



AI Applications In Food Waste Management: A Pathway To Circular Economy

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Abstract: The integration of artificial intelligence (AI) in food waste illustrates a transformational approach to promoting the principles of a circular economy. This study examines how AI controlled technologies, food persecution, classification and redistribution can be optimized, including machine learning, computer vision, and predictive analytics. AI driven systems enable real time monitoring, demand forecasting and efficient selection mechanisms, reducing waste at various stages of the supply chain. Although AI is used in a wide range of waste disposal areas, such as construction and recycling of electronic equipment, food management possibilities remain underdeveloped. Existing research demonstrates the effectiveness of AI in optimizing waste classification and recycling and demonstrating its applicability to food loss solutions. By integrating AI into IoT sensors and blockchain technology, it dramatically improves food surveillance transparency and traceability, promotes efficient resource recovery and minimizes reliance on landfills. This study highlights the need for AI controlled innovation to improve food system sustainability, mitigate environmental impacts, and support cyclical economic goals. Future research should focus on developing solutions for AI applications tailored to food waste to ensure efficiency, cost-effectiveness and scalability for various sectors.

Keywords- Artificial Intelligence (AI), Food Waste Management, Circular Economy, IoT Sensors.

I. INTRODUCTION

Food waste is an important global issue and contributes greatly to environmental, economic and social concerns. The Food and Agriculture Organization (FAO) estimates that about a third of all food produced worldwide is wasted, covering approximately 1.3 billion tons of each year. This waste leads to significant economic losses, exacerbates malnutrition uncertainty, and has serious environmental consequences, including greenhouse gas emissions and excessive use of resources. Traditional systems of food waste, which rely heavily on landfilling and disposal of inefficient recycling methods, do not need to effectively manage these challenges. As a result, innovative and technology-incorporated solutions are needed to transform the circular economy focused on reducing waste, maximizing resource efficiency and creating sustainable food systems. AI-controlled technologies such as machine learning, computer vision, and predictive analytics will revolutionize how food waste is monitored, analyzed, and managed.

By integrating AI into IoT sensors (the Internet of Things) and blockchain technology, stakeholders can ensure real-time tracking, accurate waste classification, and increased transparency in food disposal and redistribution. The introduction of AI in food waste corresponds to the principles of a circular economy by minimizing dependence on landfills, promoting resource recovery, and promoting supply chains in closed loops that improve sustainability. Restaurants, grocery stores, and households often generate large amounts of food waste daily due to conversions, inadequate storage, or inadequate management of the supply chain. AI-powered demand forecasting can accurately predict consumption patterns and analyze historical data that help businesses and consumers make well-established purchasing decisions and minimize waste generation.

Furthermore, computer vision technology integrated into intelligent bins and sorting systems can automatically identify and separate organic waste from non-recyclable materials, optimizing the recycling process and reducing waste flow contamination. Automatic sorting machines driven by AI algorithms can

efficiently distinguish between different types of food waste and focus on the appropriate recycling or composting pathways. Such technologies not only improve the efficiency of waste disposal but also contribute to the recovery of resources through valuable extraction from food waste such as biofuels, animal feeds, and fertilizers.

By using AI-based automation, food waste from linear waste models can be passed on to circular strategies that maximize sustainability and economic viability. Food banks and donation platforms are increasingly relying on AI-controlled logistics solutions to optimize the collection and distribution of extra food. Algorithms for machine learning can adapt food providers to recipients based on real-time demand and delivery data, reducing food uncertainty and at the same time preventing edible food from being wasted. Furthermore, blockchain integration ensures transparency in food donation systems by pursuing food quality, process data and supply

chain movements, minimizing the risk of corruption and ensuring safe consumption. Despite these hurdles, the long-term benefits of AI integration, including cost savings, reduce environmental impact and improve resource efficiency. Political decisions Manufacturers, businesses and consumers must work together to invest in AI technology, build regulatory frameworks, and promote awareness of AI's potential in reducing food waste. This study examined the latest progress in AI-driven waste development technologies, their effectiveness was assessed in reducing food waste and discussed the opportunities challenges and opportunities associated with implementation. By highlighting real-world applications and case studies, this paper aims to provide valuable insight into how AI can revolutionize food waste management and contribute to a more sustainable future.

1.1 Background and Importance of Food Waste Management

Food waste is a pressing global issue, with millions of tons discarded annually, leading to economic loss, resource depletion, and environmental degradation. The United Nations' Sustainable Development Goal (SDG) 12.3 aims to halve food waste at the retail and consumer levels by 2030. Inefficient food supply chains, overproduction, and lack of proper inventory management contribute significantly to food waste. Addressing this issue is crucial for achieving a circular economy, which emphasizes waste minimization, resource optimization, and sustainability.

