AI-BASED WASTE MANAGEMENT OPTIMIZATION IN THE HALAL FOOD INDUSTRY OF MALAYSIA: A MINI REVIEW

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ABSTRACT Solid waste management (SWM) has become a critical issue in Malaysia, with increasing amounts of waste generated every year and limited resources available to manage it effectively. Additionally, the halal food industry is rapidly growing and expanding globally due to the rising Muslim population, predicted to reach 2.2 billion by 2030 at an annual growth rate of 1.5 percent. This increasing production and consumption of halal food has an impact on the environment. Artificial intelligence (AI) has the potential to revolutionize solid waste management by improving efficiency, reducing costs, and optimizing waste management processes. This mini review provides an overview of the impact of AI on solid waste management in Malaysia, focusing on the current trends, challenges, and opportunities in the industry, particularly in the halal food sector. The review offers insights into the potential of AI in enhancing waste collection, optimizing waste management processes, improving resource recovery and recycling, and reducing waste to landfill. Additionally, the review explores the current initiatives, projects, and developments in the field of AI and solid waste management in Malaysia and identifies areas for future research and collaboration. The review concludes that AI has a significant role to play in improving solid waste management in Malaysia, and continued investment and development in this area is necessary to achieve sustainable waste management practices. Furthermore, its findings have the potential for wider applications and inspire future research in AI-based waste management solutions across various industries. The findings and recommendations of this review have the potential to be adapted and implemented in other industries facing similar waste management challenges.

KEY WORDS: *Artificial intelligence, Machine Learning, Halal food waste, Sustainable waste management, Malaysia.*

1. INTRODUCTION

The increasing population in Malaysia and worldwide has led to a significant rise in solid waste production, posing a critical challenge for many countries to manage effectively. While Muslims represent a substantial market segment for halal food, it is imperative to recognize that they are not the exclusive consumers of such products. The halal food industry is a rapidly growing global market, driven by the expansion of the Muslim population, which is predicted to reach 2.2 billion by 2030, growing at a rate of 1.5% annually [1]. With the increasing demand for halal food, there is an opportunity for food manufacturers to expand and introduce new sustainable products to the market. Currently, the halal food market is estimated to be worth over $2 trillion, up from $1.5 trillion in 2018 [1]. Worldwide, many approaches have been tested to effectively manage the increasing volume of waste. Several innovative solutions were tested to optimize waste management

processes and reduce the amount of waste sent to landfills. Nevertheless, it is noteworthy that these endeavors often neglect to specifically target the halal food sector. In Malaysia, the most commonly used method of solid waste management is landfilling disposal [2]. The process involves collecting and transporting waste to designated landfill sites, where it is deposited and compacted in a controlled manner. While landfilling is considered the easiest and cheapest method of managing solid waste, it has significant environmental and health effects, namely the release of methane and other greenhouse gases, as well as the potential for groundwater contamination. Alternatively, solid waste management in Malaysia includes other methods such as recycling, composting, and incineration. Nevertheless, these methods are not adopted as widely as landfill disposal.

Many programs have been implemented or planned by the Malaysian government, with a main aim to promote sustainable solid waste management practices, including reducing waste generation, encouraging waste reduction and recycling, and improving waste management infrastructure. Artificial intelligence (AI) and machine learning (ML) have the potential to offer sustainable solutions to solid waste management challenges by using advanced algorithms and data analytics. These algorithms can analyze vast amounts of data, such as waste generation patterns, collection, and resource recovery and recycling efforts, to optimize solid waste management processes. Table 1 summarizes the findings from the chosen articles.

Table 1. Summary of findings from related articles using AI and ML

Models/Technology	Application	Results	Ref.
Artificial intelligence and Deep Learning	Visual inspection process within the manufacturing process	Model inspected 715 images and achieved an accuracy of 99.86% in inspecting products, outperforming all the other existing models from published works. AI image recognition can help design out food waste by ensuring the packing of only quality products, reducing return rates and subsequent waste.	[3]
ML algorithms	Quality control for food items during manufacturing and packaging.	ML algorithms successfully predicted deviations in production, thereby offering the potential to reduce food wastage by ensuring the packing of only quality products, reducing return rates and subsequent waste.	[4]
	To predict the unexpected level of hazards in a food supply chain network.	predict the unexpected level of hazards in a food supply chain network.	[5], [6]
Blockchain and AI	Sustainability and data monetization in the food supply chain.	A combination of AI and blockchain can ensure traceability in the food supply chain to decrease food waste.	[7]

The objective of this mini review is to explore the use of AI in solid waste management and the halal food industry in Malaysia and to provide a concise assessment of the current trends, challenges, and opportunities. The review aims to explore how AI can be utilized to address waste management challenges throughout the process, from waste generation to resource recovery. By analyzing these issues, the review aims to identify areas for future research and improvement.

