ISSN: 3021-7636
International Journal of Science Technology and Health

Review Article
Vol. 4 (2), 2026, page 69-76
DOI: https://doi.org/10.69930/ijsth.v4i2.65

Smart Waste Management for the Free Nutritious Meal Program: A Systematic Literature Review Based on IoT and Deep Learning

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Received : 15 May 2026	Accepted: 28 July 2026	Published: 31 July 2026

Abstract: The implementation of the Free Nutritious Meal (MBG) program in Indonesia presents significant logistical challenges, particularly regarding the generation of kitchen waste in diverse geographical settings such as coastal and inland areas. An intelligent approach is needed to manage this waste sustainably. This study conducts a systematic literature review integrating concepts from the Internet of Things (IoT), Deep Learning, Multi-Criteria Decision Making (MCDM), and community-based collective action to formulate a conceptual model. The proposed Eco-Dashboard integrates real-time IoT sensors to act as an Early Warning System (EWS) for waste capacity. By employing Deep Learning algorithms, the system gains predictive capabilities to forecast waste accumulation, while enhanced MCDM techniques provide adaptive decision-making logic for waste collection routes and resource recovery. Furthermore, the model incorporates socio-technical frameworks to ensure high community engagement. The adaptive and predictive Eco-Dashboard model offers a comprehensive, localized solution for kitchen waste management. Furthermore, this framework directly supports the United Nations Sustainable Development Goals (SDGs), specifically contributing to SDG 11.6 by mitigating urban and environmental impacts and SDG 12.5 by promoting substantial waste reduction and resource recovery. By bridging technological infrastructure with community-driven food-sharing initiatives, this model ensures that MBG program waste is managed efficiently, preventing environmental hazards in both coastal and inland ecosystems.

Keywords: MBG; EWS; Kitchen Waste Management; Deep Learning; IoT

1. Introduction

The Free Nutritious Meal (MBG) program represents a strategic policy by the Indonesian government aimed at improving public nutrition, particularly for schoolchildren and vulnerable populations. However, the large-scale implementation of this program has the potential to significantly increase the volume of organic kitchen waste, especially across coastal and inland areas that possess distinct geographical and infrastructural characteristics. If left unmanaged, the accumulation of organic waste poses severe environmental threats, including ecosystem disruption, soil and water contamination, and the proliferation of diseases (Kaza et al., 2018).Driven by population growth, rapid urbanization, and increased consumer demand, municipal solid waste generation is escalating drastically on a global scale (Mittal et al., 2016). Within this context, organic food waste emerges as a primary contributor to urban pollution, necessitating immediate and efficient intervention (Haraguchi et al., 2019). Conventional waste management systems, which heavily rely on manual labor and scheduled pickups, are increasingly deemed ineffective due to their high operational costs and inability to provide continuous, real-time monitoring (Arthur et al., 2024). The rapid advancement of the Internet of Things (IoT), Artificial Intelligence (AI), Machine Learning (ML), and Deep Learning (DL) provides significant opportunities to develop smarter, more adaptive waste management frameworks. IoT acts as a key enabler by facilitating real-time data collection through smart sensors that monitor bin capacity, waste levels, and environmental pollutants (Wahyudi et al., 2025). The deployment of IoT-based smart dustbins significantly enhances collection efficiency and minimizes the risk of hazardous waste overflow in residential areas (Kansara et al., 2015). Furthermore, Deep Learning technologies exhibit robust capabilities in analyzing waste generation patterns and predicting future waste accumulation based on historical and environmental data (Dawar et al., 2025). Models utilizing DL and ML algorithms are instrumental in automating waste classification, optimizing transportation schedules, and improving resource recovery processes (Fang et al., 2023). The integration of AI into municipal waste management has consistently proven to boost recycling efficiency, thereby supporting the broader objectives of sustainable development (Rahman et al., 2022).

