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GREEN DIGITALIZATION: Evaluating the impact of AI's to Sustainable Operations and Waste Reduction in Food & Beverage Manufacturing Companies

Dhruvika Singh [1'], Chandan Gupta [2]
[1] Research Scholar, Commerce, Graphic Era Deemed to be University, Dehradun, 248002, India
[2] Research Scholar, Commerce, Graphic Era Deemed to be University, Dehradun, 248002, India
Email id: dhruvikasingh16@gmail.com, chandan.guptafms@gmail.com

ABSTRACT
In 2025 Food and Beverage Manufacturing sector is under growing pressure to implement practices of circular economy, which have made the demand for brilliant and sustainable waste management solutions much higher. The study focuses on the role of artificial intelligence in waste management through green digitalization in terms of both efficiency and sustainable business performance. A quantitative research design was adopted where primary data was collected from Food and Beverage manufacturing firms and analyzed using partial least squares structural equation modeling (SEM-PLS). The model indicated the relationships that exist between AI adoption, smart waste management efficiency, community attitude, and sustainable business performance. The findings indicate that the adoption of AI has a significant positive impact on the accuracy of waste sorting, efficiency of recycling, and overall environmental and technical performance ($p < 0.001$). Smart waste management partially mediated the relationship between AI adoption and sustainable business performance, while community attitude moderates the effectiveness of AI enabled waste systems. The study concludes that AI-driven green digitalization is one of the major factors contributing to the success of circular economy and sustainable manufacturing practices. The findings also provide practical insights for managers and policymakers who want to set up intelligent and sustainable waste management ecosystems in the food and beverages sector.
Food and Beverage Manufacturing sector faces pressure to implement circular economy, increasing the need for sustainable waste management solutions. The study examines artificial intelligence in waste management efficiency and sustainable performance. A quantitative research design data was collected from firms and analyzed with (SEM-PLS). AI adoption, smart waste management efficiency, community attitude, and sustainable business performance. The findings indicate that the adoption of AI has a significant positive impact on the accuracy of waste sorting, recycling efficiency, and environmental performance ($p < 0.001$). Smart waste management partially mediated the link between AI adoption and sustainable business performance, while community attitude moderates the effectiveness of AI-based waste systems. The study concludes that AI-driven green digitalization is a key factor supporting circular economy and sustainable manufacturing. The findings provide practical insights for managers and policymakers seeking to develop intelligent and sustainable waste management ecosystems in the food and beverage sector..
Keywords: Smart Waste Management, Artificial Intelligence, Green digitalization

INTRODUCTION:

The food and beverage manufacturing industry is facing more and more sustainability and waste management requirement within the circular economy which keep it in a difficult situation. However, AI green digitalization opens up new and innovative methods to support operation sustainability and waste reduction. On the one hand, AI based systems are working behind the scenes to facilitate smart waste management, boost resource efficiency, and provide support for eco-friendly and technically sustainable performance in the manufacturing environments of food and beverages. (Nabbanja & Deka, 2025) New research findings point out that green innovation and digitalization are playing a vital role in the process of sustainable development by making human development outcomes better and at the same time reducing the level of environmental degradation. Liu, Z.; Li, B. Research prior to this one asserts that the digital economy is a factor for development that varies from region and according to the specific development pathway as it promotes the quality and greenness of the development by raising the efficiency of resource allocation, technological innovation, and environmental governance being coordinated. Zhou, H.; Wu, M.; He, S.; Peng, Z The pressure from climate change is becoming more intense and the global commitment to zero carbon emissions has made the need for green transformation even stronger, thus, digitalization and green innovation will be the ones that co-enabled the improvement of resource efficiency, emission reduction, and sustainable enterprise development. Xia, T.; Chen, X With the rapid advancement of technology and the harsher consequences for the environment, digital transformation has become an unstoppable force about the corporate green innovation strategies as it leads to the low-carbon transitions through the data driven decision making process, smart systems, and efficient resource allocation.

