Management and Production Engineering Review
Volume 17 • Number 1 • March 2026 • pp. 1–11
DOI: 10.24425/mper.2026.158640

The Impact of Industry 4.0 on Sustainable Supply Chains: Managerial Support as a Mediating Factor in Ghana's Beverage Sector

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Received: 31 March 2025
Accepted: 21 October 2025

Abstract
This study investigates the impact of Industry 4.0 on sustainable supply chain practices in Ghana's beverage industry, emphasizing the role of managerial support. Data were collected from 200 beverage firms in Greater Kumasi using a structured questionnaire and analyzed with SPSS 23 and SmartPLS SEM. Results show that Industry 4.0 positively influences both sustainable supply chain practices and managerial support. Managerial support also enhances sustainability and partially mediates the relationship between Industry 4.0 and supply chain sustainability. The findings suggest that the adoption of Industry 4.0 technologies, coupled with active managerial involvement, strengthens sustainable practices in the beverage sector. The study contributes to understanding how digital transformation and leadership jointly promote sustainability in developing economies. Future research should examine other manufacturing sectors and the role of Industry 4.0 in driving creativity and innovation.

Keywords
Sustainable Supply Chain, Managerial Support, SmartPLS SEM, beverage sector.

Introduction

The concept of Industry 4.0 originated in the digital manufacturing sector (Ghobakhloo, 2018) and involves a network of intelligent machinery and industrial processes (Zheng et al., 2021). According to Erboz (2017), Industry 4.0 also signals a shift from a manufacturing sector that relies heavily on physical goods to one that combines digital and physical operations. Strange & Zucchella (2017) argued that, despite its broad scope, Industry 4.0 supports supply chains by enhancing operational performance, optimizing the value chain, increasing productivity, and offering greater flexibility in tasks. Culot et al. (2020) claimed that integrating Industry 4.0 into the supply chain has improved "data-management capabilities" and created opportunities to "offer service-oriented products". They have transformed the footprint of manufacturing and supply chain businesses. Additionally, it has enabled mass customization of products and reduced material waste through the use of process analytical tools, 3D printing, continuous manufacturing, and other advanced techniques. Furthermore, the World Economic Forum (2018) predicted that Industry 4.0 would significantly impact the global economy, with a projected value of $14.2 trillion by 2030. Sung (2018) further argued that, although Industry 4.0 offers many benefits, it also presents challenges such as costs related to hiring new employees, acquiring these technologies, and addressing technological issues. Additionally, Luthra & Mangla (2018) noted that Industry 4.0 could negatively affect businesses by increasing the risk of operational failures due to technical glitches, cybersecurity breaches, higher maintenance costs, and staff training difficulties.

Chaabane et al. (2011) also asserted that maintaining a company's reputation, ensuring continuity, and controlling operational costs all depend on a sustainable supply chain. Additionally, Chaabane et al. (2011) argued that implementing SSC operations is essential for manufacturing companies to understand the importance of being socially and environmentally responsible, as well as recognizing economic implications. According to the UN Sustainable Development

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Goals, improving supply chain operations is crucial for increasing organizational effectiveness (Bastas & Liyanage, 2018). Therefore, beverage managers' primary responsibility is to lead in allocating appropriate resources and driving necessary changes at different levels (Chen et al., 2021). Khan et al. (2021a) revealed that, despite increasing interest in Industry 4.0, there remains a lack of empirical research on its impact on sustainable supply chains. Ghobakhloo et al. (2021) found that integrating Industry 4.0 technologies with circular economy principles remains an underexplored research area. Sharma et al. (2022) also argued that the mediating role of managerial support in Industry 4.0 technologies and its impact on the sustainable supply chain are still not well understood.

Ultimately, Sony & Naik (2020) found that managerial support is essential for integrating Industry 4.0 technologies into a company's sustainable supply chain. This is because management oversees these companies' operations and carefully considers their input. Additionally, they can select technologies that support product development, reduce waste, and help maintain a competitive edge. Despite these insights, some limitations still exist in this area of study; however, the authors aim to investigate Industry 4.0 and the Sustainable Supply Chain: The Mediating Role of Managerial Support in the Beverage Sector based on this evidence. The study used the Resource-Based View (RBV) to explain how managerial support influences the interaction between Industry 4.0 and the sustainable supply chain. In doing so, the authors believe that linking Industry 4.0 to SSC can help align and integrate these two relevant fields, thereby expanding the scope of Industry 4.0 theories and practices in advancing sustainable supply chains among beverage firms in Ghana, specifically in the Greater Kumasi area of the Ashanti region. In doing so, the paper aims to answer these four key research questions:

1. Does Industry 4.0 affect Sustainable Supply Chains?
2. Does Industry 4.0 have an indirect effect on managerial support?
3. Does managerial support indirectly influence sustainable supply chains?
4. Does managerial support mediate the relationship between Industry 4.0 and sustainable supply chains?

