

FOOD WASTE MANAGEMENT STRATEGY WITH GREEN AND DIGITAL TECHNOLOGY

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ABSTRACT

Food waste presents a critical global challenge that impacts environmental sustainability, food security, and economic stability. Traditional waste management approaches often lack the agility and scalability required to address the growing volume of food waste, particularly in urban environments. This paper explores an integrated strategy combining green and digital technologies—specifically Artificial Intelligence (AI) and the Internet of Things (IoT)—to improve the classification, sorting, and conversion of food waste into useful resources. Through a comparative analysis of five core techniques—computer vision, sensor-based monitoring, sensor fusion with machine learning, object detection, and rule-based systems—this study evaluates the strengths and limitations of each approach in real-world applications. The proposed model supports smart sorting for food donation, animal feed, composting, and maggot farming (BSF), offering a scalable solution that aligns with SDG 11, 12, and 13 as well as Indonesia's circular economy goals. Results highlight the importance of multi-sensor data integration and AI-based classification in optimizing food waste management while addressing social, environmental, and economic impacts. The study concludes by recommending a collaborative, adaptive framework that enhances sustainability through technological innovation and stakeholder engagement.

Keywords: Food Waste Management, Waste, Digital, Green Technology, Artificial Intelligence, IoT, Composting, Food Donation

1. Introduction.

Food waste is a global crisis that has a profound impact on the environment, human health, and the economy. In total, approximately 1.3 billion tons of food are lost or wasted globally each year, which represents nearly one-third of all food produced for human consumption [1]. On the other hand, in developing countries, food is wasted not only at the consumption level, but also during all stages of the supply chain due to deficiencies in logistics, infrastructure, and knowledge [2]. Solution of these issues needs change in behavior with innovation-based technologies which can transform the current scenario into sustainable, effective and contribute to meet the food waste management requirement.

This is when green and digital technologies to solve the food waste crisis come into play. Green technologies are the environmentally friendly methods like composting, anaerobic digestion and bio-conversion; Digital technologies like Internet of Things, data analytics, blockchain and artificial intelligence to optimize waste tracking, sorting and decision making [3]. The duality of this has been called Green-Digital Synergy and is seen as a strategic pathway for Sustainable Development Goals (SDG 11: Sustainable Cities and Communities, 12: Responsible Consumption and Production, SDG 13: Climate Action) as well as an alignment to national perspectives on low-carbon and circular economic development [4].

Specific approaches have shown promise recently; IoT-based smart bins have been studied extensively [5], while AI applications monitoring food expiration dates [6] and blockchain-based food traceability systems have also been implemented to reduce food waste and improve efficiency [7]. Nevertheless, for the development of integrated, context aware, and scalable systems that leverage green processing methods in combination with digital intelligence, a research gap exists in terms of urban and community-level implementation. This paper attempts to find social-inclusive and adaptive-measurable framework for food waste management utilizing a micro and macro approach where these concepts of green and digital technologies can potentially work in tandem, until by-line, and in co-creating food waste management strategies-based approaches.

The adoption of green and digital technology in food waste reduction can effectively address these challenges globally. Food waste treatment systems based on these technologies not only optimize waste utilization but also enhance food security and sustainability while minimizing environmental pollution. Overviewing the use of digital solutions like, e.g., Artificial Intelligence (AI), Internet of Things (IoT), and Big Data for optimization of food waste management processes in different sectors (HoReCa) (hospitality and restaurant business, catering) [8, 9]. The upcoming sections are identified as core parts of this strategy.

Food Waste Management Using Digital Technologies

1. AI and IOT: The use of AI and IOT technologies is helping farmers to better monitor their crops and livestock, predict issues and optimize supply chain performance, from harvesting to transportation to storage to the point of sale [10].
2. Smart Software Solutions: Entities, such as smart kitchen appliances and real-time inventory management systems, are used by the hospitality sector to reduce waste generation and operational expenses [11].
3. Mobile Apps and Platforms: Digital innovations such as mobile apps and social media platforms enhances public awareness and assistance in preventing and monitoring food waste [8].

Sustainable Practices and Green Technologies

1. Waste In-Processing Solutions: Technologies such as food digesters, composting systems, etc. convert food waste into useful products (biogas, organic fertilizers, etc.) ensuring a circular economy [11].
2. Nanotechnology and Green Extraction: These advanced technologies are used to recycle food waste and extract valuable nutrients; this plays important role to have sustainable food systems [8].

Hurdles and Working Together

1. Scalability and Cost: Digital and green technologies offer advantages, but problems regarding cost, scale, and coordination are still present among stakeholders [12].

