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Integrating green logistics and Industry 4.0 to drive sustainable performance: A circular economy and waste management perspective

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ABSTRACT

In the context of growing environmental concerns and digital transformation, small and medium-sized enterprises (SMEs) in emerging economies face increasing pressure to improve sustainable performance (SP). Green logistics management (GLM) and Industry 4.0 technologies (ID4.0) have emerged as promising solutions. However, previous studies have often examined these dynamics individually and failed to capture the mediation mechanisms particularly circular economy practices (CEP) and waste management (WM) that transform digital and green capabilities into sustainable outcomes. This study aims to develop and empirically test an integrated model that investigates the direct and indirect effects of green logistics management and ID4.0 on SP, with CEP and WM as mediating variables. The model is evaluated using Partial Least Squares Structural Equation Modeling (PLS-SEM) conducted in R. Data were collected from 144 respondents representing manufacturing and logistics SMEs in Vietnam. The findings confirm that GLM positively influences both CEP (β = 0.644) and SP (β = 0.276), while ID4.0 significantly impacts WM (β = 0.575) but has only a modest direct effect on SP (β = 0.126). CEP (β = 0.225) and WM (β = 0.388) both play significant mediating roles, reinforcing their importance in sustainable performance. This study contributes to sustainability research by validating a comprehensive framework that connects digitalization, green logistics, and environmental process integration. For practitioners, the results offer a strategic roadmap for SMEs to enhance SP through the simultaneous adoption of ID4.0 technologies, green logistics practices, and circular economy principles.

Keywords: green logistics management, Industry 4.0, waste management, circular economy, sustainable performance, SMEs, Vietnam

INTRODUCTION

In the last few years, worries about the environment, limited resources, and stricter rules have made sustainability a strategic goal for businesses and policymakers. Improving sustainable performance is very important, but it is also very hard for small and medium-sized businesses (SMEs), which make up more than 97% of all businesses in emerging countries. These businesses often have very few resources, limited technology, and changing market conditions, which makes it hard for them to adopt and use environmentally friendly practices successfully (Dey et al., 2022). In Vietnam, only 6.9% of SMEs have adopted Industry 4.0 technologies (Cirera et al., 2021), while it was found that Vietnam has 54% of them poorly managed (Schulte & Busch, 2025). These statistics highlight a significant gap between technological awareness and the actual implementation of effective environmental practices.

Two important supporting factors have emerged in this transformation: Green Logistics Management and Industry 4.0. GLM promotes environmental efficiency in logistics operations such as transportation, storage, and reverse logistics, contributing to reduced carbon emissions and better use of resources (Zhou et al., 2023). Meanwhile, Industry 4.0 technologies such as Internet of Things (IoT), Artificial Intelligence (AI), and big data analytics enable companies to improve transparency, traceability, and operational flexibility (Sun et al., 2022). These technologies make it easier to include environmental practices in core operations by improving waste monitoring, automating tasks, and making supply chains work better.

However, the mere adoption of these green practices and smart technologies does not automatically translate into optimal sustainable performance. They require practical, actionable operational mechanisms, namely Circular Economy Practices (CEP) and Waste Management (WM) (Pan et al., 2024; Qammar et al., 2023). CEP focuses on maintaining product and material value through principles like reduce, reuse, and recycle, effectively eliminating waste in the production-consumption loop (Pan et al., 2024). Similarly, WM serves as a critical process that utilizes technological advancements to minimize waste generation and prevent environmental pollution (Qammar et al., 2023). While the independent benefits of GLM and ID4.0 are well-documented, realizing their full potential for sustainable performance heavily relies on these internal transformational practices. Integrating both CEP and WM provides a comprehensive lens to explain these internal changes such as CEP acts as a strategic value-creation mechanism that transforms GLM efforts into Sustainable Performance (SP), while WM serves as the operational control mechanism that converts Industry 4.0 technology capabilities into practical sustainable development outcomes.

Prior research has frequently investigated the direct impacts of ID4.0 on supply chain performance (Karmaker et al., 2023) or the isolated effects of GLM on sustainability outcomes (Zhou et al., 2023). Nevertheless, empirical studies integrating these elements into a unified framework remain unexplored. Specifically, the mediating mechanisms through which CEP and WM transfer the strategic benefits of GLM and ID4.0 into holistic SP have not been adequately explored (Karmaker et al., 2023; Qammar et al., 2023). Furthermore, there is a lack of research utilizing a dual-theoretical approach, combining the Natural Resource-Based View model, Cyber-Physical Systems (CPS) theory and Niche theory, to explain how external and technological stimuli are processed internally to achieve the sustainable performance.

To address these existing gaps, the research objective (RO) is: (RO1) To evaluate the direct impacts of operational green logistics and digital technologies on the sustainable performance of Vietnamese SMEs, (RO2) To examine how GLM and ID4.0 distinctly act as antecedents to activate Circular Economy Practices (CEP) and Waste Management (WM), (RO3) To empirically assess the mediating roles of CEP and WM.

This study offers several key contributions. First, it proposes a comprehensive framework that integrates green logistics, digital technologies, and environmental process mechanisms to explain sustainable performance. Second, it empirically validates the mediating roles of circular economy practices and waste management. Third, by applying and testing the model within the context of Vietnamese SMEs, the study provides practical insights for firms in emerging markets seeking to align operational performance with long-term sustainability objectives.

LITERATURE REVIEW

Theory Support

The primary theories explaining the relationship between green logistics management (GLM), circular economy practices (CEP), and sustainable performance are explained by the Natural Resource-Based View (NRBV). Originally proposed by Hart (1995), the NRBV extends the traditional Resource-Based View (RBV) by incorporating the critical relationship between a firm and its natural environment. According to this theory, organizations can achieve a sustainable competitive advantage by developing unique capabilities that facilitate environmentally sustainable economic activities. Within this context, GLM and CEP act as strategic, rare, and inimitable resources that align directly with the NRBV's core strategies, namely pollution prevention and product stewardship. Companies can lessen environmental damage, make better use of resources, and save money on waste disposal and energy use by following these green practices. This leads to better economic, environmental, and social performance.

The integration of Industry 4.0 technologies and waste management (WM) is theoretically supported by Cyber-Physical Systems (CPS) theory and Niche theory. Introduced by Hutchinson (1961), Niche theory emphasizes how biological or organizational entities respond to the depletion of natural resources by minimizing waste and maximizing the utilization of available resources. This theory justifies the strategic imperative of WM and the 3Rs principles (Reduce, Reuse, Recycle) in achieving sustainable development goals. Conversely, CPS theory, as discussed by Park et al. (2012), elucidates the mechanisms of modern smart production systems where physical devices and digital software are deeply intertwined. ID4.0 technologies operate as cyber-physical systems that monitor, synchronize, and exchange information across the physical factory floor and the cyber computational space. Together, CPS and Niche theories explain how technological advancements provide the necessary digital infrastructure to execute efficient physical waste management, ultimately mitigating ecological impacts.

In this framework, Circular Economy Practices (CEP) and Waste Management (WM) are conceptualized as distinct mechanisms. Grounded in the Natural Resource-Based View (NRBV), CEP represents a strategic, long-term capability focused on product life-cycle redesign and closed-loop material flows. Conversely, drawing from Cyber-Physical Systems (CPS) theory, WM functions as an immediate operational control mechanism that addresses physical waste output on the shop floor. While Green Logistics Management (GLM) provides the physical infrastructure for recovery and recycling (activating CEP), Industry 4.0 supplies the digital visibility and real-time data required to optimize waste handling (activating WM). This distinction ensures that the two mediators do not overlap: CEP transforms strategic green intent into systemic value, while WM converts digital intelligence into practical environmental efficiency.

