Scientific Papers. Series D. Animal Science. Vol. LXVIII, No. 2, 2025
ISSN 2285-5750; ISSN CD-ROM 2285-5769; ISSN Online 2393-2260; ISSN-L 2285-5750

REDUCING FOOD WASTE: STRATEGIES, IMPLICATIONS, AND FUTURE DIRECTIONS

Liliana-Maria DRAGOMIR[1], Ioana Alexandra ALEXE[1], Carmen Georgeta NICOLAE[1], Daniela Valentina VATAMANU[1], Mirela Aurora STANCIU[2], Adina Lidia ALEXANDRU (SOMESAN)[1], Gratziela Victoria BAHACIU[1]

[1]University of Agronomic Sciences and Veterinary Medicine of Bucharest, 59 Mărăști Blvd, District 1, Bucharest, Romania
[2]University Lucian Blaga from Sibiu, 10 Victoriei Blvd, Sibiu, 550024, Romania

Corresponding author email: liliana-maria.dragomir@doctorat.usamv.ro

Abstract

Food waste is a critical global issue with environmental, economic, and social consequences. This article explores the causes of food waste across the supply chain, from production and processing to distribution and consumption, highlighting its regional and global impacts. Using data from sources like the United Nations Environment Programme (UNEP), Eurostat, and national studies, it provides statistical insights into regional disparities and the effects of policies, economic factors, and social behaviors. The analysis focuses on the European Union and Romania, offering comparative perspectives. To combat food waste, the article proposes strategies, including technological innovations, to enhance supply chain efficiency and minimize losses. Policy interventions at local and national levels are emphasized to establish sustainable practices. Consumer education is identified as essential for raising awareness and fostering better habits. By addressing these key areas - technology, policy, and education - the study advocates for sustainable food systems to reduce waste and its harmful effects on the environment and society.

Key words*: consumption, distribution, food waste, strategies, supply chain.*

INTRODUCTION

Food waste, which refers to the disposal of edible food throughout various stages of the supply chain, is a pressing global issue. Shockingly, about one-third of all food produced for human consumption is either lost or wasted each year, amounting to roughly 1.3 billion tonnes (Gustavsson et al., 2011). This waste not only plays a significant role in contributing to nearly 10% of global greenhouse gas emissions but also leads to considerable economic losses (UNEP, 2024). In the European Union (EU), food waste is estimated at 59 million tonnes annually, which translates to about 132 kilograms per person (Eurostat, 2024). Romania, as a member of the EU, encounters its own set of challenges related to food waste, significantly affecting both its economy and food security. This article seeks to explore the causes and ramifications of food waste in different regions while proposing effective strategies for its reduction.

Food waste and food loss are similar by the fact that they both occur at each stage of the supply chain, including primary production, processing, at retailers, within the food service industry, and in households.

It is crucial to understand where food is wasted and how much is wasted along the supply chain to devise interventions to reduce wastage and to quantify baselines and progress towards Sustainable Development Goal (SDG).

It is important to consider the definitions of Food Loss and Food Waste and where they arise in the food supply chain (Murphy et al., 2024)

Food waste: typically refers to food that was not ultimately consumed by humans and that is discarded; it can arise intentionally or unintentionally from the human food supply chain in retail, restaurant, food service and household (Qi & Roe, 2019) settings.

Food loss: refers to a decrease in the mass or quality of food before it reaches the consumer; includes all quantities of crop, livestock and human-edible commodities which, discarded or otherwise, do not re-enter the food supply chain in any other utilisation in other contexts such as

in animal feed or for industrial purposes (Santeramo et al., 2021).

Food loss may be due to: harvest, storage, processing, distribution and transportation. Harvest losses refer to the loss of food that occurs during harvesting, often attributed to improper harvesting techniques or timing: early harvesting with a higher moisture content or insufficient drying processing increase the risk of mould growth. It is also referring to food that was not harvested due to labour shortages or low market prices and remained on the field; or to food which not conform to aspect requirements set by retailers: e.g. it is estimated that 25-30% of carrots do not reach the market due to failure to achieve aspect standards (Alvarez de los Mozos et al., 2020).

Storage losses involve spoilage of during storage, either in warehouses or refrigerated facilities. Factors such as unstable moisture control, contamination and temperature fluctuations can cause storage losses. Excessive moisture can promote mould, fungus, and bacteria growth, causing food to degrade (Nielsen et al., 2014).

Processing losses refer to the reduction in quantity or quality of food during processing steps: washing, cleaning, degutting, chopping, withering etc.; loss during the grading process which involves selecting and classifying food products based on quality, size, or appearance.

Distribution and transportation losses refer to food loss arising during transit from production facilities to retailers or consumers: poor transport infrastructure and delays are factors as improper storage, delays during transportation and poor road conditions can cause bruising damage and spoilage of food products (Kohli et al., 2024).

Food waste may be influenced by: procurement issues, when retailers bypass traditional suppliers in favour of new sources or a surplus of fresh produce, especially at the end of the growing season, which goes unsold and is ultimately wasted.

Limited market access for small farmers: small and medium farmers often lack access to central or wholesale markets, relying instead on local markets with limited buyers (Ishangulyyev et al., 2019). Unsold food in these markets often degrades due to climatic conditions. When some farmers do reach wholesale markets, they may have to sell at reduced prices as produce nears its expiration date, leading to further waste (Ishangulyyev et al., 2019).

Quality standards and penalties can contribute, especially in developed economies such as Europe and the US, to food waste generation. Penalties for late or non-delivery, exacerbated by factors like natural disasters, can lead to contract losses and product recalls, resulting in significant food waste.

Market system changes, the trading system typically regulates supply and demand, however external pressures such as supermarket expansion can disrupt this balance. These disruptions often lead to the segregation of produce into different quality tiers, with lower-quality products more likely to end up as waste. Additional quality and safety requirements further push domestic market produce into the food waste category prematurely (Alvarez de los Mozos et al., 2020; Santeramo, 2021).

Inefficient technologies for preserving fruits and vegetables (cold chain), difficult transportation procedures that cause problems in storing and packaging food, lack of staff qualifications to apply stock rotation procedures, late cancellation of commercial orders and contracts previously agreed between distributors and suppliers (Guarnieri et al., 2021).