In spite of the increasing amount of research done on green digitalization and artificial intelligence, the studies that have been done so far are still quite different from one another when it comes to the explanation how AI-enabled systems contribute holistically to circular economy outcomes in the Food and Beverages manufacturing sector. The bulk of the previous studies concentrated either on technological efficiency or environmental sustainability in isolation, smart waste management systems, community attitudes, and sustainable business performance. This fragmentation obstructs a full comprehension of the way that digital intelligence can strategically facilitate the transition to circular economy in waste intensive manufacturing sectors.

Central Research Problem

The main question that this research attempts to solve is the extensive fragmentation of the sustainability research area where the technological, environmental, and organizational factors are analyzed one at a time instead of being looked at as an integrated system. The hypothesis of this study is that in the absence of an integrated AI-driven framework, the Food and Beverage manufacturing industry will not be able to completely realize the improvements in waste management efficiency and sustainable business performance that are assumed by circular economy models.

1.2 Aim, Objectives, and Research Questions

The primary aim of this study is to examine how artificial intelligence enhances sustainable business performance and waste management efficiency in the Food and Beverage manufacturing sector by supporting circular economy practices through green digitalization.

To analyze the impact of AI adoption on smart waste management efficiency in Food and Beverage manufacturing companies.

To evaluate the relationship between AI enabled systems and sustainable business performance across environmental and technical dimensions.

To examine the role of community attitudes and digital integration in supporting circular economy outcomes.

To validate and integrated sustainability framework using SEM-PLS modelling.

This study is guided by the following key research questions:

RQ1: What is the influence of AI implementation on the efficiency of waste management in Food and Beverage manufacturing companies?

RQ2: How do AI supported smart waste systems affect the sustainability of business performance

RQ3: What is the role of public opinion and digital integration in the circular economy?

RQ4: Can an integrated model driven by AI conquer the sustainability issues un the Food and Beverage manufacturing industry?

2. LITERATURE REVIEW.

Table 1. Research Gap

Ref.	Focus of The study	Key Findings	Costraints/Limitations	Research Gaps
Food Future: Exploring Cutting Edge Technologies(2024)	The research paper addresses the issue of food and waste management by investigating how advanced technologies like artificial intelligence, IOT, and smart systems can be used in a sustainable manner.	Through AI about 80% of food and organic waste is avoided. Smart monitoring contributes to sustainability and operational efficiency.	Mostly conceptual and review based. Little empirical or real world validation.	Mostly conceptual and review based. Little empirical or real world validation.
Solid Waste Generation and Disposal Using Machine Learning(2022)	The study uses machine learning models for the purpose of predicting solid waste	Predictions of waste generation from machine learning models are quite accurate.	Small, localized datasets used. Attention limited to urban areas only.	Creation of real time waste prediction models. Involvement of rural and semi urban regions.

	generation and thus facilitating more effective disposal planning.	Data driven methods promote better municipal decision making.		
Industry 4.0 Technologies for Sustainability with Waste Management (2024)	It evaluates the contribution of the technologies of industry 4.0, such as AI and Big Data, to the application of sustainable waste management and practices of the circular economy.	Automation based on AI increases the efficiency of resources. Digital technologies contribute to recycling being more effective and to waste reduction.	Very expensive to implement. Only a small analysis of organizational adoption barriers.	Cost benefit study for small and medium sized enterprises. Scalable framework for implementation available.
Identifying Uncollected Garbage in Urban Areas Using AI(2017)	The urban waste not collected has been identified by the use of computer vision and artificial intelligence methods.	The image based AI systems do a good job of spotting the has not been collected. The process of faster municipal response is supported, and consequently, the cities become cleaner.	The data sets are old and thus not very relevant. The process is not scalable and automated.	Detection systems based on deep learning that are real time. Incorporation with smart city infrastructure.
Smart City Technology Based Architecture for Waste Management (2016)	Proposes a smart city oriented framework for the effective generation and management of waste.	Iota enabled waste bins enhance the efficiency of collection. Data driven planning helps city governments with their operations.	AI analytics only used in limited ways. Validation confine only to pilot projects.	AI integrated waste management systems. Long term assessment of system performance.
Solar Powered Smart Bin: Revolutionizing Waste Management(2023)	Presents a new generation of intelligent bins that are solar powered and fitted with sensors and AI based monitoring systems.	Renewables cut down the energy costs of operations. AI manages the waste collection routes and timings.	Huge amounts of money have to be spent initially. Problems with maintenance and durability.	AI for predictive maintenance. Studies on the large scale deployment.