In modern waste management, decision-making is a highly complex process that must balance multiple, often conflicting, parameters. Multi-Criteria Decision Making (MCDM) methods are extensively utilized to evaluate and select the best operational alternatives based on factors such as cost-efficiency, environmental sustainability, and the urgency of waste collection (Suvitha et al., 2024). While techno-centric solutions like IoT and AI are highly effective, a divergent hypothesis within the current research field argues that purely technological approaches often fail if they neglect the socio-technical context. Scholars emphasize that the success of sustainable waste systems heavily relies on community participation and grassroots collective action. For instance, socio-technical frameworks in food-sharing initiatives demonstrate that sustainable surplus food redistribution requires active volunteer engagement, collaborative networks, and accessible digital tools (Berns et al., 2023). Bridging this gap between advanced technological infrastructure and grassroots community adoption remains a critical challenge in current literature. In response to these multidimensional challenges, this study aims to formulate a conceptual Eco-Dashboard model based on an Early Warning System (EWS) by integrating the capabilities of the Internet of Things (IoT), Deep Learning, Multi-Criteria Decision Making (MCDM) logic, and community-based collective action. This adaptive and predictive model is specifically designed to sustainably orchestrate the management of organic kitchen waste from the MBG program across coastal and inland topographies.

Although various previous studies have explored the utility of IoT, Deep Learning, or MCDM within the waste management domain in isolation, this research offers novelty by integrating these technological innovation pillars with community-based collective action into a holistic Eco-Dashboard framework. Through a model design precisely tailored for kitchen waste management within the MBG program in Indonesia, this study effectively bridges the socio-technical discourse gap in designing waste governance management systems. Ultimately, the primary conclusion of this research asserts that the hybrid synergy between advanced predictive technological instruments and a social framework centered on community participation will construct a comprehensive, locally relevant, and highly effective solution to mitigate the ecological hazards of organic waste in regions with high geographical variability.

2. Methods

This study employed a Systematic Literature Review (SLR) approach using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework to identify, evaluate, and synthesize previous studies related to IoT-based smart waste management, Deep Learning, and Multi-Criteria Decision Making (MCDM). The SLR method was selected due to its ability to provide a systematic, transparent, and reproducible analytical process (Rethlefsen et al., 2021). The research procedure consisted of literature identification, article screening, data extraction, and thematic synthesis. Relevant literature was collected from reputable international journals indexed in major scientific databases, focusing on intelligent waste management technologies and community participation frameworks. The literature search process utilized several keywords, including "smart waste management," "IoT waste management," "Deep Learning waste prediction," "MCDM waste management," and "food-sharing community."

The inclusion criteria for article selection were as follows: (1) articles published in reputable international journals; (2) studies discussing the implementation of IoT, Artificial Intelligence (AI), Deep Learning, or MCDM in waste management systems; (3) studies relevant to organic waste management and environmental sustainability; and (4) articles available in full-text and accessible formats.

