

REDUCING FOOD WASTE THROUGH CE AND AI MECHANISMS

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Abstract. Global data shows that the level of waste is a serious environmental problem. One tenth of it is food waste, and it can be significantly reduced by applying the principles and mechanisms of the circular economy. The purpose of this paper is to examine how the amounts of food waste can be reduced by returning it to the circular cycle and being fully utilized. The results of the scientific research are expressed in a developed roadmap aimed at companies in the food industry, which reveals the individual steps through which, with the help of various AI technologies, companies can achieve more efficient production with less food waste.

1 Introduction

Waste and its continuous growth are a global problem, both for us and for the future survival of the planet. Among the main wastes generated by the food industry and by every household is food waste. In essence, these are unwanted products or materials that arise during the production, processing, delivery or consumption of food [1]. According to data from the Food and Agriculture Organization of the United Nations (FAO) [2]. About one third of the food produced in the world is wasted and becomes food waste. FAO study (2016) [3] confirms these findings by showing the main sources of food waste. The largest share among them are households and catering - leftovers from daily meals and food with an expired shelf life; followed by the food industry - leftovers from food production, for example, parts of animal products that are not suitable for consumption [1]; agricultural production - parts of plants or fruits rejected during sorting due to defects or small size. The consequences of food waste are associated with loss of nutrients, lower profits for producers and higher costs for end consumers [4]. The reasons for the high level of food waste are dictated by unsustainable patterns of food production and consumption, associated with inefficient use of land and water resources. Poor infrastructure, technology and financial constraints are often cited as some of the causes of food waste and loss [5]. The consequences are associated with threats to the climate and biodiversity [6]. About 10% of global greenhouse gas emissions come from rotting food waste (FAO, 2016) in the form of landfill waste [7], which could be recycled. In addition, the social consequences are also of great importance, the amount of wasted food could feed millions of hungry people around the world. The issue of food waste is important to address, both for the purposes of on management on waste, as well as for development on purposeful strategies for prevention [7],

which will lead to effective solutions to reduce their quantity and improve environmental sustainability. This paper intensifies the debate on the topic by posing the research question of how food waste can be reduced through the mechanisms of circular economy (CE) and artificial intelligence (AI). To find an answer, the following paragraphs sequentially examine: first, the background of the circular economy in relation to food waste and the mechanisms it offers for its reduction. Issues related to the modern application of artificial intelligence in supporting the reduction of paper waste are also examined. As a result, a methodology is proposed that combines CE and AI and enhances their synergy. As a result, a roadmap is proposed aimed at individual producers in the food industry. It aims to assist them in the transition to strengthening circularity and optimizing processes by reducing waste in production.

2 Literature review

2.1. Background to the EU's attitude towards food waste

The circular economy puts waste issues at the forefront. Da Silva and Schiehnem (2022) emphasize the fundamental focus on directing consumption towards resource conservation, sustaining products for longer periods of time, eliminating waste and pollution [8]. The issue of food waste is addressed in Target 12.3 of the UN Sustainable Development Goals [9]. According to this target, the EU is committed to halving food waste by 2030. The report 2016/2223(INI) [10] examines the factors behind food waste. It concludes that they are rooted in each individual stage of the chain: production, processing, sale, transport or consumption, and concludes that the problems can be largely solved by improving communication between all actors, which

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will align supply and demand. It also emphasizes the need for a common methodology for assessing food quantities [10]. In this regard, the EU promotes the recycling of food waste and the creation of new products from it, as part of the transition to a circular economy [11]. The main application of food waste in the context of sustainability is reduced to the production of electricity, fuels and biofertilizers in agriculture [5]. In addition, some of them are suitable as raw materials for new products. For example, in cosmetics and textiles, as food additives. They can then be used in various industrial applications, for example, biodegradable packaging from corn husks. Redistribution is also an alternative falling within the scope of the circular economy. It is aimed at food products that are not sold and are donated to food banks or sold at a lower price. The main directions of the circular economy concept relating to food waste are presented in Fig. 1.

