Addressing Food Waste in the retail sector

EU policies, challenges and future research opportunities

One of the biggest inefficiencies of the agri-food chain is food waste, a concerning, fast-growing phenomenon whose very existence seriously challenges planetary boundaries. While having taken the back seat in policies and research, addressing retail sector holds great potential for reducing food waste in the entire supply chain The present brief discusses current food waste externalities and how to internalise them with retailers as key players. Finally, it outlines the limitations of the proposed practices and presents recommendations on what areas should be targeted to combat food waste for further research funding.

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Authors:
Elena Marchetti,
Chiara Antonelli,
Federico Sgarbi

The agri-food chain is key to reaching most of the UN Sustainable Development Goals. Yet, it unveils one of its biggest inefficiencies: food waste. One-third of all globally produced food is wasted, which translates into 1.3 billion tonnes of wasted resources per year. As a result, food waste accounts for 8% of greenhouse gas (GHG) emissions produced by humankind, making it comparable to road transport pollution (Lee, 2022). As such, it contributes to the depletion of limited natural resources on which the food system depends, such as land, water and biodiversity, and along the food supply chain. Food waste is also driven by food loss, which generally refers to decreases in food mass across the edible food supply chain (Barrett et al., 2013) As a cause of negative economic, environmental and social effects, food waste is considered to be one of the sustainability issues that needs to be addressed. Its externalities are not only environmental but also

economic and social: economic and social costs generated by food waste are estimated to amount respectively to 1 trillion USD and 900 billion USD per year (FAO, 2014). Therefore, it is necessary to internalise and mitigate these externalities. Although the retail sector is not among the largest contributors to food waste, it holds great potential for reducing food waste in the entire supply chain, since 13% of global food waste is generated in the retail stage (UNEP, 2021). Given its market structure, there are few and very large retailers which grants them considerable market power with both producers and consumers and the possibility to leverage change. Analysing food management, increasing the value of food and raising the cost of food waste are some powerful strategies towards new food systems and related innovative trends, and will be reviewed in the brief.

Defining and understanding food waste

The definition of food waste remains a topic of ongoing debate within the scientific community, lacking unanimous consensus (Boda, 2017). The debate regards whether the notion should include solely edible food or if it should extend to all discarded food throughout the supply chain.

The California Department of Resources Recycling and Recovery (CalRecycle)'s definition of food waste incorporates both damaged edible food intended for human consumption and inedible food material (Food and Agriculture Organization, herein after FAO, 2014). FAO defines food waste as edible food material suitable for human consumption that is damaged or lost (ibid). Stuart (2009) broadens this definition by encompassing, aside from edible food for human consumption, edible food meant for humans that is used for animal feed and food processing by-products (Stuart, 2009). Another food waste definition introduces over-nutrition, namely the disparity between the energy value of food consumed per capita and the actual energy value needed per capita (Parfitt, Barthel, & Macnaughton, 2010). The present policy brief applies the FAO's definition of food waste: food originally intended for human consumption but ultimately discarded.

Food waste takes place in the final stages of the supply chain, namely in the distribution, retail, sale and final consumption. Food waste should be distinguished from food loss. The latter refers to the decrease in food quality and quantity along the first phases of the supply chain, i.e. through the production, post-harvest, and processing stages (Cattaneo, Sánchez, Torero, & Vos, 2020). Consequently, food loss can be identified as discarded food that is not suitable for human consumption. While a certain level of food loss is somewhat unavoidable, being the result of process-based factors, food waste stems from decision-based factors (Uzea, Gooch, & Sparling, 2013).

Table 1. Stages of food wastage. Elaboration based on Wong et al., 2021.

Stage	Definition	Example
Production	Food losses during harvesting	Edible commodities not harvested or spilt during harvesting; food losses occurred due to mechanical damage
Storage	Food losses occurring during transport and storage	Presence of pathogens and pests, poor transport infrastructure
Process and packaging	Losses in product evaluation, processing and packaging	Contamination; inadequate packaging technologies
Distribution	Food losses at distribution level, in wholesale and retail markets	Poor storage infrastructure in transportation, overproduction due to error in demand forecast; product returns for damaged products; poor handling in markets
Consumption	Food losses occurring downstream, at the household level	Overpurchasing; spoilage during storage; exceed best by/before date

In the EU, households throw away 570 million tonnes of food per year, equating to 131 kg of food waste per capita (Fleck, 2024). Indeed, food production comprises high carbon-intensive activities and releases large amounts of methane when decomposing in landfills (Lee, 2022).

