Chapter 9
Food Loss, Food Waste, and Sustainability in Food Supply Chains

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9.1 Introduction

Food supply chains are a major part of many discussions about sustainability. Considering that these supply chains account for more than a quarter of global greenhouse emissions (Poore and Nemecek 2018), this attention certainly seems warranted. From a broader sustainability perspective, food supply chains are arguably even more essential, considering that about half of the world's habitable land is used for agriculture, 70% of global freshwater withdrawals are used for agriculture (see Chap. 4 by Hoekstra (2024) for more details), 78% of waterway pollution with nutrient-rich pollutants (i.e., freshwater eutrophication) is the result of agriculture, and 94% of mammal biomass (excluding humans) is livestock (Ritchie and Roser 2020; FAO 2011; Poore and Nemecek 2018; Bar-On et al. 2018). The management of food supply chains therefore has major impacts on climate change, land use, water management, pollution, and biodiversity (Ritchie and Roser 2020).

With regards to climate change, different parts of the food system contribute to greenhouse emissions, as shown in Fig. 9.1. Clearly, raising animals and growing crops account for most emissions (31% and 27%, respectively), especially if we also consider the land use involved (an additional 24%). The part of the supply chain after primary production (processing, transport, packaging, and retail) contributes the remaining 18% of the food system impacts.

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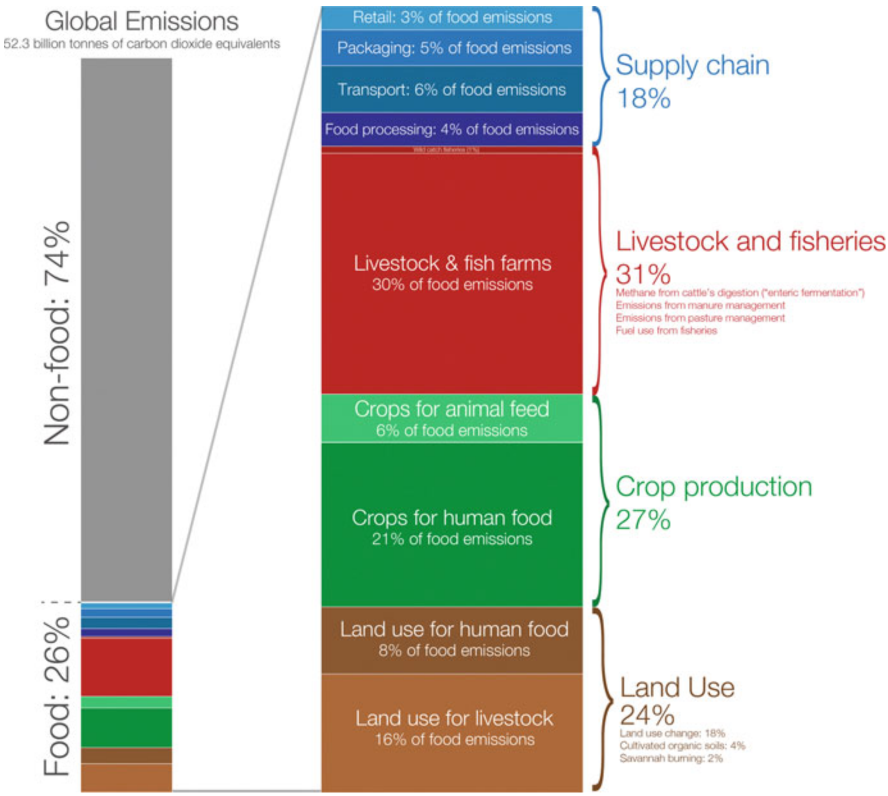

Fig. 9.1 Global greenhouse gas emissions from food production (Ritchie and Roser 2020, based on Poore and Nemecek 2018). Cropped from original figure licensed under CC BY 4.0

The fact that a significant share of emissions is related to animal production systems (including the related animal feed production and land use) does not only mean that emissions are mostly caused early in the supply chain. It also means that compared to other food products, meat consumption has relatively high impacts. Reduction of meat consumption is therefore also one of the main discussion topics in relation to the sustainability of the human diet (refer to Chap. 3 by Boukherroub et al. (2024) for a detailed discussion about carbon footprinting).

In addition to the environmental concerns, food supply chains also have important social and economic impacts. Many people around the world depend on agriculture and other food supply chain activities for their income (refer to Chap. 21 by Sodhi and Tang (2024) for a discussion about social responsibility in supply chains). Even in high-income countries, in which the number of people involved in agriculture is significantly lower than in low-income countries, many people are still involved in downstream food supply chain activities (such as food processing, retail, or foodservice). And even though many people earn their livelihood in food and agriculture, a key socio-economic concern is food insecurity: many people do