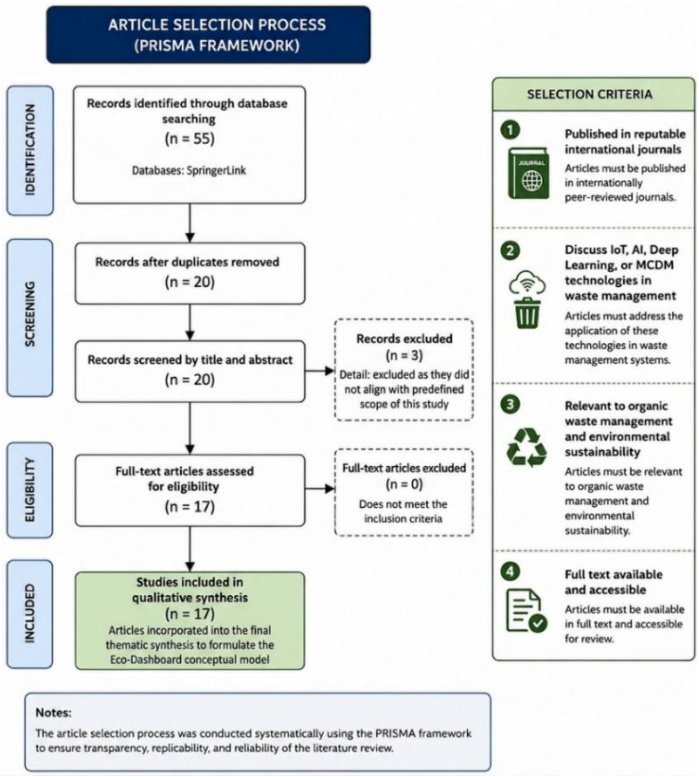

Figure 1. The PRISMA framework was applied to ensure a rigorous and structured article selection process (Rethlefsen et al., 2021).

Following the screening stage, the selected articles were analyzed thematically to identify the contributions of IoT, Deep Learning, and MCDM technologies to sustainable waste management systems. The conceptual Eco-Dashboard model proposed in this study consists of four primary components: (1) IoT-based sensors functioning as an Early Warning System (EWS) for real-time waste monitoring; (2) Deep Learning algorithms for predicting waste accumulation patterns; (3) MCDM techniques for adaptive and data-driven decision-making processes; and (4) community collective action as a socio-technical approach to support sustainable waste management practices.

As this study is based exclusively on secondary data obtained from published scientific literature, no human participants, animals, or intervention-based experiments were involved. Therefore, ethical approval was not required. Furthermore, no proprietary datasets or restricted materials were used in this study, and all referenced sources are publicly accessible through their respective publishers and scientific databases.

3. Results and Discussion

In accordance with the PRISMA guidelines, the initial literature search conducted on the selected database, SpringerLink, yielded a total of 55 articles. Following the removal of duplicate records, 20 articles were screened based on the relevance of their titles and abstracts. During this screening phase, 3 articles were excluded as they did not align with the predefined scope of this study. Subsequently, a comprehensive full-text assessment was performed on the remaining 17 articles to evaluate their eligibility. Ultimately, all 17 articles completely satisfied the inclusion criteria and were incorporated into the final thematic synthesis to formulate the Eco-Dashboard conceptual model.

The literature review findings indicate that the integration of the Internet of Things (IoT) into waste management systems significantly improves the efficiency of real-time waste monitoring. Ultrasonic sensors, gas sensors, GPS technology, and cloud computing are identified as the primary components of smart waste management systems (Arthur et al., 2024). These technologies enable automated monitoring of waste bin capacity, thereby reducing the risks of overflow and environmental contamination. The findings suggest that IoT-based waste monitoring systems can enhance operational responsiveness and support more sustainable waste management practices in densely populated and geographically diverse regions.

Furthermore, IoT sensor implementation supports the development of an Early Warning System (EWS) for organic waste management within the Free Nutritious Meal (MBG) program. Sensors can provide automated notifications when waste containers approach maximum capacity or when hazardous gas emissions increase due to organic waste decomposition (Abdulla Al Mamun et al., 2015). Real-time monitoring systems therefore enable faster and more efficient waste collection processes, minimizing delays that may contribute to environmental pollution and public health risks.

From a predictive perspective, Deep Learning technologies are widely utilized to forecast waste accumulation patterns based on historical datasets, food distribution quantities, population density, and regional characteristics. Deep Learning models are capable of analyzing large-scale datasets to produce more accurate predictions compared to conventional statistical approaches (Li & Chen, 2023). In addition, image-classification-based Artificial Intelligence (AI) models can support automated waste segregation processes, thereby improving the effectiveness of organic waste recycling systems(Fang et al., 2023).

These findings demonstrate that predictive analytics and intelligent classification technologies can contribute substantially to the optimization of sustainable waste management systems.