While the FAO's definition is globally acknowledged as the most comprehensive and referenced, no official EU document or communication provides a clear definition at the EU level (European Court of Auditors, hereinafter ECA, 2016). However, it is possible to retrieve a definition from the framework employed by Eurostat in collecting data for food waste, which is denoted as any "parts of food intended to be ingested (edible food) and parts of food not intended to be ingested (inedible food)" (Eurostat, 2023). This definition is aligned with the one provided by FUSIONS (Food Use for Social Innovation by Optimising Waste Prevention Strategies)[1], which qualifies food waste as "any food, and inedible parts of food, removed from the food supply chain to be recovered or disposed" (FUSIONS, 2016, p. 1). Thus, the metrics collected by Eurostat comprise a wider scope compared to those of the FAO, as besides edible food they cover inedible food as well.

Most food waste occurs at the household level, with 53% of food waste in Europe generated at this stage (Eurostat, 2023). It is estimated that in the EU alone in 2020 households generated

[1] FUSIONS is a project on the transition to a more resource efficient Europe launched by the European Commission. It ran from August 2012 to July 2016 (FUSIONS, n.d.)

31 million tonnes of food waste, equivalent to a market value of approximately 70 billion euro (ibid). Furthermore, food waste represents the critical issue of resource allocation: while 10% of the food produced in the EU is thrown away, about 7% of the people living in the EU cannot afford a high-quality meal (Seberini, 2020).

Box 1: Household composition and food waste

Some studies have investigated household compositions that are more likely to generate large streams of food waste (Waste and Resource Action Program, hereinafter WRAP, 2009; Parfitt, Barthel, & Macnaughton, 2010). Single-person households produce more food waste per capita than multi-person households. Moreover, households with children are more likely to waste food compared to households without children. Age is also an influencing factor, as younger people produce more food waste than the elderly, with retired people generating the least (Hamilton, 2005). A study from WRAP in 2007 identifies young professionals between 19-34 years old working full-time and young families between 25-45 years old as the households producing most food waste (Brook Lyndhurst, 2007). Furthermore, high-income households waste more food than low-income ones (ibid).

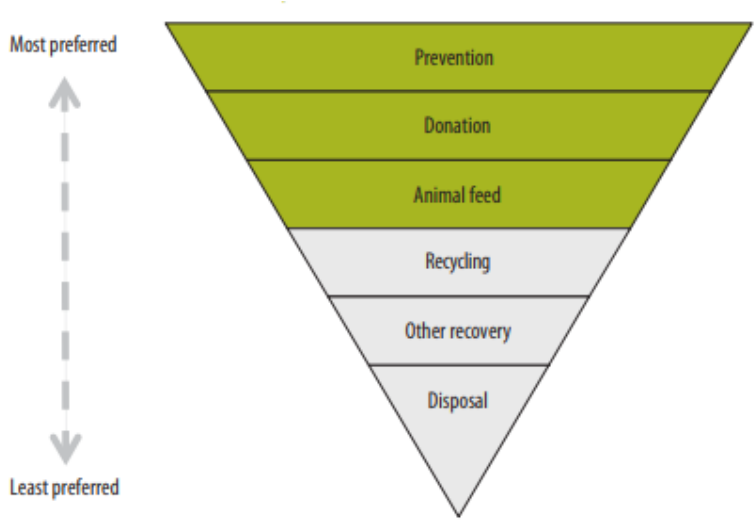
Food waste reduction is a key feature of a sustainable food production system that could feed 10.2 billion people within the planetary boundaries of biosphere integrity, land-system change, freshwater use and nitrogen flows (Gerten, et al., 2020). To avoid exceeding these planetary boundaries, the current food system can feed only 3.4 billion people, posing a trade-off between environmental quality and food security. On the contrary, sustainable agricultural practices based on reducing food waste as well as dietary shifts, better water management and redistribution of cropland, would manage to feed 10.2 billion people within planetary boundaries (ibid).

Aside from households, most of the food waste occurs in the retail sector and food services, i.e. out-of-home waste which encompasses bars, supermarkets, events, mass-catering and all sorts of food services (Candeal, et al., 2023). Globally, 17% of food production is discarded at the retail, food service and consumer stages (UNEP, 2021). This data reinforces the evidence from the same study from UNEP in 2021, which reported that 13% of global food wasted in 2019 was generated in the retail sector (UNEP, 2021). As such, retailers play a significant role in food waste mitigation, especially in Western economies. The European food system resembles an hourglass: the upper part represents producers and manufacturers while the lower part represents consumers. The narrow middle part constitutes the retail sector, characterised by a high level of market concentration, that controls the flow of food items from producers to consumers. Therefore, large retailers hold substantial market power, allowing them to foster changes in the food system from upstream to producers and consumers (Adam, 2015; Zhang et al., 2022).

Reducing Food Waste in the EU: Policies and Strategies

The EU has not established a specific food waste hierarchy, nor it has provided guidelines on its application (ECA, 2016). Nevertheless, a framework can be retrieved from the general waste hierarchy outlined in the Waste Framework Directive. Article 4 of Directive 2008/98/EC delineates the waste hierarchy, classifying waste management actions from most to least desirable according to their environmental impact. Wageningen University has adapted it to food waste, as illustrated in Figure 1.