Hypothesis Development

Direct relationships

Green logistics management (GLM) refers to the strategies in supply chain management that aim to reduce the environmental footprint of freight distribution, focusing on material handling, packaging, waste management, and transport (Zhou et al., 2023). On the other hand, circular economy practices (CEP) represent an economic system that replaces the traditional "end-of-life" concept with reducing, reusing, recycling, and recovering materials in the production and consumption processes (Kirchherr et al., 2017). According to the Natural Resource-Based View (NRBV) theory developed by Hart (1995), green logistics can be considered strategic resources that provide a competitive advantage while protecting the natural environment (Cousins et al., 2019). The NRBV theory suggests that implementing GLM provides the necessary physical and informational infrastructure to support closed-loop systems (Pan et al., 2024).

Recent empirical studies have confirmed the strong relationship of GLM and CE. Sharma et al. (2023) found that green logistics initiatives significantly contribute to the adoption of closed-loop practices in manufacturing. Similarly, Zhou et al. (2023) highlighted how reverse logistics and energy-efficient transportation play a critical role in facilitating circular flows. Besides, Seroka-Stolka and Ociepa-Kubicka (2019) investigated the relationship between GLM and CEP through an example in sewage sludge management. In emerging markets, where environmental regulations are still developing, GLM serves as an operational enabler that bridges traditional practices with circular solutions (Karmaker et al., 2023). Although previous literature often discusses green supply chain practices and circular economy as parallel or overlapping concepts (Pan et al., 2024), there is a growing consensus that they have a clear causal relationship. Therefore, we propose the following hypothesis:

H1. Green logistics management has a positive impact on Circular Economy practices.

Sustainable performance is evaluated based on the Triple Bottom Line (TBL) framework, which requires firms to balance economic profitability, environmental protection, and social responsibility (Agyabeng-Mensah et al., 2020; Ciliberto et al., 2021). Grounded in the Natural Resource-Based View (NRBV), GLM acts as a rare and inimitable organizational resource that generates a sustainable competitive advantage (Agyapong et al., 2023; Cousins et al., 2019). By implementing GLM, firms develop internal capabilities that solve operational inefficiencies and reduce environmental damages, which directly enhances their sustainability outcomes. For example, Zhou et al. (2023) found that GLM significantly improves the sustainability performance of manufacturing enterprises. Similarly, Karmaker et al. (2023) demonstrated that green supply chain management practices have a significant positive association with sustainable supply chain performance. While previous studies often isolated these impacts, GLM is increasingly recognized as a comprehensive operational driver for the Triple Bottom Line. Therefore, we propose the following hypothesis:

H2. Green logistics management has a positive impact on Sustainable Performance

The positive relationship between CEP and SP is theoretically supported by the Natural Resource-Based View (NRBV) (Pan et al., 2024). Grounded in the Natural Resource-Based View (NRBV), CEP serves as a rare and inimitable strategic resource that enables firms to optimize material use, prevent pollution, and gain a sustainable competitive advantage (Karmaker et al., 2023). A meta-analysis conducted by Yin et al. (2023) demonstrated that the implementation of CEP significantly improves both the commercial and ecological performance of manufacturing firms. Similarly, Pan et al. (2024) found that practices focusing on circulating products and materials positively affect environmental, financial, and operational performances. While some prior studies highlight the short-term financial challenges of adopting circular systems, current literature indicates that CEP is a fundamental mechanism that translates environmental efforts into holistic sustainability outcomes by retaining the highest utility of resources (Pan et al., 2024). Therefore, we propose the following hypothesis:

H3. Circular Economy practices have a positive impact on Sustainable Performance

Industry 4.0 technologies, including the Internet of Things (IoT) and big data analytics, provide a smart manufacturing infrastructure that is essential for effective Waste Management (WM) operations, which focus on reducing, reusing, and recycling materials (Matarneh et al., 2024; Qammar et al., 2023). Grounded in the Cyber-Physical Systems (CPS) and Niche theories, Industry 4.0 technologies serve as the digital foundation that enables organizations to monitor resource consumption in real-time and respond to resource depletion by minimizing physical waste (Park et al., 2012; Qammar et al., 2023). Empirical evidence highlights that smart technologies, such as advanced robotics and data analytics, significantly optimize material tracking, streamline the disassembly of end-of-life products, and generate less waste than traditional manufacturing methods (Awan et al., 2021; Frank et al., 2019; Masi et al., 2017). While prior studies frequently emphasize the economic benefits of digitalization, current research indicates that Industry 4.0 technologies are a fundamental operational enabler that directly translates digital data into practical waste mitigation actions. Therefore, it is hypothesized that the adoption of Industry 4.0 technologies positively and directly impacts waste management (H4).

H4. Industry 4.0 technologies have a positive impact on Waste Management

The positive relationship between ID4.0 technologies and SP is primarily supported by the Resource-Based View (RBV) and the Cyber-Physical Systems (CPS) theory. Grounded in the RBV and CPS theory, these advanced technologies act as valuable organizational resources that enable real-time monitoring and resource optimization, creating a sustainable competitive advantage (Karmaker et al., 2023; Park et al., 2012). Empirical evidence indicates that the adoption of ID4.0 significantly reduces energy consumption and waste generation, lowers operational costs, and improves workplace safety through automation (Ardanza et al., 2019; Tortorella & Fettermann, 2018; Yin et al., 2023). While prior research often isolates these TBL dimensions or focuses on developed nations, current literature suggests that ID4.0 is a comprehensive driver for holistic sustainability, which is particularly crucial for firms operating in emerging economies (Karmaker et al., 2023). Therefore, we propose the following hypothesis:

H5. Industry 4.0 technologies have a positive impact on Sustainable performance

Waste management (WM) refers to the systematic execution of the 3Rs principle (reduce, reuse, and recycle) to control excessive production and optimize the utilization of raw materials within organizational operations (Qammar et al., 2023). Grounded in Niche Theory (Hutchinson, 1961), WM explains how organizations effectively respond to the depletion of natural resources by maximizing the utilization of available materials and minimizing physical waste generation. Empirical evidence demonstrates that implementing robust WM strategies significantly lowers material procurement costs, reduces ecological pollution, and prevents public health risks associated with hazardous waste (Alola & Adebayo, 2023; Irfan et al., 2023; Pan et al., 2024). While some previous studies have viewed waste management merely as an end-of-pipe regulatory compliance mechanism, current literature indicates that WM is a proactive operational capability. By controlling excessive production and extending the utility of resources, WM functions as a direct investment that yields long-term financial returns and environmental preservation (Qammar et al., 2023). Therefore, we propose the following hypothesis:

H6. Waste management has a positive impact on Sustainable Performance

The mediating of circular economy practices and waste management

The role of circular economy as a mediator is supported by studies demonstrating its multifaceted impact on SP, economic growth, and environmental management. Clark et al. (2016) highlighted the significance of design elements in research and development processes within the field of chemistry. They emphasized the need for careful planning to optimize resource use. Hysa et al. (2020) identified three core components of the circular economy: environmental, social, and economic indices. These elements serve as intermediaries between circular practices and economic development, thereby reinforcing the hypothesis that CE exerts an indirect impact on sustainable growth. In agriculture, Solodovnik et al. (2022) propose that institutional modifications propelled by digitalization and the principles of Circular Economy can enhance environmental management systems. Therefore, we propose the following hypothesis:

H7. Circular economy practices mediates the relationship of green logistics management and sustainable performance