The paper advances current understanding by clarifying the link between Industry 4.0 and sustainable supply chain, highlighting how managerial support acts as a mediator in this connection. Additionally, since Industry 4.0 functions as a firm-specific resource, it encourages managerial support, which then affects how Industry 4.0 benefits sustainable supply chains. The study offers practical and theoretical insights into optimizing the benefits of Industry 4.0 in sustainable supply chains. Furthermore, it presents a more comprehensive conceptual model of the relationships among Industry 4.0, managerial support, and sustainable supply chains. The rest of the paper includes the literature review, research methodology, results presentation, analysis, discussion, conclusion, and directions for future research.

Literature review and hypotheses development

The fourth industrial revolution has attracted attention from academics and researchers worldwide (Liao et al., 2017). Understanding the previous three revolutions is essential to understanding their significance fully. The first laid the foundation for industrialization; the second introduced complex automation and established the basis for power; and the third prepared the way for computers and adaptable automation.

The fourth stage establishes the foundation for Industry 4.0 by leveraging modern information and communication technology. It also led to the development of data networks, industrial automation, and advanced manufacturing technologies such as 3D printing, intelligent production, human-computer interaction, and remote operations (Khan et al., 2021b). Fatorachian & Kazemi (2021) argued that Industry 4.0 provides several benefits. These include improvements in logistics, faster delivery times, fewer delayed shipments, inventory reduction, prevention of losses or damages, and higher forecast accuracy.

Researchers found that implementing Industry 4.0 poses several technical challenges, including political, technological, social, and economic obstacles (Queiroz et al., 2021). According to Unger et al. (2017), one of the biggest hurdles is staff skills and qualifications, particularly their ability to analyze failures, solve problems, and manage machine adjustments or setups.

According to Carter & Rogers (2008), a sustainable supply chain involves the strategic, transparent integration and achievement of an organization's social, environmental, and economic goals. This is accomplished through systematic coordination of key inter-organizational business processes with the ultimate goal of improving each organization's long-term financial performance and that of its supply chains.

To achieve a sustainable supply chain, Pagell & Wu (2009) argue that businesses must reassess their existing supply chains and incorporate sustainable objectives into all aspects of their operations, from procure-

ment to distribution and logistics. In contrast, Mota et al. (2015) contend that the economic dimension aims to position the company for long-term profitability by reducing costs and increasing revenue through digitization and process automation. Financial responsibility is crucial for a company to fulfill its obligations to its partners, employees, and the communities in which its supply chain operates. The environmental dimension emphasizes protecting the environment from potential harm caused by a company's operations and its partners. Mota et al. (2015) identify industrial emissions, resource use, and energy consumption as key factors affecting environmental sustainability. However, reducing the use of raw materials, energy, and water is a common strategy to improve ecological sustainability (Kubule et al., 2019).

At the same time, the social dimension focuses on setting measurable goals to enhance positive social impact, including fair treatment, health, and safety of employees and suppliers within the supply chain (Mota et al., 2015).

Industry 4.0 and Sustainable Supply Chain

Achieving sustainable supply chains requires firms to develop resources and capabilities that provide long-term competitive advantage. The RBV highlights that these resources must be valuable, rare, hard to replicate, and non-substitutable (Barney, 1991). Industry 4.0 technologies, including the Internet of Things (IoT), blockchain, big data analytics, and artificial intelligence, are increasingly seen as resources that can support sustainability. These tools improve visibility and traceability, enhance forecasting, and strengthen decision-making processes, all of which help reduce waste, ensure compliance with environmental standards, and promote circular economy practices ([x]Chauhan et al., 2022). From this perspective, Industry 4.0 has the potential to provide firms with valuable and rare resources that contribute to more sustainable supply chains.