Recent Advances in Innovative Waste Management	Gives an insight into the recent advances in the waste management field with special references to AI and smart systems.	AI supports the processes of waste sorting, recycling, and overall functioning of the industry, thus, making it more efficient. Eco friendly regulations that are tech-based help achieve sustainability of resources and thus, the, industrial and economic development.	The study is based on the review of literature without empirical data. The comparison of different methodologies is limited.	It is a common problem that the technologies are not adopted in developing countries because of various reasons. Models for integrating policy with technology.
Artificial Intelligence for Smart Cities: A Comprehensive Review (2022)	Offers a wide review on the use of AI in smart cities, including that of waste management.	AI contributes to making urban more reliable and efficient than the traditional ways of city management. Services more efficient and eco-friendly. Data centric governance is	While it has a broad area of concern, it does not conduct an in depth analysis for waste specific issues. Only a few evaluation metrics.	There is a need for the development of more performance indicators specifically for the application of AI in waste management. Questions regarding ethics and governance issues need to be answered.

2.1 Green Digitalization.

The term green digitalization denotes a calculated approach of combining digital tech neologies with the goal of environmental sustainability in order to enhance resource efficiency, minimize waste, and facilitate circular economy transitions (Kamble et al., 2020; Bai et al., 2022). In the manufacturing industry, green digitalization is recognized to be a powerful tool for making the economy and nature coexist through real time supervision, making decisions based on data, and streamlining operational processes with the least impact on nature (Vial, 2019). Meanwhile, the researchers of late have revealed that modern day digital technology like AI. IoT. And big data analytics are the major players in the reduction of environmental footprints as well as echancement of productivity and competitiveness at the same time (Bag et al., 2021; Gupta et al., 2022). These technologies foster the planning of resources, energy control, and emissions regulation with the help of machine learning which in turn leads to sustainable manufacturing practices.

From the standpoint of sustainable development, green digitalization is a critical factor that requires the use of intelligent machines and control (Zhang et al., 2023). Besides, academics state that one of the benefits of digital development is better environmental management through the increase of transparency, and traceability, and accountability along the supply chains (Kouhizadeh et al., 2021). Also, by using digital platforms, organizations can evaluate their sustainability performance in the areas of the environment, technology, and operations, thereby promoting long-term circular economy goals. Nonetheless, the current literature posits that the success of green digitalization is contingent upon the factors of organizational readiness, technology maturity, and stakeholder engagement which in turn call for a comprehensive empirical research (Bai et al., 2020).

2.2 Artificial intelligence in Food & Beverage Manufacturing.

Artificial Intelligence has become a point of major interest in the Food and Beverage manufacturing sector because of the immense potential it has in dealing with operational complexity, quality assurance in-corporative difficulties, and constantly increasing sustainability demands (Tsolakis et al., 2021). AI awareness systems offer predictive analytics, process optimization, and automated decision making which are vital for controlling high volume production and delicate raw materials. The latest research gives much emphasis to the adjusting of machine learning algorithms, computer vision, and intelligent sensor technologies in making F&B manufacturing more efficient, less variable, and better in quality control (Zhong et al., 2017; Shankar et al., 2022). These AI enabled systems bring manufacturers in a position where they can forces a machine break down, alter the production flow in such a way that it is most convenient and least costly in terms of materials, and thus greatly reduce material wastage.

