Food Loss and Waste

Quantification, Impacts and Potential for Sustainable Management

Food Loss and Waste: Quantification, Impacts and Potential for Sustainable Management

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PREFACE

This report is an overview of food waste and its potential role as a feedstock for material and energy valorisation within the framework of IEA Bioenergy Task 36. The purpose of this report, as all the work carried out by Task 36, is to inform countries on the issues around food waste, including quantification and arisings across the supply chain, towards implementing solutions in the waste/resource management and Waste-to-Energy sector that would facilitate their transition towards circularity. The topics covered in this report were selected due to their relevance in the field of waste management and waste-to-energy, particularly in the context of sustainability.

IEA Bioenergy Task 36, working on the topic 'Material and Energy Valorisation of Waste in a Circular Economy', seeks to raise public awareness of sustainable energy generation from biomass residues and waste fractions including MSW as well as to increase technical information dissemination. As outlined in the 3-year work programme, Task 36 seeks to understand what role waste-to-energy and material recycling can have in a circular economy and identify technical and non-technical barriers and opportunities needed to achieve this vision.

See http://task36.ieabioenergy.com/ for links to the work performed by IEA Bioenergy Task 36.

EXECUTIVE SUMMARY

According to the UN Environment Program, approximately 1.052 billion tonnes of food are wasted annually, equivalent to about one third of all food produced for consumption (1). Food waste is an issue that poses societal, economic, and environmental impacts. Worldwide, efforts and initiatives are being developed and implemented to reduce food waste. There is a specific Sustainable Development Goal relating to food waste, UN SDG 12.3; "By 2030, halve per capita global food waste at the retail and consumer levels and reduce food losses along production and supply chains, including post-harvest losses" (2).

Food Loss and Waste (FLW) occurs at each stage of the supply chain, including primary production, processing, at retailers, within the food service industry, and in households. Food loss refers to a decrease in the mass or quality of food before it reaches the consumer. Food waste typically refers to food that humans did not ultimately consume and that is discarded. 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 quantify baselines and progress towards SDG 12.3. Major sources of food loss in the supply chain include; harvest losses, storage losses, processing losses and distribution losses. Further, the generation of food waste is closely tied to the efficiency of the supply chain. Waste occurs for several reasons, including; procurement issues, limited market access for small farmers, quality standards and penalties and market system changes.

The food system is a major contributor to environmental impacts, including producing significant greenhouse gas (GHG) emissions. Food production requires extensive resources such as land, fertiliser, water etc. As food is wasted along the supply chain, it results in environmental impacts as all upstream activities and resources used in production are wasted. Furthermore, FLW causes water pollution and nitrogen loss. The environmental impacts of different waste management options for municipal food waste, including avoidance, composting, anaerobic digestion (AD) and incineration have been considered using Life cycle assessment (LCA). An avoidance strategy for wasted food showed the best environmental performance, while AD resulted in the lowest environmental impact for unavoidable food residues and minimal food waste. Current treatment methods are suboptimal, including landfilling, incineration, composting and anaerobic digestion, each of which has environmental impacts. Food waste contains valuable materials, such as carbohydrates, lipids and amino acids, and it is a promising feedstock for producing value-added chemicals and fuels. It is important to characterise food waste to identify optimal valorisation routes, extracting higher value from food waste while reducing impacts.

The consumption stage is the final stage in the food supply chain where individuals or households purchase, prepare, and consume the food products. In 2019, 17% of the total food available to consumers was wasted. The dynamics impacting consumer attitudes and behaviours regarding food waste are a complex mix of socio-economic, social, psychological, situational and demographic factors. Campaigns which focus on social norms and behaviours of others and educational campaigns aimed at improving consumers' knowledge and skills in cooking and food storage have been recommended to tackle food waste. In addition to food waste generated from food which ends up in a bin, waste from food packaging and water scarcity also amplify the overall environmental, social and economic impacts of food waste.

