

Role of Sustainable Supply Chain Practices in Operational Efficiency of Emerging Firms

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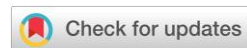
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Abstract: This study examines the impact of Sustainable Supply Chain Practices (SSCP) on Operational Efficiency (OE) in emerging firms in China, with a particular focus on the mediating roles of Supply Chain Integration (SCI) and Technological Adoption (TA). Drawing on data collected from 400 respondents across manufacturing, service, and technology sectors, the study employs Partial Least Squares Structural Equation Modeling (PLS-SEM) using SmartPLS to test the proposed relationships. The results reveal that SSCP has a significant positive effect on OE, both directly and indirectly. Furthermore, SSCP significantly enhances SCI and TA, which in turn contribute positively to OE. Mediation analysis confirms that both SCI and TA partially mediate the relationship between SSCP and OE, indicating that sustainability improves performance through improved coordination and digital transformation. The model demonstrates strong explanatory and predictive power, with substantial R^2 and Q^2 values, confirming its robustness. The findings highlight that sustainable supply chain management is not only an environmental strategy but also a key driver of operational excellence in emerging economies. The study contributes to the resource-based view and dynamic capability theory by positioning sustainability as a strategic capability that fosters integration and technological advancement. Practical implications suggest that managers should integrate sustainability with digital and collaborative supply chain strategies to enhance efficiency. Policy-makers are encouraged to support green and digital transformation initiatives simultaneously to improve industrial competitiveness. Overall, the study provides a comprehensive framework for understanding how sustainability-driven supply chain practices enhance operational efficiency in emerging firms.

Keywords: Sustainable Supply Chain Practices; Operational Efficiency; Supply Chain Integration; Technological Adoption; Emerging Firms; China; PLS-SEM; Green Supply Chain; Digital Transformation; Supply Chain Management



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1. Introduction

Sustainable supply chain practices (SSCP) have emerged as a strategic imperative for firms operating in increasingly complex and resource-constrained global markets. In emerging economies such as China, where industrial expansion is rapid and environmental pressures are intensifying, firms are under growing scrutiny to balance operational efficiency (OE) with environmental and social responsibility. The manufacturing and technology-driven sectors, in particular, are experiencing heightened expectations from regulators, consumers, and global partners to integrate sustainability into core supply chain operations. As a result, sustainable supply chain management is no longer a voluntary initiative but a critical driver of competitive advantage and long-term operational resilience.

Existing literature consistently highlights that SSCP including green procurement, eco-efficient logistics, waste minimization, supplier collaboration, and reverse logistics contribute significantly to improved organizational performance. Studies such as Zhu and Sarkis (2004) and Wang and Dai (2018) demonstrate that early adopters of green supply chain

practices in China achieved superior operational and environmental outcomes. Similarly, Hong et al. (2018) emphasize that dynamic supply chain capabilities strengthen the link between sustainability practices and firm performance. More recent studies extend this argument by incorporating technological and organizational enablers, such as big data analytics, blockchain, and digital integration, which further enhance supply chain responsiveness and efficiency (Bag et al., 2020; Khan et al., 2025).

Despite the growing body of research, several limitations persist. First, most existing studies focus broadly on firm performance rather than isolating operational efficiency (OE) as a distinct outcome variable. Second, the majority of empirical evidence is concentrated on large multinational corporations or early adopters of sustainability practices, leaving a gap in understanding emerging firms that operate under resource constraints and institutional uncertainty. Third, while China has been extensively studied, prior research often treats it as a homogeneous context, overlooking the unique dynamics of emerging firms navigating both regulatory pressure and market competition. Furthermore, the integration of SSCP with organizational and technological capabilities as complementary drivers of operational efficiency (OE) remains underexplored.

