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EMERGING TRENDS IN FOOD WASTE REDUCTION AND RESIDUE VALORIZATION: ADVANCING SUSTAINABILITY IN THE FOOD SERVICE INDUSTRY - STUDY CASE IN ROMANIA

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Abstract

The food service industry faces a growing challenge of managing food wastage while transitioning toward sustainable practices. This research explores emerging trends in food residue valorisation, focusing on innovative techniques for transforming food waste into valuable by-products such as bioenergy, animal feed, and bio-based packaging materials. Key advancements in bioprocessing technologies, including anaerobic digestion, composting, and enzymatic treatments, are evaluated for their efficiency and scalability. Additionally, this study examines the role of digital tools, such as AI-driven waste tracking and optimization systems, in minimizing waste generation. The integration of circular economy principles within the food service sector is highlighted as a pivotal strategy to address environmental, economic, and social sustainability. By identifying and analysing these new trends, the research provides actionable insights for stakeholders aiming to reduce waste and valorise residues effectively as well in agrifood industry and in food service industry, particularly in Romania's case.

Key words*: anaerobic digestion, circular economy, zero waste, sustainable food service, upcycling.*

INTRODUCTION

Food waste is one of the most pressing global environmental issues. It occurs across all stages of the food supply chain, but a significant portion is generated in the food service industry, from restaurants to ready-to-eat (RTE) meals. This waste contributes to increased greenhouse gas emissions, depletion of natural resources, and the loss of valuable nutrients. In recent years, the food service sector has shifted towards more sustainable practices, with a focus on waste reduction and residue valorisation (Arancon et al., 2013; Berenguer et al., 2022)

Food residue valorisation refers to the process of converting waste by-products into valuable materials, biofuels (Castro-Muñoz et al., 2021), or functional food ingredients. Through such practices, the food industry not only reduces waste but also contributes to environmental sustainability and economic growth. Recent innovations in packaging technologies have proven to be pivotal in extending the shelf life of food products and reducing waste in the process.

The objective of this review is to examine the emerging trends in food waste reduction, with a particular focus on the valorisation of food residues and advances in packaging technologies. Through an extensive analysis of the literature, it is explored how these innovations are advancing sustainability and reducing environmental impacts in the food service industry.

Recent research highlights emerging trends in food waste reduction and valorisation within the food service industry. Innovative waste management practices are being explored to address sustainability challenges, with implementation varying based on management's perspectives and goals (Martín-Ríos et al., 2018). The circular economy concept is gaining traction, emphasizing environmental protection and economic development through efficient utilization of food industry waste and by-products (Sharma et al., 2021). Encapsulation techniques for bioactive compounds extracted from food waste show promise, though further research on regulatory and toxicity considerations is needed (Borah et al., 2023). Waste valorisation strategies are being

developed to produce chemicals, materials, and fuels sustainably, moving beyond traditional disposal methods like landfills and incineration (Arancon et al., 2013). These approaches include biorefinery concepts for producing valuable products such as succinic acid and bioplastics from bakery waste (Arancon et al., 2013; Burange et al., 2016). The focus is shifting towards higher-value, marketable products from second-generation waste valorisation strategies (Burange et al., 2016). Other good practices in the Netherlands (Verkleij et al., 2019) underline the importance of promote the effort of collaborative teamwork to reduce with 50% the food waste.

MATERIALS AND METHODS

This review analyses various academic published articles, accessed via Science Direct, Web of Science (Enformation platform), Google Scholar, books, and case studies focused on food waste management, residue valorisation, and sustainable packaging. A systematic review methodology was employed to synthesize the key findings from the most recent research.

The literature was analysed using the following criteria, words searching and issues: "*Emerging technologies for food waste valorisation: Trends in turning food residues into valuable by-products*"; "*Innovations in sustainable packaging: Focus on active, intelligent, and biodegradable packaging*"; "*Environmental and economic impacts: Considerations of the sustainability of these technologies and their effect on reducing waste and conserving resources*"; "*How does the Romanian government has implemented measures to promote sustainability by reducing food waste*"; "*Actions to reduce food waste in the Romanian food service industry*".

