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Factors Influencing Industrial Waste Applying Information Technology and Managing Information Systems Towards Minimizing Waste Management

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Abstract

This study explores the surging of demand for manufactured products with the increasing of world's population. While the manufacturing sector is essential in meeting this demand, it also faces the significant challenge of reducing the environmental impact of industrial waste. Manufacturing industrial waste primarily arises from by-products, over-extraction of natural resources, and inefficient production processes. Poor management of manufacturing processes would lead to adverse social impacts to human health, natural resources depletion, ecosystem destruction, and contribute to global warming and climate change. Additionally, improper waste disposal can result in financial losses and legal penalties for non-compliance with environmental regulations. Hence, it is imperative for the manufacturing sector to leverage emerging technologies and management strategies to mitigate these challenges. Therefore, this study used a quantitative approach to analyse primary data collected from the survey questionnaire to examine the relationship between independent and dependent variables. Combination of financial, technical, social, and governmental factors addressed in this project underscores the multifaceted approach required for effective waste management

Keywords

Industrial Waste, Managing Information Systems, Waste Management

1.1. Background

According to data from the World Economic Forum, industrial waste from manufacturing activities constitutes over half of the world's annual waste production (Pratt, 2021). Manufacturing processes, which convert raw materials into finished products, generate significant waste, including hazardous materials that require proper disposal. Historically, manufacturing processes used a linear "take-make-dispose" approach with waste management often being an afterthought.

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This was particularly evident before 2017, when developed economies exported non-biodegradable plastic waste to developing countries for landfill disposal. However, China's 2017 ban on various types of plastic waste prompted developed economies to reconsider this unsustainable approach (Wang et al., 2019). Consequently, manufacturing has shifted towards a circular economy model, emphasizing the continuous use of resources in a closed-loop system.

Zero-waste manufacturing is one example within the circular economy to minimize industrial waste. This strategy comprises of six themes: design for zero waste, smart waste audit and reduction planning, smart waste collection, high-value mixed waste processing, collaborative platform for industrial symbiosis, and waste-to-resource conversion and recycling (Kerdlap et al., 2019). This approach has shown promise, particularly with the integration of Internet-of-Things (IoT) applications.

The manufacturing sector also faces legal and societal pressure from governments and environmentally-conscious consumers to reduce its carbon footprint and minimize industrial waste. Treaties like the Kyoto Protocol and Paris Agreements have strengthened the global commitment to combat climate change, compelling the manufacturing sector to re-evaluate their production processes and waste management practices.

1.2. Research Gap

Despite the potential of Information Technology (IT) and management systems to transform waste management in the manufacturing industry, several research gaps remain. Firstly, there is limited understanding of how social factors like organizational mindset, norms, and collaborative practices, influence the adoption of sustainable waste management practices. Secondly, the specific challenges and opportunities of technical factors like advanced IT systems and management tools to minimize waste minimization are underexplored. Thirdly, the impact of financial factors to incentivize manufacturing businesses to develop effective waste management and technologies requires further investigation. Lastly, the role of government policies in shaping waste management practices and influencing the adoption of IT solutions needs further investigation, especially across regulatory environments.

While there has been substantial research on industrial waste management and its environmental impact, the lack of studies on factors impacting the application of IT and management systems to reduce industrial waste. Existing research often focus on broader waste management strategies or specific technologies, lacking a comprehensive analysis of how the Management of Information Systems (MIS) are influenced by social, technological, economic, and regulatory forces to drive sustainable waste management in manufacturing.

By understanding these factors, this study aims to fill this research gap to understand how various factors can influence the adoption and implementation of IT solution and management systems to minimize industrial waste, thus enabling the manufacturing industries can holistically minimize industrial waste across the entire manufacturing value-chain.

1.3. Problem Statement

With the advent of technologies like artificial intelligence (AI), IoT, and cloud computing, the manufacturing sector can adopt more data-driven, automated, and integrated approaches to reduce its industrial waste. However, successful implementation of these technologies requires overcoming a myriad of challenges, including technological limitations, organizational resistance, and regulatory complexities.