2. CURRENT STATE OF SOLID WASTE MANAGEMENT AND HALAL FOOD INDUSTRY

Despite efforts by the government and private sector to improve waste management systems and infrastructure, many areas in Malaysia still rely on traditional methods such as landfill disposal and open dumping. Currently, there are 146 non-sanitary operating discharges in Malaysia, including landfills, open dumps, and other non-sanitary sites [3]. Several research has discussed the significant environmental and health impacts of using such disposal methods. This section will discuss an overview of the solid waste generation and management in Malaysia and the challenges and limitations of traditional solid waste management methods.

2.1. Overview of the solid waste generation and management in Malaysia

Solid waste generation in Malaysia has increased significantly in recent years, attributed to population growth and economic development. Recently, Malaysia generates approximately 39 million tons of waste per year [4], 65% of which is household solid waste which has increased twofold in the last two decades due to population growth and urbanization [5]. Waste per capita also doubled, increasing from 0.90 in 2005 to 1.17 in 2022 [6]. The majority of this waste is generated in urban areas, including household waste, industrial waste, construction, and demolition waste. The latest statistics indicate that Malaysia generated almost 3 million tonnes per year of household food waste. As per the World Bank, urban areas generate two to three times the amount of solid waste compared to their rural counterparts [7].

Malaysia has set a goal to reduce the amount of solid waste sent to landfills from 82.5% in 2021 to 40% by 2023 [5]. Despite efforts by the government to promote waste reduction and recycling, and the potential to recycle up to 80% of the collected dry waste, the current recycling rate in Malaysia is still low, estimated at around 20-22% [8]. The need for sustainable and efficient solid waste management in Malaysia is critical and has been widely discussed. Furthermore, there is a pressing need for initiatives dedicated to promoting waste reduction, recycling, and the integration of advanced technologies such as AI. However, there are still significant challenges to improving solid waste management in Malaysia, including a lack of consistent and comprehensive data, limited public awareness and participation, and a need for further investment and innovation in solid waste management technologies and practices.

2.2 Current state-of-art for AI in Halal Food industry Waste Management

The essential need for sustainable and efficient food systems has underscored the urgent necessity for improvements in the area of solid waste management in the food industry [9]. Furthermore, studies have explored different approaches to improve waste management practices in the industry, including reducing waste generation [10], improving segregation and collection of waste [11], and implementing innovative waste treatment and disposal technologies, and implementing innovative waste treatment and disposal technologies.

Tseng et al. [12] has focused on identifying innovational solutions and areas of improvement in food chain using data-driven of sustainable food supply chain for reducing food waste and enhancing waste management practices. The study also provided a comparison between halal and non-halal food supply chains. Additionally, the study highlights the most significant indicators for both halal and non-halal sustainable food supply chain, food safety was fundamental for both supply chains, food consumption,

security, and food waste management were the mostly important in non-halal food supply chain. Whereas, Islamic values, halal certification, and halal supply chain trust were the most crucial indicators in a halal food supply chain (HFSCs). The literature review has concluded that supply chain management represents a critical aspect of halal food production [13], and therefore, integrating eco-friendly and sustainable practices into supply chain management constitutes an effective approach.

Similarly, Rejeb [13] has conducted a review and bibliometric analysis on 74 journal articles. Despite a growing number of publications in the last two decades, the analysis suggests that halal food supply chains remain a relatively new area of research. The main focus of the review was to identify trends in publications on HFSCs, including the top contributing countries, publishing journals, and research methods employed in the collected studies. It could be clearly noticed that currently there is limited systematic data-driven approaches exists to identify the most suitable indicators for promoting sustainability in both halal and non-halal food supply chains [12-13]. Moreover, halal food supply chains (HFSCs) are becoming more complex, uncertain, and fragmented.