RESULTS AND DISCUSSIONS

1. Active packaging and shelf-life extension

Active packaging is a technology that integrates materials or components into packaging systems that actively interact with the contents to improve food quality and shelf life. As discussed by Prasad & Kochhar (2014), active packaging includes components like oxygen scavengers, moisture regulators, and antimicrobial agents, which can significantly extend shelf life and reduce food waste. These packaging systems are designed to react with environmental factors (e.g., oxygen, moisture) to maintain the food's freshness.

For example, Dharma (2023) explored the use of turmeric and red ginger as natural antimicrobial film coatings for RTE meat products. This active packaging method extends the shelf life by preventing microbial growth, which is a significant contributor to food spoilage.

The most common active packaging technologies and their effect on food are presented in Table 1.

Table 1. Active packaging technologies and their effects (adapted from Prasad & Kochhar, 2014; Dharma, 2023)

Active packaging type	Function	Effect on food
Oxygen Scavengers	Absorb oxygen from the package	Reduces oxidation and spoilage
Moisture Regulators	Control moisture inside the package	Prevents bacterial growth and mold
Antimicrobial Agents	Release antimicrobial substances	Inhibit the growth of bacteria, molds, fungi

2. Modified Atmosphere Packaging (MAP)

Modified Atmosphere Packaging (MAP) involves altering the composition of gases inside the package to slow down the deterioration of food products. Berenguer et al. (2022) noted that MAP is commonly used for fresh produce, meats, and dairy products. By adjusting the levels of oxygen, nitrogen, and carbon dioxide, MAP creates an optimal environment that:

- Slows microbial growth;
- Reduces oxidation;
- Preserves food texture, colour, and flavour.

In Figure 1, there is a presentation of different gaseous composition in MAP for different types of food.

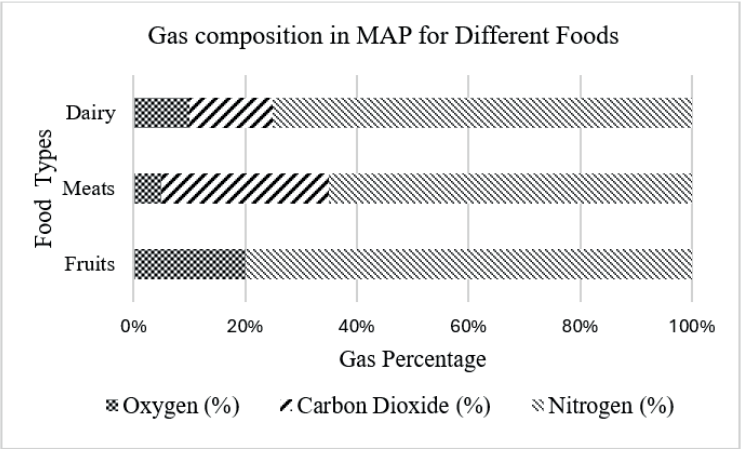

Figure 1. Evolution of Average Milk Yield

It can be observed (Figure 1) that for dairy, the composition of MAP is High in N_2 (inert gas to prevent oxidation), low CO_2 (minimal antimicrobial need); for meats: High CO_2 (extends shelf life by inhibiting bacteria), moderate O_2 (preserves red colour) and for fruits: Balanced O_2/CO_2 (slows ripening; exact ratios vary by fruit type).

3. Smart and intelligent packaging systems

Intelligent packaging goes beyond simple preservation by integrating technology that monitors and reports the status of the food. Smart labels, time-temperature indicators (TTIs), and freshness sensors provide real-time data to consumers, helping them make informed decisions about food quality and safety. As discussed by Biji et al. (2015), these technologies enhance consumer confidence and reduce food waste by ensuring products are consumed within their optimal time frame.

For instance, Corradini (2018) reviewed time-temperature indicators (TTIs), which change colour to indicate whether a product has been exposed to improper temperatures during storage or transportation. This type of intelligent packaging is crucial for perishable foods, particularly in the meat and dairy industries.

4. Valorisation of food waste and by-products

Food industry waste, including peels, seeds, and shells, has enormous potential for valorisation (Ribeiro, 2022; Roy et al., 2023). By converting these residues into valuable products such as biofuels, bioplastics, and functional food ingredients, the food service industry can minimize waste and contribute to a circular economy. Lin et al. (2014) and Ravindran et al. (2016) highlighted various methods for transforming food waste into value-added products.