However, the link between Industry 4.0 and sustainable supply chains is complex. In many developing economies, the adoption of these technologies remains low, which limits their impact. Their effective use also depends on supporting skills, such as knowledge sharing, learning, and collaboration within supply networks, which are not easily replicated (Al-Okaily et al., 2024). Without these essentials, investments in advanced technologies may not lead to meaningful sustainability results and could even cause additional issues, such as increased costs or technological dependence. This shows that Industry 4.0 offers both opportunities and challenges for creating sustainable supply chains. On one hand, it provides firms with digital tools that can transform supply chain operations and support long-term sustainability goals. On the other hand, its effectiveness depends on the environment where it is implemented, especially in settings with resource limitations and institutional obstacles. This is where the study proposes the following hypothesis:

H1: Supply chain sustainability is positively impacted by Industry 4.0.

Industry 4.0 and Managerial Support

According to RBV, resources generate sustainable competitive advantage only when they are valuable, rare, inimitable, and non-substitutable (Barney, 1991). Industry 4.0 technologies, including the IoT, artificial intelligence, blockchain, and big data analytics, demonstrate these qualities by enabling real-time information flows, improving supply chain transparency, and supporting predictive decision-making ([x]Chauhan et al., 2022). Despite their potential, these technologies do not create value on their own. Their effectiveness depends on how companies implement and integrate them into operations, which requires organizational alignment and strong leadership.

Managerial support is crucial in this transformation. Managers provide strategic guidance, allocate resources, and nurture a culture of innovation essential for integrating digital technologies into supply chain practices (Dubey et al., 2020; [x]Kamble et al., 2018). Thus, managerial support acts as a key capability that turns Industry 4.0 resources into firm-specific advantages, aligning with the RBV framework. Based on this, the following hypothesis is proposed:

H2: Industry 4.0 has a positive indirect effect on managerial support.

Managerial Support and Sustainable Supply Chain

The RBV highlights that an organization's capabilities determine how resources are utilized to build and maintain competitive advantage (Barney, 1991). In sustainable supply chain management, managerial support is a vital capability. Managers play a crucial role in setting strategic goals, allocating resources, and coordinating cross-functional tasks, all of which are essential to transforming sustainability-focused resources into tangible performance results ([x]Teece et al., 1997). Empirical studies support this view.

Dubey et al. (2020) demonstrated that leadership commitment promotes the adoption of digital and environmentally responsible strategies, resulting in improved environmental and social outcomes. [x]Similarly

et al. (2018) found that managerial support boosts sustainability efforts by increasing employee engagement and securing essential resources. These findings indicate that without active managerial involvement, sustainability goals are more likely to stay aspirational rather than become practical. Based on this reasoning, the following hypothesis is proposed:

H3: Managerial support has a positive impact on sustainable supply chain practices.

The Mediation Role of Managerial Support

The RBV highlights that a company's competitive advantage comes not just from possessing valuable, rare, and difficult-to-imitate resources, but from turning those resources into unique capabilities that competitors cannot easily copy (Barney, 1991; [x]Teece et al., 1997). In today's supply chains, technologies like the IoT, blockchain, big data, and artificial intelligence are powerful tools that offer real-time monitoring, enhance decision-making, and open up new opportunities for sustainability ([x]Chauhan et al., 2022).

However, having technology alone is not enough. Its actual benefits rely on how effectively it is used within the organization. Support from managers is key to this process. Managers not only direct the strategic deployment of technology but also promote innovation and make sure digital tools align with long-term sustainability goals. Without this backing, Industry 4.0 adoption risks becoming just a technical task with limited impact.

Evidence from previous studies supports this stance. Dubey et al. (2020) demonstrated that leadership commitment allows firms to adopt digital and environmentally responsible strategies, resulting in better sustainability outcomes. Likewise [x]Kamble et al. (2018) found that managerial involvement boosts sustainability efforts by motivating employees and mobilizing essential resources. These findings indicate that while Industry 4.0 technologies have potential, managerial support is what unlocks their actual value.

In this context, managerial support acts as the link between Industry 4.0 and sustainable supply chain. When managers are actively involved, digital resources are turned into capabilities that are both valuable and hard to copy, providing the firm with not only better sustainability performance but also a lasting competitive edge. This is where the study proposes the following hypothesis:

H4: Managerial support mediates the relationship between Industry 4.0 adoption and sustainable supply chain practices.

Figure 1 presents the research model developed by the authors.