Figure 1: Food waste hierarchy. Source: Storup et al., 2016



In September 2015, the EU committed itself to meeting the Sustainable Development Goal (SDG) Target 12.3 to halve food waste at the **consumer and retail level** by 2030 (Zero Waste Europe, 2024). To achieve such a target, the EU has embraced several policies and strategies. In May 2020, the EU adopted the Farm to Fork Strategy as a part of the European Green Deal to enhance the transition towards a sustainable food system. Food waste reduction is a key part of the strategy, with binding food waste targets for MS as one of its objectives (European Commission, n.d.). The strategy encompasses several targets, among which is the reduction of food waste by 50% by 2030 (ibid). Aside from the Farm to Fork Strategy, food waste is a relevant topic to other policies contributing to the European Green Deal, including the biodiversity strategy, which addresses society's resilience to food insecurity, the bioeconomy strategy, which aims to ensure food and nutrition security, the circular economy action plan, the common agriculture policy, the common fisheries policy and the internal market and tax policy. Food waste is, therefore, a recurring and extremely relevant issue in European policies and has been identified as one of the eleven pathways towards a sustainable, healthy and inclusive food

system in the Food 2030 2.0 policy framework. Additionally, food waste is linked to other funding programmes under Horizon Europe, amongst them Circular Bio-Based Europe and EIT Food (Directorate-General for Research and Innovation, 2023).

In the last decade, the Commission has released several documents providing guidelines and targets to combat food waste. In September 2011, it published the Roadmap to a Resource Efficient Europe, outlining guidelines on how to limit food waste. In December 2015, it implemented a Circular Economy Package, containing legislative proposals on food waste (ECA, 2016). However, the European Parliament's expectations were not met, as it persistently asked the Commission (in 2011, 2012, 2015 and 2016) to take further action in addressing food waste (ibid). In July 2023, the Commission advanced a revision of the Waste Framework Directive, proposing legally binding food waste reduction targets: MS are requested to reduce food waste by 10% and 30% respectively in processing and manufacturing and retail and consumption (Directorate-General for Environment, 2023). In March 2024, the European Parliament voted to raise the legally binding targets to 20% for processing and manufacturing and 40% for retailers and consumers (European Parliament, 2024, link). In June 2024, the Council adopted its position revision of the Waste Framework Directive.

Several other initiatives have been taken at the EU level to contribute to the EU fight against food waste. In 2012, the Commission introduced a Working Group on food loss and waste, composed of representatives from several DGs, including DG ENV and DG AGRI, and stakeholders of the food supply chain (ECA, 2016). In 2016 the Commission introduced the EU Platform on Food Losses and Food Waste, a multi-stakeholder platform providing support to all actors involved "in defining measures needed to prevent food waste; sharing best practice; and evaluating progress" (European Commission, n.d.). In 2021, it introduced the EU Food Loss and Waste Prevention Hub, a website offering the sharing of best practices and solutions among stakeholders to reduce food waste (Directorate-General for Environment, 2023). It then launched the RestwithEU project, the EU's pilot project that recommends digital and resilient tools for food waste reduction to SMEs in the restaurant industry (ibid). Furthermore, under the Single Market Programme[2], in collaboration with the European Health and Digital Executive Agency, the Commission offers grants to MS and relevant stakeholders to assist them in food waste assessment (ibid).

[2] The Single Market Programme is an EU funding programme to assist the single market that was established with the COVID-19 pandemic.

The hidden costs of food waste: environmental, economic and social impacts in the retail sector

Food waste externalities can be categorised in terms of economic, environmental and social costs. The **economic costs** encompass the value of the wasted food items, their production, transportation, storage and treatment costs (ECA, 2016). **Environmental costs** refer to the damage and degradation of natural resources and the environment resulting from food waste throughout its production and disposal cycles. The decomposition of food waste notably releases a large quantity of methane into the atmosphere (Seberini, 2020). **Social costs** stem from poor resource allocation associated with food waste (ibid).

Collecting quantitative data on food waste is significantly challenging due to the difficulties of assigning a monetary value to environmental impacts, leading to a lack of reliability (ECA, 2016). Various studies have tried to quantify food waste globally, including a full-cost accounting (FCA) of food wastage footprint conducted by the FAO (FAO, 2014). The FCA findings estimated an economic cost equivalent to 1 trillion USD per year, an environmental cost of 700 USD billion USD and a social cost of 900 billion USD per year (ibid). Water scarcity and soil erosion alone caused by food wastage are estimated to generate respectively a cost of USD 164 billion and USD 35 billion annually.

Food waste translates into an inefficient market with foregone benefits and increased prices for all the supply chain actors. Retailers experience lost savings and reduced profitability (Kor, Prabhu, & Esposito, 2017). The main practices contributing to food waste in the retail sector are "**inappropriate quality control, overstocking and inaccurate forecasting**" (Buisman, Haijema, & Bloemhof-Ruwaard, 2019, p. 274). A qualitative analysis by Teller et al. in 2018 provides a ranked list of eleven root causes of food waste in the retail sector. The primary root cause is the limited predictability of consumer demand, followed by poor management by the personnel (Teller, Holweg, Reiner, & Kotzab, 2018).