The implementation of AI and Machine Learning (ML) technologies also contributes to optimizing waste collection and transportation processes. GPS- and IoT-based systems enable waste management operators to determine more efficient transportation routes based on waste bin capacity levels and regional conditions (Mao et al., 2021). Such optimization approaches can reduce operational costs and energy consumption during waste transportation activities (Zhang et al., 2022). Consequently, intelligent route optimization systems provide both economic and environmental benefits within smart waste management frameworks.

In the decision-making aspect, the Multi-Criteria Decision Making (MCDM) method plays a significant role in supporting the Eco-Dashboard system. This method facilitates the evaluation of multiple alternatives based on various criteria, including operational cost, urgency level, waste capacity, and environmental impact (Senapati et al., 2021). (Suvitha et al., 2024) further explain that fuzzy-based MCDM approaches offer greater flexibility in addressing uncertainty and dynamic conditions within modern waste management systems. The findings indicate that MCDM techniques can improve adaptive decision-making processes and enhance resource allocation efficiency.

On the other hand, the success of sustainable waste management systems is influenced not only by technological advancement but also by community engagement. (Berns et al., 2023) emphasize that community-based collective action plays a crucial role in sustaining food-sharing initiatives through participatory configurations, socio-technical practices, and collaborative community interactions. Community-centered approaches encourage active public participation in reducing food waste and promoting equitable resource distribution. These findings highlight the importance of integrating technological infrastructure with social participation mechanisms to achieve long-term sustainability goals.

The review also reveals that smart waste management implementation in developing countries continues to face several challenges, including limited infrastructure availability, high implementation costs, and low levels of digital literacy among communities (Wahyudi et al., 2025). Therefore, integrating advanced technologies with community-based approaches is considered a more realistic and sustainable strategy for developing countries with diverse socio-economic and geographical conditions.

Based on the synthesized findings, the proposed Eco-Dashboard model integrates IoT, Deep Learning, MCDM, and community collective action into a unified adaptive and predictive system. The system is capable of monitoring waste capacity in real time, forecasting waste accumulation patterns, optimizing decision-making processes, and enhancing community participation in managing organic waste generated by the MBG program. Overall, the conceptual model demonstrates strong potential as a comprehensive solution for sustainable kitchen waste management in both coastal and inland ecosystems.

Conclusions

This study proposes a conceptual Eco-Dashboard model integrating the Internet of Things (IoT), Deep Learning, Multi-Criteria Decision Making (MCDM), and community collective action to support the management of organic kitchen waste generated by the Free Nutritious Meal (MBG) program. The integration of IoT-based sensors enables the system to perform real-time waste monitoring through an Early Warning System (EWS), while Deep Learning technologies provide predictive capabilities for forecasting future waste accumulation patterns.

Furthermore, the implementation of MCDM techniques supports more adaptive and data-driven decision-making processes, particularly in determining waste collection priorities and resource recovery strategies. In addition to technological integration, community-based collective action is identified as a crucial factor in ensuring the sustainability of socio-technical waste management systems. Community participation strengthens collaborative waste reduction practices and promotes environmentally responsible behavior within local ecosystems.

Overall, the proposed adaptive and predictive Eco-Dashboard model demonstrates significant potential as an innovative solution for improving the efficiency, sustainability, and environmental friendliness of MBG waste management systems in both coastal and inland regions. The integration of intelligent technologies with community-driven approaches offers a comprehensive framework for addressing the environmental challenges associated with large-scale food distribution programs. Future studies are recommended to focus on system implementation, empirical validation, and real-world performance evaluation to further enhance the applicability and scalability of the proposed model.

Funding

This research received no external funding.

Acknowledgments

We would like to express our gratitude to all parties who have provided support in the preparation of this article. We extend our thanks to academic institutions and research organizations for providing access to scientific resources and references that have contributed to the analysis in this study. Non-material support, such as academic discussions, constructive feedback, and motivation from colleagues and the academic community, has also played a significant role in the completion of this research. Without the support of various parties, this study would not have been successfully completed.

Conflicts of Interest

The authors confirm that they have no financial or personal affiliations that could have influenced the research process or the outcomes reported in this paper.

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