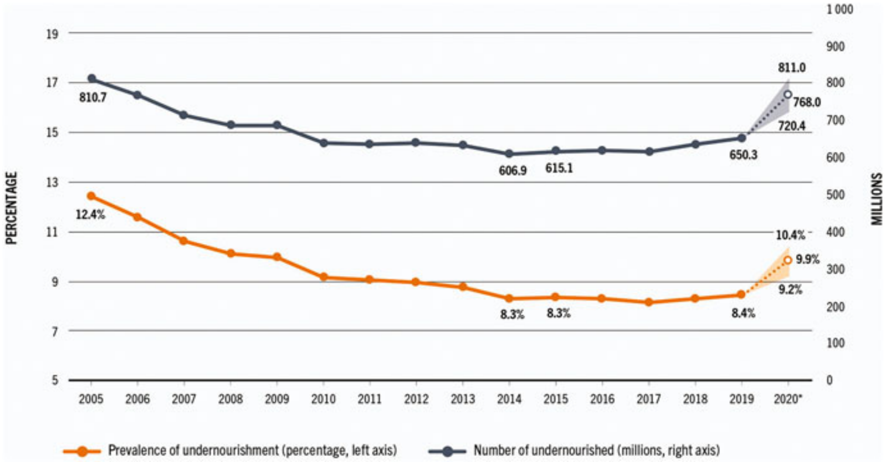

Fig. 9.2 Development of the number of undernourished people in the world (projected values for 2020 in the figure are illustrated by dotted lines; shaded areas show lower and upper bounds of the estimated range) (FAO 2021). Adapted from original figure licensed under CC BY-NC-SA 3.0

not have sufficient access to food. As illustrated in Fig. 9.2, almost 10% of the world's population are considered undernourished (FAO 2021). It should be noted that this is not just referring to developing countries. For instance, recent 2020 statistics show that 10.5% of US households were considered food insecure for at least part of the year (Coleman-Jensen et al. 2021). In their 2030 Agenda for Sustainable Development, the United Nations (UN) therefore also has Zero Hunger as the second of their 17 sustainable development goals (SDGs) (United Nations 2015).

Considering the environmental concerns regarding climate change and the social concerns regarding food insecurity, it is worrying that a lot of the food that is produced does not make it to consumption. Throughout the food supply chain, a significant share of food products is lost or wasted. In a seminal study for the UN's Food and Agriculture Organization (FAO), Gustavsson et al. (2011) report that a third of the globally produced food is lost or wasted at some point during the food supply chain. This means that related environmental impacts were made for nothing, and that many people remain food insecure. Reducing the food that is lost or wasted is a key part of the twelfth UN SDG: Responsible Consumption and Production.

From a supply chain perspective, this also changes the view on the environmental impacts of food production presented in Fig. 9.1. Even though most of the environmental impacts are made early in the food supply chain, if the resulting food products get lost or wasted in later supply chain stages, the actors involved in these stages have an impact on a larger share of environmental impacts than the statistics in Fig. 9.1 would suggest. For instance, in Europe, more than half of the food losses and waste occur at the household level (Stenmarck et al. 2016; Eurostat 2022), as can be seen in Fig. 9.3. Another 34% of food loss and waste occurs somewhere

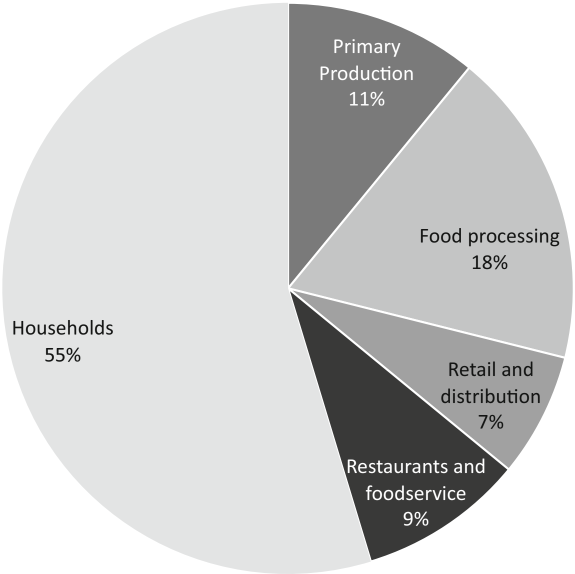

Fig. 9.3 Division of food loss and waste by sector for the European Union (Eurostat 2022)

along the supply chain between primary production and consumers (in processing, retail and distribution, or in restaurants and foodservice).

In general, studies show that the total amount of food loss and waste is comparable between countries and regions (e.g., Gustavsson et al. 2011). However, why and where this loss and waste occurs varies significantly. Typically, in developing countries, more food products are lost in the beginning of the supply chain, due to a lack of proper postharvest handling and storage technologies. Refrigeration of perishable products is for instance more likely to be insufficient. In developed countries, these early stages are much more professionalized, and more products are lost and wasted later in the supply chain, as seen in Fig. 9.3. Here, consumer behavior plays a much more important role.

Preventing or reducing the amount of food lost or wasted from farm to fork is therefore essential. This is also reflected on the agenda of many policy makers. For instance, in 2023, the European Commission aims to introduce legally binding targets to reduce food waste (European Commission 2022). Also, in 2015, the US Department of Agriculture (USDA) and the Environmental Protection Agency (EPA) set a goal to cut food loss and waste in the US in half by 2030 (EPA 2022a).

In the remainder of this chapter, we discuss food loss and food waste in the context of sustainable supply chain management. In Sect. 9.2, we further introduce the concepts of food loss and food waste. Then, in Sect. 9.3, we provide an overview of the drivers behind food loss and food waste. Section 9.4 subsequently goes into potential actions to prevent or reduce loss and waste in food supply chains. Finally, Sect. 9.5 concludes this chapter with a brief outlook towards the future of sustainable food supply chains.