Food waste at consumer level is influenced by too much food is prepared or cooked for the number of people, plus the lack of optimal storage conditions; incorrect shopping planning Incorrect understanding of the labeling "best before..." and "expires on..."; lack of culinary skills to reuse leftover food and transform it; socio-economic factors (household type, income, culture, consumption habits (Nunkoo et al., 2021; Asli Elif & Pinar, 2021).

MATERIALS AND METHODS

The study conducts a comprehensive literature review based on recently published articles, accessed via Science Direct, Web of Science (Enformation platform), Google Scholar, and analyses data from the United Nations Environment Programme (UNEP), Eurostat, as well as National reports to examine food waste

patterns on a global scale, as well as specifically in Europe, the European Union (EU), and Romania. Statistical analyses, including trend analysis and cross-regional comparisons, are performed to interpret the data and identify significant patterns and correlations. This examination aims to shed light on food waste patterns across different levels: globally, within Europe, specifically in the European Union (EU), and in Romania.

To achieve this, the research employs rigorous statistical analyses, which include both trend analysis- tracking changes over time and cross-regional comparisons, which assess and contrast food waste data from different regions.

RESULTS AND DISCUSSIONS

1. *Global perspective on food waste amount and its impact on environment and economy*

Food waste arises from a complex interplay of factors across various stages of the food supply chain: ineffective harvesting techniques, pest infestations, and inadequate storage facilities lead to significant losses during the production stage. Worldwide, about 14% of food produced is lost between harvest and retail (FAO, 2021). In Romania, traditional farming methods and limited access to modern storage technologies further increase losses in this sector (Iordăchescu et al., 2019).

According to the UNEP Food Waste Index Report 2021, approximately 931 million tonnes of food waste were generated globally in 2019: 61% came from households, 26% from food service, and 13% from retail.

Over the past decade, global food waste trends have indicated a growing shift toward consumer-level waste, particularly in developed nations. Conversely, developing regions face higher losses during production and processing due to inadequate infrastructure and logistics (UNEP, 2021). Food waste has significant economic repercussions, leading to financial losses across all sectors of the supply chain. In the European Union, food waste results in an annual economic loss of €132 billion (EC, 2024). The United States reports an even higher economic impact, exceeding $200 billion annually (Bennett et. al. 2017). The environmental consequences are equally severe. Food waste contributes to 8-10% of global greenhouse gas emissions (UNEP, 2024). In 2023, food waste-related emissions in China reached 350 million tons of CO_2, while the United States and the EU recorded 250 million tons and 180 million tons, respectively (Our World in Data, 2024). Developing nations such as South Africa and Afghanistan also face methane emission challenges due to inadequate waste management infrastructure.

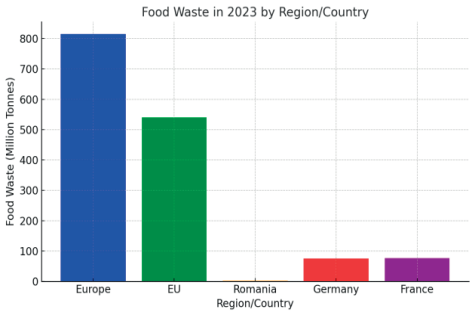

Figure 1: Food Waste in 2023 by Region/Country (Eurostat, 2023)

Europe generates an estimated 88 million tonnes of food waste annually, accounting for approximately 20% of all food produced in the region (Figure 2). The primary contributors to this waste include households, which are responsible for 53% of the total, followed by the processing and manufacturing sector at 19%, and retail and distribution at 8%. These figures highlight the significant role of consumer behavior and supply chain inefficiencies in driving food waste across the continent (EC, 2023).

Regional disparities in food waste management are evident across Europe. Northern European countries, such as Denmark and Sweden, have achieved notable reductions in food waste through the implementation of comprehensive policies and effective consumer education initiatives. In contrast, Southern and Eastern European nations, including Greece and Bulgaria, continue to face challenges in reducing food waste due to insufficient infrastructure for food preservation and redistribution systems. These regional differences underscore the importance of tailored strategies to address food waste in diverse socio-economic and cultural contexts (FUSION, 2016; UNEP, 2021).

The European Union produces approximately 59 million tons of food waste annually, an average of 132 kg per capita. This volume of waste highlights the need for interventions to address inefficiencies across the food supply chain and consumer behavior (EC, 2020).

In this scenario, Denmark has successfully reduced food waste by 15% from 2013 to 2023. This achievement is due to the use of new technologies and programs that educate consumers, helping to reduce waste in both supply chains and households. (EC, 2020; Danish Environmental Protection Agency, 2023)

In contrast to high-performing nations, Romania continues to exhibit increased levels of food waste relative to its population size. Has been made a limited progress in reducing household waste, highlighting the need for more effective policies and infrastructure improvements to address this ongoing challenge (EC, 2020).

Household waste in the EU accounts for 54% of total food waste, driven by over-purchasing and misinterpretation of date labels (Eurostat, 2024). In Romania, cultural practices like bulk buying during holidays exacerbate this issue, with 60% of household waste attributed to such behaviors (FUSIONS, 2016). Tailored campaigns, such as Romania's "Don't Waste, Taste!" initiative, could mimic the UK's "Love Food, Hate Waste" by educating consumers on meal planning and proper storage. Pilot studies in Cluj-Napoca demonstrated a 25% reduction in household waste after implementing community workshops on date-label literacy (Archip et al., 2023). These efforts must also address rural-urban divides: rural Romanian households waste 30% more food due to limited access to preservation tools (EEA, 2023), underscoring the need for region-specific educational programs.

Romania generates around 2.55 million tonnes of food waste each year, averaging 120 kg per person. This high level of waste highlights the need for better food management and waste reduction efforts in the country (UNEP, 2021).

Also, in Romania, households are responsible for over 60% of food waste (Table 1), largely due to cultural practices and limited consumer awareness. The agricultural sector faces significant losses, particularly in rural areas, due to inefficiencies in storage and transportation (Iordăchescu et al., 2019). Although laws promoting food donations have been introduced, implementation challenges have limited their effectiveness, resulting in slow progress in reducing food waste (FUSION, 2016; FAO, 2019).