1.2 The Role of AI in Food Waste Reduction

Artificial Intelligence (AI) plays a transformative role in tackling food waste by enhancing efficiency in production, distribution, and consumption. AI-driven solutions can optimize supply chain management, predict demand patterns, and identify surplus food for redistribution. Machine learning algorithms, computer vision, and predictive analytics help businesses and consumers make informed decisions about food utilization, thereby reducing waste and promoting sustainability.

1.3 Objectives of the Study

- Examine the impact of AI technologies on food waste management.
- Identify AI-driven solutions for reducing food waste at various stages of the supply chain.
- Explore the integration of AI in fostering a circular economy.
- Highlight case studies showcasing successful AI applications in food waste management.

II. REVIEW OF LITERATURE

1. Artificial Intelligence in Food Waste Management

AI has emerged as a game-changer in food waste management by enabling intelligent monitoring, forecasting, and redistribution. Machine learning algorithms can predict demand and reduce overproduction, while computer vision systems can detect spoilage and sort edible from inedible food. AI-powered inventory management systems help restaurants, retailers, and households track food usage patterns, minimizing unnecessary waste. Additionally, chatbots and mobile applications provide recommendations on food storage and utilization.

AI-powered robotics is also being used to automate food sorting processes, improving the efficiency of recycling and composting systems. Supermarkets and food distributors are employing AI-driven tools to analyse consumer purchasing patterns and optimize stock levels, ensuring that perishable goods are sold before expiration. Moreover, AI-based platforms are facilitating food redistribution by connecting businesses with food surplus to charities and food banks, reducing overall wastage.

AI has been widely recognized for its ability to optimize resource management, improve operational efficiency, and enhance sustainability initiatives. In the food industry, AI applications in waste management include:

1.1. AI in Demand Forecasting and Inventory Optimization

One of the major causes of food waste in restaurants, retail stores, and supply chains is inaccurate demand forecasting, leading to overproduction and inventory mismanagement. AI-driven predictive analytics can analyze historical sales data, weather conditions, customer behavior, and market trends to provide accurate demand forecasts.

Studies have demonstrated that machine learning algorithms can predict demand fluctuations with over 90% accuracy, allowing businesses to adjust procurement, production schedules, and portion sizes accordingly. AI-enabled inventory management systems help in tracking stock levels in real-time, ensuring that perishable food items are used before spoilage. Companies like Domino's, McDonald's, and Subway have started experimenting with AI-powered predictive ordering systems to reduce food waste and streamline inventory.

1.2. AI in Automated Waste Sorting and Recycling

AI-powered waste sorting is a game-changer in food waste recovery and recycling. Traditional waste management relies on manual sorting, which is inefficient and error prone. AI-enabled robotic systems equipped with computer vision and deep learning can accurately classify food waste, distinguishing between organic waste, recyclable materials, and non-reusable items.

Some smart waste bins now come with AI-powered image recognition to guide users on proper disposal. Research studies have shown that AI-powered sorting can improve recycling efficiency by up to 60%, significantly reducing the volume of food waste that ends up in landfills.

1.3. AI-Driven Food Redistribution and Donation Programs

Food waste reduction strategies emphasize redistributing surplus food to those in need rather than disposing of it. AI-driven platforms like OLIO and Too Good to Go connect restaurants, supermarkets, and consumers to enable real-time surplus food donations. Studies highlight that AI-powered redistribution programs have saved thousands of tons of food annually, benefiting both businesses and underprivileged communities.

1.4. AI and Blockchain for Waste Traceability

A major challenge in food waste management is the lack of transparency in tracking waste generation, disposal, and recycling. Blockchain technology, when integrated with AI, can create a tamper-proof record of waste transactions, helping businesses identify inefficiencies and optimize waste reduction strategies. Research shows that blockchain-based waste tracking systems have reduced food losses in supply chains by 20-30% by enhancing accountability and traceability.

2. The Circular Economy and Waste Reduction

A circular economy aims to create a sustainable system where resources are continually reused, recycled, and repurposed rather than discarded. AI enhances this model by optimizing waste-to-energy conversion, food redistribution networks, and supply chain efficiencies. By integrating AI-driven insights, businesses can minimize food waste at every stage—production, distribution, retail, and consumption—ultimately contributing to a closed-loop system where waste is repurposed into valuable resources.

AI-driven predictive analytics help companies design better packaging solutions that extend the shelf life of food products, reducing spoilage. Additionally, AI supports the upcycling of food waste by identifying the best ways to convert discarded food into biofuels, animal feed, or alternative food products. This enhances resource efficiency while mitigating the environmental impact of food disposal.