- Bio-based materials: Food residues such as fruit peels can be processed into bioplastics and bio-based packaging materials or chemical materials and biofuels (Ong et al., 2018; Nayak et al., 2023).
- Bioactive compounds: The extraction of bioactive compounds from food residues (such as phytonutrients) can lead to new functional food ingredients (Luca, 2022).

Different methods for transforming food waste into value-added products are presented in Table 2.

Table 2. Valorisation of Food Industry Wastes (adapted from Ravindran et al., 2016; Borah et al., 2023)

Food waste type	Valorisation product	Applications
Fruit peels	Bioplastics, bioactive compounds	Packaging, functional foods
Coffee grounds	Biofuels, nutraceuticals	Energy production, health supplements
Vegetable trimmings	Animal feed, fertilizers	Agriculture, sustainability

There is also valuable research in Romania related with high utilization of by-products, such as pomace from different natural juices made from carrots, apple, pear also. In Table 3 there is a non-exhaustive list of the Romanian researcher of valorisation products in food industry.

Also, Vodnar et al. (2015) has been developed an edible film with antimicrobial properties to increase the pork meat preservation under refrigerated condition; Pop et al. (2013) have developed different antibacterial extracts from plants, underlying the focus on sustainability and reducing the food waste in Romania. Szabo et al. (2018) have used the tomato by-products to obtain different valuable nutritive products. Socaci et al. (2018) investigated the influence of the extraction solvent on phenolic content, antioxidant, antimicrobial and antimutagenic activities of brewers' spent grain.

Utilisation of by-products for valorisation were investigated to reduce food waste. The obtaining of bioactive compounds from red beetroot peel powder were studied by Constantin et al. (2025) with the developing of merengue products, by Stoica et al. (2024) for whey-fruit based beverage development and apple for potentially functional apple snacks by Stan et al. (2025). Despite the un-commercial shape, apples can be valorised in crispy snacks reducing with 80% the food waste. In Table 3 there are mentioned some important contribution.

Table 3. Ways of valorisation of some vegetable by-products into sustainable products

By-products type	Valorisation product	Applications
Red beetroot peel powder	Bioactive compounds, natural dye and food preservative	Meringue Products (Constantin et al., 2025)
Red beet peel	Phenolics and betalains compounds	Whey-fruit-based beverage (Stoica et al., 2024)
Apple snacks	Apples	Potentially Functional Apple Snacks (Stan et al., 2025)

5. Sustainable and edible packaging

Sustainable packaging materials, such as biodegradable polymers and edible films, are essential for reducing plastic waste in the food industry. Trajkovska Petkoska et al. (2021) reviewed several sustainable packaging materials, including those made from plant-based sources like PLA (polylactic acid) and starch-based films. Furthermore, edible packaging made from natural ingredients such as seaweed, rice, and proteins offers a novel approach to reducing waste.

For example, Gil & Rudy (2023) highlighted how edible packaging made from fish gelatine could be used for meat products, offering both environmental benefits and added functionality to the food packaging industry.

6. 3D Printing in packaging

3D printing technology is revolutionizing packaging by enabling the creation of customized packaging designs. As Bumbudsanpharoke & Ko (2022) discussed, 3D printing allows for on-demand production, reducing waste in packaging production and enabling the creation of packaging with optimized shapes to minimize material usage. The use of this technology contributes to sustainability by reducing the environmental impact of overproduction and excess packaging.

Figure 2. 3D Printed Packaging for Customization (source: www.packnode.org)

The rise of 3D printing technology is revolutionizing the packaging industry, enabling unparalleled customization, faster prototyping, and more sustainable production

processes. This innovative method is reshaping how packaging is designed and manufactured. 3D printing is used to create prototypes, molds, and even fully functional packaging components. It allows designers to test and iterate quickly, reducing time-to-market for new products. For customized packaging, 3D printing enables intricate designs tailored to specific products or brands.

Key advantages of 3D printing technology of packages:

- Flexibility: Adapts to small-batch production, ideal for limited editions or unique product lines.
- Sustainability: Reduces material waste by producing only what is needed.
- Speed: Accelerates the prototyping process, allowing for rapid innovation.