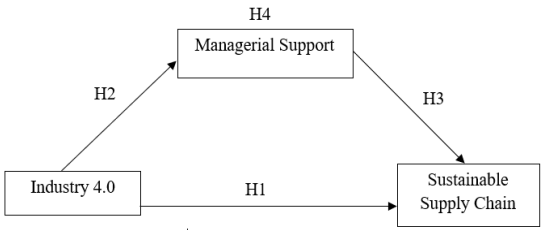

Fig. 1. Research Model

Materials & Methods

This study examines the impact of Industry 4.0 on sustainable supply chains, with a particular focus on the role of managerial support. Although interest in Industry 4.0 is increasing worldwide, adoption remains limited in sub-Saharan Africa, particularly in Ghana. Examining its effects within Ghana's beverage industry provides valuable insights for companies aiming to improve operational efficiency and long-term competitiveness. The study also helps fill a gap in existing research by offering empirical evidence from a developing country setting.

An explanatory research design was used to examine the cause-and-effect relationships among the variables. The population consisted of 260 beverage companies located in Greater Kumasi, Ashanti Region, with the firm serving as the unit of analysis. From this population, 200 questionnaires were returned, resulting in a 77 percent response rate. Simple random sampling was employed to ensure that every firm had an equal chance of being selected. This method was suitable because it minimizes bias, improves representativeness, and provides a fair and transparent way to identify patterns across the population (Saunders et al., 2007).

Questionnaires were sent to senior managers in operations, supply chain, and production departments. This is because managers are responsible for strategic decisions, resource allocation, and sustainability initiatives, and they are well-positioned to evaluate how Industry 4.0 technologies are being implemented. Previous research highlights the importance of managerial support in aligning technological adoption with sustainability goals ([x]Teece et al., 1997; Dubey et al., 2020).

Non-responses accounted for 23 percent of the original sample, a common occurrence in organizational surveys where heavy workloads or low interest often lead to decreased participation. Nonetheless, a 77 percent response rate is generally considered enough for organizational research and can yield reliable results ([x]Baruch & Holtom, 2008). Confidentiality assurances and the random selection of firms also helped reduce the risk of non-response bias.

The structured questionnaire used in the study covered Industry 4.0, sustainable supply chains, and managerial support. Items were adapted from validated scales to ensure content validity and reliability. Construct validity was confirmed through factor loadings, AVE, and composite reliability, while discriminant validity was tested using the Fornell–Larcker criterion, cross-loadings, and the HTMT ratio. Responses were measured on a seven-point Likert scale ranging from "strongly disagree" to "strongly agree." A pilot test was conducted to refine the instrument, and Cronbach's alpha confirmed the internal consistency of the scales. Data were analyzed using SPSS 23 and SmartPLS, applying structural equation modeling (SEM) to test the hypotheses. SEM was especially suitable as it allowed for the simultaneous assessment of multiple relationships while accounting for measurement error, thereby enhancing the robustness of the findings.

The study's constructs were defined as follows. Industry 4.0 was evaluated through indicators such as the level of information sharing across supply chains, the integration of digital processes, the use of multidisciplinary teams, software compatibility, ecosystem readiness, security measures, availability of technologies and machinery, and the reliability of machine-to-machine communication. Sustainable supply chain practices were measured through resource efficiency, waste reduction, environmental responsibility, and how sustainability is integrated into supply chain decision-making. Managerial support was operationalized through items reflecting leadership commitment, resource allocation, employee training, and aligning Industry 4.0 initiatives with sustainability goals. All items were rated on a seven-point Likert scale, providing a detailed assessment of managers' perceptions.

Taken together, this study offers evidence on how Industry 4.0 affects sustainable supply chains in a developing economy, while also highlighting the mediating role of managerial support. The findings expand theoretical discussions on digitalization and sustainability and provide practical guidance to managers in the beverage industry, aiming to integrate Industry 4.0 technologies with sustainable practices to stay competitive.

Results

The study involved 200 participants, with men accounting for 62.5% and women 37.5%. There was an almost equal distribution between senior and junior staff. Most participants were between 21–40 years old (56%), followed by those aged 41–50 (25.5%) and over 50 (18.5%). Regarding education, 39% held professional certifications, 26% earned master's degrees, and 22% had bachelor's degrees. Participants had moderate work experience, with 45.5% reporting 6–10 years, 25.5% reporting 11–15 years, 19.5% reporting less than 5 years, and 9.5% reporting over 15 years. Overall, the sample represented a well-educated and experienced workforce suitable for the study (Table 1).