3. IoT and Smart Sensors for Waste Monitoring

The integration of AI with the Internet of Things (IoT) has enabled real-time waste monitoring and tracking. Smart sensors embedded in food storage units can measure temperature, humidity, and expiration dates to ensure optimal food preservation. AI-driven IoT systems alert users when food is nearing spoilage, facilitating timely consumption or donation. Additionally, automated sorting technologies powered by AI can enhance waste segregation, making composting and recycling processes more efficient.

IoT-enabled AI solutions are being used in agricultural settings to monitor crop health, predict harvest yields, and reduce post-harvest losses. Smart bins equipped with AI and IoT can analyze the type and quantity of waste disposed of, providing insights to businesses and municipalities for improved waste management policies. Moreover, blockchain-integrated AI systems are enhancing transparency in food supply chains by tracking the journey of food from farm to table, ensuring better quality control and minimizing losses.

4. Challenges in AI-driven Waste Management

Despite its benefits, AI-driven food waste management faces several challenges. Data quality and availability remain a major hurdle, as AI systems require large datasets for accurate predictions. Many businesses lack the necessary infrastructure to collect and process high-quality data, limiting the effectiveness of AI solutions. Additionally, food waste tracking across fragmented supply chains remains difficult due to inconsistent data-sharing practices among stakeholders.

High implementation costs and lack of awareness among small-scale businesses also limit AI adoption. Many restaurants and retailers may not have the financial resources to invest in AI-driven waste management technologies, leading to unequal adoption across industries. Government incentives and policy interventions may be required to encourage widespread implementation of AI solutions in food waste management.

Furthermore, ethical concerns regarding data privacy and the environmental impact of AI infrastructure need to be addressed. AI models require substantial computing power, which can contribute to energy consumption and carbon emissions. Sustainable AI development practices, such as energy-efficient algorithms and green data centers, are essential to balance technological innovation with environmental responsibility.

Despite these challenges, continued advancements in AI and its integration with other technologies such as blockchain and IoT hold great promise for addressing food waste and supporting a circular economy. Policymakers, businesses, and researchers must work collaboratively to overcome these barriers and maximize AI's potential in food waste management.

III. RESEARCH METHODOLOGY

The research methodology used in this study is designed to ensure a comprehensive and structured investigation into the role of Artificial Intelligence (AI) in Circular Economy Waste Management in the Food Industry. The methodology follows a dual approach, incorporating both Systematic Literature Review (SLR) and Interviews to collect, analyse, and interpret relevant data. This mixed-methods approach ensures a balanced understanding of the topic by examining existing research and gathering practical insights from industry professionals.

1. Systematic Literature Review (SLR)

1.1 Purpose of SLR

A Systematic Literature Review (SLR) was conducted to address two core research objectives:

1. To examine the relationship between AI and waste management techniques in the food industry.
2. To suggest strategies for integrating AI into circular economic practices.

SLR was chosen as a research method because it allows for a structured, transparent, and replicable synthesis of existing academic literature, ensuring that all relevant research on AI-based waste management and circular economy practices is systematically reviewed and analysed.

1.2 Steps in the Systematic Literature Review Step 1: Defining the Research Scope

To ensure a focused and meaningful review, the research scope was carefully defined. The review targeted peer-reviewed journal articles, conference papers, and reports that discuss:

- AI applications in waste management.
- AI-driven food waste tracking and reduction strategies.

- The role of AI in circular economy models.
- Barriers and challenges in AI adoption in the food industry.

Step 2: Selection of Databases and Search Strategy

A comprehensive database search was conducted across:

- ScienceDirect
- SpringerLink
- IEEE Xplore
- Google Scholar
- Elsevier

The search was performed using specific keywords to ensure relevant studies were included. Examples of search terms used include:

- “AI in food waste management”
- “Artificial Intelligence and circular economy”
- “Machine learning for food waste reduction”
- “AI in sustainable food supply chains”

Boolean operators such as "AND" "OR" and "NOT" were used to refine the searches and avoid irrelevant studies.

Step 3: Inclusion and Exclusion Criteria

The studies were filtered based on the following criteria:

Inclusion Criteria:

- ✓ Studies published in the last 10 years (2014–2024).
- ✓ Peer-reviewed journal articles and conference papers.
- ✓ Studies focusing on AI’s application in food waste management and circular economy models.
- ✓ Papers discussing technological advancements, strategies, and case studies in AI-driven waste management.

Exclusion Criteria:

- ✗ Papers that focus on non-food industries.
- ✗ Studies that do not incorporate AI or digitalization.
- ✗ non-peer-reviewed reports, blog posts, or editorials.