Despite its benefits, 3D printing in packaging faces challenges like high initial costs and limited scalability for large-scale production. However, advancements in materials and printing technology are addressing these barriers, making it more accessible to businesses of all sizes.

As 3D printing continues to evolve, it is set to become a cornerstone of the packaging industry, offering solutions that are not only innovative but also aligned with the demands of modern consumers and sustainability goals.

7. How has the Romanian government implemented measures to promote sustainability by reducing food waste

As a member of the European Union, Romania has demonstrated a strong commitment to implementing significant regulatory measures in recent years to align with the objectives set by the European Parliament. These measures specifically aim to mitigate food waste, targeting a 10% reduction in household food waste and up to a 30% reduction in the food industry, including the food service sector. Among the important undertakings are:

1. Legislation to Combat Food Waste: In 2016, Romania enacted Law no. 217/2016, obligating entities in the agri-food sector to adopt measures preventing food waste. These measures encompass actions such as selling products nearing their expiration dates at reduced prices, donating near-expiry food to registered organizations, and repurposing unfit food for animal consumption, composting, or biogas production. Non-compliance with this law can result in fines ranging from RON 1,000 to RON 10,000, depending on the size of the enterprise (cms-lawnow.com);
2. Amendments to Strengthen Food Waste Reduction: In March 2024, Law no. 49/2024 was enacted to further enhance efforts against food waste. This law mandates that businesses such as shops, restaurants, and canteens implement at least two measures to reduce food waste before discarding food. These measures include reducing prices on products nearing expiration, donating food, or repurposing it for animal feed. Additionally, the law simplifies procedures for non-governmental organizations to receive non-perishable food and establishes a national platform, managed by the Ministry of Agriculture, for reporting food waste data (foodcomplianceinternational.com);
3. National Strategy for Food Waste Reduction: The government is developing a comprehensive National Strategy for the Prevention and Reduction of Food Waste. This strategy aims to outline actions to prevent and reduce food waste, set quantifiable targets, promote anti-waste measures, assign responsibilities, and allocate necessary financial resources. The strategy is to be updated every five years and presented to the Romanian Parliament before adoption (agroberichtenbuitenland.nl).
4. Public Awareness and Education Campaigns: The Ministry of Agriculture and Rural Development, in collaboration with the Department for Sustainable Development, has initiated campaigns to raise public awareness about food waste. These efforts include creating impactful anti-waste messages and translating educational materials from the Food and Agriculture Organisation (FAO) for distribution in schools across Romania (ec.europa.eu).

Through these comprehensive measures, the Romanian government aims to significantly

reduce food waste, promoting sustainability and environmental responsibility nationwide.
Actions to reduce food waste in the Romanian food service industry have been guided by national sustainability goals and aligned with EU regulations promoting circular economy practices, presented in Table 4.

Table 4. Good practice in food waste management and sustainability in the Romanian food service industry