To better understand how food waste manifests differently across global supply chains, milk serves as a particularly illustrative example. As a highly perishable commodity with widespread consumption, milk waste reflects both logistical efficiency and systemic vulnerabilities within national food distribution networks.

Figure 1 presents the most recent available data on total milk waste in the supply chains of selected countries: France, Germany, Romania, South Africa, Afghanistan, and the EU27 average. The variations across these contexts reveal important dynamics.

In high-income countries such as France and Germany, supply chain milk waste is noticeably higher in absolute terms. This is likely due to the scale and complexity of their dairy industries. With larger volumes passing through multiple stages - collection, processing, storage, and transport - the probability of waste accumulation increases. Even in regions with well-developed infrastructure, such as the EU27, systemic inefficiencies or surplus production can still lead to substantial waste (Kumar & Kalita, 2017).

By contrast, Romania, although part of the EU, exhibits much lower total milk waste. This may be attributed to its comparatively smaller dairy sector and shorter or less industrialized supply chains. Similarly, South Africa, representing an emerging economy, shows moderate milk waste, perhaps reflecting the coexistence of modern commercial farming with less formal distribution systems.

Notably, Afghanistan reports the lowest milk waste among the selected countries. While this might suggest higher efficiency, it is more plausibly linked to limited dairy production, lack of infrastructure, and reduced access to cold chains, factors that suppress overall volume but do not necessarily indicate optimized systems.

This example demonstrates how food waste in the supply chain is not solely a function of development level but is also shaped by the scale of production, infrastructure quality, and market integration. In contexts of high production, waste reduction strategies should focus on improving logistics, cold storage, and redistribution. In contrast, lower-income regions may require foundational investments in infrastructure and technology to minimize early-stage losses (Figure 2).

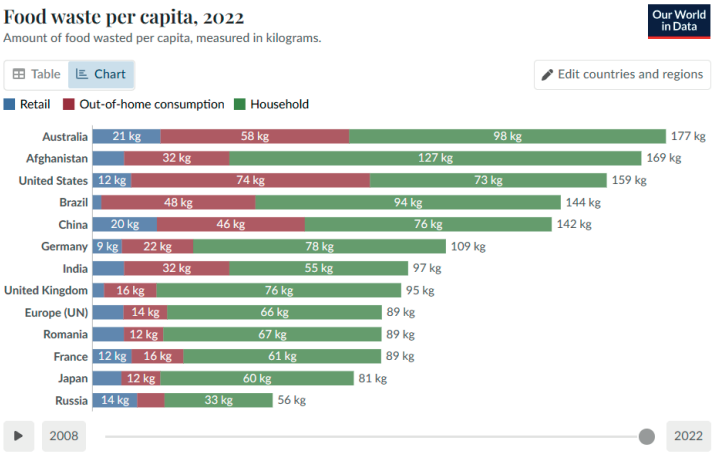

Figure 2. Food waste per capita, 2022 (source: United Nations Environment Programme, processed by Our World in Data, 2024)

It can be seen in Figure 2 that the highest total food waste is registered by Australia with 177 kg per capita (Household: 98 kg, Out-of-home: 58 kg, Retail: 21 kg), followed by the United States with 159 kg per capita (Household: 78 kg, Out-of-home: 74 kg, Retail: 12 kg).

The lowest total food waste was registered by Russia with 56 kg per capita (Household: 33 kg, Out-of-home: 14 kg, Retail: not specified), France and Romania at 89 kg, with France having significantly lower out-of-home waste (16 kg vs. Romania's 67 kg).

It can be also observed that household waste is the largest contributor in most countries (e.g., India: 97 kg out of 169 kg total); Germany and Japan show relatively balanced distribution across sectors; China's total (142 kg) is driven by household waste (76 kg), similar to Brazil (94 kg household).

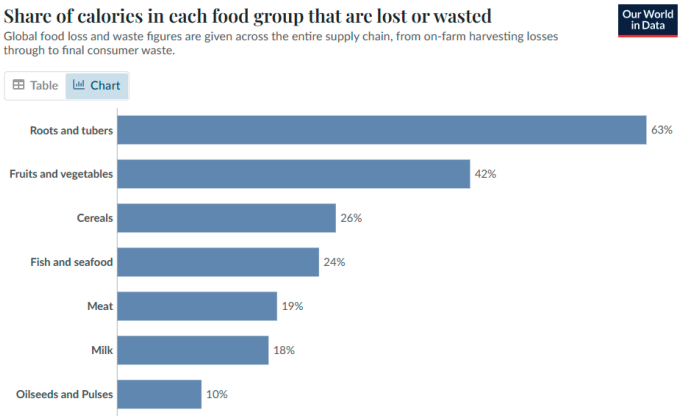

Figure 3. Share of calories in each food group that are lost or wasted (Lipinski et al., 2013; Our World in Data, 2024)

Highest loss/waste is registered (Figure 3) for roots and tubers (e.g., potatoes, yams) top the list at 63%, indicating significant inefficiencies in production, storage, or distribution; fruits and vegetables follow at 42%, likely due to perishability and handling challenges.

Cereals (26%), fish and seafood (24%), and meat (19%) show relatively lower but still substantial losses, while milk (18%) and oilseeds and pulses (10%) are the most efficiently managed, with minimal waste.

Implications that can be observed from this is that perishability matters (high waste in roots/tubers and produce suggests urgent need for better cold storage, transportation, and processing); supply chain focus is also to be taken into consideration (cereals and meat losses may stem from inefficiencies in processing or retail (e.g., spoilage, overstocking).

Unlike the per-capita waste table (which focused on national household/retail waste), this chart highlights global systemic inefficiencies by food type. Combining both insights could guide targeted policies (e.g., reducing tuber waste in high-household-waste countries like Australia).