9.2 Distinguishing Food Loss and Food Waste

The terms food loss and food waste are both used to describe food that does not end up making it to the intended human consumption. The two terms are, however, sometimes used interchangeably, and sometimes they are used to point to different things. To clarify, we briefly discuss two of the leading definitions that have been used: one by FAO and another by the European Commission.

A key difference between the FAO definition and the EC definition is that FAO distinguishes between food loss and food waste, whereas the EU only refers to food waste. FAO refers to food loss as “the decrease in the quantity or quality of food resulting from decisions and actions by food suppliers in the chain, excluding retailers, foodservice providers and consumers” (FAO 2022a) and to food waste as “the decrease in the quantity or quality of food resulting from decisions and actions by food suppliers in the chain, including retailers, foodservice providers and consumers” (FAO 2022b). Basically, loss is used in the initial stages of the supply chain, and waste is used in the later stages.

In the overview of the food supply chain shown in Fig. 9.4, this distinction is also illustrated. As can be seen, both the FAO and EU perspective start at primary production, after products are harvested, up to the point of consumption.

The EU instead uses food waste to refer to all waste streams throughout the supply chain (as also shown in Fig. 9.4). Formally, the EU, in its waste directive, simply defines food waste as all food that has become waste (EU 2018). Here, it refers to the Food Law to define food as “any substance or product, whether processed, partially processed or unprocessed, intended to be, or reasonably expected to be ingested by humans” (EU 2002).

In the remainder of this chapter, we will follow the FAO terminology as much as possible, distinguishing between food loss and food waste where useful, and otherwise refer to food loss and waste or the acronym FLW.

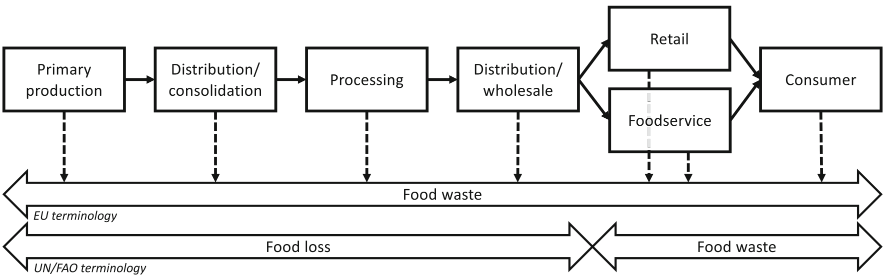

Fig. 9.4 General structure of food supply chains with an illustration of the distinction between food loss and food waste based on UN/FAO and EU terminology (partly based on Akkerman et al. 2010; Cruijssen et al. 2022)

9.3 Drivers of Food Loss and Food Waste

In recent years, many studies have been performed to identify the sources and drivers behind FLW. Here, we do not aim to repeat such a literature study, but instead focus on summarizing the main findings from recent studies. Previous overviews sometimes had a broad scope covering most of the supply chain, but some studies also zoomed in on specific supply chain stages. The content of this section is mainly based on the reviews done by Bhattacharya et al. (2021), de Moraes et al. (2020), Dora et al. (2021), Juvan et al. (2021), Magalhães et al. (2021), Raak et al. (2017), Shafiee-Jood and Cai (2016), Spang et al. (2019), and Surucu-Balci and Tuna (2021).

9.3.1 General Classification of FLW Drivers

In general, the literature on drivers of FLW discusses their findings across different product categories, not necessarily identifying different drivers behind different products. In this section, we structure our discussion around the supply chain stages identified in the previous section. The focus will be on identifying what specific drivers play a role in each supply chain stage. However, we first introduce several broader, overarching driver categories that lead to FLW across the different supply chain stages. These more general driver categories do often have specific dynamics in different supply chain stages, which we then reflect on in the individual sections. Also, some of the drivers might not apply to every stage (e.g., drivers related to consumer behavior are mostly relevant in the retail, foodservice, and consumption stages). Table 9.1 presents an overview of driver categories, together with the main underlying drivers mentioned in the literature.

9.3.2 Primary Production

Primary production is the stage in which drivers related to environmental conditions are arguably more relevant than in any other stage. This is related to, for example, weather conditions, the possibility of disease and contamination, as well as damages by insects or birds.

As in any of the supply chain stages, standards and regulations play a key role. Already this early in the supply chain, products that do not satisfy often rigorous quality demands will be discarded. Here, quality demands can relate to weight, size, shape, and appearance. This either means that products are left on the field or that they are sorted out soon after they are harvested. Standards and regulations related to food safety might also play a role here, as food can also be wasted due to safety concerns.

