological and environmental competencies. For scholars, it opens a new research avenue on the behavioral micro foundations of dual transformation in Industry 4.0 contexts.

Declarations

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Conflicts of Interest
The author declares no conflicts of interest that could have influenced the research, authorship, or publication of this article.

Ethical Approval
The study complied with institutional and national ethical guidelines and adhered to the Declaration of Helsinki and COPE standards. Because the data relied solely on managerial opinions and contained no personal identifiers, formal Institutional Review Board (IRB) approval was not required.

Informed Consent
All participants were informed of the research purpose and voluntarily provided consent prior to completing the survey.

Authors' Contributions
The author designed the study, conducted the analysis, interpreted the results, and wrote the manuscript. All sections were reviewed and approved by the author before submission.

Data Availability
An anonymized dataset supporting this study's findings is available from the corresponding author upon reasonable request.

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