CONTEXT AND BACKGROUND

According to the UN Environment Program, approximately 1.052 billion tonnes of food are wasted annually, equivalent to about one third of all food produced for consumption (1). Food waste is an issue that poses societal, economic, and environmental impacts. There is a considerable social impact related to food waste as food waste increases food insecurity; 60% of food waste is suitable for human consumption (3), and it is estimated that 735 million people do not have enough to eat (4). Food waste occurs at each stage of the supply chain, including primary production, processing, at retailers, within the food service industry, and in households (5; 6). According to the Food Waste Index Report 2021 (1) an estimated 931 million tonnes of food was disposed of in waste bins of households, retailers, restaurants and other food services in 2019. This amounts to 17% of the total food available to consumers. Food waste has considerable economic impacts; in Europe alone, food waste costs about 143 billion euro annually (7) and this impacts different sectors. For example, primary production of fruit and vegetables can result in substantial quantity of non-marketable produce that is often sold at a lower price to the processing industry or is used as animal feed or returned to the fields as a fertiliser (8). In Europe alone, it is estimated that primary production accounts for 10% of total food loss and waste produced across the food chain (9). Food production has significant environmental impacts, accounting for 34% of global anthropogenic greenhouse gas (GHG) emissions (10), and other impacts including biodiversity loss, deforestation, drought, and freshwater pollution. According to the UNFAO[1], 8% of global GHG emissions are related to food waste (11) and if food waste were a country, it would be the third largest emitting country in the world. If food waste is not managed and disposed of correctly, it can cause environmental issues such as an increase in methane released from landfills, unpleasant odours, and increased pollution of waterbodies. However, if food waste is managed correctly, valuable products can be derived.

Worldwide, efforts and initiatives are being developed and implemented to reduce food waste. There is a specific Sustainable Development Goal (SDG) relating to food waste, UN SDG 12.3 (2).

UN SDG 12.3: “By 2030, halve per capita global food waste at the retail and consumer levels and reduce food losses along production and supply chains, including post-harvest losses” (2). There are two sub-indicators used to measure progress towards this target:

- INDICATOR 12.3.1A - The Food Loss Index (FLI), measuring losses along the food supply chain starting from post-harvest losses on the farm up to but not including retail stage.
- INDICATOR 12.3.1B - The Food Waste Index, measuring food waste at retail and consumer level (households and food service).

The United Nations SDGs focus on actions to reduce food waste globally. There are also regional initiatives to tackle food waste. The European Commission (EC) committed to achieve the SDG target in the European Circular Economy Action Plan (12), defining food

[1] UNFAO: Food and Agriculture Organization of the United Nations

waste as a priority area. Further, the EC amended the Waste Framework Directive 2008/98/EC, setting as obligatory the monitoring and reporting on food waste by Member States (MSs) to: (i) establish a baseline to monitor the achievement of food waste reduction targets; and (ii) help in the identification of relevant food waste streams to be valorised in a circular economy perspective (13).

FOOD LOSS AND WASTE

Food Loss and Waste (FLW) occurs 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 SDG 12.3. It is important to consider the definitions of Food Loss and Food Waste and where they arise in the food supply chain.

Food loss refers to a decrease in the mass or quality of food before it reaches the consumer. Food loss 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 (14). The primary reason for food loss is inefficiency in the food supply chain, including inadequate infrastructure and logistics, limited technology, insufficient skills, knowledge, and management capacities; as well as challenges in accessing markets promptly after harvest (15). Food loss can occur along the supply chain; during harvesting, in storage, and during processing and transportation (16).

Food waste typically refers to food that was not ultimately consumed by humans and that is discarded (17). Food waste can arise intentionally or unintentionally from the human food supply chain in retail, restaurant, food service and household settings (16).