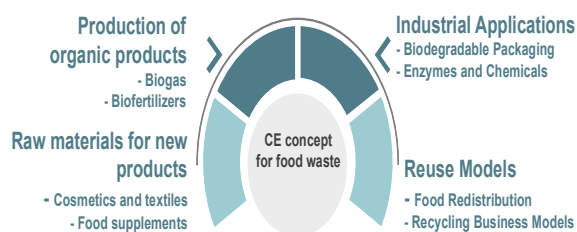


Fig. 1. Concept for food waste recovery according to the circular economy
 Source: Figure created by the author

The concept of CE for food waste is to close the loop. This would slow down the flows, ensuring that food is used to its full potential before it is thrown away [12]. In practical terms, closing the loop is a great idea, but it faces a number of barriers in its implementation. The most common challenges include the need for significant investments in technology, increased supply chain management, cultural and business issues, etc. [13]. This means that achieving circular economy goals in terms of food waste requires collaboration and sustained efforts from all actors in the food system, accompanied by a high degree of flexibility and innovation [14]. In this regard, Moraga and al. (2019) call for reducing primary material inputs and production, promoting the recycling of waste as secondary raw materials [15]. In this way, resource consumption will be reduced, their utility will be increased, and the value of materials will be more durable [16]. In summary, the CE prioritizes the importance of effective food waste management, prioritizing the reduction of adverse environmental impacts by promoting ecological products, renewable energy sources, ecodesign of products, consumer goods with low environmental impact, waste recovery and dematerialization [17].

2.2 Background of the application of AI in food waste recovery

Artificial intelligence has already proven to work in all industries, stimulating them to several optimizations and more efficient solutions. Its application to food waste is no exception. Several authors are considering issues related to resource recovery, including reuse, recycling and obtaining energy from waste, using artificial intelligence [18], [19]. An effective solution in this direction is the use of circular production strategies, by improving energy efficiency and extending the useful life of products and components, extracting maximum value from resources [20]. AI has the potential to reorganize entire food systems and the way food is produced and distributed [21]. It can be applied at any stage of the food waste management process (Fig. 2).

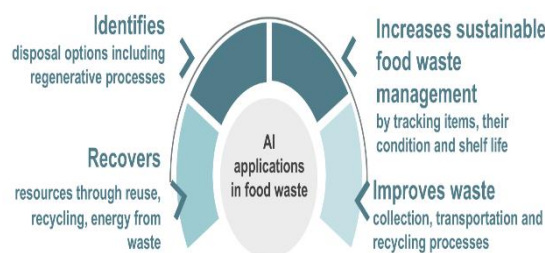


Fig. 2. Applications of AI in food waste management
 Source: Onyeaka, H., Tamasiga, P., Nwauzoma, UM, Miri, T., Juliet, UC, Nwaiwu, O., & Akinsemolu, AA (2023). Using artificial intelligence to tackle food waste and enhance the circular economy: Maximizing resource efficiency and minimizing environmental impact: A review. *Sustainability*, 15(13), 10482.

- In terms of identification, AI supports the process of regenerating returned products or identifying the most appropriate and affordable ways to dispose of them. It helps create decision-making tools regarding product quality and the need for reprocessing.
 - Effective in terms of solutions related to the treatment of biowaste and obtaining bioenergy. In this way, it contributes to reducing waste quantities, saving natural resources and recovering food materials.
 - Optimization of food materials by tracking individual items in terms of their condition, suitability for reuse and recycling options.
 - Effective management and improvement of collection processes, transportation, sorting and recycling of various wastes [16].
- There is also increasing interest in various smart technologies. According to a study by Onyeaka et al. (2023) [16], various smart technologies already have a permanent place in food waste management, and specific applications can be seen in Fig. 3.

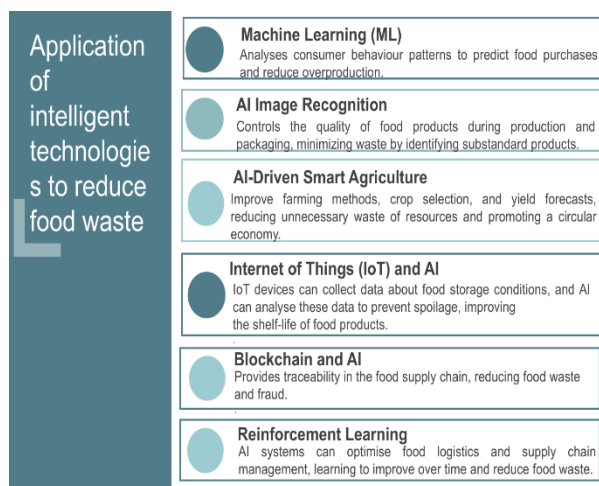


Fig. 3. Application of smart technologies to reduce food waste
 Source: Figure created by the author

The presence of its constantly developing capabilities is the reason for its main place in this paper.