Table 1
Demographic Information

Variable	Category	Frequency	Percent	Cumulative Percent
Sex	Male	125	62.5	62.5
	Female	75	37.5	100.0
Position	Senior staff	100	50.0	50.0
	Junior staff	100	50.0	100.0
Age	21–30 years	56	28.0	28.0
	31–40 years	56	28.0	56.0
	41–50 years	51	25.5	81.5
	50 years and above	37	18.5	100.0
Education Level	SHS	12	6.0	6.0
	A/O Level	14	7.0	13.0
	First Degree	44	22.0	35.0
	Master's Degree	52	26.0	61.0
	Professional	78	39.0	100.0
Years of Experience	Less than 5 years	39	19.5	19.5
	6-10 years	91	45.5	65.0
	11-15 years	51	25.5	90.5
	15 years and above	19	9.5	100.0

Table 2 presents the descriptive and normality statistics for the study variables. The mean values are 4.66 for Industry 4.0, 5.38 for Sustainable Supply Chain, and 5.42 for Managerial Support, with skewness and kurtosis values within the ±2 threshold (George & Mallery, 2010; Kline, 2011), confirming data normality. The higher means for managerial support and sus-

tainability indicate that beverage firms in Ghana are already adopting practices that enhance supply chain resilience. However, the lower mean for Industry 4.0 suggests that digital transformation is still in its early stages. These findings imply that strong managerial commitment and sustainability efforts lay the groundwork for resilience, but investing in more Industry 4.0 tools could further enhance efficiency and competitiveness. For managers, this highlights the need to balance ongoing sustainability initiatives with gradual investments in digital technologies. For policymakers, this underscores the importance of supportive infrastructure and training to accelerate digital transformation across the sector.

Table 2
Descriptive and Normality Tests

Variable	Mean	Standard Deviation	Skewness	Kurtosis
IND 4.0	4.656	1.551	–0.056	–1.353
SSC	5.380	1.236	–0.511	–0.639
MS	5.421	1.095	–0.302	–0.832

Notes: IND 4.0: Industry 4.0; SSC: Sustainable Supply Chain; MS: Managerial Support.

Table 3 presents the results of the common method variance test. We found two factors with eigenvalues over one, accounting for 67.1% of the total variance. Since no single factor dominates the variance, common method bias is unlikely to threaten the validity of the results (Podsakoff et al., 2003). This aligns with Hair et al. (2019), who note that when multiple factors explain more than half of the variance, measurement errors are spread out rather than concentrated in one construct. For Ghana's beverage industry, this is reassuring, as it suggests that the observed relationships among Industry 4.0 adoption, managerial support, and sustainable supply chains are rooted in organizational realities rather than statistical artifacts. This enhances confidence in the study's evidence, providing a solid foundation for designing strategies to advance digital transformation, sustainability, and competitiveness in the sector.

Table 4 shows the results of the multicollinearity assessment for factors affecting sustainable supply chain practices. Industry 4.0 adoption and managerial support have significant positive effects, with coefficients of 0.541 and 0.268, respectively, and p-values under 0.001. The tolerance value (0.577) and VIF (1.734) are within acceptable limits, indicating that the two

Table 3
Common Method Variance

Factor	Initial Eigenvalues	% of Variance	Cumulative %	Extraction Sums of Squared Loadings	% of Variance	Cumulative %	Rotation Sums of Squared Loadings	% of Variance	Cumulative %
1	6.779	61.63	61.63	6.468	58.80	58.80	4.041	36.73	36.73
2	1.187	10.79	72.42	0.913	8.31	67.10	3.341	30.37	67.10
3	0.777	7.06	79.48	–	–	–	–	–	–
4	0.575	5.23	84.71	–	–	–	–	–	–
5	0.467	4.25	88.96	–	–	–	–	–	–
6	0.364	3.31	92.27	–	–	–	–	–	–
7	0.269	2.45	94.72	–	–	–	–	–	–
8	0.222	2.02	96.74	–	–	–	–	–	–
9	0.179	1.62	98.36	–	–	–	–	–	–
10	0.126	1.14	99.50	–	–	–	–	–	–
11	0.055	0.50	100.00	–	–	–	–	–	–

Notes: Extraction Method: Principal Axis Factoring; Rotation Method; Varimax with Kaiser Normalization; Only factors with eigenvalues > 1.0 are typically considered for retention (Factors 1 and 2 in this case).

predictors are not highly correlated. This means that each factor contributes independently to sustainability outcomes, which boosts confidence in the model's reliability. For Ghana's beverage sector, this suggests that companies can benefit from advancing digital adoption while also strengthening managerial commitment, as both make unique contributions to improving efficiency and competitiveness.