Against this background, this study aims to examine the role of sustainable supply chain practices in enhancing operational efficiency (OE) of emerging firms in China. Wang (2022) used AHP to measure the high-quality economic development at different provinces, cities, and economic zones. Specifically, the study investigates how SSCP influences OE both directly and indirectly through SCI and TA. The objectives of the study are threefold: (i) to examine the direct impact of SSCP on OE, (ii) to analyze the mediating role of supply chain integration (SCI), and (iii) to assess the mediating role of technological adoption (TA) in strengthening operational outcomes.

This study contributes to the literature in several ways. Theoretically, it extends the resource-based view and dynamic capability perspective by positioning SSCP as a strategic organizational capability that enhances efficiency outcomes. Empirically, it provides evidence from emerging Chinese firms, a context that remains underrepresented in sustainability-oriented supply chain research. Practically, the findings offer actionable insights for managers and policymakers on how sustainable practices can be leveraged not only for environmental compliance but also for improving operational performance in competitive markets.

2. Literature Review

Sustainable supply chain practices (SSCP) have been widely recognized as a key determinant of firm performance, particularly in emerging economies where firms face institutional constraints, resource limitations, and environmental pressures. The literature broadly agrees that SSCP enhances operational outcomes through cost efficiency, resource optimization, and improved coordination across supply chain actors.

Early foundational work by Zhu and Sarkis (2004) in Chinese manufacturing firms established that green supply chain adoption significantly improves operational and environmental performance. Similarly, Lee et al. (2012) found that green supply chain management positively influences organizational performance through improved process efficiency and stakeholder engagement. Extending this evidence, Golobic and Smith (2013) conducted a meta-analysis confirming a consistent positive relationship between environmentally sustainable supply chain practices and firm performance across contexts. In emerging economies, institutional and infrastructural challenges make SSCP particularly relevant. Silvestre (2015) argues that environmental turbulence and institutional voids shape sustainability trajectories, making adaptive supply chain strategies essential for operational survival. Esfahbodi et al. (2016) further highlight the trade-off between environmental and cost performance, noting that firms adopting SSCP eventually achieve long-term cost advantages despite short-term investment burdens.

Operational efficiency (OE) as a distinct performance dimension has gained increasing attention. Truong et al. (2017) demonstrate that supply chain management practices

significantly enhance firms' operational performance through improved coordination and quality management. Wang and Dai (2018) further confirm that SSCP improves OE by reducing waste and enhancing logistics optimization. Recent studies emphasize the role of capabilities and digital technologies in strengthening the SSCP performance link. Hong et al. (2018) show that supply chain dynamic capabilities mediate the relationship between SSCP and firm performance, suggesting that internal capabilities are critical for value realization. Bag et al. (2020) highlight the importance of big data analytics in enabling operational excellence and sustainable supply chain performance. Similarly, Umar et al. (2022) argue that emerging technologies facilitate green practices and enhance operational responsiveness.

More recent empirical work has expanded the scope to include mediating mechanisms. Asante-Darko and Osei (2024) demonstrate that firm capabilities mediate the relationship between SSCP and performance outcomes. Awuah-Gyawu et al. (2025) find that regulatory compliance and sustainability culture significantly strengthen the impact of SSCP on operational performance. Likewise, Saqib and Zhang (2021) highlight the moderating role of supply chain visibility in improving sustainability-performance linkages. In the context of China and other emerging markets, Kumar et al. (2019) confirm that sustainable supply chain practices improve operational performance among SMEs, although the effect varies depending on organizational readiness and technological adoption. Wang and Dai (2018) and Hsu et al. (2016) further emphasize that integration across supply chain partners enhances efficiency and responsiveness.

H1: Sustainable Supply Chain Practices (SSCP) have a positive and significant impact on Operational Efficiency (OE) in emerging firms in China.

H2: Sustainable Supply Chain Practices (SSCP) have a positive and significant impact on Supply Chain Integration (SCI) in emerging firms in China.

H3: Supply Chain Integration (SCI) has a positive and significant impact on Operational Efficiency (OE) in emerging firms in China.