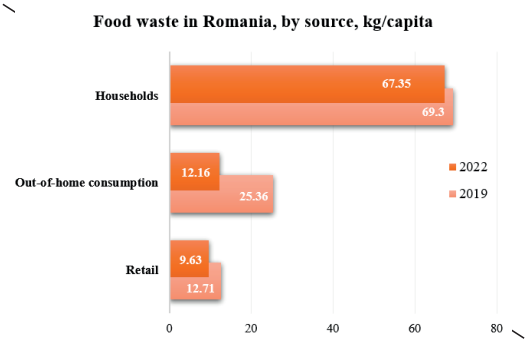

Figure 4. Food waste in Romania, by origin in kg/capita for 2022 vs. 2019 (original, based on Our World in Data)

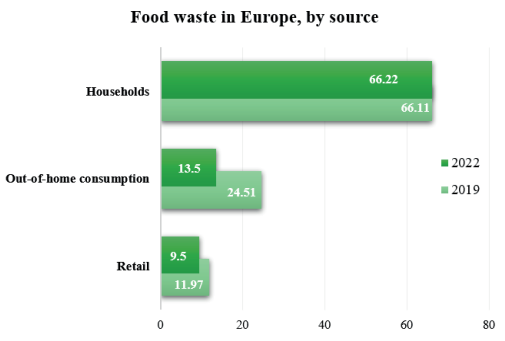

Figure 5. Food waste in Europe, by origin in kg/capita for 2022 vs. 2019 (original, based on Our World in Data)

Regarding the food waste (Figure 4) it can be observed that household waste in Romania registered a slight decrease (~2 kg) from 2019 to 2022, suggesting minor improvements in household food management. The Out-of-home Consumption Waste (e.g., restaurants, cafes), a sharp decline (~13 kg), likely due to pandemic-related reductions in dining out (2019-2022 spans COVID-19 disruptions or / and policy changes or awareness campaigns targeting hospitality sectors.

Romania's total household waste (~67 kg in 2022) is lower than the EU average (e.g., Germany: 78 kg, France: 61 kg), but aligns with Eastern European trends (Russia, 33 kg).

The dramatic drop in out-of-home waste contrasts with stable household waste, highlighting sector-specific impacts.

The household waste remained quite stable at EU level (Figure 5), while the Out-of-home Consumption (restaurants, etc.) declined with ~6 kg, likely due to COVID-19 reducing dining out, and the retail (supermarkets, shops) also declined with ~2.5 kg, possibly from improved inventory management or policies.

Households dominate food waste ~70-80% of Europe's food waste (Figure 6) comes from households (similar to global patterns). The Post-Pandemic Shifts determined the Out-of-home waste to drop sharply (2022 < 2019) but may rebound as dining normalizes, and the retail Progress by small reductions suggest efficiency gains (e.g., dynamic pricing, donations).

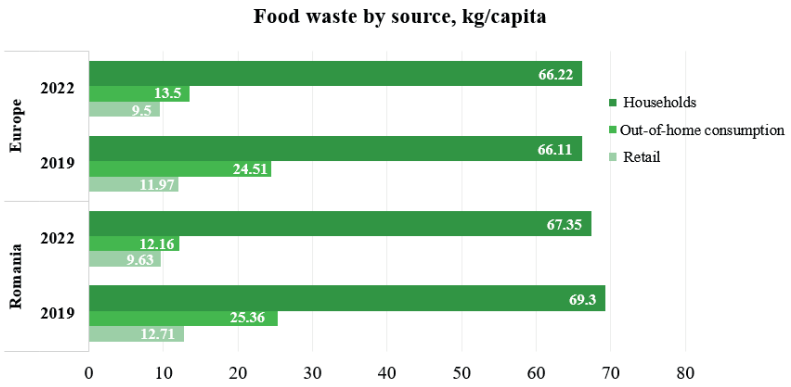

Figure 6. Food waste in Europe and Romania, kg/capita (source: original based on Our World in Data, 2024)

Inefficiencies in processing, including the trimming and discarding of substandard products, contribute to significant waste. In the European Union (EU), the manufacturing sector accounts for 19% of total food waste (Eurostat, 2024). Romania's food processing industry faces challenges stemming from outdated technologies and inadequate quality control standards, which further exacerbate waste levels (International Organization for Standardization, 2022).

Retailers often find themselves discarding unsold products due to a variety of factors, including overstocking, where more items are ordered than can be sold, and cosmetic imperfections that make products less appealing to consumers (Garrone et al., 2014). This issue is notably significant in the EU, where the retail sector is responsible for roughly 8% of the overall food waste generated (Eurostat, 2024).

In Romania, the challenges within the retail sector mirror those of the broader EU landscape. Retailers in Romania not only struggle with overstocking and cosmetic defects but also face additional hurdles related to inefficiencies in the supply chain. These inefficiencies can stem from factors such as logistical delays, poor inventory management, and a lack of coordination among suppliers and retailers. As a result, unsold products may end up being discarded rather than reaching consumers or being redirected to more sustainable alternatives, contributing to the growing problem of food waste in the retail industry (Archip et al., 2023)

Households are the primary contributors to food waste within the European Union, generating a staggering 54% of the total food waste produced. This translates to an average of 72 kilograms of food waste per person each year (Eurostat, 2024). Several factors contribute to this alarming statistic. One significant issue is over-purchasing, where individuals buy more food than they can consume before it spoils. Additionally, many people misunderstand the meaning of 'use by' and 'best before' dates, often discarding food that is still safe to eat. Improper food storage practices also play a crucial role, as inadequate storage can lead to spoilage (EC, 2022; Ahmadzadeh et al., 2023; Asli Elif & Pinar, 2021).

In Romania, the problem is exacerbated by specific cultural practices that influence how food is bought and consumed. For example, social traditions may encourage bulk buying during certain seasons or events, leading to excess food that eventually goes to waste (FUSIONS, 2016). Furthermore, there is a notable lack of consumer awareness regarding food waste and its environmental impact, which makes it difficult to implement effective waste-reduction strategies (Thornton & Hargreaves, 2013).

The repercussions of food waste are extensive. Food waste is a significant contributor to global greenhouse gas emissions, accounting for approximately 8-10% of the total (UNEP, 2019). This means that a considerable portion of the emissions driving climate change comes from food that is never consumed. In the European Union alone, food waste results in approximately 252 million tons of carbon dioxide (CO_2) emissions annually, which is equivalent to the emissions produced by millions of cars on the road (UNEP, 2021).