Table 5 presents the results of the exploratory factor analysis, which clusters related survey items together. The analysis revealed two distinct factors. The first factor encompasses items related to Industry 4.0 adoption and sustainable supply chain practices, with loadings ranging from 0.532 to 0.832, indicating a strong correlation among these items. The second factor focuses on managerial support, with high loadings between 0.755 and 0.850, representing a clear construct. The analysis, conducted using principal axis factoring with Varimax rotation, converged in three iterations, confirming that the factors are distinct and accurately capture the study's central concepts. For beverage companies in Ghana, this suggests that digital adoption, sustainability practices, and managerial support are key dimensions that can be targeted through policy and strategy to enhance long-term competitiveness.

Table 6 shows the results of the Kaiser–Meyer–Olkin (KMO) measure and Bartlett's test of sphericity, which assess whether the dataset is suitable for factor analysis. The KMO value of 0.877 indicates excellent sampling adequacy, while Bartlett's test is significant (Chi-square = 3226.201, df = 171, $p < 0.001$), confirming that the correlations among items are strong enough to justify factor analysis. Together, these results indicate that the data are well-suited for uncovering meaningful factor structures. For Ghana's beverage firms, this reinforces confidence that the measures used in the study reliably capture the dynamics of Industry 4.0, managerial support, and sustainable supply chains.

Table 6
Kaiser–Meyer–Olkin (KMO)

Test	Statistic	Value
Kaiser–Meyer–Olkin (KMO) Measure		0.877
Bartlett's Test of Sphericity	Approx. Chi-Square	3226.201
	Degrees of Freedom (df)	171
	Significance (Sig.)	0.000

Table 7 presents the results for construct validity and reliability. All constructs demonstrate strong internal consistency, with Cronbach's alpha values ranging from 0.815 to 0.890, exceeding the recommended 0.70 threshold. Composite reliability (ρa and ρc) also falls between 0.824 and 0.918, confirming that the items consistently capture their intended constructs. The average variance extracted (AVE) values range from 0.541 to 0.627, all above the 0.50 benchmark, which indicates sufficient convergent validity. These results confirm

Table 4
Assessment of Multicollinearity

Model	Predictor	B	Std. Error	Beta	t	Sig.	Tolerance	VIF
1	(Constant)	1.406	0.232	–	6.047	0.000	–	–
	IND 4.0	0.541	0.039	0.679	13.868	0.000	0.577	1.734
	MS	0.268	0.055	0.238	4.858	0.000	0.577	1.734

Notes: Dependent Variable: SUSTAINABLE; B: Unstandardized coefficients; Beta: Standardized coefficients; VIF: Variance Inflation Factor.

Table 5
Exploratory Factor Analysis

Factor	Items (Loadings)
Factor 1	IND3 (0.801), IND4 (0.787), IND5 (0.532), IND7 (0.784), SSC1 (0.832), SSC2 (0.570), SSC3 (0.600)
Factor 2	MS2 (0.756), MS3 (0.755), MS5 (0.775), MS6 (0.850)

Notes: Extraction Method: Principal Axis Factoring; Rotation Method; Varimax with Kaiser Normalization; Rotation converged in 3 iterations.

that the measures used in this study are both reliable and valid for assessing Industry 4.0 adoption, managerial support, and sustainable supply chain practices. For practice, this means that managers and policymakers can trust the results as a sound reflection of real organizational experiences, making the findings helpful in designing strategies to strengthen digital transformation and sustainability in the beverage sector.

Table 7
Construct Validity

Construct	Cronbach's Alpha	Composite Reliability (ρa)	Composite Reliability (ρc)	Average Variance Extracted (AVE)
IND 4.0	0.846	0.891	0.887	0.541
MS	0.890	0.918	0.918	0.627
SSC	0.815	0.824	0.872	0.578

Table 8 shows the cross-loading results used to evaluate discriminant validity. For a valid measure, each indicator should load more strongly on its intended construct than on the others. The results meet this expectation, with most items showing their highest loadings on the constructs they were designed to measure. Several items also exceed the recommended 0.70 threshold, further confirming their strength. For example, IND3 and IND4 load above 0.91 on Industry 4.0, MS2 and MS3 load above 0.87 on managerial support, and SSC1 to SSC3 load above 0.80 on sustainable supply chain. These results indicate that the indicators clearly represent their respective constructs while remaining distinct from other factors, reinforcing both the reliability and validity of the measurement model. In practice, this means managers and policymakers can rely on the study's measures as an accurate reflection of how technology adoption, leadership support, and sustainability efforts function as separate yet interconnected drivers of performance.