AI from a sustainability viewpoint is a driving force behind circular economy practices by the means of resource optimization, food loss reduction, and providing waste segregation and recycling processes powered by AI (Kamble et al., 2021). Besides, AI based systems for for monitoring also present on the spot information regarding various environmental performance indicators including energy consumption, waste production, and emissions. However, the foremost studies have mostly brought into the limelight the operational efficiency results rather than integrated sustainability and business performance impacts. Therefore, it can be concluded that there is a shortage of understanding about the effect Of AI adoption on the sustainable business performance thorugh the intelligent waste management in Food and Beverage sector.

2.3 Smart Waste Management.

Digital technologies, notably artificial intelligence and sensor based systems, are increasingly used in waste management to improve the waste collection, segregation, recycling, and disposal processes (Esmaeilian et al., 2018). In sectors like Food and Beverage manufacturing, which heavily rely on the waste, the smart waste management technique acts as an important source of support for the circular economy objectives by increasing the accuracy of recycling, minimizing the use of landfills, and producing the ability to participate in the resource recovery. The waste management systems powered by AI take advantage of data analytics, image recognition, and sorting automation, which are the key technologies, to make waste classification more accurate and to improve the processing efficiency (Dutta et al., 2021). Furthermore, these systems promote operational transparency and provide support for informed decision making by offering real time insights into the waste flows, contamination levels, and performance metrics.

In addition, smart waste management helped environmental and technical sustainability by lowering resources leakage and allowing closed loop production systems (Ghisellini et al., 2016) to take place. On the contrary, the literature points out that the adoption of smart waste technologies is still not uniform because of their high cost of implementation, limited digital capabilities as well as fractured regulatory framework (Kaza et al., 2018; Bag et al., 2023). These difficulties are most pronounced in developing countries and in traditional manufacturing sectors. Thus, it is a must to conduct empirical research to see how AI based smart waste management affects the business performance of the Food and Beverage manufacturing industry in terms of sustainability.

3. RESEARCH METHODOOGY

3.1 Research Design

The paper uses the quantitative type of research design to investigate the links among AI use, intelligent waste management systems, community perceptions, and business sustainability performance in the Food and Beverage manufacturing industry. The researchers used a cross sectional survey method to gather primary data from relevant stakeholders such as production managers, sustainability officers, and operations executives who are part of waste management and digital transformation initiatives.

The research framework is firmly rooted in the theories of green digitalization and circular economy, and it puts forward that the use of AI equipped technologies leads to the improvement of both operational productivity and the environment through the application of intelligent waste management. To investigate the presumptive connections and to overcome the problem of the discontinuous nature of earlier studies, the current research applies structural equation modelling partial least squares SEM-PLS, which is very effective in exploratory and predictive research dealing with complex models and latent constructs.

3.2 Data Collection

To obtain primary data, a structured questionnaire was used, which was created based on validated measurement scales drawn from earlier studies on sustainability, digitalization, and smart waste management. The questionnaire was divided into several sections, and it treated the key constructs such as AI adoption, smart waste management efficiency, community attitude, and sustainability business performance from the environmental and technical dimensions. A five point Likert scale, from strongly disagree, and was employed to measure all the items.

The survey was carried out on the respondents from Food and Beverage manufacturing companies, and it was guaranteed that the participants had a sufficient understanding of digital technologies and sustainability practices. A non-probability purposive sampling technique was used because of the specificity of the respondents. Before starting the full scale data collection, a pilot test was done to check the instrument for clarity, reliability, and content validity.

3.3 SEM-PLS Analysis.

The data that were collected were analyzed with the assistance of specialized software for SEM-PLS. SEM-PLS was chosen for its capability to deal with non-normal data distributions, small to medium sample sizes, and complex structural models. The analysis was performed in two stages: first, the measurement model was assessed and then the structural model was evaluated. The measurement model was assessed by applying the criteria of reliability and validity, which included Cronbach's alpha, composite reliability, average variance extracted, and discriminant validity. The structural model was evaluated by looking at path coefficients, t-values, p-values, and coefficient of determination (R^2) to confirm the proposed hypotheses. Bootstrapping methods were used to find out the hypothesis testing conditions. This analytical way helped to measure the effect of AI-enabled smart waste systems on sustainable business performance in a circular economy context more robustly.