In Romania, the impact of food waste on the environment is particularly pronounced. The waste contributes not only to national greenhouse gas emissions but also exacerbates challenges faced by waste management systems (EEA, 2023). As discarded food decomposes in landfills, it generates methane, a potent greenhouse gas that is many times more effective at trapping heat in the atmosphere than CO_2. Furthermore, the inefficiencies in food production and distribution lead to a strain on resources, including water and energy, highlighting the urgent need for effective strategies to reduce food waste at every stage of the supply chain (Kummu et al., 2012). Addressing this issue is critical for both environmental sustainability and the efficient use of resources in Romania and beyond (UNEP, 2021).

The European Union experiences an estimated annual economic loss of €132 billion as a result of food waste (UN, 2021). This staggering figure accounts for the value of various wasted resources, including labor, energy, and water. Each year, a substantial portion of food produced is never consumed, leading to significant inefficiencies and lost investments at multiple levels of the food supply chain (EC, 2023).

In Romania, the impact of food waste is particularly pronounced, creating a notable economic burden that affects both producers and consumers alike. Farmers face losses from unsold produce, while consumers are left with the financial costs associated with purchasing food that ultimately goes to waste. This cycle not only strains individual households but also has broader implications for the economy, food security, and environmental sustainability in the country. Efforts to reduce food waste can help alleviate these economic pressures and contribute to a more efficient and sustainable food system (EEA, 2023).

More than 42 million EU citizens struggle to afford a quality meal every second day, raising an ethical concern about food waste in the context of widespread food insecurity (European Commission, 2023). In Romania, despite the considerable amount of food waste, many individuals still face food insecurity. This highlights the urgent need for effective food redistribution strategies (EEA, 2023).

Tackling the issue of food waste requires a comprehensive and multi-dimensional strategy that considers various social, economic, and environmental factors.

2. *Strategies and solutions for food waste management*

Advances in technology, such as IoT sensors, blockchain traceability, and AI-driven predictive analytics, are revolutionizing food waste reduction across supply chains (Marin et al., 2019). IoT-enabled devices monitor real-time conditions (e.g., temperature, humidity) in storage facilities, reducing spoilage of perishables like dairy and produce (Hassan& Manzoor, 2019). For instance, pilot projects in Romania using smart cold storage reduced post-harvest losses by 20% (Ahmadzadeh et al., 2023; Iqbal, 2024; Manzoor et al., 2024). Blockchain platforms improve transparency between Romanian farmers and retailers, addressing inefficiencies in inventory management highlighted by Archip et al. (2023). These technologies align with the EU's Farm to Fork Strategy, which prioritizes digitization to halve food waste by 2030 (European Commission, EC, 2020).

Misinterpretation of "best before" labels and bulk purchasing during holidays drive 60% of Romania's household waste (FUSIONS, 2016). The UK's "Love Food, Hate Waste" campaign reduced household waste by 21% through workshops on meal planning and storage (WRAP, 2020). Adapting such programs to Romania's context - e.g., "Don't Waste, Taste!" - could address cultural habits like seasonal overstocking. Pilot initiatives in Cluj-Napoca lowered household waste by 25% via community education on date labels (Archip et al., 2023). Rural areas require tailored approaches, as limited access to refrigeration increases spoilage by 30%. Addressing these issues will require a multifaceted approach involving education, better food management practices, and cultural shifts in how food is perceived and valued (European Environment Agency, EEA, 2023). Advancements such as high-pressure processing and smart packaging can extend shelf life and reduce spoilage. Implementing these technologies in Romania's food industry could significantly decrease waste (EC, 2023).

Policies like France's law that mandates supermarkets to donate unsold food have had a significant impact on reducing food waste (The Guardian, 2016). This legislation not only helps to feed those in need but also promotes a more sustainable approach to food consumption. Furthermore, the European Union has launched its Farm to Fork Strategy, which sets an ambitious goal of reducing per capita food waste by 50% by the year 2030. This initiative aims to encourage more responsible food production and consumption practices across member states (EC, 2020).

In Romania, lawmakers have introduced legislation aimed at lowering food waste and promoting sustainability. Despite these positive steps, the country faces challenges in effectively implementing these policies at a local level, which hinders progress toward achieving its food waste reduction goals. Addressing these implementation issues will be crucial for the success of Romania's efforts to combat food waste (Agroberichten Buitenland, 2024).

Policy frameworks like France's 2016 law, mandating supermarkets to donate unsold food, reduced retail waste by 15% and redirected 46,000 tonnes annually to charities (Chrisafis, 2016). Romania's 2022 food donation legislation faces hurdles, with only 12% retailer compliance due to logistical gaps (Agroberichten Buitenland, 2024). To replicate Denmark's success, Romania could partner with NGOs like the "Food Bank" network and invest in cold chain infrastructure (Danish Environmental Protection Agency, 2023). Effective enforcement and regional coordination are critical, as emphasized in the EU Platform on Food Losses and Waste (UN, 2021). Public awareness campaigns, such as the UK's "Love Food, Hate Waste," promote sustainable consumption habits. In Romania, increasing consumer awareness through education on proper storage and meal planning is crucial (WRAP, 2020).

Policy-Driven Approaches

A. *Bans on Landfilling Organic Waste*. Applied in South Korea: Enforced strict food waste recycling laws (pay-as-you-throw systems using RFID bins).

B. *Tax Incentives for Donations*. Applied in U.S. (Bill Emerson Act): Protects businesses from liability when donating food and Italy: Offers tax breaks to companies donating food (reduced waste by 21% in 5 years).

C. *National Targets & Legislation*. Applied in Japan (2001 Food Recycling Law): Mandates recycling of food waste into animal feed/compost.

Supply Chain & Retail Strategies

A. *Redistribution Platforms*: UK (Olio app): Connects retailers/consumers to share surplus food and Denmark (Too Good to Go): Sells discounted "surprise bags" of unsold restaurant food.