Table 9.1 General food loss and waste drivers

Driver category	Key drivers
Environmental conditions	Conditions during, e.g., drying or storage; product disease or contamination; product damage by insects or rodents
Standards and regulation	Failure to meet quality standards (weight, shape, size, visual defects); food safety concerns; social norms
Lack of infrastructure or technology	Lack of adequate or efficient storage, refrigeration, transport, or handling technology; inadequate packaging; inadequate waste management services
Lack of skills or expertise	Improper handling of products; poor organization culture regarding FLW; labor shortages; lack of product knowledge; lack of planning skills
Economic factors and incentives	Lack of managerial incentives to reduce FLW; market conditions, social norms and attitudes, high transportation costs
Supply chain management issues	Inefficient procurement channels; poor forecasting practices (uncertain demand); inefficient inventory management; logistical inefficiencies, lack of communication and collaboration; mismanagement of cold chains
Consumer behavior	Lack of FLW awareness; overbuying discounted products, lack of inventory management and planning skills; attitudes towards leftovers

The lack of appropriate infrastructure or technology is also prevalent. In primary processing, this mainly relates to technology related to quality preservation (e.g., refrigeration) and harvesting. In addition, the use of lower quality input materials is mentioned, as this can affect the quantity and quality of the products being produced. It is interesting to note that this would imply a broader perspective on FLW, as such unrealized yield would typically not be measured. In general, the importance of these drivers related to infrastructure also depends on the context, as these drivers are often much stronger in developing countries.

In addition to technology, the human factor also plays a key role. This for instance concerns the potentially improper handling of delicate products. More specifically, for primary processing, the literature points out the lacking knowledge of cultivation techniques and harvesting timing as important drivers. Like the technological drivers, these expertise-based drivers are often stronger in developing countries.

Economic factors also play a significant role in the primary processing stage. The main issue here is that crops are sometimes left on the field due to unfavorable market conditions: low prices can mean that harvesting efforts are not worth it.

Finally, the literature reports different drivers related to the complexities of supply chain management. Uncertainties related to demand forecasts or harvest yields can lead to overproduction, which in turn leads to products being wasted. This also includes aspects related to how different supply chain actors collaborate and communicate. For instance, to meet supply agreements with retail, overproduction might be unavoidable.

9.3.3 Distribution/Consolidation

After harvesting, during the initial distribution and consolidation of products, many of the food waste drivers present during primary production, especially since in many cases there is still a lack of adequate infrastructure and technology, and similar environmental conditions influence product degradation. Also, the sorting and possible rejection of products due to quality standards continue during this stage, potentially even more so.

During distribution and consolidation, environmental conditions also refer to storage conditions, especially related to products that require drying during this stage. During storage, damages by insects and rodents are also a relevant factor. Especially in developing countries, these environmental conditions play a key role in these early parts of the supply chain.

In terms of skills and expertise, improper handling of delicate products is still a key driver, but during distribution and consolidation, there is also more emphasis on the lack of investment in knowledge regarding postharvest technologies. Furthermore, the improper stacking and overfilling of bins during the distribution process is mentioned as an additional driver.

From a supply chain management perspective, overstocking still plays a significant role, but in this stage, it is not only linked to poor forecasting and uncertainty in demand, but also specifically linked to the existence of take-back agreements. Finally, when temperature-controlled supply chains are used, they are not always managed appropriately, also contributing to FLW.

9.3.4 Processing

The literature on FLW does typically not distinguish between primary and secondary processing, even though some FLW drivers mentioned in the literature seem more applicable to the primary processing stage in which food products are transformed to commodities (e.g., cutting and trimming losses or processing by-products).

High quality standards for products remain a challenge in this stage of the supply chain, but now also extends to processed food products, which often also have strict guidelines on visual characteristics.

Lack of adequate infrastructure and technology concerns processing and packaging aspects here, which includes lacking technology for quality preservation, defective equipment, and inadequate packaging technology. Skills and expertise of operators in processing environments also contribute to FLW: process inefficiencies and defective products can be caused by a lack of skilled staff (or general human error).

In addition to lacking processing technology, several inherent characteristics of processing activities lead to food waste drivers. During processing, parts of the food products used as ingredients might be trimmed, leading to losses. This includes both edible food losses and inedible by-products that might still have other uses. In many processing environments, part of the production volume is furthermore lost due to product sampling for destructive quality-control tests and due to losses around product changeovers and cleaning operations.

Finally, in addition to the overstocking due to uncertainty and take-back agreements, the lack of information sharing as well as inadequate inventory management is mentioned as FLW drivers. Also, the lack of attention to by-product flows in supply chain management activities is relevant here as processing activities are a major source of by-products.

9.3.5 Distribution/Wholesale

After processing, in the distribution and wholesale stage, drivers related to quality standards and improper product handling skills remain to be somewhat relevant. Product handling issues in this stage specifically relate to moving products in and out of storage and to product damage by transportation equipment. Also, some economic factors and incentives are mentioned: high transportation costs and a lack of incentives to reduce food waste are part of these discussions.

In this stage, two categories of food waste drivers are however most prominent in the literature: drivers related to lacking infrastructure and technology and drivers related to supply chain management.

The lack of infrastructure and technology is mostly related to inadequate cold chain technology. Proper cold chain logistics equipment for storage and transportation is clearly important and lacking or inadequate transportation equipment or cold storage facilities is a key driver mentioned by many authors. In addition, poor product packaging material is also mentioned within this category.

Since this supply chain stage purely deals with logistics activities, it might not be surprising that the literature mentions many FLW drivers related to supply chain management issues. Like other supply chain stages, lacking communication and supply chain collaboration are often mentioned. More specific logistics-related drivers are found in relation to poor forecasting practices and inefficient inventory management, but the literature also mentions aspects like the proliferation of product portfolios, the management of promotional activities, and handling seasonality in supply or demand.