Challenges deriving from business collaboration, intricate supply chains, high initial costs, and shortage of technical expertise to effectively integrate technology into waste reduction efforts, are significant obstacles preventing the manufacturing sector from meeting circular economy standards (Jæger and Upadhyay, 2020). Nevertheless, if executed properly, the integration of IT and management systems can reduce industrial waste generation and steer the sector towards more sustainable and eco-friendly practices.

1.4. Research Problem and Questions

This essay aims to address the following four research questions for the manufacturing sector:

1. How do social factors like mindset, norms, and collaborative practices influence the effectiveness of IT solutions for sustainable waste management practices to minimize industrial waste?
2. What are the technical factors, including challenges and opportunities, in utilizing IT systems to minimize industrial waste?
3. How do financial factors like economic incentives, cost savings, and potential financial benefits support the use of IT solutions for waste reduction, resource optimization to minimize industrial waste?
4. How do government policies impact the reduction of industrial waste and the adoption of IT solutions for sustainable waste management?

2.0 LITERATURE REVIEW

Integration of IT into various aspects of society has transformed how organizations operate, interact, and implement policies. In the context of sustainable development, IT holds significant potential to drive progress by enhancing efficiency, reducing waste, and promoting inclusive growth (Goel and Vishnoi, 2022). Nonetheless, this integration comes with its challenges and complexities.

2.1. Dependent Variable – Minimizing Industrial Waste (MIW)

Minimizing industrial waste is a critical component of sustainable development (Freitas et al., 2021). Minimizing industrial waste, generated during production processes, involves reusing materials, recycling waste products, and ensuring proper disposal of non-reusable waste. IT plays a multifaceted role in minimizing industrial waste by optimizing supply chain management, enhancing production efficiency, and improving waste management practices (Lin and Wei, 2023).

Shojaeinasab et al. (2022) highlighted that IT solutions like Enterprise Resource Planning (ERP) systems and Manufacturing Execution Systems (MES), are crucial in minimizing industrial waste. These technologies provide comprehensive data analytics and reporting capabilities, which help organizations identify sources of waste generation and implement strategies to reduce them. For example, ERP systems facilitate lean inventory management and efficient usage of raw materials, thus minimizing waste from overproduction.

Furthermore, digital platforms for circular economy practices are identified key areas that IT can minimize industrial waste (Kovacic, Honic and Sreckovic, 2020). These platforms facilitate the reuse of resources and reduce waste by connecting businesses with surplus materials to those that can use them. Ixmeier et al. (2023) highlight how IT-enabled platforms for material exchange have successfully reduced waste in the construction and manufacturing industries, where excess materials are disposed in landfills.

2.2. Independent Variable 1 – Social Factors (SF)

Social factors play a critical role in determining how IT is adopted and utilized for sustainable development (Rodríguez-Espíndola et al., 2022). According to Neumeyer, Santos and Morris (2020), societal attitudes towards technology, digital literacy, and the digital divide significantly influence the effectiveness of IT solutions in promoting sustainable outcomes. For instance, in communities with high digital literacy, IT solutions like smart energy meters and waste management mobile applications garner more engagement for promoting environmental sustainability, such as. Conversely, in areas with limited access to technology or low digital literacy, the benefits of IT integration are less pronounced (Schirmer et al., 2022).

Furthermore, social acceptance of technology, shaped by cultural and ethical considerations, can either facilitate or deter the deployment of IT for sustainable development. Steiber and Alvarez (2023) notes that in regions with strong cultural resistance to technological change, sustainable IT solutions are less likely to be embraced. This resistance often stems from fears about job displacement due to automation or data privacy concerns (Leesakul et al., 2022). However, social factors can also provide opportunities to foster a sense of ownership and empowerment to engage local communities to support community-driven IT.