While the direct benefits of Industry 4.0 technologies have been extensively discussed, this study argues that the translation of digital capabilities into Sustainable Performance (SP) requires a concrete operational mediator, namely Waste Management (WM) (Qammar et al., 2023). Grounded in Cyber-Physical Systems (CPS) theory and Niche theory, ID4.0 provides the intangible cyber data regarding resource flows and inefficiencies, which must be executed by the physical processes of WM (reducing, reusing, and recycling) to address tangible ecological and economic challenges (Hutchinson, 1961; Park et al., 2012). Empirical evidence confirms that ID4.0 technologies significantly optimize material tracking and reduce manufacturing errors, which subsequently empowers WM practices to minimize pollution and lower material procurement costs efficiently (Matarneh et al., 2024; Pan et al., 2024; Qammar et al., 2023). Addressing the gap in previous studies that often overlook the operational execution phase of digitalization, this research emphasizes that Industry 4.0 technologies alone cannot independently clean the environment or generate sustainable value. Instead, WM functions as the mandatory operational bridge that converts smart technological inputs into comprehensive economic, environmental, and social outcomes. Therefore, we propose the following hypothesis:

H8. Waste management mediates the relationship of Industry 4.0 technology and sustainable performance

From these hypotheses, the authors proposed the model research shown in **Figure 1**.

METHODOLOGY

Sample and Data Collection Procedure

Respondents were chosen using a non-probability purposive sampling method based on 2 criteria: (1) holding senior and middle management and engineering positions in a manufacturing company; (2) have at least 3 years of experience as professionals in operations, supply chain or sustainability. Potential respondents were then identified through LinkedIn or direct communication. In addition, an Internet survey was conducted to collect answers from various Vietnamese manufacturing companies. It was sent to experts from industry organizations using Google Forms. The questionnaire was developed using measurement items adapted from previous literature and was pre-tested with a pilot group of 30 respondents to ensure content validity and clarity. Participation was voluntary, and respondents were assured of anonymity and confidentiality to enhance the accuracy and reliability of the data.

An a priori power analysis was conducted using G*Power 3.1.9.4 to determine whether the sample size was adequate for testing the proposed structural model. Since the model involved multiple predictive relationships among latent constructs, the analysis employed the F-test family, specifically linear multiple regression with a fixed model and R^2 deviation from zero. Following Cohen's guideline, a medium effect size was specified ($f^2 = 0.15$), with a significance level of $\alpha = 0.05$, statistical power of $1 - \beta = 0.95$, and four predictors, corresponding to the maximum number of direct paths pointing to a single endogenous construct in the structural model. The results indicated that the minimum required sample size was 129 observations. Since the final valid sample consisted of 144 respondents, which exceeded the minimum required sample size, the sample size was considered adequate for subsequent structural model analysis. The distribution process targeted 200 potential firms, resulting in 144 valid responses, a response rate of 72%. To ensure data independence, each firm was represented by exactly one qualified respondent (senior or middle manager).

Measures

To ensure the validity and reliability of the structures used in this study, all measurements were adjusted from well-established sources in the previous literature following the 5-point Likert. GLM is measured by 4 items adapted from Yongrok and Ning (2011): (1) Green packing materials, (2) Reduction of warehouse fee, (3) Optimize the route, (4) Load and unload efficiently. The Industry 4.0 adoption (ID4.0) construct is measured using the framework proposed by

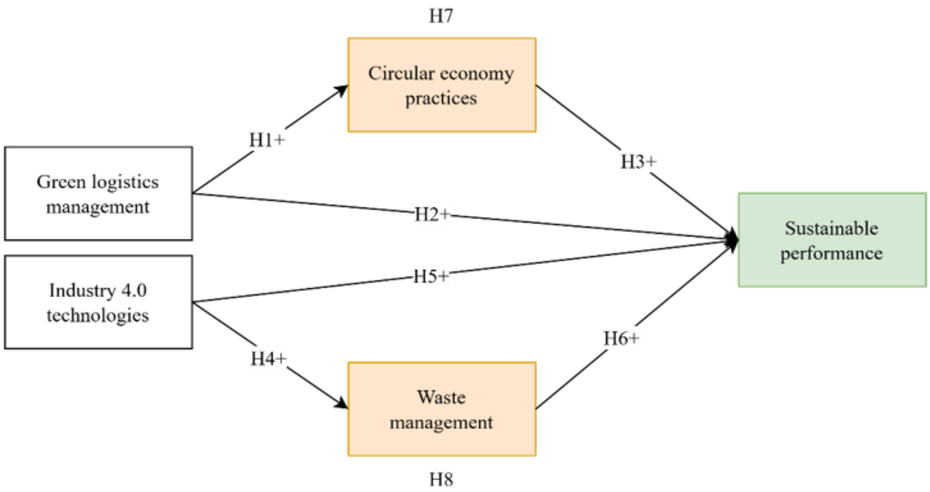

Figure 1. The proposed model (Source: Authors' own elaboration)

Table 1. Inner VIF results

	CE	GLM	ID	SP	WM
CE				2.298	
GLM	1.000			1.908	
ID				1.924	1.000
SP					
WM				1.845	

Karmaker et al. (2023): (1) Recruitment of capable human resources, (2) Development of effective risk management system using artificial intelligence, (3) Digitalization of production processes, (4) Establishment of time-series database. In terms of circular economy practices, the scale adapted from Khan et al. (2022) uses 4 items: (1) Design of products to be easily repaired/refurbished, (2) Design of processes to maximize resource recovery and reuse, (3) Using closed loops in the production, (4) Transfer/sell by-products to other organizations. To evaluate WM, items were drawn from Barr et al. (2001), which emphasized individual and organizational behaviors towards waste reduction, reuse, and recycling: (1) Sorting and segregating waste materials for appropriate disposal or recycling, (2) Look for packaging that can be easily re-used or recycled, (3) Reducing the overall volume of waste generated through process discipline and careful handling. Finally, sustainability performance is measured using indicators proposed by Kamble et al. (2020), which consider the economic, environmental, and social aspects of organizational performance: (1) Minimization of waste generation, (2) Decrease of cost for materials purchased, (3) Improved labor relationship, (4) Significant decrease in rate of consumer complaints, (5) Improvement in overall environmental compliance and regulatory standing.

The measurement items, particularly for WM and GLM, were deliberately adapted to reflect the operational realities of resource-constrained SMEs in emerging economies. In the Vietnamese context, advanced automated environmental systems are often beyond the financial reach of SMEs; thus, behavioral-level practices, such as reusing packaging materials, represent the most accurate measure of their actual green capabilities. Furthermore, Sustainable Performance (SP) is operationalized as a broad construct to align with the Triple Bottom Line (TBL) framework, capturing how SMEs integrate social, environmental, and economic survival into a unified performance strategy.

Common Method Bias

To mitigate the potential effects of Common Method Bias (CMB), we implemented several procedural remedies during the survey design and data collection stages, following the recommendations of Podsakoff et al. (2003). Firstly, we ensured the anonymity and confidentiality of the respondents. The introduction to the survey explicitly stated that the data would be used solely for academic research purposes and that there were no right or wrong answers. Secondly, we refined the survey instrument through a pilot test, ensuring that all questions were simple, specific, and concise. Finally, we utilized a proximal separation approach by randomizing the order of the measurement items.

We examined the Variance Inflation Factor (VIF) values for all latent variables. The analysis revealed that all inner VIF values ranged from 1.000 to 2.298 (see **Table 1**), which are strictly lower than the threshold of 3.3. Therefore, we conclude that common method bias is not a critical concern to the validity of our study's results.