- **Oversupply/overstocking**. Retailers are used to filling their shelves as much as possible to meet consumers' preferences which results in an over-supply and over-stock of food. Several studies revealed that retailers are incentivised to over-order food items, as half-empty shelves are normally associated with poor management and do not meet the preferences of consumers, who prefer fully stocked shelves (Zhang, Wedel, & Bloem, 2022).
- **Inappropriate quality control.** Additionally, retailers tend to discard perishable food that does not meet certain high cosmetic standards. To align with consumer preferences and to offer them the freshest products available, retailers engage in the common practice of the 'rule of one-third'. Such a rule consists of keeping in-store processed

food within one-third of its shelf life[3], thus well before its actual expiration date. Consequently, a significant number of supermarkets return to the producers those items that have exceeded one-third of their shelf life, increasing the numbers of food waste at the retail level (Adam, 2015).

- **Inaccurate forecasting**. Retailers typically order more food than required to compensate for expected food damage and losses during transport and storage. This practice leads to excess food orders that remain unsold. Moreover, a larger amount of waste implies greater waste treatment costs, preventing retailers from potential savings to invest in something else. Accordingly, food waste can cost retailers approximately 4% of their sales (Sarma, 2023). The food category with the highest waste rate in the retail sector is perishable food, which approximately accounts for 50% of sales in grocery stores (ibid). As a matter of fact, between 5 and 7% of perishables are estimated to be thrown away (ibid). An analysis of Swedish retail stores revealed that 3% of fruit and vegetables are pre-store rejected, which means that a good portion of the perishables category is thrown away before it is even offered for sale to consumers (Eriksson, Strid, & Hansson, 2012). The study identifies the practice of reclaiming significant volumes of delivered products by retailers to suppliers as the primary cause of food waste in grocery stores (ibid). It suggests limiting the number of possible reclamations and enhancing the controls by the suppliers over the quality of such reclamations (ibid).
- **Incentives for overpurchase.** The retail sector contributes to household waste by incentivising over-purchasing practices with certain marketing strategies. Moreover, date labels cause confusion among consumers. Very often consumers do not distinguish 'best-by' labels from 'use-by' labels, thereby avoiding the purchase of food items close to the date indicated in the 'best-by' label or throwing them away after that date, even though the products are still technically fit for human consumption (Adam, 2015).

Mitigating food waste: Economic instruments to address food waste

The design of policies tackling external costs is identified in the Food 2030 2.0 framework among the research and innovation needs to mitigate food waste[4]. There is a growing body of literature on market-based measures at the national, city and municipal levels to internalise

[3] Shelf life is the time between production and use-by date

[4] See Pathway 5 of "Food 2030 Research and Innovation – Pathways for Action 2.0", available at https://op.europa.eu/en/publication-detail/-/publication/abbb2634-9001-11ee-8aa6-01aa75ed71a1/language-en

food waste externalities (Collinge and Oates, 1982; Katare et al., 2016; Lee and Jung, 2017; Lee, 2022).

Addressing consumers through unit-based pricing methods. The unit-based waste pricing method has been widely studied among scholars. By incorporating the 'polluter pays principle', it provides economic incentives to minimise food waste production. An analysis of the effects of a food waste tax in South Korea finds that even a very small charge ($0.06 per kg, on average $1.3 per household per month) leads to a substantial reduction in food waste (Lee, 2022). Following the implementation of the tax, households experienced on average a decrease in food waste by 20% per year, equivalent to 53 kg. Annual grocery spending was reduced by 5.5%, corresponding approximately to $172. Despite the reduced food spending, nutrition levels remained the same, suggesting that the decreased purchases were in products previously bought but not consumed (ibid). Additionally, the tax reduced GHG emissions from food waste by 145 kg of CO_2 annually per household. The effect of the tax was mostly driven by raised awareness of individuals rather than pecuniary matters. The tax was collected via a smart card system that measured the food waste levels and made the results visible to the households. Changes in household behaviour were fostered by increased attention to food waste (ibid).

Unit-based waste pricing is either community-based or household-based. The former relies on a group incentive system, where the price of the waste charge of an apartment complex is equally divided among households. The latter draws upon a form of individual incentive, with each household being charged based on the food waste's weight generated. A study by Lee and Jung (2017) compares the two systems by using two separate districts in South Korea as samples. Municipalities with an individual-based system showed a lower food waste rate compared to those with a community-based system. The individual system used Radio Frequency Identification (RFID) to electronically fee households according to their food waste's weight. However, the individual system requires a level of information that policymakers are unlikely to possess (Lee and Jung, 2017).