Out of the 74 chosen papers, Malaysia is the predominant country with 37 publications. The article highlights the increasing global demand for Halal food products and the need to ensure their sustainability [13]. However, there is a lack of research on the sustainability of HFSCs compared to non-halal food supply chains. Moreover, the existing literature on HFSCs focuses mainly on the certification process and the religious requirements of halal food, rather than the sustainability issues. Besides, HFSCs face similar sustainability challenges as non-halal food supply chains, including food safety, environmental impact, and social responsibility. The review also indicated that it was not until 2007 that literature regarding the creation of sustainable HFSCs appeared. From then, the research on sustainability in the context of halal food gradually gained momentum, and by 2014, it had made significant progress.

Furthermore, Bux [14] provided a comprehensive review of the literature on the intersection of halal food sustainability, certification, and blockchain technology. The authors examine the challenges faced by the halal food industry in ensuring sustainability and ethical production practices and explore the potential of blockchain technology to address these challenges. Authors elaborated that blockchain technology has the potential to enhance transparency and traceability in the halal food supply chain, which can help to prevent fraud, ensure ethical production practices, and increase consumer trust. However, the article primarily focuses on the potential of blockchain technology to enhance transparency and traceability in halal food certification. Yet, blockchain technology has also been explored in the context of waste management.

França et al. [15] has proposed a system that utilizes blockchain technology to provide financial management for waste collection in the municipality. The objective of this system is to promote health, environmental education, and socio-economic inclusion of citizens, with the use of social currency. Additionally, the author concluded that the restructuring and supervision of existing solid waste management models through blockchain technology can potentially decouple economic growth from the depletion of non-renewable resources. This approach may lead to the conservation of non-renewable resources and the retrieval of materials through an improved solid waste management system.

Lastly, Reynolds et al. [10] presents an overview of 17 practical measures for preventing food waste during the consumption and consumer phase of the supply chain. The

measures were identified by conducting a rapid review of literature published between 2006 and 2017. The review revealed that certain interventions, such as using color-coded refrigerator, product labelling, and providing information, could be implemented on a large scale in households. Similarly, plate and portion size adjustment, modification of menus and nutritional guidelines, and changes in class curriculum could be effective in preventing food waste outside of the home.

Overall, the current halal food supply chain and production systems in Malaysia lack the presence of AI technology, presenting a significant challenge that requires attention. Implementing AI technology in the halal food industry presents various opportunities to achieve a sustainable production system, minimize waste, and ensure food safety. Studies have shown that the incorporation of AI technology in the food industry can improve quality control, reduce production time, and minimize food waste [11-12], [16-17].Therefore, it is crucial for the Malaysian government, private sectors and Muslim community to invest in AI technology to enhance the Halal food production system and promote sustainable practices.

3. THE ROLE OF AI IN SOLID WASTE MANAGEMENT

AI is the use of technology to mimic the human brain. Recently, AI has gained popularity as a computational approach to address various issues across numerous fields. AI has been utilized in several aspects of Solid Waste Management (SWM) to enhance the performance and productivity of waste management operations [18-19]. It has been discovered that AI is better equipped to handle complex, unpredictable, and missing data, and it is able to continuously improve based on experiences [18]. Some of the key areas in which AI has been used in solid waste management include waste sorting and recycling [20] waste collection optimization [21] environmental monitoring [22], and public awareness and education (Fig. 1).

Likewise, ML has emerged as a transformative technology with broad applications across various industries, including the realm of artificial intelligence (AI) [16]. ML, a subset of AI, encompasses a diverse set of techniques that enable computer systems to learn from data and make predictions or decisions without being explicitly programmed.

While numerous research efforts have concentrated on the application of AI and ML technologies in solid waste management, there is a notable scarcity of research in the specific domain of the halal food industry. Sinthiya et al. [24] has conduct a systematic literature review on AI-based smart waste management covering between 2001 to 2021, the research analyzed 40 research papers. Each has utilized different types of AI models - including pure ML and deep learning models in addition to hybrid models - for different application to enhance SWM systems. Mostly, the articles have focused on the municipal solid waste management field, with limited discuss for organic food waste. Nevertheless, the systematic literature review has only used one database, Scopus, which has limited the research outcomes.

Fig. 1: Applications of AI in Food Waste Management adopted from Owen et al. [27].