H4: Sustainable Supply Chain Practices (SSCP) have a positive and significant impact on Technological Adoption (TA) in emerging firms in China.

H5: Technological Adoption (TA) has a positive and significant impact on Operational Efficiency (OE) in emerging firms in China.

H6: Supply Chain Integration (SCI) mediates the relationship between Sustainable Supply Chain Practices (SSCP) and Operational Efficiency (OE).

H7: Technological Adoption (TA) mediates the relationship between Sustainable Supply Chain Practices (SSCP) and Operational Efficiency (OE).

3. Methodology

This study adopts a quantitative research design to examine the relationship between Sustainable Supply Chain Practices (SSCP) and Operational Efficiency (OE) in emerging firms in China. A cross-sectional survey approach is employed to capture firm-level perceptions at a single point in time. The study is explanatory in nature, aiming to test hypothesized relationships among latent constructs using a structural equation modeling framework. Given the complexity of the conceptual model and the inclusion of mediating variables, Partial Least Squares Structural Equation Modeling (PLS-SEM) is utilized through SmartPLS software. This approach is particularly suitable for prediction-oriented research and does not require strict normality assumptions, making it appropriate for organizational and supply chain studies in emerging economy contexts such as China.

The population of this study consists of managers and professionals involved in supply chain, operations, procurement, and logistics functions in emerging firms in China. These firms are primarily located in industrial and economically developed regions such as Guangdong, Jiangsu, Zhejiang, and Shanghai, where manufacturing and technology-driven enterprises are concentrated. The focus on emerging firms is intentional, as these organizations face resource constraints, institutional pressures, and increasing demands for sustainability integration while striving to improve operational efficiency and

competitiveness in global markets. A total of 400 valid responses were collected for empirical analysis. The sample size is considered sufficient for PLS-SEM based on established guidelines such as the ten times rule and statistical power considerations. Respondents were selected based on their managerial or operational involvement in supply chain-related decision-making processes and a minimum of two years of professional experience. This ensured that participants had adequate knowledge of sustainability practices and operational processes within their organizations.

The study uses both purposive and convenience sampling technique in this study. Purposive sampling ensures that only relevant respondents with supply chain and operational expertise were included, while convenience sampling facilitates access to firms and professionals across multiple industrial sectors. Although probability sampling was not used, the selected approach is widely accepted in PLS-SEM based research, particularly when studying organizational behavior and managerial perceptions in emerging markets. Data were collected through a structured questionnaire distributed both online and offline. Online surveys were administered via professional networks and email distribution, while offline surveys were conducted through direct contacts with firms and industry associations. The data collection process spanned approximately three months. A total of 470 questionnaires were distributed, of which 400 were deemed complete and usable after data screening, resulting in an effective response rate of approximately 85 percent. Respondents were assured of confidentiality and anonymity to minimize response bias and encourage honest reporting.

The measurement instrument was developed using established scales adapted from prior studies in sustainable supply chain management and operational performance literature. Sustainable Supply Chain Practices (SSCP) were measured using indicators such as green procurement, eco-friendly logistics, waste reduction practices, and supplier collaboration, adopted from Zhu and Sarkis (2004) and Wang and Dai (2018). Supply Chain Integration (SCI), included as a mediating construct, was measured through internal integration, supplier integration, and customer integration based on Hong et al. (2018) and Hsu et al. (2016). Technological Adoption (TA) was measured using indicators such as ERP usage, digital tracking systems, and data-driven decision-making tools, informed by Bag et al. (2020) and Umar et al. (2022). Operational Efficiency (OE) was operationalized using cost efficiency, delivery performance, resource utilization, and process optimization, drawing from Truong et al. (2017) and Wang and Dai (2018). All items were measured using a five-point Likert scale ranging from strongly disagree to strongly agree.