Table 9 presents the results of the discriminant validity test for Industry 4.0, managerial support, and sustainable supply chain. The diagonal values, which represent the square root of AVE, are higher than the correlations with other constructs, indicating that each construct is distinct ((Fornell & Larcker, 1981).

In addition, all HTMT values fall below the 0.90 threshold, further confirming discriminant validity (Henseler et al., 2015). Together, these results show that the constructs are clearly defined and reliable, providing a solid foundation for the structural model analysis. In practice, this means that Industry 4.0 adoption, managerial support, and sustainability efforts can be treated as separate but complementary drivers of competitiveness.

Table 8
Cross-Loading

Indicator	IND 4.0	MS	SSC
IND1	0.426	0.327	0.316
IND2	0.638	0.439	0.477
IND3	**0.914**	0.665	**0.780**
IND4	**0.919**	0.676	**0.818**
IND5	0.614	0.480	0.511
IND6	0.692	0.465	0.613
IND7	**0.816**	0.609	**0.755**
MS1	0.507	0.608	0.561
MS2	0.581	**0.871**	0.668
MS3	0.674	**0.896**	0.691
MS4	0.295	0.432	0.338
MS5	0.578	**0.856**	0.668
MS6	0.583	**0.870**	0.660
MS7	0.718	**0.884**	0.734
SSC1	**0.808**	0.608	**0.801**
SSC2	0.641	0.614	**0.818**
SSC3	0.672	0.634	**0.813**
SSC4	0.598	0.606	0.691
SSC5	0.520	0.567	0.662

Notes: Loadings above 0.70 are considered strong indicators of construct validity.

Table 9
Discriminant validity: Fornell–Larcker criterion

Construct	IND 4.0	MS	SSC
IND 4.0	**0.74**	0.62	0.58
MS	0.62	**0.79**	0.65
SSC	0.58	0.65	**0.76**

Notes: Diagonal values in bold represent the square root of AVE (Fornell).

Table 10 displays the results for predictive relevance, model fit, and effect size. The Q^2 predict values for managerial support (0.522) and sustainable supply chain (0.735) show that the model has moderate to strong predictive ability (Hair et al., 2017). The Root

Mean Square Error (RMSE) and Mean Absolute Error (MAE) values indicate acceptable prediction accuracy, with sustainable supply chain outcomes performing slightly better. For managerial support, the R^2 value of 0.485 and the adjusted R^2 of 0.480 suggest that Industry 4.0 adoption and sustainable supply chain practices together explain nearly half of the variance. This indicates a moderate effect size, meaning the model strikes a good balance between explanatory and predictive power. In practice, this implies that as beverage firms in Ghana increase their use of Industry 4.0 tools and sustainability practices, managerial support is likely to improve significantly, enhancing overall supply chain resilience.

Table 10
Predictive Relevance (Q^2), Model Fit Statistics, and Effect Size (R^2)

Model	1	2	3	4	5	6	7
MS	0.52	0.70	0.54	0.70	0.49	0.48	0.79
SSC	0.74	0.52	0.37				

Notes: (1) Q^2 predict: Represents predictive relevance of the model; (2) RMSE: Root Mean Square Error; (3) MAE: Mean Absolute Error; (4) R, (5) R^2, (6) Adjusted R^2; and (7) Standard Error of the Estimate.

Table 11 summarizes the results of hypothesis testing, which explored how Industry 4.0, managerial support, and sustainable supply chain practices are connected. The findings show that Industry 4.0 has a strong positive effect on managerial support ($\beta = 0.730, T = 19.26, P < 0.001$), meaning that when firms adopt digital technologies, managers become more engaged and supportive of organizational processes. Industry 4.0 also directly improves sustainable supply chain practices ($\beta = 0.600$, $T = 12.61$, $P < 0.001$), suggesting that technology adoption contributes to better sustainability outcomes on its own. In addition, managerial support positively influences sustainable supply chains ($\beta = 0.359$, $T = 7.32$, $P < 0.001$), showing that management plays a critical role in driving sustainability initiatives. Overall, the results suggest that Industry 4.0 adoption can improve sustainable supply chains, but its impact is even greater when managers actively support and guide the process. This reinforces the idea that technology and leadership must work hand in hand to achieve the best results.