Analytical Procedure and Software

The data analysis was conducted using R statistical software. Specifically, Partial Least Squares Structural Equation Modeling (PLS-SEM) was performed using the SEMinR package, which is widely applied for variance-based structural equation modeling. The SEMinR package enables efficient estimation of PLS path models and supports the assessment of measurement and structural models in line with current methodological standards (Hair et al., 2022).

Table 2. Demographic profile of respondents

Variable	Category	Frequency (n)	Percentage (%)
Gender	Male	92	63.9%
	Female	52	36.1%
Age	Under 30 years	45	31.3%
	30–39 years	58	40.3%
	40–49 years	29	20.1%
	50 years and above	12	8.3%
Education Level	Bachelor's Degree	84	58.3%
	Master's Degree	50	34.7%
	Doctorate/PhD	10	6.9%
Position	Operational Staff	35	24.3%
	Middle Manager	66	45.8%
	Senior Manager/Executive	43	29.9%
Working Experience	Less than 5 years	28	19.4%
	5–10 years	49	34.0%
	11–15 years	41	28.5%
	More than 15 years	26	18.1%
Type of Enterprise	Small enterprise (10–49 employees)	49	30.6%
	Medium enterprise (50–249 employees)	99	69.4%
Business Sector	Food and Beverage Manufacturing	38	26.4%
	Electronics and Electrical Equipment	29	20.1%
	Textile and Garment	24	16.7%
	Packaging and Logistics	30	20.8%
	Other Manufacturing	23	16.0%

Table 3. Construct reliability and discriminant validity

	GLM	ID	CE	WM	SP	CR	AVE
GLM	0.867					0.924	0.752
ID	0.557	0.889				0.938	0.791
CE	0.644	0.640	0.897			0.943	0.804
WM	0.559	0.575	0.612	0.901		0.928	0.812
SP	0.708	0.647	0.721	0.752	0.874	0.942	0.764

HTMT: 0.614 – 0.831; CR: Composite Reliability; AVE: Average Variance Extracted

The analysis followed a two-step approach. First, the measurement model was evaluated by examining internal consistency reliability, convergent validity, and discriminant validity using indicators such as Composite Reliability (CR), Average Variance Extracted (AVE), and the Heterotrait-Monotrait ratio (HTMT). Second, the structural model was assessed by analyzing path coefficients, coefficient of determination (R^2), predictive relevance (Q^2), and effect sizes (f^2), following established guidelines in the PLS-SEM literature (Hair et al., 2022). To test the significance of the hypothesized relationships, a bootstrapping procedure with 5,000 resamples was employed. This approach allows for robust estimation of standard errors and confidence intervals for the path coefficients.

RESULTS

Preliminary Assessment of the Research Sample

Table 2 provides an overview of the demographic characteristics of 144 respondents from manufacturing and logistics SMEs in Vietnam. The majority of respondents are male (63.9%), and a significant portion is aged 30–39 (40.3%), indicating that the workforce is predominantly young and male. Most participants possess at least a bachelor's degree (58.3%), while a noteworthy percentage holds a postgraduate degree (41.6%). In terms of professional backgrounds, 45.8% of respondents are middle managers, followed by senior managers/executives at 29.9% and operations staff at 24.3%. Additionally, most have between 5 to 15 years of experience, reflecting substantial exposure within the industry. The sample primarily consists of mid-sized enterprises (69.4%), operating across various sectors, including food and beverage (26.4%), electronics (20.1%), and packaging/logistics (20.8%), highlighting performance across key industry areas.

Measurement Scale Assessment

The results in **Table 3** indicate that all constructs demonstrated high levels of internal consistency, with composite reliability values ranging from 0.924 (GLM) to 0.943 (CE). These values are well above the acceptable threshold of 0.70, as suggested by Hair et al. (2022). This finding confirms that the items used to measure each construct are highly consistent. Regarding convergent validity, all constructs showed Average Variance Extracted (AVE) values exceeding the recommended cutoff of 0.50, with values ranging from 0.752 to 0.812. These results confirm that the constructs capture a significant proportion of the variance in their respective indicators. Discriminant validity was assessed using the Heterotrait-Monotrait (HTMT) criterion. The HTMT values ranged from 0.614 to 0.831, which are below the conservative threshold of 0.85. Furthermore, a bootstrapping procedure was conducted to assess the HTMT. The results confirm that the

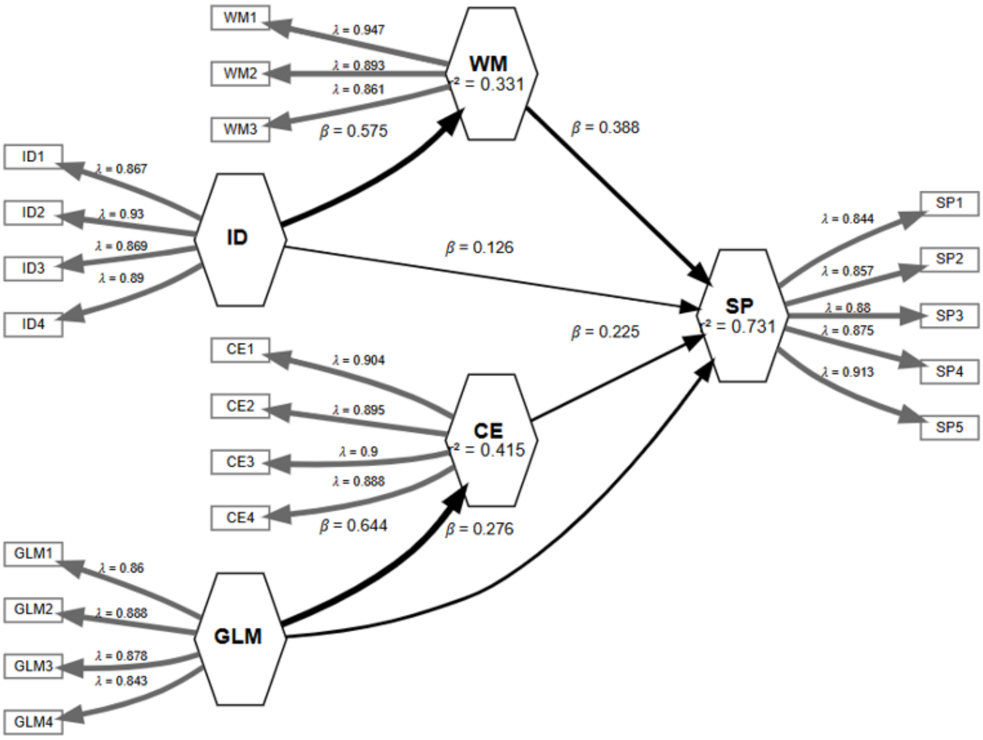

Figure 2. Structural model (Source: Authors' own elaboration)

Table 4. Evaluation of predictive explanatory

	R^2	Adjusted R^2	Q^2
SP	0.731	0.723	0.549
CE	0.415	0.411	0.322
WM	0.331	0.326	0.261

upper bounds of the 95% confidence intervals for all HTMT values do not include the value of 1.0, thereby robustly establishing the discriminant validity among all constructs.

To evaluate the presence of multicollinearity among the predictor constructs, we examined the Variance Inflation Factor (VIF) values in the inner model. VIF values indicate how much the variance of an estimated regression coefficient increases due to collinearity. In the context of PLS-SEM, a VIF value below 3.3 is considered acceptable, indicating no significant collinearity issues (Hair et al., 2022).