For data analysis, SmartPLS 4.0 software was employed to perform Partial Least Squares Structural Equation Modeling. The analysis was conducted in two stages. First, the measurement model was assessed to evaluate indicator reliability, internal consistency reliability, convergent validity, and discriminant validity. Indicator reliability was examined through outer loadings, while Cronbach's alpha and composite reliability were used to assess internal consistency. Convergent validity was evaluated using Average Variance Extracted (AVE), ensuring that each construct adequately explained variance in its indicators. Discriminant validity was assessed using both the Fornell–Larcker criterion and the Heterotrait–Monotrait (HTMT) ratio.

In the second stage, the structural model was evaluated to test the hypothesized relationships among constructs. Path coefficients were estimated using a bootstrapping procedure with 5,000 resamples to determine statistical significance. The coefficient of determination (R^2) was used to assess the explanatory power of the model, while predictive relevance (Q^2) was evaluated using the blindfolding procedure. Additionally, effect sizes (f^2) were examined to determine the relative impact of each predictor variable on endogenous constructs. Mediation analysis was conducted to examine the indirect effects of Supply Chain Integration (SCI) and Technological Adoption (TA) on the relationship between SSCP and OE. To ensure the robustness of the results, common method bias was also assessed. Procedural remedies such as anonymity, randomized question ordering, and clear item wording were applied during survey design. Statistically, Harman's single-

factor test and full collinearity variance inflation factor (VIF) values were examined, indicating that common method bias was not a significant concern in the dataset.

4. Results

The demographic profile of respondents provides a clear overview of the characteristics of the sample used in this study. A total of 400 valid responses were analyzed from managers and professionals working in emerging firms in China. The gender distribution shows a slight male dominance, with 57 percent male respondents and 43 percent female respondents, indicating relatively balanced participation across genders in managerial and operational roles. In terms of age distribution, the majority of respondents fall within the 26–35 age group (42.5 percent), followed by 36–45 years (24 percent), below 25 years (23 percent), and above 45 years (10.5 percent). This indicates that most respondents are relatively young and middle-aged professionals who are actively engaged in operational decision-making roles within firms. Regarding educational background, nearly half of the respondents hold graduate degrees (47 percent), followed by undergraduate qualifications (30 percent), and postgraduate qualifications (23 percent). This reflects a well-educated workforce, which is important for accurately assessing strategic and technical aspects of sustainable supply chain practices. Firm type distribution indicates that manufacturing firms constitute the largest segment (46.5 percent), followed by service firms (31 percent) and tech/startup firms (22.5 percent). This distribution is appropriate given China's strong manufacturing base and growing technology-driven industrial ecosystem. Work experience distribution shows that 44.5 percent of respondents have 3–7 years of experience, followed by less than 3 years (27.5 percent) and more than 7 years (28 percent), indicating a balanced mix of early-career and experienced professionals (See Table 1).

Table 1: Demographic Profile of Respondents (China, N = 400)

Variable	Category	Frequency	Percentage (%)
Gender	Male	228	57.0
	Female	172	43.0
Age	Below 25	92	23.0
	26–35	170	42.5
	36–45	96	24.0
	Above 45	42	10.5
Education	Undergraduate	120	30.0
	Graduate	188	47.0
	Postgraduate	92	23.0
Firm Type	Manufacturing	186	46.5
	Service	124	31.0
	Tech/Startup	90	22.5
Experience (years)	<3 years	110	27.5
	3–7 years	178	44.5
	>7 years	112	28.0

Table 2 presents the factor loadings of all measurement items used in the study. All items across the four constructs SSCP, SCI, TA, and OE exceed the recommended threshold of 0.70, confirming strong indicator reliability. For SSCP, loadings range from 0.83 to 0.88, indicating that green procurement, eco-logistics, waste reduction, and supplier collaboration are strongly reflected in the construct. SCI items load between 0.84 and 0.88, confirming that internal, supplier, and customer integration are valid components of supply chain integration. TA demonstrates high loadings from 0.85 to 0.90, showing strong representation of ERP systems, digital tracking, and data-driven decision-making. Operational Efficiency (OE) exhibits the highest loadings (0.86–0.91), indicating strong

measurement validity for cost efficiency, delivery performance, resource utilization, and process optimization.