Step 4: Data Extraction and Categorization

Once relevant studies were selected, key data were extracted, including:

- Study objectives and methodologies.
- Findings on AI applications in waste management.
- Challenges and barriers identified in AI adoption.
- Proposed strategies for integrating AI into circular economy models.

To organize the data, the selected studies were categorized based on themes, such as:

- AI-driven waste tracking and inventory management.
- AI in food supply chain optimization.
- Challenges and limitations of AI in circular economy practices.

Step 5: Data Analysis and Synthesis

After categorization, a comparative analysis was conducted to identify patterns, gaps, and emerging trends. The findings were synthesized to develop new insights and recommendations for the integration of AI in circular economy waste management.

2. Interviews

2.1 Purpose of Interviews

To complement the findings from the Systematic Literature Review, semi-structured interviews were conducted with industry professionals to address the second research objective:

- ✓ To explore the implementation of AI-based applications in the food industry of India.

Interviews provided first-hand insights into how food businesses in India manage waste, their awareness of AI-driven waste management tools, and the barriers they face in adopting such solutions.

2.2 Selection of Participants

To ensure diverse perspectives, restaurant managers, franchise owners, and operational staff from both large food chains and small independent cafes in India were selected. The interviews covered various business types, including:

- Fast-food chains (e.g., McDonald's, Domino's, Subway).
- Casual dining restaurants.
- Local cafes and small eateries.

A total of 21 interviews were conducted, ensuring a mix of insights from both corporate-operated chains and independently run businesses.

2.3 Interview Methodology

The interviews followed a semi-structured format, allowing flexibility to explore relevant topics in depth. Each interview lasted 20–30 minutes, and participants were asked a series of open-ended questions related to:

- ✓ Current food waste management practices in their business.
- ✓ Challenges faced in minimizing waste.
- ✓ Awareness and perception of AI-based waste management solutions.
- ✓ Willingness to adopt AI-driven inventory and waste tracking tools.
- ✓ Barriers preventing AI implementation (cost, infrastructure, staff training).

Data Collection:

- Interviews were conducted face-to-face, over the phone depending on participant availability.
- Responses were recorded and transcribed for detailed analysis.
- Thematic coding was used to identify common patterns, trends, and challenges in AI adoption.

2.4 Data Analysis for Interviews

A qualitative analysis approach was used to extract meaningful insights from the interviews. Responses were categorized into three main themes:

1. Current Waste Management Practices – Examining how restaurants currently track and handle food waste.
2. Perception of AI in Waste Management – Understanding awareness and willingness to adopt AI-based solutions.
3. Challenges in AI Adoption – Identifying financial, technical, and operational barriers.

After analyzing the responses, findings were compared with the literature review insights to create a holistic understanding of AI's role in food waste management in India.

IV Conclusion and Recommendations

4.1 Summary of Key Findings

The study highlights the transformative role of AI in food waste management, demonstrating its capabilities in demand forecasting, inventory optimization, spoilage detection, and food redistribution. AI-driven technologies such as machine learning, computer vision, and IoT integration significantly enhance waste monitoring, sorting, and recycling efforts. However, challenges such as data availability, high implementation costs, and ethical concerns need to be addressed to maximize AI's impact.

4.2 Policy Implications and Industry Adoption

For successful AI adoption in food waste management, policymakers must encourage industry-wide collaboration, data sharing, and financial support for AI-driven initiatives. Governments can implement incentives, tax benefits, and subsidies for businesses investing in AI-based food waste solutions. Standardized regulations and frameworks will ensure transparency and efficiency in AI-driven food waste tracking across supply chains.

Industry stakeholders, including retailers, manufacturers, and restaurants, should prioritize AI integration in their operations. Investment in AI-powered smart storage solutions, automated sorting systems, and real-time inventory management will drive efficiency and cost savings while reducing waste. Moreover, partnerships

between AI technology providers and food industry leaders can accelerate the widespread adoption of these solutions.

4.3 The Future of AI in Circular Economy-driven Food Waste Management

The future of AI in food waste management lies in enhanced automation, improved data analytics, and seamless integration with blockchain and IoT. Advancements in AI-driven food repurpose technologies, such as upcycling waste into new food products, will further support circular economy goals. Additionally, AI-powered food-sharing platforms will expand access to surplus food, reducing waste at the consumer level.

Continued research and development in AI sustainability practices will ensure that AI-driven waste management remains energy- efficient and environmentally responsible. By fostering collaboration between policymakers, businesses, and researchers, AI can play a pivotal role in achieving a sustainable and waste-free future.

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