As shown in **Table 1**, all VIF values fall within the range of 1.000 to 2.298, which is well below the recommended threshold. Specifically, the highest VIF value of 2.298 was observed between CE and SP. This was followed by the VIF values for ID4.0 → SP (1.924), GLM → SP (1.908), and WM → SP (1.845). The lowest VIF value recorded was 1.000 for constructs GLM → GLM and ID4.0 → ID4.0, indicating no multicollinearity within those constructs.

These results confirm that multicollinearity does not pose a threat to the estimation of path coefficients within the structural model. Consequently, the predictors can be interpreted independently and reliably, which supports the robustness of the model's explanatory power.

Structural Models Assessment

Figure 2 illustrates the structural relationships among the constructs in the proposed model. The path coefficient values (β) range from 0.126 to 0.644, indicating moderate to strong effect sizes (Hair & Alamer, 2022). The R^2 value for Sustainable Performance (SP) is detailed in **Table 4**. The structural model demonstrates statistically significant path relationships and satisfactory levels of explained variance, validating the hypothesized connections among green logistics, Industry 4.0, the circular economy, waste management, and sustainable performance.

To evaluate the explanatory quality of the structural model, we examined the adjusted R^2 values for all constructs. As presented in **Table 4**, the adjusted R^2 for Sustainable Performance (SP) is 0.723, indicating that the model accounts for approximately 72.3% of the variance in SP after considering model complexity. According to the guidelines by Hair et al. (2022), this suggests substantial explanatory power. For the mediating variables, CE and WM resulted in adjusted R^2 values of 0.411 and 0.326, respectively. These findings indicate that the predictors - GLM and ID4.0 - offer a moderate level of explanatory power for CE and WM. According to Hair et al. (2019), adjusted R^2 is a more conservative metric than standard R^2, particularly in models with multiple exogenous variables. The values obtained in this study reflect a satisfactory model fit.

The predictive relevance (Q^2) values obtained through the blindfolding procedure indicate that the structural model exhibits substantial predictive capability. Specifically, the Q^2 value for SP is 0.549, suggesting a very high level of predictive

Table 5. f square testing results

	GLM	ID	CE	WM	SP
GLM			0.709		0.148
ID				0.494	0.031
CE					0.082
WM					0.299

Table 6. Hypotheses testing results

Direct paths	Original sample	Bootstrap Mean	SD Bootstrap	T-Statistic	2.5% CI	97.5% CI	p value
GLM → CE	0.644	0.638	0.073	8.832	0.479	0.757	0.000
GLM → SP	0.276	0.271	0.066	4.198	0.141	0.410	0.000
ID → WM	0.575	0.573	0.078	7.371	0.415	0.708	0.000
ID → SP	0.126	0.128	0.065	1.936	0.015	0.261	0.047
CE → SP	0.225	0.228	0.070	3.205	0.090	0.356	0.001
WM → SP	0.388	0.389	0.063	6.161	0.264	0.511	0.000

Table 7. Results of testing the mediating role

	Original Sample (O)	Sample Mean (M)	Standard Deviation (STDEV)	T Statistics (|O/STDEV|)	2.5% CI	97.5% CI	p value
GLM → CE → SP	0.145	0.144	0.047	3.055	0.052	0.240	0.002
ID → WM → SP	0.223	0.221	0.048	4.648	0.131	0.318	0.000

relevance, well above the 0.35 benchmark recommended by Hair et al. (2022). The Q^2 values for CE (0.322) and WM (0.261) also exceed the 0.15 threshold, indicating medium-to-high predictive relevance. These results demonstrate that the model not only explains a significant portion of variance (as shown by R^2), but also performs effectively in predicting unseen data for all endogenous constructs.

The f^2 effect size analysis provides further insight into the relative contributions of predictor constructs within the structural model. The results show that GLM has a very strong effect on CEP (f^2 = 0.709), suggesting that GLM plays a foundational role in facilitating circular transitions. Similarly, ID4.0 exerts a large effect on WM (f^2 = 0.494), affirming the relevance of digital capabilities in optimizing waste-related operations in **Table 5**.

Regarding SP, WM demonstrates the largest localized effect (f^2 = 0.299), while GLM shows a moderate effect (f^2 = 0.148). In contrast, Circular Economy exhibits only a small effect (f^2 = 0.082), and ID4.0's direct effect on SP is minimal (f^2 = 0.031), reinforcing the earlier findings that its impact is largely channeled through WM.

Hypothesis Testing Results by Bootstrapping

To evaluate the statistical significance of the proposed structural relationships, a bootstrapping technique with 5,000 resamples was used. The results are summarized in **Table 6**, which includes original sample estimates (β), bootstrapped means, standard errors, t-statistics, 95% confidence intervals (CIs), and p-values. The analysis confirmed that all six direct hypotheses were statistically significant at the $p < 0.05$ level. Specifically, GLM had a strong and significant effect on the CE (β = 0.644, t = 8.832, p = 0.000), with a confidence interval ranging from 0.479 to 0.757. This finding confirms that green logistics plays a crucial role in promoting circular practices within supply chains.

GLM also demonstrated a moderate and significant effect on SP (β = 0.276, t = 4.198, p = 0.000), suggesting that logistics practices not only enhance environmental processes but also contribute directly to broader performance outcomes.

ID4.0 showed a strong effect on WM (β = 0.575, t = 7.371, p = 0.000), indicating that digital technologies play a vital role in improving operational efficiency related to waste management. While its direct effect on SP was relatively weaker (β = 0.126, t = 1.936, p = 0.047), it was still statistically significant, suggesting that ID4.0 may exert more of its influence indirectly. Furthermore, both CE (β = 0.225, t = 3.205, p = 0.001) and WM (β = 0.388, t = 6.161, p = 0.000) had significant direct effects on Sustainable Performance, underscoring their importance as mediators that connect upstream practices to outcomes. All 95% confidence intervals for the tested relationships excluded zero, confirming the robustness of the estimates and supporting the theoretical assumptions underlying the proposed model.

Testing the Mediating Roles

The analysis indicates that the CE significantly mediates the relationship between GLM and SP. The indirect effect from GLM to CE to SP was measured at 0.145, with a T-value of 3.055 and a p-value of 0.002. The 95% confidence interval [0.052, 0.240] does not include zero, confirming the statistical significance of the mediation effect. In a similar vein, WM was found to significantly mediate the relationship between ID4.0 and SP. The indirect effect from ID4.0 to WM to SP was 0.223, with a T-value of 4.648 and a p-value of less than 0.001. The confidence interval [0.131, 0.318] also excludes zero, reinforcing the reliability of this mediating relationship in **Table 7**.

DISCUSSION

The Role of GLM, CE and SP

The results indicate that GLM has a positive impact on CE, with a coefficient (β) of 0.644. The hypothesis is accepted with a significance level of $p < 0.05$. This finding aligns with the work of Zhou et al. (2023), which highlights that green logistics encourages manufacturing companies in Bangladesh to reuse product packaging materials, leftover materials, and engage in waste recycling. This supports the view that GLM not only enhances logistics operations but also facilitates the shift from linear economic models to circular models, particularly for businesses in developing economies like Vietnam.

In addition, GLM showed a positive response to SP ($\beta = 0.276$ and $p < 0.05$). This result is consistent with the findings of Zhou et al. (2023) and Agyabeng-Mensah et al. (2020). However, the effect size is relatively lower than studies conducted in high-income economies. Specifically, Zhou et al. (2023) demonstrated a GLM → SP relationship with $\beta = 0.481$, which is significantly higher than what was observed in Vietnam. This disparity can be attributed to several factors, including infrastructure vulnerabilities, a lack of green certification, and limited regulatory enforcement in Vietnam, which weaken the potential benefits of GLM on company performance.