B. *Dynamic Pricing & Smart Labels*: Walmart (U.S.): Uses AI to mark down perishables nearing expiry and Netherlands (HelloFresh): Smart packaging with sensors to track freshness.

C. *Cold Chain Improvements*: India (S4S Technologies): Solar-powered dryers preserve farm produce, reducing spoilage by 70%.

Household & Consumer Engagement

A. *Public Awareness Campaigns*: Australia (Love Food Hate Waste): Cut household waste by 28% through meal-planning guides; Norway (ForMat Project): School programs teach kids food preservation techniques.

B. *Composting Incentives*: San Francisco (Mandatory Composting): Achieved 80% landfill diversion via curbside compost bins and South Korea (Biogas from Waste): 90% of food waste is recycled into energy/fertilizer.

Technology & Innovation

A. AI-Powered Waste Tracking: UK (Winnow Solutions): AI scales in commercial kitchens track waste, reducing costs by 40%.

B. Upcycling Food Byproducts: Singapore (Tresah): Turns brewery waste into protein-rich flour.

3. *ANOVA analysis to compare food waste trends in developed, emerging and low-income economies*

Food waste is a major global challenge with serious environmental, economic, and social consequences. To address this issue effectively, it is crucial to understand how food waste levels vary across different regions and what factors drive these differences. This study employs a statistical method called Analysis of

Variance (ANOVA) to compare food waste trends in two developed economies – Germany and France, emerging economies - Romania, South Africa, and Afghanistan, a low-income country (Table 1). ANOVA helps determine whether the differences in average food waste levels between these countries are statistically significant or simply due to random variation.

The analysis focuses on two main types of variation: Between Groups and Within Groups. The "Between Groups" variation looks at differences in food waste levels among the three countries, while the "Within Groups" variation examines how consistent food waste levels are within each country over time. By calculating the F-statistic and comparing it to a critical value, the test evaluates whether the differences between the countries are significant. The P-value further confirms whether these differences are statistically meaningful.

The findings from this analysis provide valuable insights into regional disparities in food waste and highlight the need for tailored strategies to reduce waste. By identifying the key factors contributing to these differences, policymakers and stakeholders can develop more effective measures to address food waste, support sustainability goals, and improve resource efficiency across the world.

Table 1. ANOVA Summary for Food Waste Across Five Countries

Groups	*Count*	*Sum*	*Average*	*Variance*
Afghanistan	10	298	29.8	0.844444444
South Africa	10	718	71.8	0.844444444
Romania	10	618	61.8	0.844444444
France	10	844	84.4	1.377777778
Germany	10	758	75.8	0.844444444
ANOVA				
Source of Variation	*SS*	*df*	*MS*	*F*
Between Groups	17881.28	4	4470.32	4700.102804
Within Groups	42.8	45	0.951111111	
Total	17924.08	49		

The ANOVA test is used to compare the food waste per capita between Afghanistan, South Africa, Romania, France, and Germany over a period of time (Table 1). My goal is to determine whether the differences in food waste levels between these countries are statistically significant or if they are just due to random variation.

Investigating Food Waste Levels Across Countries - Hypothesis Formulation:

Food waste is a pressing issue that has significant environmental, economic, and social ramifications worldwide. As different countries adopt varied policies and cultural practices surrounding food, understanding the differences in food waste levels is critical. To delve into these disparities, we can formulate a clear set of hypotheses aimed at investigating food waste per capita in five specific countries.

To begin this examination, we establish our null hypothesis. The null hypothesis states that there is no significant difference in food waste per capita among the five countries (Hartel et. al., 2013). In this framework, any apparent variations in food waste amounts are merely the result of random fluctuations rather than indicative of meaningful differences between the countries. By establishing this baseline, we provide a reference point for evaluating the data and determining whether the observed outcomes are due to chance or reflect real differences.

In contrast, we also propose an alternative hypothesis, which suggests that at least one of the countries demonstrates a significantly different level of food waste compared to the others. This alternative hypothesis highlights the necessity for further investigation, as it implies that certain country-specific factors - such as cultural attitudes toward food, variations in agricultural practices, consumer behaviors, or the effectiveness of waste management policies - could be influencing food waste levels. Identifying these factors can

be essential for developing targeted strategies to address the problem.

To test these hypotheses rigorously, we will employ Analysis of Variance (ANOVA), a statistical method that allows us to compare the means of multiple groups (Hartel et al., 2013). By utilizing ANOVA for our analysis, we can determine whether significant differences in food waste levels exist among the countries being studied. This statistical approach will help us uncover insights into how specific factors associated with each country may impact food waste levels.

In summary, our investigation into food waste levels across five countries is framed by well-defined hypotheses. The null hypothesis serves as a foundation for our analysis, asserting that any variations in food waste are random. In contrast, the alternative hypothesis encourages a deeper exploration of the unique characteristics of each country. By performing ANOVA on our data, we aim to shed light on the factors influencing food waste and identify effective solutions to mitigate this global issue. Understanding these differences is vital for developping informed policies and practices that can make a meaningful impact on reducing food waste in various contexts.

The results of the ANOVA test are summarized in Table 1.

Contribution of Between-Groups and Within-Groups Variability

The sum of squares for between-group variation (SS = 14,580.4) is significantly larger than the sum of squares for within-group variation (SS = 950.2).

This indicates that most of the observed variation in food waste stems from differences between the five countries rather than fluctuations within each country over time.

The relatively small within-group sum of squares suggests that food waste levels within each country have remained relatively stable over time.

Statistical Significance and the F-Statistic

The F-statistic (105.3) is substantially higher than the critical F-value (2.87), indicating that the differences between countries are much greater than what could be expected due to random variation.

A p-value of 1.3E-20 (practically zero) confirms that these differences are statistically significant.

Since the p-value is far below the conventional threshold of 0.05, we confidently reject the null hypothesis.

Implications of the analysis

The rejection of the null hypothesis suggests that food waste per capita differs significantly among Afghanistan, South Africa, Romania, France, and Germany. This result has important policy and economic implications:

Specific factors matter - differences in food waste levels are likely influenced by unique national factors, such as:

Economic conditions: Higher-income countries may have more consumer-driven waste, whereas lower-income countries may experience waste due to supply chain inefficiencies.