Similarly, Abdallah [18] provided an extensive analysis of how artificial intelligence is utilized in managing solid waste worldwide. The main focus of the review was to evaluate different AI models and tools utilized in this field, in addition to highlight the advantages and drawbacks of each. He studied 84 research studies worldwide, and 8 in Malaysia covering from year 2004 to 2019. Similar to a review by Sinthiya et al. [24], most of the articles has focused on municipal solid waste management applications including waste generation, waste classification, and system improving models. However, organic waste was rarely discussed with no mention to halal food.

Despite the growth in research in this area, artificial intelligence systems are mainly still at the research and development stage [18]. Furthermore, the findings from the previously discussed systematic literature review and other literature reviews indicate that the majority of articles have predominantly concentrated on municipal solid waste (MSW). In contrast, there has been relatively less attention given to addressing other fields [18-19], [24]. Although municipal waste consists mainly of food waste, in Malaysia, food waste is approximately 37% of municipal waste composition [25].

4. OPPORTUNITIES AND CHALLENGES OF ARTIFICIAL INTELLIGENCE IN SOLID WASTE MANAGEMENT

The application of artificial intelligence (AI) presents numerous opportunities, while on the other hand, it also poses global challenges [18-19]. The employment of AI and ML

has been widely discussed among governments, organizations, and researchers for an extended period, across diverse fields.

Kutty and Abdalla [16] provided a macroscopic overview of the tools and techniques used in sustainable food security-related projects, with a focus on data management systems and food waste management. According to the authors, achieving global food security requires addressing a series of challenges, including food waste accumulation in the food supply chain, tackling gender disparities, and climate-related concerns to promote sustainable consumption and production practices at several stages of the food supply chain. The findings could also be applied in the halal food sector by customizing database management systems, tools, and data visualization platforms. Moreover, proper knowledge and understanding of the existing tools and techniques for tracking and assessing food waste at several stages of the halal food supply chain is also essential.

4.1. Opportunities of AI in Halal food industry

Since the implementation of the Third Industrial Master Plan 2006-2020 (IMP3), Malaysia has aimed to become a worldwide Halal centre, Malaysia has seen significant investments, both from the public and private sectors, towards the development, execution, and acceptance of AI technologies [13]. AI could be utilized in several areas of such systems, namely, Quality Control, Traceability, Demand forecasting, Resource Optimization, and Risk Management.

4.1.1. Quality Control

Quality assurance is critical in the halal food industry for several reasons. However, in the context of waste management, quality assurance is essential to ensure limited food waste during the production stage. AI technologies could reduce food waste by identifying potential issues early and enabling proactive intervention, thus preventing food spoilage, extending the shelf life of food products, and reducing food disposal [16-17].

Maiyar et al. [17] has examined "REAMIT" project, which stands for "Remote Evaluation of Ambient Intelligence Technologies in Intelligent Food Procurement" project. The REAMIT project is an EU-funded research project that aims to develop a system that utilizes Internet of Things (IoT) sensors to monitor food quality in real-time throughout the entire supply chain. The project's goal is to improve food safety and reduce food waste by providing better quality control and traceability of food products. The system uses a combination of sensors, including temperature, humidity, and gas sensors, to monitor food conditions. The collected data is then analyzed using AI and ML algorithms to detect anomalies and predict potential issues.

While the REAMIT project's primary goal is broader in scope, its advancements in real-time food quality monitoring, data analysis, and predictive capabilities have the potential to benefit various sectors, including the halal food industry. The application of these technologies can enhance the quality assurance and traceability of halal food products, ensuring compliance with Islamic dietary laws and meeting the growing demand for high-quality halal products. Thus, the innovations stemming from projects like REAMIT open up exciting opportunities for improving the halal food industry's quality control processes and overall sustainability.

Likewise, an AI-based image recognition system has been developed for efficient sorting of apple fruits [26]. The system has shown remarkable results with an average

accuracy of 99.70%. Additionally, the accuracy of the Convolutional Neural Network (CNN) based apple sorting system was observed to be 99.38%. These results demonstrate the sorting image recognition system's ability to accurately classify apples based on their characteristics, allowing for non-destructive testing and grade classification of the fruit. Such a system could be developed with further research and development of automated fruit sorting systems and other food types.

This technology's potential extends to addressing food waste in the context of halal food production and supply chains. By adapting and expanding this system to halal food products, it could play a crucial role in minimizing waste and improving quality control. With further research and development of automated sorting systems for halal food and other food types, we can enhance the efficiency of waste reduction efforts and ensure compliance with Islamic dietary laws, thereby promoting sustainability in the halal food industry.