2.3. Independent Variable 2 – Technical Factors (TF)

The technical aspects of IT infrastructure (e.g. hardware, software, and connectivity) are integral to effective sustainable development (Mhlanga, 2021). Technical constraints like inadequate infrastructure, poor interoperability, and cybersecurity issues can impede the effective deployment of IT solutions aimed at sustainability. Ahammed and Khan (2022) highlighted challenges like frequent power outages and limited internet access significantly hamper the deployment of smart grids and other carbon-reducing technologies in developing countries that lack robust IT infrastructure.

Meanwhile, advancements in technology provide significant opportunities for sustainable development. Innovations in AI, blockchain, and the IoT pave the way for more efficient resource management, improved transparency in supply chains, and enhanced environmental monitoring (Oriekhoe et al., 2024). For example, IoT sensors in agricultural fields can optimize water usage and reduce waste, while AI algorithms can predict and mitigate the impact of natural disasters, contributing to sustainable environmental management. However, the rapid pace of technological change necessitates continuous system upgrades and adaptations, posing both technical and financial challenges (Mourtzis, Angelopoulos, and Panopoulos, 2022).

2.4. Independent Variable 3 – Financial Factors (FF)

According to Bilderback (2023), the financial implications of integrating IT into sustainable development efforts are significant and multifaceted. The cost of implementing advanced IT solutions are a major barrier, particularly for low-income countries and small enterprises (Mhlanga, 2021). Technologies like renewable energy management systems, smart city infrastructure, and automated waste recycling plants require substantial initial investments and regular maintenance costs and employing skilled personnel to manage these technologies compounds the financial burden.

However, there are also financial opportunities associated with IT in sustainable development like long-term cost-savings through enhanced operational efficiencies, and generation of new revenue streams. On top of improving supply chain management and carbon footprint reduction, cloud-based solution also helped businesses achieve significant cost-savings through improved logistics and inventory management (Yenugula et al., 2023). Furthermore, tax breaks, subsidies and governmental financial incentives for green IT initiatives help to lessen upfront costs and encourage wider adoption (Yan, Qamruzzaman and Kor, 2023).

2.5. Independent Variable 4 – Government Policies Factors (GPF)

Government policy plays a pivotal role in shaping the integration of IT in sustainable development. Regulatory frameworks, standards, and incentives can either promote or hinder the adoption of sustainable IT practices (Anwar et al., 2020). Chen et al. (2021b) indicates that countries with proactive policies supporting green IT initiatives like promoting renewable energy use in data-centers and mandating electronic waste recycling, gained greater progress toward sustainability goals.

However, inconsistent and/or outdated governmental policies and regulations can be counterproductive to the adoption of new technologies (Ullah et al., 2021). For example, a lack of clear guidelines on data privacy and security for IoT devices has been a major barrier to their deployment in many regions. Furthermore, fragmentation in government policies between different jurisdictions causes misalignment of standards and regulations that complicates the scaling of IT solutions across borders (Chen et al., 2021a).

2.6. Underpinning Theory

Transaction Cost Theory (Kim and Dianna, 2023) presents various transactional costs that organizations incur like search and information costs, bargaining and decision costs, and policing and enforcement costs. Advanced technologies may potentially reduce these transaction costs by improving information flow, coordination, and transparency (Ioakimidis, 2023). For example, IT can reduce search and information costs by providing real-time data and analytics, streamline bargaining and decision-making processes through digital platforms, and lower policing and enforcement costs by automating compliance checks and monitoring systems.

In the context of sustainable development, IT can significantly reduce transaction costs from implementing sustainable practices (Parmentola et al., 2021). Digital platforms can facilitate efficient resource allocation and waste management, reducing the costs of managing these processes manually. Furthermore, blockchain technology can enhance supply chains transparency, thus reducing the costs associated with ensuring ethical sourcing and compliance with environmental regulations. These reductions in transaction costs enable organizations to re-direct resources toward sustainable development initiatives (Bachmann et al., 2022).