Action	Example	Impact
Waste Reduction in Restaurants	Cluj, Timisoara and Bucharest's restaurants are offering smaller portion sizes to minimize leftovers, encouraging customers to only take what they can finish. Additionally, restaurants like **Caru' cu Bere** in Bucharest are part of food waste reduction initiatives by working with local charities to donate excess food at the end of the day.	Up to 30% of food waste reduced in one year (2021-2022, according with Ghenea, 2022)
Repurposing Food Scraps	Some restaurants and food service businesses in Romania are repurposing food scraps. For instance, vegetable peels, stems, and other by-products from meal preparation are used to make broths or soups, which are then served to customers as a sustainable offering. Additionally, they are turning stale bread into croutons or breadcrumbs, and fruit scraps are used to make juices or preserves.	The purchasing cost of ingredients decreased up to 30% while the enhancing of the taste increased with 50% without makeover with taste-enhancers. (Săftoiu et al., 2021)
Zero-Waste Kitchens	Careful planning to reduce food waste, reusing ingredients creatively, and composting organic waste. Some chefs have started using techniques like fermentation or pickling to preserve food by-products or underutilized ingredients, which also results in innovative new dishes	Decreasing of the food waste by careful planning of the menu and purchasing ingredients with up to 20% in one year time (Radu & Mihailescu, 2023)
Sustainability Partnerships	Some food service chains and restaurants in Romania partner with food recovery organizations, such as **Feed Forward**, which helps reduce food waste by redistributing excess food to those in need. These partnerships are essential in supporting the circular economy and reducing food waste in the food service industry.	Reducing food waste by sustainability partnership reached 20% in the involved restaurants (Andrei I., 2020)
Food Waste Awareness Campaigns	**„Sunt un Restaurant Sustenabil"** ("**I am a Sustainable Restaurant"**) is an initiative in Romania aimed at raising awareness and encouraging food service businesses to adopt sustainable practices. This initiative focuses on reducing food waste, offering portion control options, and repurposing food by-products. It also promotes partnerships with local NGOs to donate leftover food to people in need.	Up to 30% of food waste was reduced by activating awareness campaigns in 2020. However, the Covid19 impacted severely the food service industry, and some data could be overrated (Hossu et al., 2021)
Food Waste Reduction Apps	In cities like Bucharest, several food service businesses have begun using apps like **Too Good to Go** or **Savery – stop food waste** which allows them to sell surplus food at discounted prices, helping to reduce waste and provide affordable meals to customers. This is particularly useful for cafés, bakeries, and small food outlets that often have excess food at the end of the day	Using the apps enable the users to find ways not to throw away the extra-food but to sell with discounted price (up to 35% for each order, or half price for the second order). Mainly pizza, shawarma, poke-bowl or noodles food service units are using these apps with a reduction of food waste reaching 30% yearly. (Constantin, I., 2022)
Biodegradable Packaging and reusables containers	Several food service providers are shifting to biodegradable or compostable packaging to reduce waste. This includes adopting eco-friendly takeaway containers made from plant-based materials, helping reduce the environmental impact of disposable packaging in the food service industry. Also, on European Union recommendation, the reusable containers will be warmly supported starting with 2027 in food service industry, especially in take-a-way system or home-delivery system based on abonnement.	By shifting to biodegradable packaging and reusable containers the food service industry in Romania can mitigate the food-waste with up to 10% (Popescu, C., 2020)

CONCLUSIONS

Emerging trends in food waste reduction and residue valorisation hold great promise for transforming the food service industry towards greater sustainability. The integration of active, intelligent, and biodegradable packaging systems plays a crucial role in extending the shelf life of food and reducing spoilage. Furthermore, the valorisation of food industry by-products into valuable resources supports the transition to a more circular economy, where food residues are converted into biofuels, bio-based materials, and functional food ingredients.

These advancements not only address the growing concerns over food waste but also contribute to significant environmental and economic benefits. Future research should continue to explore ways to improve the efficiency of these technologies, focusing on scalability, cost-effectiveness, and minimizing the overall environmental footprint of food production and packaging.

By embracing these innovative technologies, the food service industry can make significant strides toward sustainability, ensuring a more efficient, waste-free, and eco-friendly future.

The food service industry in Romania is increasingly recognizing the critical importance of sustainability and food waste reduction in aligning with both local and European Union sustainability targets. Numerous initiatives within the sector demonstrate a clear commitment to adopting circular economy principles and minimizing environmental impact. From repurposing food scraps into value-added products to reducing portion sizes and implementing zero-waste kitchen practices, the sector is actively engaged in fostering sustainable practices.

Collaborations with food recovery organizations, the adoption of digital tools such as food waste reduction apps, and the transition to biodegradable packaging reflect the growing trend toward environmental responsibility.

Moreover, Romania's food service sector is also advancing the idea of creating more efficient food systems through partnerships and technological innovations, contributing to the reduction of food waste. While challenges remain in ensuring widespread adoption of these practices, the sector's ongoing efforts illustrate a significant commitment to reaching EU sustainability targets and reducing its ecological footprint.

In conclusion, Romania's food service industry has made notable strides in mitigating food waste, but continued investment in education, collaboration, and innovative solutions will be essential in achieving long-term sustainability goals. Through these combined efforts, the sector can play a vital role in building a more sustainable and resource-efficient food system.

Particularly, at the Faculty of Animal Productions Engineering and Management, the Science in Gastronomy licence program deliver an exhaustive Sustainable gastronomy program, aiming to create awareness on reducing the food waste by taking the appropriate measures.

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