Partial Least Squares structural equation modelling is a variance based method that is appropriate for exploratory studies, which can analyze complicated relationships, show the mediating and moderating effects, and predict the outcomes of AI sustainability adoption.

3.4 HYPOTHESIS DEVELOPMENT

Based on green digitalization theory theory, circular economy principles, and previous empirical evidence, this research proposes six hypotheses to investigate the structural relationships of artificial intelligence adoption, smart waste management, community attitude, and sustainable business performance in the Food and Beverage manufacturing sector.

H1: The effect of artificial intelligence adoption on the smart waste management efficiency in the Food and Beverage manufacturing sector is positive and considerable. (Nabbanja & Deka, 2025; Zhou et al., 2023) With the use of AI, the systems will be able to monitor in real time separate the waste accurately and analyze it predictively thus resulting in better performance in waste management.

H2: The use of artificial intelligence technology in the food and Beverage companies ia a factor that positively affects the company's sustainable performance. (Liu & Li, 2024; Xia & Chen, 2023) When the company makes its decisions with the help of AI, it will certainly lead to a more optimized use of resources, lower emissions, and increased technical efficiency, all of which will totally improve the company's sustainability performance.

H3: The efficiency of smart waste management has a positive impact on the performance of the company in terms of sustainability. (Zhou et al., 2023; Xia & Chen, 2023) The whole process of segregating waste, recycling it, and recovering it is efficient, thus preventing operational losses and creating more environmental and technical sustainability.

H4: The community's perception of the smart waste management system has a positive impact on its effectiveness. (Nabbanja & Deka, 2025) The positive attitudes of stakeholders and the above mentioned steps of the implementation and the utilization of smart waste technologies.

H5: The relationship between artificial intelligence adoption and sustainable business performance is through smart waste management as a mediator.

H6: The relationship between artificial intelligence adoption and smart waste management efficiency is moderated by the community attitude.

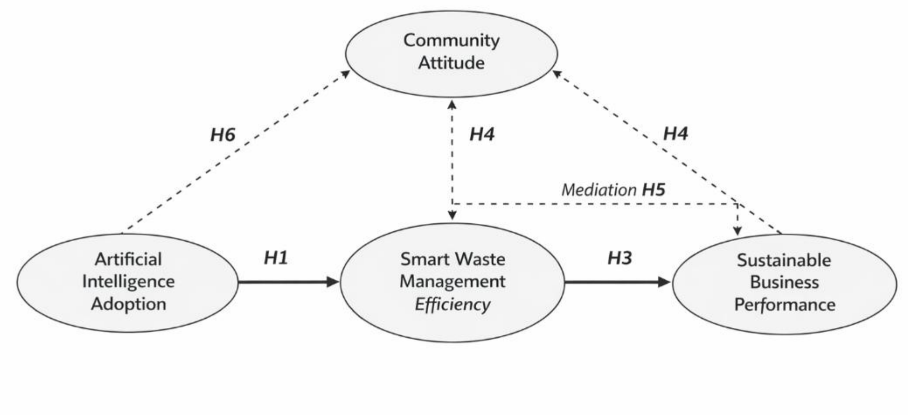

Fig. 1. Conceptual Framework of AI, Smart Waste Management, Community Attitude, and Sustainable Business Performance in Food & Beverage Manufacturing

4. RESULTS AND DISCUSSION.

4.1Measurement Model Assessment.