Many of the drivers mentioned in this stage are more relevant in developed countries, as the distribution and wholesale stages are often more prominent in the more professionalized, longer supply chains found in those countries.

9.3.6 Retail

In general, in the retail stage, we continue to see quality standards play a similar role as in other supply chain stages, but we see some retail-specific aspects mentioned in relation to other driver categories. The FLW literature does not specifically exclude certain types of retail but seems to mostly be relying on data from traditional brick-and-mortar retail environments.

In relation to infrastructure and technology, lacking or inadequate cold chain equipment, as well as poor packaging, are still prominent FLW drivers mentioned by many authors. The lack of infrastructure, however, also extends to managing waste streams, and some of the literature specifically mentions the lack of access to recycling and collection for composting, as well as the lack of storing and transporting infrastructure for the donation of surplus product to organizations such as food banks.

The lack of a donation infrastructure is also mentioned in relation to economic factors and incentives. More specifically, the literature points to the fear of lawsuits in relation to donations: if donated food would lead to food safety issues after donation, retailers could be held responsible or incur reputational damage. In addition to a general lack of incentives to reduce waste, this even adds an incentive against redistribution. A similar incentive exists due to a fear of finding donated products back on grey markets, which retailers would also like to prevent.

FLW drivers in the skills and expertise category relate to improper handling of delicate fresh products. Some of the literature also emphasizes the lack of knowledge on recycling and waste minimization, as well as the presence of a poor organizational culture with regards to waste reduction.

Many supply chain management issues are mentioned as food waste drivers in the retail stage. Inefficiencies in inventory management and resulting expiry date problems are a key driver here. Also connected to poor forecasts and lacking communication and collaboration with other supply chain actors, managing inventories can be difficult.

Finally, the literature also identifies some drivers related to specific retail practices. Especially in this stage of the supply chain, a wide range of products and brands is often present, complicating the supply chain management issues mentioned above. More specifically, factors such as promotions lead to significant fluctuations in sales and providing a visually attractive store sometimes also leads to overstocking.

9.3.7 Foodservice

For the foodservice channel, the literature also identifies a variety of specific FLW drivers. In terms of skills and expertise, FLW drivers also relate to inadequate skills related to planning and preparing meal production. This, for instance, includes lacking skills to manage leftovers, poor cutting and trimming practices, and inadequate judgment of portion sizes. Like in the retail channel, the literature here also mentions poor organization culture regarding waste reduction and a lack of knowledge on reuse and recycling options.

Several characteristics of foodservice practices are also linked to food waste drivers. More specifically, choices in relation to the menu, the amount of food on display, as well as serving sizes are all mentioned in the literature as key FLW drivers. Some other drivers found in the retail channel are also relevant here: overstocking of food for visual purposes as well as pricing strategies and promotional activities leading to fluctuations in supply and demand for certain products.

In the context of foodservice environments, FLW drivers related to consumer behavior also play an important role. A general lack of food waste awareness among consumers can lead to significant plate waste, especially in environments in which consumers get to serve themselves (e.g., in a buffet setting). Here, overestimating portion sizes plays a role as well as the customer's attitude regarding whether or not to take leftovers home from the foodservice setting.

9.3.8 Consumer

As discussed earlier in this chapter, the consumer stage is known to be a significant source of food waste, especially in developed countries. As in previous supply chain stages, some lack of infrastructure or technology is still relevant here. More specifically, inadequate storage and refrigeration can be a driver, as well as a lack of access to recycling or composting options.

In the category related to lacking skills and expertise, the literature identifies several specific drivers. In addition to more general product handling skills, there is specific mention of lacking skills in relation to food safety assessment, understanding product (date) labels, lack of food preparation knowledge, and understanding of how to use leftovers. Also, the lack of awareness regarding FLW is mentioned as a driver in this category.

The purchasing behavior of customers also relates to a series of FLW drivers. Difficulties with inventory management can be a key driver, partly related to the management of uncertainties in demand and current inventory (e.g., not using a shopping list), but also due to the sizing of packages, and overbuying behavior caused by discounted products (especially related to volume discounts). This FLW driver connects to retailer practices, and misalignment of incentives, as additional sales are clearly beneficial for retailers, and waste prevention at the consumer level might not be.

Many socio-cultural aspects further add FLW drivers. A lower perceived value of food is, for instance, mentioned in the literature, as well as having experience with specific food products (loose), attitudes towards food waste, social norms around eating, and individual eating habits.

Especially in the consumer stage, the complex combination of many behavioral and socio-cultural factors leads to significant FLW, and the overview of drivers included here only provides a brief overview of the main categories and drivers. For a more detailed discussion of individual drivers, we therefore also refer to the references mentioned earlier.

9.4 Reduction and Reuse of Food Loss and Food Waste

In this section, we first discuss some common frameworks related to reduce and reuse strategies, followed by reduce and reuse strategies, and finally discuss the not so straightforward connection between reducing FLW and addressing food insecurity.