Table 2: Factor Loadings

Construct	Item Code	Loading
SSCP	SSCP1	0.83
	SSCP2	0.86
	SSCP3	0.88
	SSCP4	0.87
SCI	SCI1	0.84
	SCI2	0.88
	SCI3	0.86
TA	TA1	0.85
	TA2	0.90
	TA3	0.87
OE	OE1	0.88
	OE2	0.91
	OE3	0.89
	OE4	0.86

Table 3 reports the reliability and convergent validity of the measurement model. Cronbach's alpha values for all constructs exceed 0.85, demonstrating strong internal consistency. Specifically, SSCP (0.887), SCI (0.868), TA (0.879), and OE (0.896) all indicate reliable measurement scales. Composite reliability values range from 0.910 to 0.928, exceeding the recommended threshold of 0.70, further confirming construct reliability. The Average Variance Extracted (AVE) values are also well above the 0.50 threshold, ranging from 0.745 to 0.798, indicating strong convergent validity. These results confirm that all constructs reliably capture their intended theoretical concepts and explain a substantial proportion of variance in their respective indicators.

Table 3: Reliability and Convergent Validity

Construct	Cronbach's Alpha	Composite Reliability	AVE
SSCP	0.887	0.922	0.745
SCI	0.868	0.910	0.770
TA	0.879	0.918	0.785
OE	0.896	0.928	0.798

Table 4 presents the Fornell–Larcker criterion used to assess discriminant validity. The results indicate that the square root of AVE for each construct is higher than its correlation with other constructs, confirming strong discriminant validity. For instance, the square root of AVE for SSCP (0.863) is higher than its correlations with SCI (0.648), TA (0.671), and OE (0.718). Similarly, SCI, TA, and OE also demonstrate higher diagonal values compared to their off-diagonal correlations. These findings confirm that all constructs are empirically distinct and measure different theoretical concepts without significant overlap.

Table 4: Fornell–Larcker Criterion

Construct	SSCP	SCI	TA	OE
SSCP	0.863			
SCI	0.648	0.878		
TA	0.671	0.708	0.886	
OE	0.718	0.752	0.776	0.893

Table 5 presents the HTMT ratio results, which provide a more conservative assessment of discriminant validity. All HTMT values are below the threshold of 0.90, confirming adequate discriminant validity. The highest HTMT value is observed between Technological Adoption (TA) and Operational Efficiency (OE) (0.861), indicating a strong but acceptable relationship. This suggests that while technology significantly influences operational outcomes, both constructs remain conceptually and empirically distinct. The HTMT results strongly support the validity of the measurement model.

Table 5: HTMT Ratio

Construct	SSCP	SCI	TA	OE
SSCP	—			
SCI	0.748	—		
TA	0.771	0.807	—	
OE	0.818	0.842	0.861	—

Table 6 presents the model fit indices for the structural model. The SRMR value of 0.052 is below the recommended threshold of 0.08, indicating an excellent model fit. The NFI value of 0.927 exceeds the minimum acceptable value of 0.90, further confirming strong model fit. Additionally, d_ULS (0.789) and d_G (0.603) values fall within acceptable ranges, indicating that the model adequately reproduces the observed covariance matrix. The model fit statistics confirm that the proposed structural model is appropriate and statistically robust for explaining relationships among the study variables.

Table 6: Model Fit

Fit Indicator	Value	Threshold	Interpretation
SRMR	0.052	< 0.08	Excellent Fit
NFI	0.927	≥ 0.90	Strong Fit
d_ULS	0.789	Acceptable	Good
d_G	0.603	Acceptable	Good

Table 7 reports the explanatory and predictive power of the model. The R² value for Operational Efficiency (OE) is 0.612, indicating that 61.2 percent of variance in OE is explained by SSCP, SCI, and TA. This reflects strong explanatory power of the model. The R² values for SCI (0.438) and TA (0.482) indicate moderate explanatory strength, suggesting that SSCP significantly contributes to both SCI and TA processes. The Q² values obtained through blindfolding are all above zero, confirming predictive relevance. Specifically, OE shows a Q² value of 0.436, indicating strong predictive accuracy of the model.