Addressing retailers through waste taxes. While for food waste mitigation at the household level scholars have focused on taxation as the main market incentive, for what concerns companies the types of market-incentives most analysed tend to vary. Collinge and Oates (1995) by comparing waste taxes and rental emission permits conclude that in the long run rental emission permits are more effective in reducing waste emissions, as permits' pricing is more flexible than the static price of a tax. The authors argue that a waste tax allows the marginal value of the firm's output to be equal to the marginal cost (both private and social) in the short run but does not guarantee that the total value of the firm's output is equal to the total cost in the long run. On the other hand, the emission permit system manages to satisfy both equilibrium conditions due to the non-stationarity of the waste price, which facilitates the exit and entry of firms into the market (Collinge and Oates, 1995). If we apply this conclusion to food

waste, the best way to mitigate retailers' food waste is through rental emission permits rather than taxation. By enabling the variation of food waste price, the permit system considers economic conditions and technological development and eventually adapts to them.

Adoption of Sustainable practices – the role of research and innovation. Given the hourglass-like structure of the European food system, the promotion of sustainable practices in the retail sector can facilitate further downstream and upstream changes gearing the system towards increased sustainability. The high-level concentration market of retailers grants them considerable market power, allowing them to pioneer a transition towards a more sustainable food system that generates less waste. Hence, incentivising retailers through funding and investments to undertake sustainable practices is crucial. The EU has made considerable efforts in terms of funding research and innovation in this field.

Funded EU projects on food waste

Between Horizon 2020 and Horizon Europe the European Commission has funded several projects on food waste reduction. It is estimated that EUR 170 million were funded in projects related to food waste and food loss. Horizon 2020 funded projects akin to increasing consumer awareness and enhanced collaboration among stakeholders. The first part of Horizon Europe (2021-2024) funded projects dealing with the development of measuring and monitoring methods, the identification of social norms associated with food waste, increased coordination among supply chain actors and the development of systemic innovations.
Food waste projects in **Horizon 2020** (2014 – 2020) include:
FRISCO (Food Retail Industry Supply Chain Optimization) – It created the FoodLoop platform to connect in real-time retailers and consumers, enabling the selling of products with a short remaining shelf life.
WASTE2FUNC (Lactic acid and biosurfactants sourced from sustainable agricultural and industrial (food) WASTE feedstocks as novel FUNCtional ingredients for consumer products) – It built a platform to collect waste from the food industry to convert it into biosurfactants and lactic acid.
FUSIONS (Food Use for Social Innovation by Optimising waste prevention Strategies) – It established a multi-stakeholder platform to promote shared visions and strategies to reduce food loss and waste throughout the supply-chain.
FoodRus (An Innovative Collaborative Circular Food System To Reduce Food Waste And Losses In The Agri-Food Chain) – It developed multidisciplinary innovations, including technological, social, organisational and fiscal solutions, to foster a collaborative circular food system.
Stenght2Food (Strengthening European Food Chain Sustainability by Quality and Procurement Policy)– It adopted a multi-actor approach to measuring the economic, environmental and social impacts of EU food quality schemes, public sector food procurement and short food supply chains.

SISTERS (Systemic Innovations for a SusTainable reduction of the EuRopean food wastage) - It aims to create a set of systemic innovations to reduce food waste produced along the supply chain, including a short-chain platform for farmers to sell discarded products.
Food waste projects in **Horizon Europe** (2021 – 2027) include:
BREADCRUMB (BRinging Evidence-bAseD food Chain solutions to prevent and RedUce food waste related to Marketing standards, and deliver climate and circularity co-Benefits) – It aims to provide policy guidance on food market standards based on empirical evidence.
ToNoWaste (Towards A New Zero Food Waste Mindset Based On Holistic Assessment)- It aims to build evidence-based assessment tools through a multi-stakeholder and multidisciplinary approach based on economic, environmental, social, psychological, ethical and demographic aspects.
Chorizo (Changing practices and Habits through Open, Responsible, and social Innovation towards ZerO food waste) – It aims to increase current knowledge on the role of existing social norms in food loss and waste behaviour and to develop solutions based on behavioural economics theories.
ROSETTA (Reducing food waste due to marketing standards through alternative market access)– It aims to quantify food waste resulting from marketing standards and propose suitable sustainable solutions.