2. Collaborative Strategies: Effective mitigation of food waste involves collaboration among governments, businesses, and research institutions to address challenges and develop sustainable practices [10].
3. Digital and green technologies offer innovative solutions for food waste management, but none are panaceas. Supportive policies, infrastructure, and public awareness campaigns are critical to supporting the successful implementation of these technologies. It is also very important to overcome problems related to data security, privacy issues, and the digital divide for effectivity and widespread utilization [12].

2. Methodology

In this research we specifically utilized AI and IOT as approach in this paper since green and digital technologies, particularly AI and the IoT, significantly enhance the efficiency of food waste management by optimizing various processes across the food supply chain. These technologies enable real-time monitoring, predictive analytics, and automated decision-making, which collectively contribute to reducing food waste and improving sustainability. The integration of AI and IoT in food waste management systems has shown promising results in various sectors, including hospitality, agriculture, and urban waste management. Below are key aspects of how these technologies enhance efficiency in food waste management, i.e.: Real-Time Monitoring and Data Collection, Predictive Analytics and Inventory Management, Optimization of Waste Collection and Recycling, Economic and Environmental Benefits.

Real-Time Monitoring and Data Collection. (1) IoT sensors and AI algorithms facilitate real-time monitoring of food storage conditions, such as temperature and humidity, to prevent spoilage and ensure optimal storage conditions [10]; (2) Smart dustbins equipped with sensors can classify and measure food waste in real-time, providing precise data on waste cycles and stock control to avoid over-ordering [13].

Predictive Analytics and Inventory Management. (1) AI-powered predictive models analyze vast datasets to forecast market demand, optimize stock levels, and reduce overproduction, thereby minimizing food waste [10]; (2) Digital tools automate inventory management and delivery times, helping foodservice units manage food waste more effectively [9].

Optimization of Waste Collection and Recycling. (1) IoT-enabled systems optimize waste collection routes, leading to significant improvements in efficiency and recycling rates, as well as reductions in operational costs[14]; (2) AI algorithms enhance sorting accuracy and recycling rates, particularly in regions with diverse waste types [14].

Economic and Environmental Benefits. (1) The integration of AI and IoT in waste management systems leads to reduced operational costs and increased profitability for businesses by minimizing waste and optimizing supply chain management; (2) These technologies contribute to environmental sustainability by reducing greenhouse gas emissions and resource wastage associated with food waste [15, 16].

While digital technologies offer substantial benefits in enhancing food waste management

efficiency, challenges such as data privacy, security, and the digital divide must be addressed to ensure successful implementation. Additionally, collaboration among stakeholders, including governments, businesses, and research institutions, is crucial for overcoming these challenges and achieving widespread adoption of AI and IoT-based solutions [10].

We propose a food waste management strategy model as shown in figure 1.