9.4.1 Reduce and Reuse Hierarchies

Throughout the supply chain, many FLW streams are reused or repurposed in one way or another, for instance, in energy production by anaerobic digestion, as an ingredient in the production of animal feed, or as donations to food banks that might still be able to repurpose towards human consumption. Figure 9.5 illustrates the hierarchy of interventions that is also recognized in EU policy. A similar hierarchy has been introduced in the US by the EPA, based on: (1) source reduction, (2)

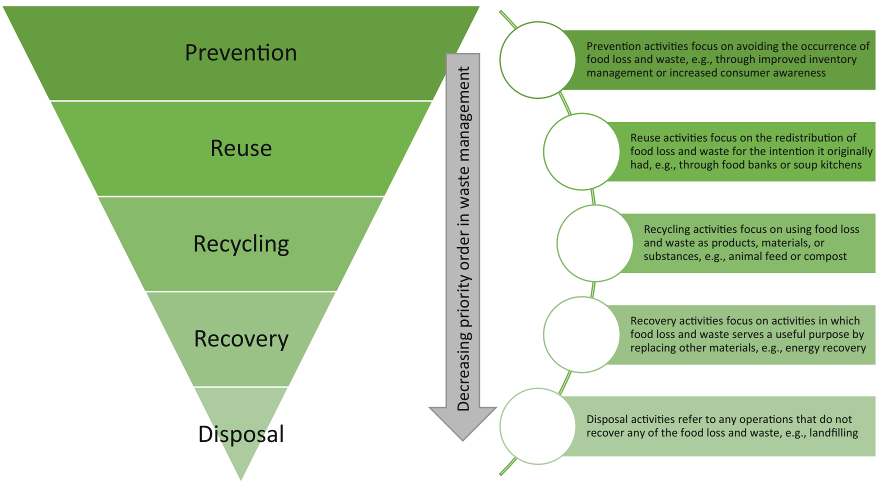

Fig. 9.5 Food waste hierarchy including selected potential interventions (based on EU 2008)

feed hungry people, (3) feed animals, (4) industrial uses, and (5) composting (EPA 2022b).

Using such hierarchies and prioritizations makes clear that there are different things we can do with FLW and that it matters which one we use, as higher levels of valorization are preferable. In most cases, this is also a good proxy for the best use in terms of the underlying environmental impacts. However, in terms of measuring the impact of efforts to address FLW, the variety of reuse options is often not appropriately captured: in most cases, if food is not used for human consumption, it is still considered FLW. This means that interventions to reuse FLW might have large positive environmental impacts, but that it is might not be appropriately incentivized by policies that aims to reduce FLW. This prevents the efficient reuse of FLW streams, see also Teigiserova et al. (2020).

The discussion of reduce and reuse strategies does however seem to gain more and more attention, also related to developments regarding the circular economy, a concept that describes an economy in which the natural environment is protected by minimizing resource consumption and increasing reuse (Beames et al. 2021). The abovementioned hierarchies and prioritizations follow the logic behind the circular economy concept.

Figure 9.6 illustrates several key ideas behind a circular economy approach in relation to FLW (Wang et al. 2021). Interested readers can refer to Chap. 16 by Saman et al. (2024) for more details about circular supply chain implementation. Most of the interventions included in the hierarchies and prioritizations are present in this approach. It should however be noted that this circular system does not need to be a closed system within the food sector, as some products derived from FLW streams might have uses outside of the food system (e.g., the production of bioplastics from FLW).

9.4.2 Food Loss and Food Waste Reduction and Reuse Strategies

Reducing or reusing FLW can be done in different ways. Many initiatives to prevent or reduce FLW aim to remove or decrease one or more of the drivers mentioned in the previous Sect. 9.3. However, considering FLW might be difficult to reduce, there are a variety of initiatives aiming to reuse FLW. Table 9.2 provides an overview of strategies, categorized by Caldeira et al. (2019).

The first category of strategies concerns redistribution, which aims for FLW to be redirected in such a way that it still ends up being consumed by humans. The example of gleaning addresses FLW in primary production, by collecting products that are left on the field after harvesting. Often, these collected products are then donated to organizations such as food banks (see, e.g., Lee et al. 2017). Similarly, surplus food in other supply chain stages can also be redistributed to such organizations aiming to address food insecurity. Finally, there are also many