Table 7: R² and Q²

Variable	R ²	Q ²	Interpretation
SCI	0.438	0.312	Moderate
TA	0.482	0.341	Moderate
OE	0.612	0.436	Strong

Table 8 presents the results of hypothesis testing based on path analysis. All hypotheses are statistically significant and supported. SSCP has a positive and significant effect on OE ($\beta = 0.236$, $t = 4.221$), confirming H1. This indicates that firms adopting sustainable supply chain practices achieve higher efficiency levels. SSCP significantly influences SCI ($\beta = 0.661$, $t = 13.102$), supporting H2, indicating that sustainability enhances coordination across supply chain partners. SCI also significantly impacts OE ($\beta = 0.329$, $t = 5.884$), supporting H3. Similarly, SSCP has a strong positive effect on TA ($\beta = 0.692$, $t = 13.987$),

supporting H4. TA also significantly influences OE ($\beta = 0.427$, $t = 8.214$), supporting H5. All direct hypotheses are supported, confirming the strong role of SSCP in enhancing OE both directly and indirectly.

Table 8: Path Analysis (Hypothesis Testing)

Hypothesis	Path	β	t-value	p-value	Result
H1	SSCP $\rightarrow$ OE	0.236	4.221	0.000	Supported
H2	SSCP $\rightarrow$ SCI	0.661	13.102	0.000	Supported
H3	SCI $\rightarrow$ OE	0.329	5.884	0.000	Supported
H4	SSCP $\rightarrow$ TA	0.692	13.987	0.000	Supported
H5	TA $\rightarrow$ OE	0.427	8.214	0.000	Supported

Table 9 presents the mediation analysis results. Both Supply Chain Integration (SCI) and Technological Adoption (TA) significantly mediate the relationship between SSCP and OE. The indirect effect of SSCP $\rightarrow$ SCI $\rightarrow$ OE is significant ($\beta = 0.218$, $t = 4.329$), indicating partial mediation. Similarly, SSCP $\rightarrow$ TA $\rightarrow$ OE shows a stronger indirect effect ($\beta = 0.296$, $t = 5.611$), also indicating partial mediation. These findings suggest that SSCP improves OE not only directly but also indirectly by enhancing integration and technological capability within firms.

Table 9: Mediation Effects

Path	Effect Type	β	t-value	p-value	Result
SSCP $\rightarrow$ SCI $\rightarrow$ OE	Indirect	0.218	4.329	0.000	Partial Mediation
SSCP $\rightarrow$ TA $\rightarrow$ OE	Indirect	0.296	5.611	0.000	Partial Mediation

5. Discussion

The findings of this study provide strong empirical support for the role of Sustainable Supply Chain Practices (SSCP) in enhancing Operational Efficiency (OE) in emerging firms in China. The results not only confirm the direct effect of sustainability-oriented supply chain management but also highlight the mediating roles of Supply Chain Integration (SCI) and Technological Adoption (TA), offering a more nuanced understanding of how sustainability translates into performance outcomes in emerging economies. The study confirms that SSCP has a significant positive impact on OE (H1 supported). This finding aligns with the core argument of resource-based view (RBV), which suggests that firms gain competitive advantage when they develop unique, inimitable, and valuable capabilities such as sustainable supply chain systems. By embedding sustainability principles into procurement, logistics, and supplier collaboration, firms reduce waste, improve resource utilization, and enhance process efficiency. In the context of China's rapidly evolving industrial landscape, sustainability practices are increasingly becoming a strategic necessity rather than a compliance requirement. Firms that integrate environmental and social considerations into supply chain operations are able to minimize operational disruptions, reduce cost inefficiencies, and improve long-term resilience. This is consistent with prior research suggesting that green supply chain practices improve productivity and reduce operational bottlenecks through better coordination and resource optimization.