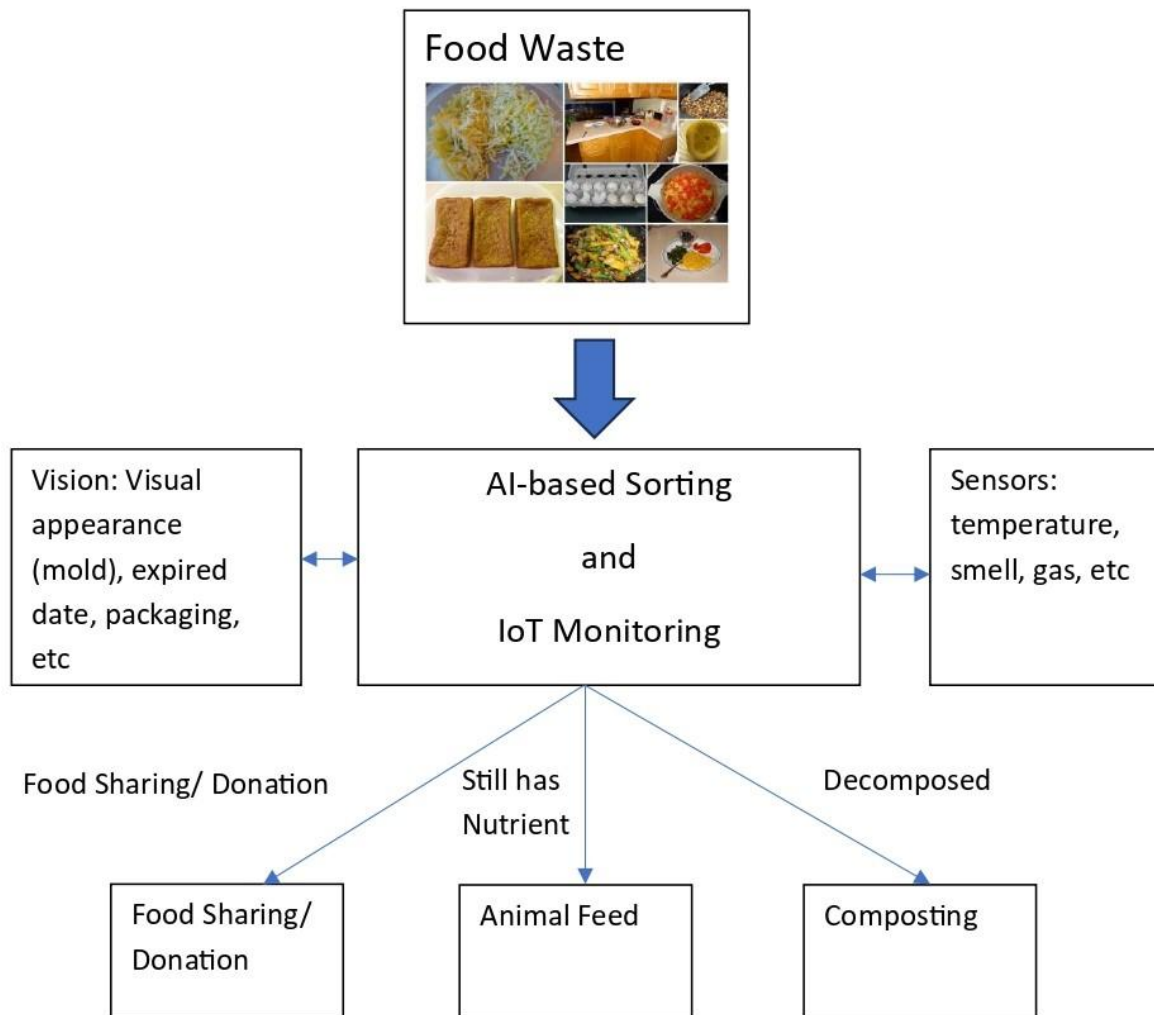


Figure 1. Food Waste Management Strategy Model

The model basically works as a method to detect food edibility through the appearance and other features. For example, if the food is still edible (e.g. detected from appearance, smell, temperature, gas, expired date, package) then the food can be utilized for food sharing and donation, otherwise it will be used for animal feed and composting.

The following is an explanation of the methods used in the model above in more detail:

1. Computer Vision is used to detect food edibility by analyzing whether there is mold

in the food, whether there is a change in color or texture in the food. The method used is AI-Deep learning with techniques including: Convolutional Neural Networks (CNNs) for image classification; YOLO, SSD, MobileNet, ResNet for object detection; Transfer Learning such as MobileNetV2 on small datasets. Input data can be taken with: ESP32-CAM, Raspberry Pi-PiCam, or webcam.

2. Multi-Sensor IoT Integration is used to monitor environmental and food condition variables in real time. The sensors used include: DHT11/ DHT22 (temperature and humidity sensors), MQ-3/ MQ-135 (gas emission sensors), CO2 (fermentation detection), pH (food acidity detection), Camera (for visual analysis).

3. Results and Discussion

The digitalisation of the food waste management sector represents an innovative approach in the context Sustainable Development Goals (SDGs) and designing smart systems. The comparative examinations of each of five AI and IoT-based techniques (computer vision, sensor-based monitoring, sensor fusion, object detection, and rule-based) demonstrate the critical concerns of practical applications of each approach in a choice set and its limitations.

CNN and YOLO, for example, are computer vision models that are extremely proficient at recognizing visible deterioration, which makes them particularly valuable for food donation and classification systems. But they fall short in detecting internal degradation. On the other hand, sensor-based systems detect spoilage at early stages using temperature, gas and pH levels which allow for proactive interventions, however; these systems need to be fused with other data sources to categorize reliably.

An effective solution is the use of multi-sensor data combined with an in-depth exploratory machine learning classifier which leads to context-based decision making in relation to real-time and historical data. However, this paradigm is heavily reliant on large amounts of high-quality, labeled datasets as well as model tuning. Rule-based systems are still appealing for early-stage deployments due to their ease of implementation, but they are not adaptable or scalable in the long run.

Economically and environmentally, from an operational perspective, these technologies also deliver: reduced greenhouse gas emissions, decreased food loss through the various supply chains that bring it to market, and a more efficient logistics and inventory management system. But their successful deployment requires strong infrastructure, policy support and digital literacy among stakeholders to overcome the technology adoption gap.

4. Conclusions

Food waste management systems need to be not just technologically sound, but also contextually adaptive, cost-effective, and user-inclusive in order to maximize their impact.

Future work will involve improving the sensor fusion model, increasing dataset diversity, and paying attention to ethical concerns like data leakage. Finally, multi-stakeholder collaboration between governments, industry and communities will need to deliver the real-life implementation of many of these innovation ideas — contributing towards SDG 12, 13 and 11 and national targets on circular economy and green growth.

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