There are several sustainable practices that retailers can implement to reduce food waste and which would benefit from increased support:

- **Technology and artificial intelligence tools**. The use of technology and artificial intelligence (AI) within the food supply chain has been proven to be beneficial to food waste mitigation. Retailers are utilizing and developing a variety of technological solutions to assist them in reducing food waste. Data analytical tools are being employed by retailers to improve demand forecasting. E-commerce platforms and memberships allow tracking the purchase patterns of individual customers, enabling the prediction of demand at the level of individual households (Zhang et al., 2022). Furthermore, new technological tools allow retailers to communicate in real-time with other stakeholders involved in food waste reduction programs, such as charity organizations and food banks (ibid). Other technological domains helping retailers to mitigate food waste include Radio Frequency Identification (RFID) and blockchains. The former is a peculiar type of labelling that classifies goods through radio signals and gathers information on the circulation of products. RFID improves coordination between retailers and other supply chain actors, fostering increased food waste reduction. Blockchains track every transaction within the supply chain, enhancing transparency and efficiency and permitting retailers to make informed decisions (ibid).
- **Dynamic pricing.** Dynamic pricing adjusts the price of a product according to its quality and market demand. If applied to perishable food, it enables varying its price under its decreasing quality until its expiration date, thereby meeting market demand

(Sanders, 2024). It can be highly beneficial in addressing unpredictable demand. However, grocery retailers have experienced limited adoption of dynamic pricing. The usage of temporary price promotion is widely used but happens rather infrequently (typically every one or two months) and is planned several months in advance, thus still encountering the issue of unpredictable demand (ibid). Food retailers applying dynamic pricing would experience a large reduction in their food waste. By building a counterfactual, Sanders (2024) demonstrates that, compared to optimal static pricing, dynamic pricing would decrease food waste by 20.82% and increase gross profits by 2.88%. Hence, dynamic pricing can potentially diminish food waste in the retail sector and simultaneously raise profitability (ibid).

- **Dynamic shelf life (DSL)** – also known as dynamic adjustable expiration date – reflects the variable quality of a product. The most used method to indicate the item's quality is changing the expiration date. DSL reduces food waste, as only products with low quality are discarded, resulting in a larger amount of sold products compared to fixed shelf life (FSL). As a matter of fact, FSL entails wasting also high-quality items (Buisman et al., 2019). Additionally, besides selling a larger quantity of goods, retailers due to the reduced amount of food waste also bear lower treatment wastage costs. Therefore, DSL leads to increased retailers' profits and benefits.

Implementation gaps and challenges to sustainable food waste management

The implementation of market incentives and retailer practices to mitigate food waste encounters several barriers. This brief identifies a lack of data, technological limits, illegal dumping, and stakeholders' resistance as the primary obstacles.

Lack of data. To be effective, environmental regulation requires a large collection of information that is often difficult for policy-makers to obtain, especially about the food waste weight of apartment complexes and of each household. The smart card system would facilitate such gathering of information.

The adoption of dynamic pricing, DSL, RFID technology and blockchain also requires extremely accurate information. Specifically, dynamic pricing and DSL need real-time data indicating products' specific conditions, i.e. temperature and freshness. Dynamic pricing to meet customer demand requires large amounts of data to accurately forecast market demand. E-commerce platforms would allow tracking transitions and thus modelling accurate future customer demand.

The information needed for the implementation of dynamic pricing, DSL, RFID and blockchain must be integrated with existing data systems already used by retailers, requiring data integration, especially with the inventory management system which can be rather resource-intensive. Overall, **the quantification of food waste still remains very limited, data is scarce and lacks reliability**. The problem persists not only at the retailers' level but also at the level of national and global policy-makers. Further research on food waste quantification techniques is needed, especially for the retail sector, to provide retailers with standard guidelines to be followed rendering food waste data reliable and comparable (Martin-Rios et al., 2021).

Limitations of current technologies. Dynamic pricing uses advanced sensors, advanced inventory management systems and automated pricing. Similarly, DSL also involves advanced technology. The adoption of such advanced technology requires substantial implementation costs. In addition to the initial costs for the infrastructure, development and implementation of such technologies, maintenance and upgrade costs are also required. Moreover, investment costs must also cover staff training.

Inadequate technology is especially a concern in the transport of foodstuffs, i.e. from producers and manufacturers to food retailers. Poor road infrastructure, mostly in areas close to farmers, and the lack of cold storage prevent some food products from reaching retailers in a fresh condition (World Resources Institute, 2023).

As previously mentioned, the lack of standardisation and communication protocols in data management and collection systems poses several challenges in delivering reliable and quality data on time (Ahmadzadeh, Tahmina, Ramanathan, & Yanqing, 2023). Further research into food transport infrastructure, technology solutions for rural development and protocol standardisation should not be overlooked.

Stakeholders' resistance. Environmental regulation as well as dynamic pricing, DLS and new technologies such as blockchain and RFID, entail costs that stakeholders are hardly willing to incur. Changes are always difficult to accept, especially if they are costly.

For the implementation of new technologies to be effective, coordination and involvement between all supply chain actors and consumers are required to gain their trust. Both customers and retailers themselves are likely to be sceptical about dynamic expiration dates in the beginning. Therefore, they should be consulted and informed on the benefits of the new measures. This opens up possible research pathways to evaluate new stakeholder engagement strategies and creating mechanisms and incentives to build their trust, to increase social acceptability.