The above results also demonstrate the positive relationship between CE and SP ($\beta = 0.225$, $p = 0.001$), which is consistent with Bag and Rahman (2023) and Meshko and Nikolaienko (2021), who found that CE improves environmental and economic efficiency. This highlights the importance of CE in assisting businesses to create value from waste and reduce costs.

The indirect relationship between GLM and SP through CEP ($\beta = 0.145$, $p = 0.002$) highlights the mediating role of the CE. While previous studies have often treated GLM and CE as separate structures (Batista et al., 2018), our findings support the integration of these theoretical frameworks. This integration is further demonstrated by the work of Bag and Rahman (2023), which suggests that green logistics is more impactful when it is incorporated within a circular framework. However, the role of CE as a mediator has not been extensively validated. This finding contributes new insights into how CE serves as a bridge between GLM and SP.

The Role of ID4.0, WM and SP

The results indicated a positive relationship between ID4.0 and WM, with a β value of 0.575 ($p < 0.001$). This finding aligns with previous studies: Zhang et al. (2023) identified 11 factors that drive smart WM in the supply chain through the implementation of ID4.0 in China, while Qammar et al. (2023) emphasized the necessity for businesses to develop ID4.0 applications for effective waste management. These findings highlight the crucial role of ID4.0 in the digitization of waste treatment systems.

Although ID4.0 has a positive but relatively weak impact on SP ($\beta = 0.126$, $p = 0.047$), this is similar to the findings of Qammar et al. (2023) who demonstrated the relationship between ID4.0 and SP with $\beta = 0.198$. This implies that, for developing countries such as Vietnam that lack technology investment, digital skills and support policies for businesses or investing in ID4.0 are costly, which does not support the financial aspect of the business. First, the prohibitive investment costs of advanced ID4.0 technologies often strain the short-term financial performance of resource-constrained SMEs. Second, there is a distinct limitation in digital capabilities and a shortage of highly skilled personnel capable of fully exploiting these technologies. Third, digital transformation in Vietnam frequently faces insufficient institutional support and underdeveloped technological infrastructure, making seamless integration difficult. Consequently, merely acquiring digital technologies does not automatically yield broad economic or environmental credit. It should also be noted that the p-value of ID4.0 → SP is close to the conventional significance threshold of 0.05. The findings suggest that the contribution of Industry 4.0 to sustainable performance is primarily transmitted through Waste Management as a mediating mechanism, rather than through a direct pathway, reinforcing the critical role of WM as the operational bridge between digital capabilities and sustainable outcomes.

WM plays a significant mediating role in the relationship between ID4.0 and SP ($\beta = 0.223$, $p < 0.001$). These findings not only validate the theoretical frameworks of Natural Resource-Based View (NRBV) but also demonstrate that WM tools and digital technologies effectively yield SP only when they are implemented together and connected through the mediating processes of environmental management (CE and WM). This highlights a new contribution from this study, as most prior research has primarily focused on direct linear relationships while neglecting the crucial mediating factor.

Furthermore, our results highlight a critical contextual dynamic: WM matters more strongly than CEP for driving sustainable performance in this context. This difference can be explained by the specific resource constraints of SMEs in Vietnam. WM involves localized, actionable, and short-term practices on the shop floor (e.g., immediate physical waste reduction, packaging reuse) that quickly translate into tangible cost savings and operational efficiency. In contrast, CEP operates as a strategic, macro-level mechanism that requires systemic changes across the entire product life-cycle and deep supply chain collaboration. For resource-constrained SMEs, such large-scale circular transitions take significantly longer to manifest as measurable performance gains compared to the immediate 'low-hanging fruit' provided by daily waste management.

IMPLICATIONS OF THE STUDY

Theoretical Implications

This study offers significant theoretical implications for sustainable production management, particularly within the context of developing countries such as Vietnam.

Firstly, the study advances the theoretical intersection of the Natural Resource-Based View (NRBV) and Cyber-Physical Systems theory. While prior literature has extensively examined green logistics and digital transformation in isolation, this study develops an integrated framework demonstrating how technological resources (ID4.0) and green physical infrastructures collectively drive the sustainable performance. By doing so, it broadens the scope of the NRBV by integrating digital capabilities as fundamental enablers of natural resource preservation.

Secondly, the findings conceptualize and validate the distinct, dual mediating roles of Circular Economy Practices (CEP) and Waste Management (WM). This contributes a nuanced understanding of how external and technological stimuli are processed internally. Specifically, grounded in the NRBV, CEP is validated as a macro-level, strategic value-creation mechanism that transforms GLM into sustainable performance. Conversely, drawing from CPS and RBV perspectives, WM is identified as the micro-level, operational execution layer. The study theorizes that digital intelligence from ID4.0 remains a latent capability unless it is operationalized through physical waste management practices on the shop floor. This dual-pathway model clarifies how green and smart inputs are transformed into sustainable performance.

Thirdly, by operationalizing Sustainable Performance (SP) as a multidimensional construct and testing it via Partial Least Squares Structural Equation Modeling (PLS-SEM), the study enriches the measurement and evaluation of sustainable value creation. The methodology confirms that in resource-constrained environments, performance cannot be evaluated solely on economic returns but must integrate environmental compliance and social operations simultaneously.

Lastly, by examining the theoretical model within Vietnam's manufacturing industry as a representation of a developing economy, the study provides valuable empirical evidence and broadens generalizations for environmental management theories, particularly for SMEs that face limited resources and increasing innovation demands.

Practical Implications

This study offers several important practical implications for manufacturing enterprises in Vietnam, particularly for SMEs that are under pressure to enhance their performance and meet sustainability requirements.

First, the findings indicate that implementing ID4.0 will not automatically lead to improved sustainable performance unless it is accompanied by effective WM strategies. Therefore, managers should prioritize the integration of ID4.0 technology with WM systems using solutions such as automated sorting, waste flow monitoring, and data analysis to optimize waste treatment.

Second, GLM is not only a strategic choice but also a crucial factor for achieving SP when used in conjunction with CEP. Businesses should restructure their supply chains towards environmental sustainability by focusing on the entire lifecycle from sourcing raw materials and designing products to recovering, reusing, and recycling outputs. Promoting CEP can enhance resource value, reduce raw material costs, and improve the company's reputation among customers and international partners.

Third, considering that the majority of manufacturing enterprises in Vietnam are small and medium-sized with limited financial and human resources, both digital transformation and green transformation should be implemented gradually. Initiatives should start with simple and low-cost solutions, such as internal waste management improvements, enhancing green operations, training employees on CEP, and leveraging by-products as input materials. Additionally, businesses may collaborate within an industry cluster model to share technology, equipment, and by-product resources.

Finally, the research underscores the importance of integrated strategic planning, where technological, environmental, and operational factors are not treated in isolation but are harmoniously coordinated within the governance model. Applying comprehensive sustainability performance assessment models, which encompass economic, environmental, and social metrics, will assist businesses in making investment and governance decisions that align with long-term objectives.

Policy Implications

To foster an ecosystem conducive to sustainable performance, macro- and meso-level stakeholders must implement targeted interventions addressing the specific constraints of Vietnamese SMEs. We propose the following specific recommendations across three key institutional levels.

First, for the Vietnamese government, policymakers should transition from generalized environmental guidelines to concrete financial and regulatory instruments. Specifically, the government should introduce targeted tax incentives or import duty exemptions for SMEs investing in green logistics technologies (e.g., energy-efficient fleets, eco-packaging materials). Additionally, establishing state-backed financial subsidy programs or low-interest loan facilities is crucial to help SMEs absorb the high initial costs of Industry 4.0 digital transformation.