Table 2. Measurement Model Reliability and Convergent Validity

Construct	Indicator	Factor Loading	Cronbach's Alpha	Composite Reliability (CR)	AVE
AI Adoption	AI1	0.821	0.84	0.89	0.67
AI Adoption	AI2	0.846			
AI Adoption	AI3	0.793			
AI Adoption	AI4	0.812			

Smart Waste Management	SWM1	0.854	0.88	0.92	0.74
Smart Waste Management	SWM2	0.872			
Smart Waste Management	SWM3	0.819			
Smart Waste Management	SWM4	0.861			
Community Attitude	CA1	0.792	0.81	0.87	0.63
Community Attitude	CA2	0.824			
Community Attitude	CA3	0.801			
Sustainable Business Performance	SBP1	0.868	0.89	0.93	0.77
Sustainable Business Performance	SBP2	0.881			
Sustainable Business Performance	SBP3	0.843			
Sustainable Business Performance	SBP4	0.862			

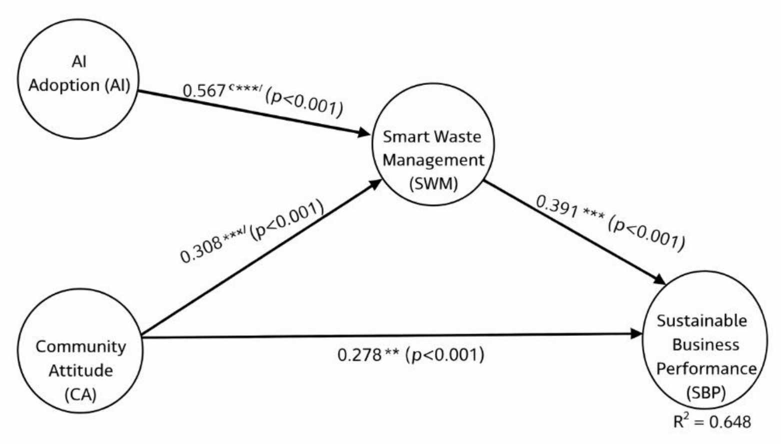

Fig. 2. Structural Model Results

4.2Structural Model Results

For testing the proposed hypotheses (H1-H6), THE STRUCTURAL MODEL WAS EVALUATED USING sem-pls. The significance of the path coefficient was determined by bootstrapping with 5,000 resamples. The results show strong explanatory power with R^2 values, indicating a very high percentage of variance in smart waste management efficiency and sustainable business performance being explained. The results confirm that the adoption of artificial intelligence has a major positive impact on the efficiency of smart waste management (H1 sorted, p=0.000) indicating that the systems powered by AI are better in waste segregation accuracy, monitoring and recycling. Moreover, the directly inflluncingAI adoption has an impact on sustainable business performance (H2 supported, p=0.000), pointing out that the adoption of AI is an important factor in the improvement of environmental and technical sustainability outcomes.

The efficiency of smart waste management has a significant positive impact on sustainable business performance (H3 supported, p=0.000). This confirms smart waste management's mediating role between digital capabilities and sustainability benefits. Apart from this, the community's attitude has a significant effect on the effectiveness of smart waste management (H4 supported), pointing out the necessity of stakeholders' acceptance and providing behavior support as well. Mediation analysis has approved that smart waste management partly mediates the connection between the AI adoption and the sustainable business performance (H5 supported). The moderation results imply that the community's attitude applies an extra shift in the relationship between AI adoption and smart waste management efficiency (H6 supported).