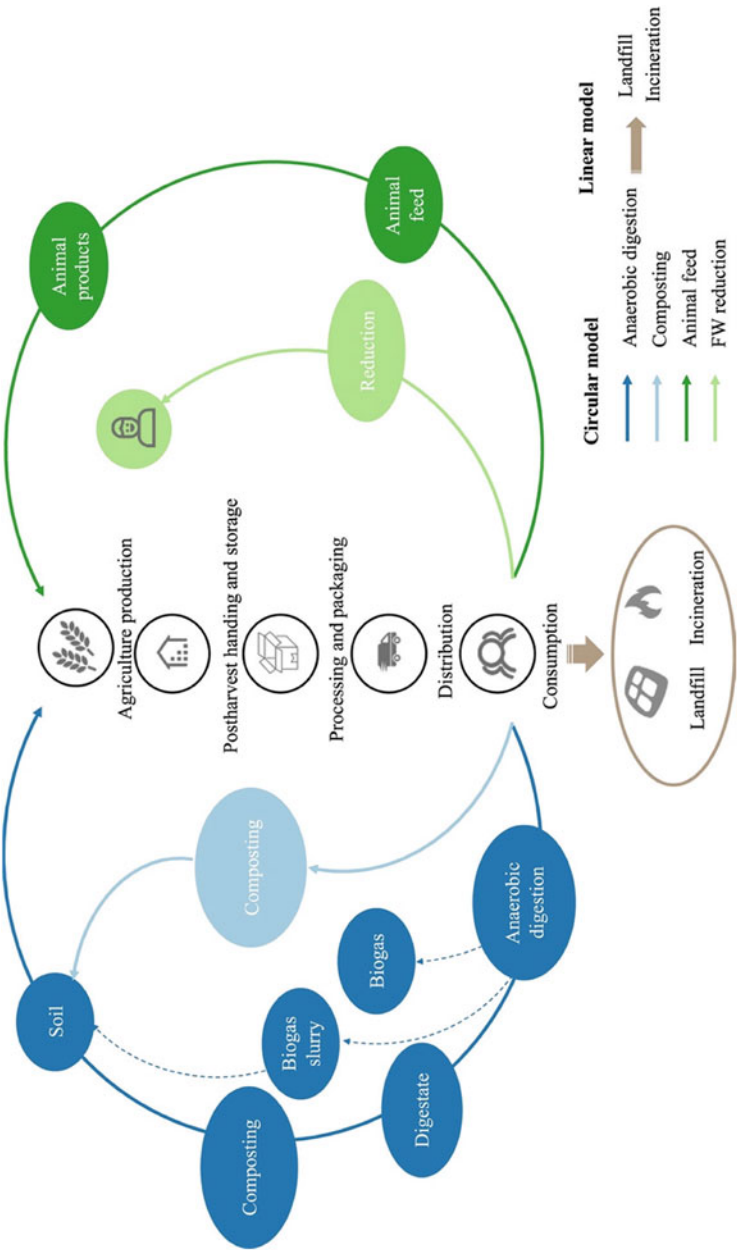

Fig. 9.6 A circular economy approach to food loss and waste (Wang et al. 2021). Original figure licensed under CC BY-NC-ND 4.0

Table 9.2 Food loss and food waste reduction and reuse strategies (based on Caldeira et al. 2019)

Category	Key strategies
Redistribution	Gleaning
	Surplus food redistribution
	Digital tools for redistribution
Food valorization	Value-added processing
	Animal feed
Consumer behavior change	Awareness/educational campaign
	School programs
	Awards
	Digital tools for behavior change
Supply chain efficiency	Process innovation
	Innovation of products—packaging
	Innovation of products—date marking
	Training & guidelines
	Price discounting
	Imperfect product sale
	Certification
	Public procurement
	Digital tools for supply chain efficiency
Food waste prevention governance	Voluntary agreement
	Regulatory framework/policy
	National food waste prevention program
	Fiscal incentives

technological innovations related to redistribution, for instance developing apps in which surplus food is offered at discounts. Well-known examples are Too Good To Go, Food For All, and Olio. Whereas some of these apps focus mainly on offering surplus food in retail and foodservice environments to consumers at a discount, some of the apps also have the option for people to offer their surplus food.

Valorization of FLW streams is another important reuse strategy. Partly, this might still include strategies that end up with products for human consumption, for instance by processing fruit waste streams into fruit juice. After redistribution for consumption by humans, valorization as animal feed is often considered the most valuable use of FLW. It avoids dedicated food production for animal feed and as such prevents significant environmental impacts.

Following up on the important role that consumers play in causing FLW, strategies aiming to influence behavioral change are also highly relevant. This includes educational efforts and campaigns that hope to make consumers more aware of the environmental and social impacts of FLW. Awareness is also the main goal behind school programs and competitions and awards for FLW reduction innovations. Finally, digital tools might also help change consumer behavior, for instance to help with food planning, food acquisition, and food storage (see, e.g., Vogels et al. 2018).

Reducing waste is a classic operations and supply chain management principle. Even though this often takes to form of wasted capacity or wasted time, the principles still translate to the reduction of FLW. Supply chain efficiency is therefore also a sizeable category of FLW reduction strategies. This entails process innovation, which could be the increase of technical efficiency in terms of producing a more stable product quality, or managerial innovations such as more intelligent processes for production and inventory management. Supply chain efficiency could also be achieved by improved packaging technology, such as for instance shelf-life-extending modified atmosphere packages. Improved date marking on packaging might also help reduce FLW in later stages in the supply chain. Training and guidelines could also help increase efficiency, especially in situations where lack of skills or expertise is a key FLW driver, such as in retail and foodservice environments. Especially for retail environments, discounting practices can significantly reduce FLW, even though this sometimes just shifts waste downstream, as discounting is also considered a key driver of waste at the consumer level. Another strategy that is mostly relevant for retailers is the sale of imperfect products. Also offering the 'ugly' or 'wonky' to consumers is something many retailers have implemented. Certification could also be strategy, as this would institutionalize the measurement and continuous reduction of waste. Certification organizations such as Bureau Veritas and the British Standards Institution already offer such certifications. An additional strategy especially relevant for the public sector is the inclusion of FLW reduction considerations in public procurement. This could for instance relate to including FLW aspects and other sustainability considerations in tenders regarding foodservice operations in public institutions. Finally, the development of digital tools to support supply chain efficiency is a strategy that uses digitalization to help improve the matching of supply and demand in food supply chains, which would help reduce the FLW caused by supply chain inefficiencies. Also, these tools can help implement the process innovations and training mentioned earlier.