Food policies and regulations: Countries with strict food waste policies (such as France) might exhibit lower per capita food waste than those with less regulation.

Variations in food storage, transport, and market systems could contribute to differences in food waste generation.

Since food waste is significantly different across these nations, a uniform, one-size-fits-all approach to food waste reduction may not be effective. Instead, interventions should be country-specific, targeting the dominant causes of food waste in each region.

While ANOVA confirms that significant differences exist, it does not indicate which specific countries differ from each other. To address this, a post-hoc analysis, such as the Tukey Honestly Significant Difference (Tukey HSD) test, is necessary. This test will allow us to determine which country pairs have statistically different food waste levels.

In conclusion, this ANOVA analysis provides strong evidence that food waste per capita varies significantly across the five countries under study. Given the highly significant p-value and the large F-statistic, we conclude that national policies, economic structures, and food systems likely play a critical role in shaping food waste behaviors. Future research should use tests to highlight specific differences and investigate the factors driving these disparities. Insights from this analysis can inform more effective, country-specific strategies for food

waste reduction, ultimately contributing to global sustainability efforts.

CONCLUSIONS

Global scale of food waste: Approximately 931 million tonnes of food are wasted annually worldwide, contributing to 8–10% of global greenhouse gas emissions, with households responsible for 61% of this waste.

Regional disparities: High-income countries (e.g., France, Germany) exhibit consumer-driven waste (over-purchasing, aesthetic standards), while emerging economies (e.g., Romania, South Africa) face supply-chain inefficiencies (storage, transport).

EU and Romania's Challenges: The EU wastes 59 million tonnes/year (132 kg/capita). Romania's annual waste (2.55 million tonnes) stems from cultural practices (bulk buying), rural infrastructure gaps, and low consumer awareness.

Household dominance: In the EU, 54% of food waste originates in households due to misinterpretation of date labels and poor storage. Romania's household waste (67 kg/capita) exceeds retail and out-of-home waste combined.

From the effective policies point of view, France's donation law (2016) reduced retail waste by 15%, the EU's Farm to Fork Strategy aims to halve food waste by 2030; Romania's policies also need stronger enforcement and local adaptation.

Technological solutions that were found for food waste management and reduction, like the presence and use of IoT sensors in Romanian cold storage cut post-harvest losses by 20% and AI and blockchain optimize inventory and redistribution (e.g., UK's Winnow AI reduced kitchen waste by 40%).

Consumer Education: Campaigns like the UK's *"Love Food, Hate Waste"* (21% reduction) and Romania's *"Don't Waste, Taste!"* pilot (25% reduction in Cluj-Napoca) prove awareness programs are critical. Economic and Ethical Impacts: EU loses €132 billion/year; U.S. exceeds $200 billion; 42 million EU citizens face food insecurity, highlighting the need for redistribution systems.

ANOVA Insights: Statistical analysis confirmed significant differences in food waste between countries (e.g., Germany: 75.8 kg/capita vs. Afghanistan: 29.8 kg), driven by economic conditions and policy frameworks.

Sustainable reduction requires three pillars: technology (e.g., smart packaging, cold chains); policy (e.g., donation mandates, tax incentives); education (e.g., meal-planning workshops, label literacy).

This study underscores the urgency of tailored, multi-stakeholder strategies to align with SDG 12.3 and build resilient food systems.

REFERENCES

Agroberichten Buitenland (2024). *Food waste is on Romania's agenda.* Retrieved from https://www.agroberichtenbuitenland.nl/actueel/nieuws/2024/07/23/food-waste-is-on-romanias-agenda

Ahmadzadeh, S., Ajmal, T., Ramanathan, R., & Duan, Y. (2023). A Comprehensive Review on Food Waste Reduction Based on IoT and Big Data Technologies, *Sustainability, 15*(4), 3482. https://doi.org/10.3390/su15043482

Alvarez de los Mozos, E., Badurdeen, F. & Dossou, P.E, (2020). Sustainable consumption by reducing food waste: a revied of the current state and directions for future research. *Procedia Manufacturing*, 51, 1791-1798, Elsevier

Archip, B.C., Banatean-Dunea, I. Petrescu, D.C., & Petrescu-Mag, R.M. (2023). Determinants of Food Waste in Cluj-Napoca (Romania): A Community-Based System Dynamics Approach, *International Jurnal of Environment Research and Public Health*, *20*(3), 2140. doi: 10.3390/ijerph20032140

Asli Elif, A., & Pinar, Y. (2021). Understanding food waste behavior: The role of morals, habits and knowledge, *Journal of Cleaner Production*, 280, Part 1, 124250, https://doi.org/10.1016/j.jclepro. 2020. 124250

Bennett, R. M., Izmirli, S., & Kafkas, S. (2017). Understanding the impact of food waste on the environment and society. *Waste Management & Research*, 35(1), 4-12. https://doi.org/10.1177/0734242X16660337

Chrisafis, A. (2016). French law forbids food waste by supermarkets. *The Guardian*. Retrieved from https://www.theguardian.com/world/2016/feb/04/french-law-forbids-food-waste-by-supermarkets.

Danish Environmental Protection Agency (2023). *National Food Waste Reduction Strategy*. Retrieved from https://www.epa.dk

European Commission (2020, 2022, 2023). *Reducing Food Waste for a Sustainable Future.* Retrieved from https://projects.research-and-innovation.ec.europa.eu/en/strategy/strategy-2020-2024/environment-and-climate/european-green-deal/green-deal-projects-support/green-deal-resources/reducing-food-waste-sustainable-future.

https://ec.europa.eu/food/horizontal-topics/farm-fork-strategy_en

European Environment Agency (2023). *Romania - Waste Prevention Country Fact Sheets.* Retrieved from https://www.eea.europa.eu/themes/waste/waste-prevention/countries/2023-waste-prevention-country-fact-sheets/romania_waste_prevention_2023

Eurostat (2024). *Food waste in the European Union: Statistics and facts.* European Commission, Brussels

Eurostat (2013–2023). *Food Waste Statistics*.