2.7. Framework

Figure 2.1 illustrates the proposed research framework to investigate IT's effectiveness to minimizing industrial wastes through the lenses of social, technical, financial, and government policy factors, grounded in Transaction Cost Theory.

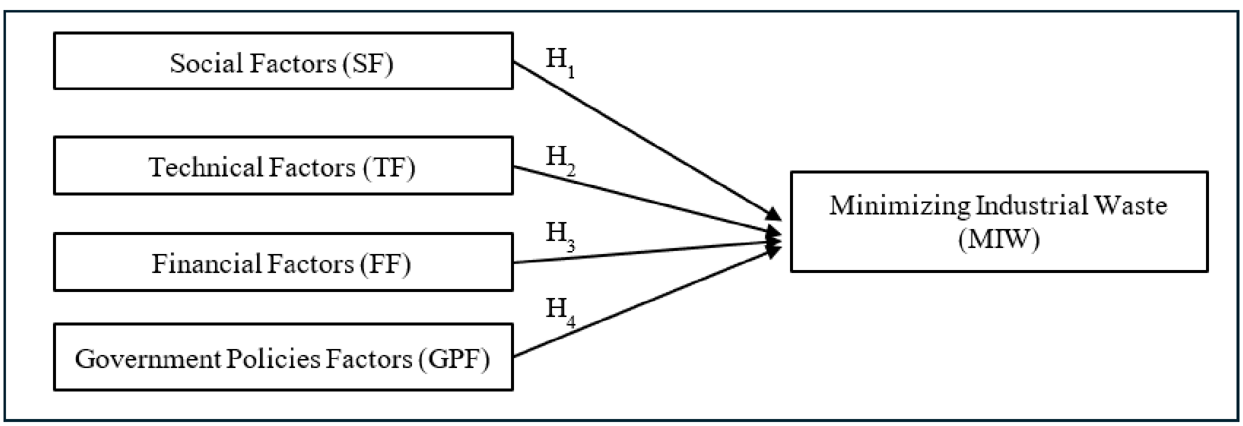

Figure 3.1: Research Framework

3.0 RESEARCH METHODOLOGY

3.1. Sample Population

While population is often regarded as being defined by geographic location, in research, a population can also be characterized by their clinical, demographic, and temporal attributes (Thacker, 2019). As this study aims to explore how the integration of Information Technology (IT) and Management Information System (MIS) can tackle industrial waste reduction in the manufacturing sector, the target population for this study are employees from the manufacturing sector in Malaysia. With approximately 2.8 million employees in the manufacturing sector in Malaysia in 2023 (Statista, 2024), and efforts were made ensure representativeness by distributing the survey to workers from various industries (e.g. semiconductor and automotive) and regions in Malaysia to enhance representativeness.

3.2. Sample Size

The sample size is set at 100 respondents as stipulated in this assignment. This amount allows for a focused and manageable data collection process and allows for statistical analysis such as multiple regression, R-squared, and Pearson correlation coefficient. While a larger sample size could yield more generalizable results, 100 respondents are considered sufficient for analysis of relationships for this study (Bullen and Bullen, 2022).

3.3. Sample Respondents

The target respondents for this study are employees working in the manufacturing sector in Malaysia, specifically those holding executive-level positions and above. These individuals are chosen due to their strategic decision-making roles and comprehensive understanding of the numerous factors influencing industrial waste management. Executives level and above often interact with various stakeholders, including government bodies, suppliers, and customers. Their insights are crucial for examining the impact of social, governmental, technical, and financial factors on minimizing industrial waste through the integration of IT and MIS. The study aims to include a diverse range of executives from different departments such as operations, manufacturing, transportation, finance, and human resources, as well as from the years of operations of the company. Furthermore, the survey forms are distributed across Malaysia, providing a wide range of perspectives.