3 Methodology

As the literature review has shown, the path of development of business organizations requires a desire to follow the principles of the Circular Economy and inclusion in circular chains with a wide range of stakeholders. It became clear that the goals for reducing food waste are known, but there is also a wide range of barriers, both investment and organizational, that hinder the individual participant in the chain. For this reason, the present methodology is aimed at the individual economic units participating in the food industry and the search for a mechanism that would facilitate their transition. Here, a roadmap is proposed to help them by providing guidance for moving through the individual steps towards reducing food waste and supporting the overall process of approaching the concepts of circularity.

The roadmap is created in accordance with the principles of circular economy development and Industry 5.0. Its implementation methodology requires going through six steps that combine the capabilities of various smart technologies with the principles of circular economy, which will benefit individual food companies.

4 Results and discussion

The results in this paper are in the form of a roadmap, intended to be followed by food manufacturing companies. It aims to help the food industry reduce the amount of food waste in their production. To achieve better efficiency in implementation, various intelligent technologies have been added to support the process, making it more adaptive and flexible. To illustrate the individual steps and better understand the roadmap, it is presented in Fig. 5.



Fig. 4. Roadmap for reducing food waste for a food manufacturing company, through AI and in the implementation of CE.

Source: Figure created by the author

Step 1: Internal audit and waste mapping

The process of reducing food waste starts with conducting an audit of the production process. The goal is to identify critical points where waste is likely to occur. Various approaches are used to collect the necessary data, including interviews with staff, monitoring of the main processes. Through them, historical information is collected about losses that have occurred, on the basis of which a primary database is prepared. It should contain information about both critical points and causes of waste formation (for example: improper storage, dosing errors, damaged packaging).

Within this step, a digital material flow map is created using IoT sensors and ERP systems. It aims to collect data in real time. For this purpose, IoT sensors are used that measure temperature, humidity, product movement, and expiration dates. The ERP system, in turn, integrates data from production, warehouse, and logistics, i.e., there is a digital material flow map with input, transformation, and output of products and potential food waste at each stage.

In order to verify the reliability of the system, preventive risk management is carried out through simulation by creating a digital twin model. Within its framework, various scenarios are tested, for example, “What happens if the temperature changes?” or “What are the consequences of a delay in deliveries?” These tests help to choose the right preventive measures in a safe environment.

Another important condition of this first step is the classification of waste through artificial intelligence. It serves to collect information about the types of waste generated, their quantities and the reasons for their formation. This can be achieved through machine learning on data from sensors and ERP. AI recognizes patterns and anomalies.

All information so far is systematized in a waste database. Based on it, future analyses, forecasting and reuse are prepared. This is where opportunities for connecting with food donation platforms, biogas plants or secondary markets are assessed.

Step 2: Integrate AI for Production Optimization

Three main activities are carried out within its framework: Demand forecasting through machine learning; Optimization of recipes and batches according to availability and expiration dates; Quality control through computer vision.

The goal of demand forecasting is to avoid overproduction and the associated waste. For this purpose, historical data related to sales, seasonality, marketing campaigns, geopolitical factors and other specifics of the external environment are used, according to the specific production. This data is used to train machine learning models related to demand forecasting. ML allows adapting the production schedule according to the forecasts, thus reducing the risk of unsold products with a short shelf life.

The optimization of recipes and batches according to availability and expiration dates allows for the effective use of available raw materials, eliminating the disposal of products due to expiration. For this purpose, AI analyzes the availability in the warehouse and expiration dates. It could offer adapted recipes according to availability or to optimize the size of batches according to the forecasted demand and production capacity. Another functionality here is the dynamic redistribution of resources to other channels, such as donations or secondary markets. In this way, in addition to making production more efficient, processes related to the corporate social responsibility of the organization are also implemented.

This second step also includes quality control using computer vision, which detects potential defects before they manifest and endanger the finished product.

The synergy between the three components significantly increases the efficiency of the production environment and makes it self-regulating. Forecasts reduce unnecessary production. Optimization ensures efficient use of resources, and quality control prevents waste from defective products.

Step 3: Applying Circular Solutions in the Production Cycle

This step is the essence of the roadmap and shows the possibilities of the circular economy to turn waste into resources. What is included in it is: Reintegration of suitable, but not commercially available products into new recipes; Processing of by-products into new food or non-food products; Composting or biogasification of unusable waste.