A final category of FLW reduction and reuse strategies is FLW prevention governance. This is a relatively broad category and includes several public or private initiatives. First, voluntary agreements could help companies across the food industry to implement efficiency improvement. Several additional strategies build on regulatory support and/or pressure, which might be required to achieve ambitious reduction goals. This entails regulatory frameworks and policy facilitating all the FLW reduction strategies mentioned in this section, national food waste prevention programs to combine and promote the FLW reduction strategies, as well as fiscal incentives for companies along the food supply chain to become more active in reducing FLW.

Many of the FLW reduction and reuse strategies discussed in this section impact the way we design and operate food supply chains. In addition to the technological challenges, consumer awareness issues, and policy requirements, many of the strategies also build on advances in operations and supply chain management (see also Akkaş and Gaur 2022; Do et al. 2021; Muth et al. 2019). This ranges from designing new supply chains for effective redistribution of surplus food to the integration of FLW prevention in the planning and control of food manufacturing operations and the consideration of FLW drivers in managing retail operations.

9.4.3 Food Loss and Food Waste in Relation to Food Security

It can be argued that reducing FLW can have a beneficial effect on food security. After all, the natural resources that are needed to produce food can be used to feed people who are acutely food insecure. Reduction of FLW could contribute to an increase in the productivity of food production advocated for in the Zero Hunger SDG. On the other hand, if FLW that is currently redistributed to people that are food insecure would be prevented from occurring at all, such FLW prevention initiatives might have unintended negative side effects for food security.

Clearly, the relation between food security and FLW reduction deserves to be discussed in more detail. Although FLW reductions can affect food security in a positive way, the relation is certainly not straightforward.

First, it is widely acknowledged that, on an aggregated level, there should be enough food for everybody on the planet. Clearly, this significantly changes when a third of food products does not find its way to human consumption. Feeding the world population and avoiding hunger is thus a matter of efficient and effective food supply chains, and a fair allocation of resources and food. When left to the free market however, food products tend to flow to those with the highest willingness to pay, which is the wealthiest part of the population. This results in an unbalanced (and arguably unfair) allocation among the world population. This is easily illustrated by observing that, next to the 700 million undernourished people (as we saw in Fig. 9.2), an estimated number of 1.6 billion people are overweight. It would be a severe simplification to just state that redistributing food between the mentioned groups of people would solve hunger. This relates to the third topic that we will discuss below on measurement of FLW in terms of nutrients instead of volume. In fact, obesity is caused by complex relationships between genetic, socio-economic, and cultural influences, and when the dietary intake is concerned, obesity is more due to the overconsumption of energy-dense foods than to the overall mass of the consumed food (Apovian 2016). However, it is a fact that cheap food is widely available in some parts of the world, while there are severe shortages in other parts of the world. An interesting question is therefore: will we still see hunger if we succeed in eliminating FLW and as a result a significantly larger food supply would stay available for consumption on the global market?

Second, the interaction between food security and FLW reduction is explicitly present in initiatives like food banks and other charitable organizations. These initiatives typically have two goals: to provide essential food items to people facing hunger and to avoid or reduce FLW by redistributing surplus food. Most of the food products donated to food banks originate from food supply chain actors such as retailers and processing companies. These are however also supply chain actors that are looking into reduction of FLW and/or interventions that reuse FLW in different ways (e.g., utilizing it as animal feed). Such reduction and reuse interventions are often also economically more interesting than donating to a charitable organization like a food bank. Such trade-offs between different FLW prevention, redistribution, and reuse interventions should clearly also be considered in addition to the identified synergies between FLW reduction and food security.

A third friction between food security and FLW reduction lies in their respective measurement. Whereas the most common measurements of FLW simply focus on weight, this in a way is a simplification. It assumes that the burden of discarding a kilo of cucumber is the same as discarding a kilo of beef or a kilo of candy. This is clearly not true. When looking through the lens of food security, people in hunger do not care about weight of food, but about nutrients. This makes a case for FLW measurements to also look at nutrients rather than weight. Also, it means we should be even more careful with high-nutrient foods than with food that is low in nutrients. And even more so with food that contains nutrients that generally people are lacking. Another concern with the focus on weight measurement is that it does not consider the natural resources that are used and emissions that were caused in the supply chain of various types of food. And research has shown that there are significant differences between the environmental impacts of products. In other words, it is important to always translate FLW measurements into environmental impacts, as we might otherwise not create the incentives for food supply chains to become more sustainable.

9.5 Conclusions

To develop more sustainable food supply chains, it is essential to reduce its environmental impacts, while still providing sufficient food for a growing population. A key challenge in this discussion is the presence of significant food loss and waste (FLW). In this chapter, we briefly discussed sustainability in food supply chains and the role of FLW in this context. We then provided an overview of the drivers behind FLW, what strategies so far have been used to reduce or reuse FLW, and how FLW reduction strategies possibly interact with strategies to address food insecurity.

From an operations and supply chain perspective, many challenges remain for practitioners and researchers alike. A lot of the FLW reduction strategies lead to the development of novel and different supply chains, for instance dealing with redistribution of surplus food, valorization of FLW streams, management of novel processing and packaging technologies, developing intelligent pricing strategies, extending product assortments, and changing procurement practices.

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