Illegal dumping. The rise in monitoring and concerns about food waste incorporated in market incentives and sustainable retail practices may lead to the collateral effect of illegal dumping. In Lee and Jung's analysis on the comparison between group and individual incentives for

food waste charging, some managers of the apartment blocks using the individual RFID-based system revealed that households showed an increase in food waste illegal dumping (Lee and Jung, 2017). Indeed, food waste-reducing measures involve substantial technological investment for companies and a high cost of good behaviour for households which may trigger the undesired effect of illegal dumping.

Illegal dumping encompasses major negative consequences. First of all, it raises costs in transportation and composting sites. Besides economic costs, it also increases social costs: public health is endangered as improper food waste disposal facilitates the transmission of diseases. Additionally, it entails unhygienic surroundings, among which are disagreeable odours (Napilay, 2023).

Moreover, illegal dumping diverts food waste from appropriate composting sites to landfills. Thus, it reduces the potential of food waste as a resource for manure and composting and increases GHG emissions, since the food waste decomposition in landfills releases large amounts of methane. At the same time, it leads to changes in the soil, making it less fertilised (ibid).

Further research needs should include solutions to reinforce and improve awareness campaigns against illegal dumping, educational policies and the involvement of stakeholders in the development of measures so that they are not perceived as unfair and imposed from above.

Research and Innovation in Food Waste Reduction

In light of the evidence provided, this section identifies areas within food waste mitigation that require further research and whether they are already addressed in current funding projects.

- **Standard measurements for food waste quantification**

  Proper management of food waste requires quantification to gain a comprehensive understanding of the issue and identify the most appropriate reduction and prevention measures. As already mentioned, there is a lack of data efficiency and reliability, not only in the retail sector.

  The last years witnessed a surge in collaborative initiatives between scholars, institutions and working groups concerning food waste quantification and standardisation (Kok, Castelein, Broeze, & Snels, 2021). In 2016, a committee of expert institutions, including UNEP, WRAP, World Resources Institute, FUSIONS, Consumer Goods Forum, and the World Business Council for Sustainable Development, created the Food Loss and Waste (FLW) protocol and developed the first FLW accounting and reporting standard that is useable by actors in the food supply chain as well as governments and non-

governmental organisations. It is a protocol for food reporting and accounting. It does not indicate a precise quantification method, as it suggests that each entity should decide according to its objectives and role in the food supply chain. However, it does provide a set of recommended quantification methods. The adoption of the FLW standard is purely voluntary. The extent of its usage remains unknown as the FLW protocol does not track it (Food Loss and Waste Protocol, 2016). In 2020, the UNEP developed a food waste index, gathering food waste data and suggesting food waste measuring methods. In 2021, Wageningen University and Research published a comprehensive analysis of current food waste quantification methodologies and standards (Kok, Castelein, Broeze, & Snels, 2021).
Despite these studies and advances in food waste quantification, "data deficiency and inconsistency remain significant concerns" (Kok, Castelein, Broeze, & Snels, 2021, p. 8). Most of these studies reveal a lack of first-hand data collection, using data drawn from the literature (ibid). Further research on the matter and tracking of existing standards' adoption is needed, especially at the retail level, to make data more reliable, easier to track and above all comparable.

Currently, food waste quantification is being addressed under Horizon 2020 and Horizon Europe through the ZeroW and Wasteless projects. The ZeroW project aims to develop a systemic approach to collecting data and monitoring food waste along the supply chain. It is conducting two Living Labs (in Slovenia and Romania) to test a FLW IT integration and infrastructure system for collecting and monitoring data (ZeroW, n.d.). It received under Horizon 2020 an overall amount of EUR 12 million funds (Bizzo, et al., 2023). It will end in 2025, after 3 years of activity. The Wasteless project is conducting research to develop tools and mechanisms to measure and monitor food waste. It aims to create a toolbox of technical innovations that measure FLW, among which is an Open Access Blockchain that enables data monitoring through an electronic ledger designed according to the FLW Standard (Wasteless, n.d.). The project with an overall amount of EUR 5.5 million funding under Horizon Europe, started in January 2023 and will end in December 2025.

- **Technological developments**
  Dynamic pricing and DSL are used by very few retailers due to their high implementation costs. Therefore, it is necessary to finance the technologies deployed in these two food mitigation practices to alleviate the cost burden on retailers. Dynamic pricing and DSL, although beneficial in terms of profits in the long run, initially entail price adjustment costs that can be rather high. Levy et al. (1997), based on a sample of large US retailers, estimated that such costs can account for up to 35% of net margins, thus

making this practice hardly affordable (Levy, Bergen, Dutta, & Venable, 1997; Lu & Reardon, 2018). Given the large reduction in food waste and the increase in long-term profitability resulting from dynamic pricing and DSL (Buisman et al., 2019; Sanders, 2024), it is necessary to finance the research of technologies involved in such practices and to promote their adoption by retailers.