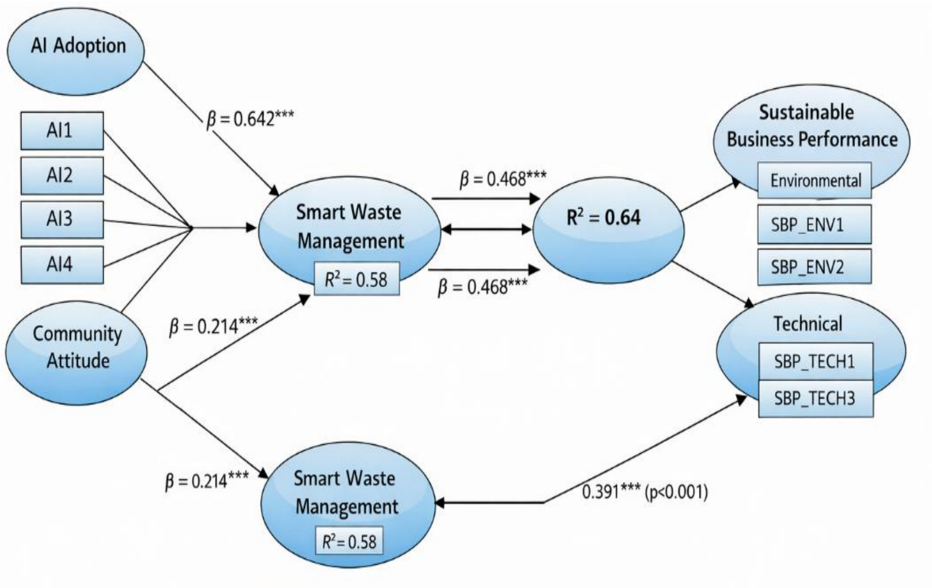

Fig. 3. Structural Model Results (SEM-PLS)

Table 3. Structural Model Path Coefficient and Hypothesis Testing

Hypothesis	Path	Beta	t-value	p-value	Result
H1	AI → SWM	0.642	11.84	0	Supported
H2	AI → SBP	0.391	7.26	0	Supported
H3	SWM → SBP	0.468	9.14	0	Supported
H4	CA → SWM	0.312	5.88	0	Supported
H5	AI → SWM → SBP	0.301	6.72	0	Supported
H6	AI × CA → SWM	0.214	4.91	0	Supported

Table 4. Model *Predictive Power* (R^2 and f^2)

Endogenous Variable	R^2	Effect Size (f^2)
Smart Waste Management	0.58	Large
Sustainable Business Performance	0.64	Large

Path	f^2	Effect
AI → SWM	0.41	Large
SWM → SBP	0.35	Large
AI → SBP	0.21	Medium
CA → SWM	0.17	Medium

4.3 Discussion

The outcomes authenticate the suggested integrated framework and offer a solution to the hypothesis of widespread fragmentation which was pointed out in earlier research. The powerful impact of AI adoption on both waste management efficiency and sustainability performance shows that green digitalization is a key enabler for the circular economy practices in the Food and Beverage manufacturing sector. The important role of smart waste management as a mediator reinforces its position as a mechanism through which AI-driven intelligence translates into tangible environmental and technical outcomes. On top of that, the moderating effect of community attitude reminds us that the sustainability transitions are of a socio-technical nature, hence, technological adoption is not sufficient without organizational and stakeholder engagement.

Thus, taken together, the results of the trace provide empirical proof supporting the intelligent and circular waste ecosystems, while also giving the managers and policy makers the practical ways to think about the AI systems that would lead to the sustainability enhancement.

This paper increases the amount of literature on green digitalization and recognizing AI based smart waste management as a mediating mechanism and also pointing out the community attitude's role as a moderator in attaining sustainable business performance.

4.4CONCLUSION

This research is aimed at findings the contribution of AI toward the sustainable performance of the business and the efficiency of the whole waste management process in the Food and Beverage manufacturing sector within the circular economy framework. Through the integrated SEM-PLS methodology, the study proves that the AI adoption leads to a considerable enhancement of the smart waste management systems and the sustainability of the technical and environmental performances mainly.

The contribution of the results to the literature has been accomplished by the addressing of the sustainability wins are not to be attained via mere technological innovations. AI enabled systems implementing smart waste management practices, and providing a positive community attitude are to be a whole integrated ecosystem working together. The findings suggest the need for managers and policymakers to invest in digital intelligence, foster environmental sustainability oriented organizational culture, and support circular waste ecosystems. The study has a limitation in its cross sectional design and sector specific focus. However, its contributions are significant. Future research might take up this framework in other manufacturing areas, use longitudinal might take up this framework in other manufacturing areas, use longitudinal data, or investigate further moderating views like regulatory support and technological readiness. Ultimately, this work confirms that AI powered green digitalization is the key facilitator for the intelligent and circular waste management systems associated with sustainable industrial development.

This study is constrained by its cross sectional criteria, sector specific focus, and limited sample. Future studies should involve longitudinal methods, consider moderators, and analyze across different industries and regions.

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