4.0 DATA ANALYSIS

Data analysis employs both descriptive and inferential statistical methods. Descriptive analysis summarizes the underlying characteristics of the data using measures of central tendency and variability and use charts, graphs, and tables for data visualization. Multiple regression analysis substantiates the relationship between the dependent and independent variables and determines the impact of various factors on the effectiveness of IT solutions on minimizing wastes.

4.1. Descriptive Analysis

Table 4.1: Descriptive analysis of demographic data.

Items	Parameter	Frequency (N = 100)	Percent (%)
Gender	Male	58	58
	Female	42	42
Firm	Manufacturing	100	100
Years of service	< 5 years	22	22
	6 yrs to 10 yrs	29	29
	11 yrs to 15 yrs	23	23
	> 15 yrs	26	26
Position	Executive	35	35
	Sr executive	27	27
	Assistant Manager	20	20
	Manger	11	11
	Sr Manager	7	7
Education Level	Certificate/SPM	2	2
	STPM/Diploma	12	12
	Bachelor Degree	67	67
	Master	16	16
	PhD	3	3
Department	Operations	13	13
	Manufacturing	12	12
	Transportations	35	35
	Finance	21	21
	HR	19	19

(Source: Developed by authors)

The descriptive analysis of the survey data (Table 4.1) reveals key insights into the demographic and professional profiles of the respondents. 58% of the respondents are male, while 42% are female, with all respondents working in the manufacturing sector. The respondents' years of service are well-distributed: 22% have fewer than 5 years, 29% between 6 to 10 years, 23% between 11 to 15 years, and 26% have over 15 years of experience. Regarding job positions, executives (35%) constitute the largest group, followed by senior executives (27%), assistant managers (20%), managers (11%), and senior managers (7%). Regarding education levels, 67% hold a bachelor's degree, 16% have a master's degree, 12% possess a diploma or STPM, 3% are PhDs, and 2% hold a certificate or SPM. The survey has representation from all departments, with transportation (35%) being the highest, followed by finance (21%), HR (19%), operations (13%), and manufacturing (12%). This diverse demographic and professional background offer a comprehensive view of the workforce engaged in industrial waste management, which is crucial for understanding their perspectives and practices in this area.

4.2. Multi-Regression Analysis

Table 4.2: Correlation between DV and IVs.

		SF	TF	FF	GPF	MIW
SF	Pearson Correlation	1				
	Sig. (2-tailed)					
TF	Pearson Correlation	.813**	*1*			
	Sig. (2-tailed)	<.001				
FF	Pearson Correlation	.731**	*.834***	*1*		
	Sig. (2-tailed)	<.001	*<.001*			
GPF	Pearson Correlation	.808**	*.733***	*.689***	*1*	
	Sig. (2-tailed)	<.001	*<.001*	*<.001*		
MIW	Pearson Correlation	*.626***	*.570***	*.573***	*.724***	*1*
	Sig. (2-tailed)	<.001	*<.001*	*<.001*	*<.001*	

**. Correlation is significant at the 0.01 level (2-tailed).

(Source: Developed by Authors)

The Pearson correlation analysis (Table 4.2) provides the following insights into the relationship between the studied factors:

1. Strong correlation of SF → MIW (r = .626, p < .001) **supports H_1** and indicates social initiatives contribute significantly and positively to waste minimization efforts. The strong interconnectedness of SF → TF (r = .813, p < .001), SF → GPF (r = .808, p < .001), and SF → FF (r = .731, p < .001) suggests social attitudes with policymaking and technical advancements, and financial resource allocation.
2. Moderate correlation of TF → MIW (r = .570, p < .001) **supports H_2** and indicates that while technical improvements are important for minimizing industrial wastes, they need support from other factors. The significant and strong correlation of TF → FF (r = .834, p < .001) and TF → GPF (r = .733, p < .001), highlights the interconnectedness of financial and policy factors to advance technical innovations.
3. Moderate correlation of FF → MIW (r = .573, p < .001) **supports H_3** and indicates financial factors play an important, albeit underwhelming, role in waste minimization. FF → GPF (r = .689, p < .001) suggests that resources allocation is significantly associated with governmental policies.
4. GPF → MIW (r = .724, p < .001) has the strongest correlation that **supports H_4**,

underscoring the significant and positive impact policies have in reducing wastes.