Second, for Logistics industry associations, industry bodies must act as collaborative hubs to overcome individual SME resource constraints. Associations should spearhead the development of standardized, cloud-based Industry 4.0 waste management platforms. By providing a shared digital infrastructure, multiple SMEs can collectively track, classify, and trade waste or by-products, thereby activating industrial symbiosis without requiring each firm to build its own independent software system.

Third, for SME support programs**,** national and international developmental programs should shift focus from theoretical sustainability advocacy to hands-on capacity building. These programs should offer subsidized digital and environmental audits to help SMEs identify precise areas where ID4.0 can optimize their specific waste streams. Furthermore, funding should be allocated to vocational training initiatives aimed at upskilling SME personnel, ensuring they possess the dual competencies required to operate digital tools and execute circular economy practices effectively.

CONCLUSION AND FUTURE RESEARCH

Conclusion

This study evaluates the impact of GLM, ID4.0, CEP, and WM on SP within the context of a growing economy. By reviewing existing academic literature, the study formulates hypotheses to examine both the direct impacts and the mediating roles of CE and WM in transforming green and digital strategies into sustainable outcomes. The proposed model is tested using the PLS-SEM method, based on survey data collected from SMEs in the manufacturing and logistics sectors in Vietnam - a country undergoing rapid industrialization yet facing challenges related to environmental infrastructure, technological capacity, and resource recycling. The findings indicate that among the four input factors, WM has the strongest direct impact on sustainable performance, followed by GLM, CE, and then ID4.0. Moreover, both CE and WM serve as crucial intermediary mechanisms, demonstrating their importance in helping Vietnamese businesses effectively implement green and digital strategies.

Limitations and Future Research

While this study provides robust empirical evidence and novel insights into the mediating roles of environmental processes, several limitations must be acknowledged, serving as avenues for future research. First, this study relies on a cross-sectional design, capturing data at a single point in time. To capture the dynamic evolution of circular economy practices and waste management maturity, future research should adopt longitudinal designs. Tracking SMEs over multiple years would provide deeper insights into how the impacts of these technological and environmental investments compound over time. Second, all variables in the structural model were measured using self-reported survey data from SME managers, with a single respondent representing each firm. Relying on one informant per organization introduces the risk of common method bias and may not fully capture the diversity of perspectives within a firm, potentially limiting the accuracy and generalizability of the findings. Future studies are strongly encouraged to utilize multi-source data collection. Combining managerial surveys with objective operational metrics such as secondary environmental audit reports, actual energy consumption logs, or real-time IoT waste tracking data, would significantly enhance the measurement validity. Finally, the empirical scope of this study is confined to SMEs within the manufacturing and logistics sectors in Vietnam. Vietnam represents a specific emerging market context characterized by rapid industrialization, high resource constraints, and developing environmental regulations. Therefore, we recommend that scholars conduct comparative studies across different countries or diverse industries (e.g., agriculture, services) to test the robustness of this integrated framework under varying institutional and economic conditions.

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REFERENCES

Agyabeng-Mensah, Y., Afum, E., & Ahenkorah, E. (2020). Exploring financial performance and green logistics management practices: Examining the mediating influences of market, environmental and social performances. *Journal of Cleaner Production*, *258*, Article 120613. https://doi.org/10.1016/j.jclepro.2020.120613

Agyapong, A., Aidoo, S. O., Acquaah, M., & Akomea, S. (2023). Environmental orientation and sustainability performance; The mediated moderation effects of green supply chain management practices and institutional pressure. *Journal of Cleaner Production*, *430*, Article 139592. https://doi.org/10.1016/j.jclepro.2023.139592

Alola, A. A., & Adebayo, T. S. (2023). Analysing the waste management, industrial and agriculture greenhouse gas emissions of biomass, fossil fuel, and metallic ores utilization in Iceland. *Science of the Total Environment*, *887*, Article 164115. https://doi.org/10.1016/j.scitotenv.2023.164115

Ardanza, A., Moreno, A., Segura, Á., de la Cruz, M., & Aguinaga, D. (2019). Sustainable and flexible industrial human machine interfaces to support adaptable applications in the Industry 4.0 paradigm. *International Journal of Production Research*, *57*(12), 4045-4059. https://doi.org/10.1080/00207543.2019.1572932

Awan, U., Shamim, S., Khan, Z., Zia, N. U., Shariq, S. M., & Khan, M. N. (2021). Big data analytics capability and decision-making: The role of data-driven insight on circular economy performance. *Technological Forecasting and Social Change*, *168*, Article 120766. https://doi.org/10.1016/j.techfore.2021.120766

Bag, S., & Rahman, M. S. (2023). The role of capabilities in shaping sustainable supply chain flexibility and enhancing circular economy-target performance: An empirical study. *Supply Chain Management*, *28*(1), 162-178. https://doi.org/10.1108/SCM-05-2021-0246

Barr, S., Gilg, A. W., & Ford, N. J. (2001). Differences between household waste reduction, reuse and recycling behaviour: A study of reported behaviours, intentions and explanatory variables. *Environmental & Waste Management*, *4*(2), 69-82.

Batista, L., Bourlakis, M., Smart, P., & Maull, R. (2018). In search of a circular supply chain archetype–a content-analysis-based literature review. *Production Planning and Control*, *29*(6), 438-451. https://doi.org/10.1080/09537287.2017.1343502

Ciliberto, C., Szopik-Depczyńska, K., Tarczyńska-Łuniewska, M., Ruggieri, A., & Ioppolo, G. (2021). Enabling the Circular Economy transition: A sustainable lean manufacturing recipe for Industry 4.0. *Business Strategy and the Environment*, *30*(7), 3255-3272. https://doi.org/10.1002/bse.2801

Cirera, X., Comin, D., Cruz, M., Lee, K. M., & Martins-Neto, A. S. (2021). *Firm-level technology adoption in Vietnam* [Policy Research Working Paper 9567]. World Bank Group: Finance, Competitiveness and Innovation Global Practice.

Clark, J. H., Farmer, T. J., Herrero-Davila, L., & Sherwood, J. (2016). Circular economy design considerations for research and process development in the chemical sciences. *Green Chemistry,* 18(14), 3914-3934. https://doi.org/10.1039/C6GC00501B

Cousins, P. D., Lawson, B., Petersen, K. J., & Fugate, B. (2019). Investigating green supply chain management practices and performance: The moderating roles of supply chain ecocentricity and traceability. *International journal of operations & production management*, *39*(5), 767-786. https://doi.org/10.1108/IJOPM-11-2018-0676

Dey, P. K., Chowdhury, S., Rodríguez-Espíndola, O., Parkes, G., Tuyet, N. T. A., Duc Long, D., Phuong Ha, T., & Budhwar, P. (2022). Impact of organisational factors on the circular economy practices and sustainable performance of small and medium sized enterprises in Vietnam. In *Supply Chain Sustainability in Small and Medium Sized Enterprises* (pp. 46-80). Routledge. https://doi.org/10.4324/9781003018551-3

Frank, A. G., Dalenogare, L. S., & Ayala, N. F. (2019). Industry 4.0 technologies: Implementation patterns in manufacturing companies. *International Journal of Production Economics*, *210*, 15-26. https://doi.org/10.1016/j.ijpe.2019.01.004

Hair, J. F., Ringle, C. M., Gudergan, S. P., Fischer, A., Nitzl, C., & Menictas, C. (2019). Partial least squares structural equation modeling-based discrete choice modeling: an illustration in modeling retailer choice. *Business Research*, *12*(1), 115-142. https://doi.org/10.1007/s40685-018-0072-4