Overall, AI has the ability to create a feedback loop for existing food safety and quality programs to evaluate their performance in meeting the expectations and goals of business quality assurance management [14-17].

4.1.2. Traceability

Food waste tracking throughout the supply chain is essential to reach a sustainable halal food waste management system. This helps identify the causes of waste and allows for more efficient management and reduction of waste. Both AI and ML could be used to analyze data and provide insights into where waste is occurring and how to prevent it. For instance, AI models can analyze data from sensors placed on food packaging to determine when food is likely to spoil, allowing for more accurate shelf-life predictions and reducing the likelihood of food being thrown away.

Additionally, ML can also be used to analyze data during food production and distribution stages [27] identifying inefficiencies and areas for improvement. It also helps provide a detailed record of waste, allowing for more targeted interventions to reduce waste.

One established application is the use of RFID, or radio frequency identification, which is a technology that uses IoT. It involves the use of a tag, which is a small electronic device that contains an integrated circuit and an antenna. The integrated circuit is responsible for storing, processing, and modulating/demodulating the radio frequency signal that is used to communicate with the reader. The tag is also able to transmit the signal via the antenna.

Zuo et al. [28] proposed the use of Radio Frequency Identification (RFID) tags in sensor applications such as humidity, temperature, gas, pH, integrity, and traceability in connection with food packaging. The authors suggest that RFID sensors offer significant advantages in terms of sensing ability and data transmission for smart packaging solutions. The future development of smart packaging is focused on simpler, low-cost, robust, and less power-demanding sensor networks, and chip-less RFID sensors have the potential to achieve these functions.

Overall, traceability is a key element in halal food waste management. Using AI and ML can help organizations to identify and reduce waste, leading to more sustainable and efficient halal food production and distribution. However, there are still challenges to be overcome, such as biocompatibility, cost, multi-tag collision, multi-parameter sensors, recycling issues, security, and privacy of RFID systems [28].

4.1.3. Demand forecasting and Resource optimization

As the population increases, so does the demand for food. According to the United Nations' Food and Agriculture Organization, approximately one-third of the world's food production, equivalent to 1.3 billion tons of food annually, is lost or wasted. Demand forecasting is crucial for reducing food waste as it helps companies to accurately predict the necessary amount of food to produce or stock to meet customer demand. Food loss and waste can happen at various stages of the food supply chain, ranging from the harvest to the retail phase. While food loss occurs primarily during production and distribution, food waste occurs mainly at the retail and consumer levels. In fact, consumer food waste accounts for the largest share of food waste throughout the entire chain, encompassing farming, processing, distribution, and retail. Estimates suggest that consumer waste ranges between 40% and 60%, whereas retail waste is typically around 10% [11] .

By utilizing AI-based demand forecasting models, companies can predict future demand for their products accurately, allowing the adjust of their production and inventory levels accordingly. Hence, it reduces the risk of overproduction and subsequent waste, while also ensuring that enough food is available to meet customer needs. In addition to cost savings and improved efficiency in the supply chain. Moreover, AI can be used to optimize the use of resources in the Halal food industry, such as water, energy, and raw materials. By using predictive analytics and ML algorithms to analyze data on resource usage and production processes, AI can help identify opportunities for efficiency improvements and cost savings.

Lutoslawski et al. [11] has proposed using a nonlinear autoregressive exogenous neural network to predict demand for processed foods, the models' showed high levels of accuracy with coefficient of determination (R^2) measure ranging from 0.962 to 0.996 depending on the product. The study suggests that such models can be used in intelligent management systems to support more efficient and sustainable food production and distribution.

Kotaro [29] has developed a “heterogeneous mixture learning” technology that employs algorithms for short-term demand estimation in food grocery stores. This technology relies on two crucial factors: (1) the automated discovery of optimal patterns and (2) the utilization of a prediction model with high readability. Its comparison with the conventional technology is shown in Fig. 2. This technology has proven to be effective in reducing unsold items, thus contributing to the reduction of food waste.