These significant and positive correlations GPF, SF, FF, and TF (in accordance of their influence) on MIW highlights that an all-encompassing approach is important of integrating IT and MIS to reduce industrial wastes, ultimately contributing to sustainable development and environmental protection.

Table 4.3: Linear regression of model.

Model Summary [b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics			Change Statistics	
					R Square Change	F Change	df1	df2	Sig. F Change
1	0.733[a]	0.537	0.518	0.6332	0.537	27.549	4	95	< 0.001

a. Predictors: (Constant), Government Policy Factor (GPF), Financial Factor (FF), Social Factor (SF), Technical Factor (TF)
b. Dependent Variable: Minimize the industrial waste (IW)

(Source: Generated by SPSS)

The linear regression analysis (Table 4.3) provides a comprehensive overview of the factors affecting industrial waste minimization. The model summary indicates a strong positive correlation (R = 0.733) between the independent variables and the dependent variable.

The high R-square value (R-square = 0.537) suggests that the model has good fit as 53.7% of the variance is explained by the predictor variable, indicating that the studied factors contribute significantly to waste reduction efforts. The high F-change value of 27.549 and a significance level (Sig. F-change) of less than 0.001 indicate that the predictor variables in the model significantly contribute to predicting the dependent variable. This suggests that the factors studied are crucial in minimizing industrial waste, as the explained variance in the model is much greater than the unexplained variance.

The adjusted R-square value (R2 = 0.518), which accounts for the number of predictors in the model, indicates that approximately 51.8% of the variance is explained when adjusting for the number of predictors, further supporting the robustness of the model. The standard error of the estimate is 0.6332, which represents the average distance of the observations from the regression line, with lower values indicating a better fit of the model to the data.

The predictor variables in the model — SF, TF, FF, GPF — are key components for effective management of industrial waste. Social factors like public awareness and corporate social responsibility, motivate industries to adopt sustainable practices. Technological factors encompassing advancements and innovations facilitate efficient waste management. Financial factors are crucial as they determine the resources available for implementing waste management technologies and practices. Government policies are vital in setting regulations and standards that industries must follow, thereby influencing waste management practices.

In summary, linear regression analysis highlights the significant impact of government policies, financial investments, social initiatives, and technological advancements on reducing industrial waste. The model's strong correlation and high explanatory power emphasize the importance of a multifaceted approach to waste management that integrates various factors to achieve sustainable development and environmental protection. The analysis provides valuable insights for industry and policymakers aiming to enhance waste management practices through strategic investments and policy interventions.

5.0 DISCUSSION

5.1.1. Implement Circular Economy Policies

The mindset change from traditional linear economy (take-make-dispose) to circular economy is essential for sustainable industrial waste management. IT can play significantly aid material recycling, reuse, and remanufacturing. By implementing digital platforms designed for circular economy practices, industries can track the lifecycle of their materials, minimize waste, and reuse resources efficiently. For example, blockchain technology could ensure transparency in supply chains, tracking material flow and ensuring waste products are effectively recycled or repurposed. Policies to encourage collaboration between businesses to build shared digital platforms that facilitate exchange of surplus materials between companies, fostering industrial symbiosis. (Kovacic et al., 2020).

5.1.2. Improving Corporate Culture

The effectiveness of IT and MIS in managing industrial waste heavily depends on the workforce's understanding and adoption of these technologies. Resistance to technological changes often stems from insufficient digital literacy and fear of job displacement due to automation. To address this, companies should invest in training programs that enhance employee knowledge of IT tools related to waste management. These programs should focus on how IT solutions can optimize processes, reduce waste, and contribute to environmental sustainability. Therefore, incorporating regular workshops, training sessions, and e-learning platforms is essential to develop employees' digital skills and improve their engagement with waste management initiatives (Neumeyer et al., 2020), and promotes a culture of innovation and sustainability, which encourage acceptance and usage of IT systems.