Hair, J., & Alamer, A. (2022). Partial Least Squares Structural Equation Modeling (PLS-SEM) in second language and education research: Guidelines using an applied example. *Research Methods in Applied Linguistics*, *1*(3), 100027-100027. https://doi.org/10.1016/j.rmal.2022.100027

Hair, J., Hult, G. T. M., Ringle, C., & Sarstedt, M. (2022). *A Primer on Partial Least Squares Structural Equation Modeling (PLS-SEM)*. https://doi.org/10.1007/978-3-030-80519-7

Hart, S. L. (1995). A natural-resource-based view of the firm. *The Academy of Management Review*, *20*(4), 986-1014. https://doi.org/10.2307/258963

Hutchinson, G. E. (1961). The paradox of the plankton. *The American Naturalist*, *95*(882), 137-145. https://doi.org/10.1086/282171

Hysa, E., Kruja, A., Rehman, N. U., & Laurenti, R. (2020). Circular economy innovation and environmental sustainability impact on economic growth: An integrated model for sustainable development. *Sustainability*, *12*(12), Article 4831. https://doi.org/10.3390/SU12124831

Irfan, M., Ullah, S., Razzaq, A., Cai, J., & Adebayo, T. S. (2023). Unleashing the dynamic impact of tourism industry on energy consumption, economic output, and environmental quality in China: A way forward towards environmental sustainability. *Journal of Cleaner Production*, *387*, Article 135778. https://doi.org/10.1016/j.jclepro.2022.135778

Kamble, S., Gunasekaran, A., & Dhone, N. C. (2020). Industry 4.0 and lean manufacturing practices for sustainable organisational performance in Indian manufacturing companies. *International Journal of Production Research*, *58*(5), 1319-1337. https://doi.org/10.1080/00207543.2019.1630772

Karmaker, C. L., Aziz, R. A., Ahmed, T., Misbauddin, S. M., & Moktadir, M. A. (2023). Impact of industry 4.0 technologies on sustainable supply chain performance: The mediating role of green supply chain management practices and circular economy. *Journal of Cleaner Production*, *419*, 138249-138249. https://doi.org/10.1016/j.jclepro.2023.138249

Khan, S. A. R., Umar, M., Asadov, A., Tanveer, M., & Yu, Z. (2022). Technological revolution and circular economy practices: A mechanism of green economy. *Sustainability*, *14*(8), Article 4524. https://doi.org/10.3390/su14084524

Kirchherr, J., Reike, D., & Hekkert, M. P. (2017). Conceptualizing the circular economy: An analysis of 114 Definitions. *Resources, Conservation and Recycling, 127*, 221-232. https://doi.org/10.1016/j.resconrec.2017.09.005

Masi, D., Day, S., & Godsell, J. (2017). Supply chain configurations in the circular economy: A systematic literature review. *Sustainability*, *9*(9), Article 1602. https://doi.org/10.3390/su9091602

Matarneh, S., Piprani, A. Z., Ellahi, R. M., Nguyen, D. N., Le, T. M., & Nazir, S. (2024). Industry 4.0 technologies and circular economy synergies: Enhancing corporate sustainability through sustainable supply chain integration and flexibility. *Environmental Technology & Innovation*, *35*, Article 103723. https://doi.org/10.1016/j.eti.2024.103723

Meshko, N., & Nikolaienko, A. (2021). Analysis of the impact of business greening, which based on circular economy principles, on sustainable tourism development in European countries. *European Journal of Management Issues*, *29*(3), 162-170. https://doi.org/10.15421/192116

Pan, X., Wong, C. W., Wong, C. Y., Boon-itt, S., & Li, C. (2024). The influences of circular economy practices on manufacturing firm's performance: A meta-analytic structural equation modeling study. *International Journal of Production Economics*, *273*, Article 109267. https://doi.org/10.1016/j.ijpe.2024.109267

Park, K.-J., Zheng, R., & Liu, X. (2012). Cyber-physical systems: Milestones and research challenges. *Computer Communications*, *36*(1), 1-7. https://doi.org/10.1016/j.comcom.2012.09.006

Podsakoff, P. M., MacKenzie, S. B., Lee, J.-Y., & Podsakoff, N. P. (2003). Common method biases in behavioral research: A critical review of the literature and recommended remedies. *Journal of Applied Psychology*, *88*(5), 879-903. https://doi.org/10.1037/0021-9010.88.5.879

Qammar, R., Abidin, Z. U., Sair, S. A., Ahmad, I., Mansour, A. a. Z., & Owidha, H. F. A. A. (2023). Impact of waste management among Industry 4.0 and sustainable development. *Environmental Science and Pollution Research*, *30*(45), 100743-100752. https://doi.org/10.1007/s11356-023-28987-8

Schulte, M. L., & Busch, P.-O. (2025). *Plastic policies in Vietnam*. The SWITCH-Asia Programme. https://www.switch-asia.eu/site/assets/files/4399/plastic_policies_vn_final.pdf

Seroka-Stolka, O., & Ociepa-Kubicka, A. (2019). Green logistics and circular economy. *Transportation Research Procedia, 39*, 471-479. https://doi.org/10.1016/j.trpro.2019.06.049

Sharma, M., Luthra, S., Joshi, S., K, A. K., & Jain, A. (2023). Green logistics driven circular practices adoption in industry 4.0 Era: A moderating effect of institution pressure and supply chain flexibility. *Journal of Cleaner Production, 383*, Article 135284. https://doi.org/10.1016/j.jclepro.2022.135284

Solodovnik, A. I., Savkin, V. I., Sidorenko, O. V., Buraeva, E. V., & Bogachev, A. I. (2022). Improving the environmental management system to ensure sustainable development of the agricultural sector in a circular economy. IOP Conference Series: Earth and Environmental Science, 981, Article 022038. https://doi.org/10.1088/1755-1315/981/2/022038

Sun, X., Yu, H., Solvang, W. D., Wang, Y., & Wang, K. (2022). The application of Industry 4.0 technologies in sustainable logistics: a systematic literature review (2012–2020) to explore future research opportunities. *Environmental Science and Pollution Research*, *29*(7), 9560-9591. https://doi.org/10.1007/s11356-021-17693-y

Tortorella, G. L., & Fettermann, D. (2018). Implementation of Industry 4.0 and lean production in Brazilian manufacturing companies. *International Journal of Production Research*, *56*(8), 2975-2987. https://doi.org/10.1080/00207543.2017.1391420

Yin, S., Jia, F., Chen, L., & Wang, Q. (2023). Circular economy practices and sustainable performance: A meta-analysis. *Resources, Conservation and Recycling*, *190*, Article 106838. https://doi.org/10.1016/j.resconrec.2022.106838

Yongrok, C., & Ning, Z. (2011). Does proactive green logistics management improve business performance? A case of Chinese logistics enterprises. *African Journal of Business Management*, *5*(17), 7564-7574. https://doi.org/10.5897/AJBM11.613

Zhang, A., Venkatesh, V. G., Wang, J. X., Mani, V., Wan, M., & Qu, T. (2023). Drivers of Industry 4.0-enabled smart waste management in supply chain operations: A circular economy perspective in China. *Production Planning & Control*, *34*(10), 870-886. https://doi.org/10.1080/09537287.2021.1980909

Zhou, B., Siddik, A. B., Zheng, G.-W., & Masukujjaman, M. (2023). Unveiling the role of green logistics management in improving SMEs' sustainability performance: Do circular economy practices and supply chain traceability matter? *Systems*, *11*(4), Article 198. https://doi.org/10.3390/systems11040198