Among the technologies employed in DSL are Time temperature indicators (TTI). TTI indicate the shelf life of food products, as they mirror temperature changes. DLS also uses RDIF technology for real-time updates on product conditions. Additionally, it employs real-time Internet of Things (IoT) sensor data, such as gas sensors to indicate carbon dioxide and other gases' levels and humidity sensors. Dynamic pricing utilizes advanced technologies as well, including real-time IoT sensors, AI algorithms for accurate demand forecasting, real-time analytics for calculating and setting optimal prices, and blockchain technology to improve traceability (Ahmadzade et al., 2023). Moreover, both DSL and dynamic pricing use electronic shelf labels that show real-time prices and expiration dates on a display, which can be changed and updated remotely.

It appears that no current project under Horizon Europe is substantially investing in these specific technologies, which is worth to be further analysed. More research funding is needed on the technologies involved in dynamic pricing and dynamic shelf life to make them progressively less expensive and more accessible.

- **Emission permits market for food retailers**

  Unlike taxation, emission permits do not set a static food waste price but a flexible one, which allows for adaptation to the economic and environmental changing conditions. Furthermore, differently from taxation, it guarantees an equilibrium not only between the marginal value of the company's output and marginal cost but also between the total value of the firm's output and the total cost in the long run (Collinge and Oates, 1995). The exit and entry of retailers into the market is thus facilitated compared to the tax. Via the quantity and value of permits, policy-makers can still choose a fixed level of maximum food waste, and at the same time, through the exchange of permits, they grant retailers market freedom. This way, retail food waste is regulated without excessively affecting the free market (ibid.).

  More research is needed on the efficiency of a permit market and other types of fiscal measures for food waste at the level of retailers, which is currently lacking. Research funding is needed for the design of fiscal measures addressing food waste at the level of retailers, as they play a key role in the supply chain.

Conclusive remarks and recommendations

It is well recognised that the current levels of food waste generate unsustainably large economic, environmental, and social costs. As food waste is a fast-growing, phenomenon, its prevention and reduction are necessary to increase engagement in the circular economy and consolidate food security. This must happen at different supply chain stages, particularly addressing the unanswered issues at the retailer and consumer levels. First, it is imperative to consider the Sustainable Development Goals (SDG) and the EU Green Deal Farm to Fork Strategy as priorities in future political milestones, as well as the targets identified in the revised Waste Framework Directive. Despite the growing awareness of the negative consequences of food waste, political commitments made at EU and Member State levels (Katsarova, 2014) and related measures implemented so far, food waste generation is not decreasing as required to make significant progress towards SDG 12.3. Yet, actions among MSs are still unbalanced and not fully developed.

The brief highlights that changing households' behaviours and retail and market incentives can play a relevant role in boosting food waste reduction (Quested et al., 2016). Analysing food management, increasing the value of food and raising the cost of food waste are some powerful strategies towards new food systems and related innovative trends. Several actions in terms of future strategies can be taken towards this direction. Food waste externalities can be internalized, for instance, through environmental regulation, namely through taxation at the household level according to the food waste weight produced and an emission permit system at the retail level. Another crucial economic instrument enhancing food waste mitigation is subsidizing smart sustainable retail practices (i.e. dynamic pricing and DSL). Considering the hourglass shape of the European food system with retailers at the centre where the flow of food products from producers to consumers passes through, retailers have large market power to initiate change. Hence, financing sustainable retail practices can spark changes both downstream with consumers and upstream with producers.

The implementation of the discussed measures, though, is hampered by a lack of food waste quantification data, technological limitations, stakeholders' resistance, and illegal dumping. As a consequence, and in light of the evidence provided in this report, to overcome the abovementioned barriers to food waste reduction, more research is needed on standard measurements for food waste quantification, technological developments, and the creation of an emission permit market for food retailers.

In addition, whilst there has been notable increase in research on food waste quantification and standardisation in recent years, there is still a lack of data reliability, preventing the design and implementation of accurate solutions. As such, it is worth to investigate further on the extent of the adoption of existing standards, as well as investigating the obstacles and gaps in their usage and eventually addressing them. Furthermore, lack of data is also a barrier to the

adoption of advanced technologies involved in DSL and dynamic pricing. Indeed, an upgrade that incorporates these technologies in retailers' IT infrastructure is needed. Greater funding to incentivise their use is required, as well as further research in their development. Public-private partnerships should be built to let public funds support technology development in the private sector. Finally, the emission permit system in food retail, its feasibility and its effects should be the target of future research.

Overall, there are clear challenges to engage with and substantially reduce food waste, globally and in the EU. However, it is imperative to take action, now more than ever, to address gaps and barriers throughout the entire supply chain, with a particular emphasis on retail and consumption levels. Keeping research and innovation on food waste high in the next EU food research Agenda with adequate financing in the next Multiannual Financial Framework will be crucial to bring substantial improvement towards sustainable food waste management and enable the crucial, urgently needed switch to circularity of a food sector, in harmony with global, planetary boundaries.

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