5.1.3. Investment in IT Infrastructure for Waste Reduction

Investment in IT infrastructure for real-time data analytics is another key to improving waste management. Utilizing advance analytics to monitor the vast volumes of data generated from manufacturing processes can help identify inefficiencies and sources of wastes, such as excess material usage, energy consumption, or malfunctioning machinery. Systems like MES and ERP can collect and analyse data across multiple production stages. (Shojaeinasab et al., 2022). These systems provide actionable insights that help businesses implement proactive measures, reducing waste before it accumulates. Therefore, it is recommended that industries adopt IoT-based sensors and AI-driven analytics tools to continuously monitor their waste generation levels.

5.2. Conclusion

Integration of IT and MIS into industrial waste management practices presents a significant opportunity for industries to reduce their environmental impact and boost operational efficiency. As the manufacturing industry grapples with increasing waste production and growing regulatory pressures, technology's role in addressing these challenges becomes increasingly critical. IT solutions, through real-time monitoring, predictive analytics, and enhanced data management systems, help companies to streamline operations and minimize waste throughout the production cycle. (Lin and Wei, 2024).

Moreover, adopting circular economy principles supported by IT platforms promotes sustainable manufacturing practices by encouraging the reuse and recycling of materials. This shift not only reduces waste but also contributes to a more resource-efficient economy. Coupled with government policies that incentivize sustainable practices, industries can gain financial benefits while meeting regulatory requirements. The implementation of these solutions, however, requires a skilled workforce capable of leveraging digital tools to optimize waste management. Therefore, companies must prioritize employee training and digital literacy for successful integration of IT into their waste reduction strategies. (Bachmann et al., 2022).

In conclusion, embracing IT and MIS in waste management, allows manufacturing industries to improve their environmental stewardship and achieve long-term sustainability. Integrating these systems promises to transform traditional waste management practices into more intelligent, efficient, and sustainable processes, thereby contributing to a greener future for the manufacturing sector.

5.3. Future Research

5.3.1. Exploring Industry-Specific IT Solutions for Waste Management

Future research should focus on the development of industry-specific IT solutions tailored to the unique waste management challenges of different manufacturing industries. For example, the waste generated by the semiconductor industry differs significantly from that of the automotive or textile industries. Research should investigate how customized IT tools, such as specialized ERP systems or IoT-enabled waste monitoring sensors, fits the specific requirements of these industries. Furthermore, studies could explore how different industries can collaborate on shared IT platforms to optimize waste reduction across supply chains. (Yenugula et al., 2023).

5.3.2. Investigating the Role of Blockchain in Waste Management Transparency

Blockchain technology holds great promise for enhancing transparency and accountability in industrial waste management. Future research should examine how blockchain can be applied to track waste across the entire supply chain, ensuring properly disposed of or recycling of waste products. Future research could explore the potential for blockchain to prevent illegal dumping or mishandling of hazardous materials by providing a tamper-proof digital ledger that records all waste-related transactions. Moreover, blockchain allow verification sustainability credentials of products by consumers and regulators to inspire trust in environmentally responsible companies. (Petrillo et al., 2021).

5.3.3. Evaluating the Long-Term Impact of IT-Driven Waste Management Solutions

While the short-term benefits of IT in waste management such as cost savings and increased efficiency are well-documented, there is limited research on the long-term sustainability impacts. Future studies should focus on evaluating the environmental, social, and economic outcomes of IT-driven waste management solutions over extended periods. (Freitas, et al., 2021) This research could assess whether the integration of IT into waste management continues to deliver sustainable outcomes as technologies evolve and regulatory frameworks change. Additionally, long-term studies could explore the scalability of IT solutions across various industries.

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