Figure 2 illustrates the results of the structural equation model (PLS-SEM) analyzing the relationships between Industry 4.0, Managerial Support, and the Sustainable Supply Chain.

Table 11
Hypothesis Testing

Path	O	M	STD EV	T	P	Decision
IND 4.0 → MS	0.730	0.733	0.038	19.26	0.000	Supported
IND 4.0 → SSC	0.600	0.599	0.048	12.61	0.000	Supported (Direct Effect)
MS → SSC	0.359	0.360	0.049	7.32	0.000	Supported
IND 4.0 → MS → SSC (Mediation)	0.262	0.263	0.034	7.71	0.000	Partial Mediation

Notes: Mediation effect calculated as the product of the two direct paths ($0.730 \times 0.359 \approx 0.262$). T-statistics for mediation were obtained via bootstrapping in SmartPLS.

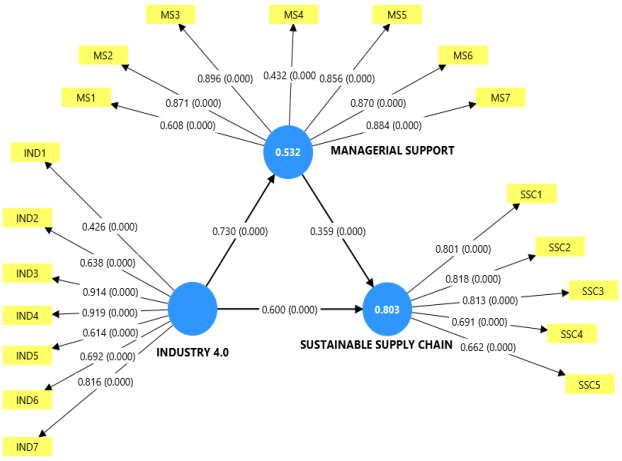

Fig. 2. Structural and Measurement Model

Discussion and conclusion

Researchers examined beverage companies in Greater Kumasi, Ashanti Region, gathering data from 200 local businesses. The findings revealed that Industry 4.0 has a substantial positive impact on managerial support ($\beta = 0.730$, $t = 19.26$, $p < 0.001$), emphasizing the importance of adopting advanced technologies to engage managers in supply chain operations. Industry 4.0 also directly boosts sustainable supply chain practices ($\beta = 0.600$, $t = 12.61$, $p < 0.001$), indicating that adopting technology can independently promote sustainability outcomes. At the same time, managerial support has a notable positive effect on sustainable supply chains ($\beta = 0.359, t = 7.32, p < 0.001$). Furthermore, it partially mediates the relationship between Industry 4.0 and sustainable supply chains, with an indirect effect of $\beta = 0.262$, $t = 7.71$, $p < 0.001$.

The study shows that Industry 4.0 technologies improve sustainable supply chains, especially when managers actively lead and support their adoption. Managerial support helps turn technological capabilities into sustainable practices across social, environmental, and economic domains. This aligns with earlier research highlighting the importance of leadership commitment in making digital transformation meaningful for sustainability (Dubey et al., 2020; Bag et al., 2018).

The findings show how managers can influence the effects of Industry 4.0. By investing in resources, training, and fostering an innovation-focused culture, managers can use digital tools to build strengths that meet their firms' specific needs, offering lasting advantages. The technologies also offer practical sustainability benefits, such as cutting waste, boosting public health, and creating new revenue streams through sustainable production. Improved communication within and across supply chains further enhances these benefits by encouraging collaboration, enabling data-driven decisions, and supporting ongoing improvement.

At the same time, the study has some limitations. It focuses on a single industry within one region, which limits how broadly the findings can be applied. The cross-sectional design also makes it hard to establish cause-and-effect relationships. Future research should therefore examine other industries, use longitudinal designs, and pay more attention to how Industry 4.0 might promote creativity and innovation in firms across developing economies. In this context, the results offer valuable insights for companies in the beverage industry within the specific setting studied, but they should be applied cautiously elsewhere. Instead of making broad generalizations, the findings serve as a basis for further research into how Industry 4.0 and managerial support together promote sustainable supply chains.

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