The reintegration of fit but substandard products aims to recover fit food with visual or marketing (cosmetic) defects, such as misshapen vegetables. Computer vision is used to identify products fit for reintegration. This includes repurposing the produce (e.g., packages of chopped vegetables) and marketing approaches such as campaigns with names such as “saved food” or “taste over appearance.”

The remaining part of the production classified as poor quality should be processed into by-products. This includes products that are not suitable for direct use but have nutritional value. Such products can be sold in the form of feed (for example, fruit peel residues), non-food products, such as bioplastics (from potato peelings or corn residues), etc.

Composting or biogasification of unusable waste provides a sustainable treatment for organic waste that cannot be reintegrated or recycled. Composting aims to break down food waste into soil conditioner, while biogasification transforms it into biogas (methane) and biofertilizer. Here, the added value of AI comes from the

analysis of the choice between the two processes depending on the composition of the waste, as well as the optimization of the process for maximum energy or compost yield.

Step 4: Digital platforms and partnerships

This step is key to building a sustainable ecosystem. It is a combination of internal optimization with external links, technology and trust. Its framework includes the following components: Creating a B2B platform to share surplus produce with other companies or NGOs; Partnerships with logistics companies for short-term food donations; Using blockchain for waste traceability and accountability.

The creation of a B2B platform for sharing surplus produce aims to prevent the waste of usable food. Its functionalities include information for announcing available produce with a short shelf life and automatic notifications for matching supply and demand between individual participants.

Partnerships with logistics companies for food donations are part of the functionality of this platform. They aim to provide short-term transportation to consumers. AI supports the process, both with predictive planning of donations according to availability and needs, and with route optimization.

Adding blockchain for traceability and accountability ensures transparency and regulatory compliance in waste and donation management.

Step 5: Training and organizational culture

Training is important from a sustainable business culture perspective. This step includes: Implementing internal policies for sustainable production; Training staff on the use of AI tools and circular economy principles; Incentives for teams that achieve waste reduction.

Internal one’s policies for sustainable production aims to create environmental practices in each of the production stages. It increases both the trust of all stakeholders and the possibilities for certification (ISO 14001, EMAS, etc.).

In turn, training staff in AI and CE increases competence and confidence in using AI technologies and developing circular thinking. This increases employee engagement, generates bottom-up ideas, and makes ideas easier to implement.

A natural extension of training is to incentivize teams that achieve results in terms of waste reduction and increased sustainability. This can take various forms (financial, recognition, growth, social, etc.).

Step 6: Monitoring, reporting and improvement

The last step of the roadmap is aimed at further development. Its main components are: Building KPIs (key performance indicators); AI for continuous monitoring and adaptation of the production process; Annual sustainability and transparency reports to partners and customers.

Building it KPI aims to measure progress in terms of sustainability, through applicable, organization-specific metrics. Commonly used indicators are the percentage of waste reduced; the percentage of recycled materials, the carbon footprint per unit of production; the number of donated products, the economic footprint, etc.

Using AI for continuously Monitoring and adaptation aims to monitor and optimize processes in real time. Annuals reports for Sustainability and transparency, in turn, report on progress and build trust among stakeholders. They show the goals and results achieved and outline the framework for future development.

Conclusion

This article outlines the state of food waste and the need for increased work on its reduction. The proposed roadmap for reducing food waste, through artificial intelligence and the principles of the circular economy, represents a comprehensive and innovative approach to sustainable production. By systematically going through six key steps — from internal audit to monitoring and reporting — it ensures not only technological transformation, but also cultural change in the organization. Among the main advantages of the roadmap, waste reduction can be highlighted through intelligent forecasting and opportunities for reuse. A serious economic effect is the transformation of waste into resources. Added value can be found in the opportunities for sustainable circular partnerships. Among the use of AI, the integration of the roadmap into a business environment also guarantees a high degree of transparency and accountability. And the active involvement of staff brings it closer to the ideas of Industry 5.0. and ensures sustainability of changes over time.

In the context of the European Green Deal and the growing demands for corporate responsibility, this roadmap is not just a tool for reducing waste - it is a strategic investment in the future of the food industry. This in turn raises many more research questions. In further work on the topic, the author aims to develop knowledge about sustainability and to explore to what extent circular business models can be scaled up in different segments of the food industry (e.g. meat processing, confectionery, dairy products)? Another research question resulting from future work is what are the social and economic barriers to the implementation of B2B platforms for sharing surplus production? Undoubtedly, the work on the topic is important and deserves the development of sustainability both in scientific terms and in business organizations.

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