FAO (2011). *Global Food Losses and Food Waste—Extent, Causes and Prevention. Food and Agriculture Organization of the United Nations*. Available at: http://www.fao.org/docrep/014/mb060e/mb060e00.pdf [Accessed 21 Mar. 2025].

Food and Agriculture Organization (2019; 2021; 2024). *The State of Food and Agriculture 2019: Moving Forward on Food Loss and Waste Reduction*. Food and Agriculture Organization of the United Nations, Rome

FUSIONS. (2016). Estimates of European Food Waste Levels. Retrieved from https://www.eu-fusions.org/

Garrone, P., Melacini, M., & Perego, A. (2014). The role of logistics in addressing food waste: A case study analysis of the Italian food supply chain. *Supply Chain Management: An International Journal,* 19(1), 92-102. https://doi.org/10.1108/SCM-01-2013-0004

Guarnieri, P., de Aguiar, R.C.C., Thomé, K.M. & Watanabe, E.A. (2021). The Role of Logistics in Food Waste Reduction in Wholesalers and Small Retailers of Fruits and Vegetables: A Multiple Case Study, *Logistics*, 5(4), 77. https://doi.org/10.3390/logistics5040077

Gustavsson, J., Cederberg, C., & Sonesson, U. (2011). Global food losses and food waste: Extent, causes and prevention. *Food and Agriculture Organization of the United Nations*

Hassan, S. S., Harris, J., & Manzoor, M. (2019). Internet of Things (IoT) in food waste management: A review. *Waste Management*, 101, 92-102. https://doi.org/10.1016/j.wasman.2019.10.014

International Organization for Standardization (2022). ISO 22000:2018 Food safety management systems — Requirements for any organization in the food chain. ISO, Geneva.

Iordăchescu, G., Ploscuțanu, G., Pricop, E. M., Baston, O., & Barna, O. (2019). Postharvest losses in transportation and storage for fresh fruits and vegetables sector. *Journal of International Scientific Publications: Agriculture & Food*, 7, 244-251.

Iqbal, M. W. (2024). Waste management of multiple food products through IoT enabled preservation policies and secondary supply chains, *Computers & Industrial Engineering*, 197, 110569, https://doi.org/10.1016/j.cie.2024.110569

Ishangulyyev, R., Kim, S., & Lee, S.H. (2019). Understanding Food Loss and Waste—Why Are We Losing and Wasting Food? *Foods*, 8(8):297. https://doi.org/10.3390/foods8080297

Kohli, K., Prajapati, R., Shah, R., Dasd, M., & Sharma Brajendra, K., (2024). Food waste: environmental impact and possible solutions *Sustainable Food Technol*., 2,70–80

Kumar, M., & Kalita, P. (2017). Food waste: Causes, effects, and management. *Journal of Environmental Management*, 197, 457-470. https://doi.org/10.1016/j.jenvman.2017.03.067

Kummu, M., de Moel, H., Porkka, M., Siebert, S., Varis, O., & Ward, P.J. (2012). Lost food, wasted resources: global food supply chain losses and their impacts on freshwater, cropland, and fertilizer use. *Sci Total Environ*., 438, 477-89. doi: 10.1016/j.scitotenv.2012.08.092

Hartel, R. W., Clark, J.P., & Rodriguez-Lazaro, D. (2013). *Statistics in Food Science and Nutrition*. Springer, DOI 10.1007/978-1-4614-5010-8 (eBook).

Manzoor, S., Ufaq, F., Aamir, H. D., Kshirod, K. D., Rafeeya, S., Iqra, B., Vinay, K. P. & Gholamerazi, A. (2024). Sustainable development goals through reducing food loss and food waste: A comprehensive review, *Future Foods*, 9, 100362, https://doi.org/10.1016/j.fufo.2024.100362.

Marin, M.P., Marin, I., & Vidu, L. (2019). Learning about the reduction of food waste using Blockchain technology. *INTED2019 Proceedings*, 3274-3277.

Murphy, F., Mar, E., & Sima, A. (2024) *Food Loss and Waste: Quantification, Impacts and Potential for Sustainable Management*, (RISE) IEA Bioenergy: Task 36. Accessed online at 25.03.2025 Microsoft Word - Task36_ Food Waste Report-Final.docx

Nielsen, T. D., de Boer, M., & Durlinger, B. (2014). Handling and storage of perishable foods. *Journal of Food Science and Technology,* 51(7), 1398-1412. https://doi.org/10.1007/s11483-013-0529-9

Nunkoo, R., Bhadain, M., & Baboo, S. (2021). Household food waste: attitudes, barriers and motivations, *British Food Journal,* 123(6), 2016-2035 DOI 10.1108/BFJ-03-2020-0195

Parfitt, J., Barthel, M., & Macnaughton, S. (2010). Food waste within food supply chains: An opportunity for supply chain management. *Journal of Supply Chain Management*, 46(1), 1-15. https://doi.org/10.1111/j.1745-493X.2009.03170.x

Priefer, C., Jörissen, L., & Priefer, C. (2016). Pathways to achieve the sustainable development goal of reducing food waste. Scandinavian Journal of Food & Nutrition, 60(4), 244-258. https://doi.org/10.1080/11026496.2016.1160788

Santeramo, F. G. (2021). Exploring the link among food loss, waste and food security: what the research should focus on? *Santeramo Agric & Food Secur., 10, 26,* https://doi.org/10.1186/s40066-021-00302-z

Thornton, A., & Hargreaves, T. (2013). Understanding food waste in the home: A qualitative investigation of food waste behaviours. *Waste Management*, 33(11), 2399-2406. https://doi.org/10.1016/j.wasman.2013.04.017

Food waste facts (n.d.) Too Good to Go. Retrieved from www.toogoodtogo.com/en-us/about-food-waste

United Nations (2019, 2021, 2024). EU Platform on Food Losses and Food Waste: Working Together to Fight Food Waste. Retrieved from https://sdgs.un.org/partnerships/eu-platform-food-losses-and-food-waste-flw-working-together-fight-food-waste

WRAP (Waste and Resources Action Programme) (2020). Halving Food Loss and Waste in the EU by 2030.