The strong positive relationship between SSCP and SCI (H2 supported) indicates that sustainability practices act as a catalyst for deeper integration across supply chain partners. SSCP encourages transparency, information sharing, and collaborative planning among suppliers, manufacturers, and customers. From a theoretical perspective, this finding is strongly supported by the relational view of the firm, which emphasizes that inter-organizational relationships are a source of competitive advantage. Sustainable practices require firms to align environmental standards, ethical sourcing, and production

processes across the entire supply chain network. This alignment naturally strengthens coordination and integration mechanisms. In emerging Chinese firms, where supply chains are often complex and globally dispersed, sustainability initiatives appear to function as a unifying framework that enhances trust, reduces uncertainty, and facilitates smoother coordination among partners.

The significant impact of SCI on OE (H3 supported) highlights the operational benefits of integrated supply chain systems. Integrated supply chains enable firms to synchronize production schedules, optimize inventory levels, and improve demand forecasting accuracy. This finding is consistent with systems theory, which posits that organizational efficiency improves when subsystems operate in a coordinated and interdependent manner. SCI reduces duplication of effort, minimizes delays, and improves responsiveness to market fluctuations. In the Chinese context, where manufacturing ecosystems are highly networked, SCI plays a critical role in ensuring that upstream and downstream partners operate cohesively. This leads to reduced lead times, lower operational costs, and improved service delivery performance.

The results confirm a strong positive relationship between SSCP and TA (H4 supported), suggesting that sustainability initiatives drive digital transformation within firms. This finding is particularly important in the context of Industry 4.0, where digital technologies such as ERP systems, IoT, and big data analytics are increasingly integrated with sustainability goals. SSCP encourages firms to adopt technologies that enable real-time monitoring of environmental performance, traceability of materials, and optimization of resource usage. This aligns with the socio-technical systems perspective, which argues that organizational performance improves when social (sustainability practices) and technical (digital tools) systems evolve together. In China, government policies promoting green manufacturing and digital transformation further reinforce this relationship, making technological adoption a natural extension of sustainability-driven supply chain reforms.

The positive effect of TA on OE (H5 supported) confirms that digital technologies play a crucial role in improving operational performance. Firms that adopt advanced technologies are better able to automate processes, reduce human error, and enhance decision-making speed. This finding is consistent with dynamic capability theory, which suggests that firms must continuously integrate, build, and reconfigure internal and external competencies to respond to changing environments. Technological adoption enhances a firm's ability to sense market changes, seize opportunities, and reconfigure operations efficiently. In emerging Chinese firms, digital technologies serve as a key enabler of lean operations, predictive maintenance, and supply chain visibility, all of which contribute to higher operational efficiency.

One of the most important contributions of this study is the identification of partial mediation effects of SCI and TA in the SSCP–OE relationship. The mediation of SCI indicates that sustainability improves operational efficiency (OE) partly by enhancing coordination and integration across supply chain actors. This suggests that sustainability is not merely an internal operational strategy but a network-level transformation process. Similarly, the mediation effect of TA shows that SSCP fosters digital transformation, which in turn improves operational outcomes. This highlights the synergistic relationship between sustainability and digitalization, often referred to as “green digital transformation.”

This study makes several important theoretical contributions. First, it extends the RBV by demonstrating that SSCP functions as a strategic capability that enhances both relational (SCI) and technological (TA) resources. Second, it integrates sustainability literature with digital transformation theory, showing how environmental practices drive technological upgrading. Third, the study contributes to supply chain integration literature by positioning SSCP as a precursor rather than just an outcome of integration. Finally, the mediation model provides a more comprehensive framework for understanding how sustainability translates into operational performance in emerging market contexts.