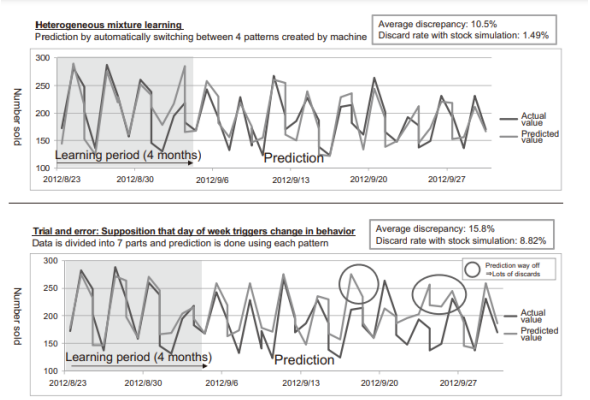

Fig 2. Comparison of results with conventional statistical algorithms.

Additionally, big data analytics and predictive analysis offer valuable benefits to the food waste industry. They enable precise predictions and informed decision-making based on data-driven insights, helping organizations optimize waste reduction, streamline resource allocation, and reduce costs. Real-time insights allow for timely responses to changing conditions, while the identification of hidden patterns and trends leads to innovative solutions. Furthermore, predictive analysis helps in mitigating risks associated with food waste. These findings suggest that the application of advanced technology and data analytics can play a crucial role in managing halal food waste, enhancing overall efficiency and sustainability in the sector.

Overall, traditional data science forecasting models have been used in the past, such as multiple regression, exponential smoothing, the Holt-Winters model, ARIMA, supervised regression and classification models, random forest, gradient boosting, and stochastic optimization. However, these methods have several limitations, including a short "life cycle", inability to learn, and lack of generalizability. AI and ML can be utilized to overcome these limitations, including deep learning models [18], [30]. AI-based demand forecasting models can predict future demand for food products accurately, allowing companies to adjust their production and inventory levels, accordingly, thus reducing the risk of overproduction and subsequent waste, while also ensuring enough food is available to meet customer needs.

4.2. Challenges for AI Implementation

AI provides numerous opportunities and benefits to improve halal food waste management in addition to the above-mentioned areas. However, there are also some challenges that need to be considered and further studied. Based on a review of previous studies and research the following challenges have been identified.

To begin with, few studies dedicated to developing AI applications consider the unique features and qualities of food waste management systems with nearly none examining halal food waste systems. Creating AI applications that are tailored to the distinctive characteristics of food waste management systems requires collaborative research between halal food scientists, computer scientists and waste management experts from different disciplines. It is essential to emphasize the need for a highly skilled AI technical team in this collaborative effort, as highlighted in the works of Xia et al. [31] and Yigitcanlar & Cugurullo [32].

Additionally, the lack of sufficient data is considered one of the major challenges in implementing AI systems for halal food waste management. AI models require extensive datasets for training and calibration [33], but current research is hindered by incomplete or inadequate waste data. This is mainly because SWM industries, particularly in developing countries, have outdated systems with limited reliable records and insufficient sensory data [18].

Furthermore, the fast-evolving and diverse range of AI models can hinder the integration of AI in managing halal food waste. While many studies have reported successful results in organic waste management, the overall progress in halal food waste has been slow, and there is a lack of focused research on halal food waste management using AI. Lastly, "The black box nature" of AI models is a significant challenge in the implementation of such approach. AI models rely on large datasets, which are often hidden

or protected in publications, making it difficult to replicate or standardize the models across various products or industries.

5. CONCLUSION REMARKS

In conclusion, the implementation of AI and ML technologies in solid waste management has shown promising results in enhancing the efficiency and productivity of waste management operations. As we reflect on these advancements, it becomes evident that AI has the potential to revolutionize Halal waste management by optimizing waste reduction strategies and streamlining supply chain operations. This promising trajectory aligns with the broader goals of sustainable and efficient waste management practices. The Islamic community can take advantage of the current rapid development and explore the utilization of AI. With adequate financial support, regulation, and certification, it is possible to commercialize tailored AI models, leading to significant economic and environmental benefits.

However, most of the current research in this area has focused on municipal solid waste management, with limited discussion on organic waste and no mention of halal food waste. There is a great opportunity for AI to be implemented in the Halal food industry to tackle waste management challenges, particularly in areas such as quality control, traceability, demand forecasting, resource optimization, and risk management. Nevertheless, there are also challenges and limitations in the implementation of AI in waste management, such as the lack of data and the excessive cost of implementing AI technologies.

Therefore, further research is needed to explore the potential of AI in managing solid waste in the Halal food industry and to address the challenges and limitations in its implementation.

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