From a managerial perspective, the findings suggest that firms should not treat sustainability as a separate function but as an integrated strategic driver of operational excellence. Managers should invest in strengthening supply chain partnerships and digital infrastructure simultaneously. Policy-makers in China and similar emerging economies should also encourage the integration of sustainability and digitalization policies, as both jointly contribute to improving industrial efficiency and competitiveness.

6. Conclusions

This study investigated the role of Sustainable Supply Chain Practices (SSCP) in enhancing Operational Efficiency (OE) in emerging firms in China, while also examining the mediating effects of Supply Chain Integration (SCI) and Technological Adoption (TA). Based on data collected from 400 respondents and analyzed using SmartPLS-based structural equation modeling, the study provides comprehensive empirical evidence on how sustainability-oriented supply chain strategies translate into improved operational outcomes.

The results reveal that SSCP has a significant and positive impact on operational efficiency (OE), both directly and indirectly. Firms that actively adopt sustainable procurement, eco-friendly logistics, waste reduction practices, and supplier collaboration mechanisms demonstrate higher levels of efficiency in resource utilization and operational performance. Furthermore, the study confirms that SSCP significantly enhances both SCI and TA, indicating that sustainability initiatives encourage stronger inter-organizational coordination and accelerate the adoption of digital technologies. In turn, both SCI and TA positively influence OE, highlighting their critical mediating roles. These findings collectively demonstrate that sustainability in supply chain management functions as a strategic enabler of operational excellence rather than merely an environmental compliance mechanism.

From a policy perspective, the findings carry important implications for emerging economies such as China. Policymakers should promote integrated frameworks that simultaneously support green supply chain development and digital transformation. Incentives such as tax benefits, subsidies for green technology adoption, and support for digital infrastructure can encourage firms to embed sustainability into core operational processes. Additionally, strengthening regulatory standards for environmental performance across supply chains can further accelerate the adoption of sustainable practices. Government-led initiatives promoting collaboration between manufacturing firms, technology providers, and logistics partners can also enhance system-wide efficiency and competitiveness.

The study makes several theoretical and practical contributions. Theoretically, it extends the resource-based view by positioning SSCP as a strategic organizational capability that enhances both relational (SCI) and technological (TA) assets. It also contributes to the dynamic capability perspective by demonstrating how sustainability practices enable firms to continuously adapt and improve operational processes in response to changing environmental and market conditions. Moreover, the study integrates sustainability and digital transformation literature, offering a more holistic framework for understanding operational efficiency in emerging markets. Practically, it provides managers with evidence that sustainability should be embedded into core supply chain and technological strategies to achieve long-term efficiency gains and competitive advantage.

Despite these contributions, the study has certain limitations. First, the cross-sectional nature of the data limits the ability to draw causal inferences over time. Longitudinal studies would provide deeper insights into how SSCP influences OE dynamically. Second, the study focuses exclusively on emerging firms in China, which may limit the generalizability of the findings to other institutional and cultural contexts. Future research could extend this model to developed economies or comparative cross-country analyses. Third, the study relies on self-reported survey data, which may introduce potential bias.

Future studies could incorporate objective performance indicators or secondary data sources to enhance robustness.

Declarations

Ethics and Guidelines: The study was conducted in accordance with the Declaration of Helsinki, and ethically approved by the Institutional Review Board of Bangladesh Maritime University (Approval Number: 2435-323-567) on [Date: 24-05-2025]. The ethical approval specifically covers the research procedures and data collection activities conducted for this study.

Consent to participate: Written informed consent was obtained from all participants prior to data collection. Consent was obtained using a standardized written form, signed by each participant before participation in the survey.

Consent to publish: The authors have provided consent to publish.

Competing interests: The authors declare no competing interests.

Data availability statement: Data will be made available on reasonable request from the corresponding author.

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Clinical Trial Number: Not Applicable.

Declaration of using generative AI: During the preparation of this work the author(s) used ChatGPT in order to correct the grammatical errors. After using this tool/service, the author(s) reviewed and edited the content as needed and take full responsibility for the content of the published article.

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