FOOD SUPPLY CHAINS AND WASTE GENERATION

The food supply chain is complex and consists of many stages; agricultural production (farming or fishing), harvesting, followed by storage, transportation, processing, and packaging, the retailing stage, and finally consumption and disposal. The REAMIT NWE project[2] identified four sources of food loss in the supply chain:

- **Harvest Losses** refer to the loss of food that occurs during harvesting, often attributed to improper harvesting techniques or timing – for example, early harvesting may result in a higher moisture content, which, when followed by insufficient drying, causes increased risk of mould growth (18). Harvest losses also include food that was not harvested due to labour shortages or low market prices (19). Food is also lost if it does not conform to cosmetic requirements set by retailers. For example, it is estimated that 25-30% of carrots do not reach the market due to failure to achieve cosmetic standards (20).
- **Storage Losses** involve spoilage of during storage, either in warehouses or refrigerated facilities. Factors such as unstable moisture control, contamination

[2] https://www.reamit.eu

and temperature fluctuations can cause storage losses. Excessive moisture can promote mould, fungus, and bacteria growth, causing food to degrade (21).

- **Processing Losses** refer to the reduction in quantity or quality of food during processing steps such as washing, cleaning, degutting, chopping, withering etc. (22). Food can also be lost 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 (20).

Food waste can be categorised into four categories which are avoidable or unavoidable and available or unavailable food waste (23).

- **Avoidable Food Waste** include wasted foods generated in processing, retail, catering and households. Avoidable food waste occurs when foods are discarded because they are regarded as 'suboptimal', or when they pass their 'best-before' date, or due to product flaws (23). Such food waste was previously in an edible condition but is discarded instead due to factors such as over-purchasing, improper storage, lack of cooking expertise.
- **Unavoidable Food Waste** relates to material from food production systems that is not consumable, typically described as by-products, co-products, or residues (e.g. manure, crop residues, leaves and peels) (23). This type of food waste is inedible for humans such as bones, eggshells, fruit skins and tea bags (24).
- **Available Food Waste** refers to food waste that is available for valorisation, i.e. these wastes cannot be prevented, and are currently not performing a critical function in the economy, i.e. it is not incorporated into soil as an amendment in agriculture (23).
- **Unavailable Food Waste** refers to food waste which is unavailable for valorisation due to their essential place providing ecosystems services, i.e. incorporation of straw in soil (23).

As outlined above, the generation of food waste is closely tied to the efficiency of the supply chain and waste occurs for several reasons, including:

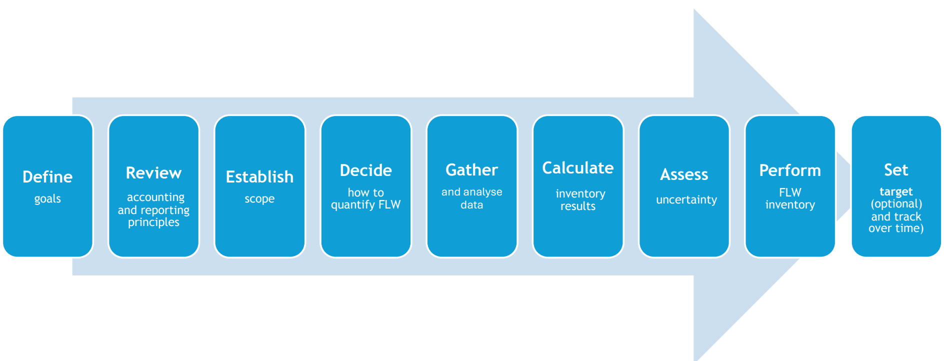
- **Procurement Issues:** FLW often arises when retailers bypass traditional suppliers in favour of new sources (21). This shift can lead to a surplus of fresh produce, especially at the end of the growing season, which goes unsold and is ultimately wasted.
- **Limited Market Access for Small Farmers**: Regional factors can affect food waste generation; small and medium farmers often lack access to central or wholesale markets, relying instead on local markets with limited buyers (25). 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 (26).

- **Quality Standards and Penalties**: In developed economies such as Europe and the US, quality standards imposed by supermarkets and export agencies contribute 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 FLW (27). Further, as outlined above, supermarkets often apply cosmetic standards.
- **Market System Changes**: The trading system typically regulates supply and demand, however external pressures such as supermarket expansion can disrupt this balance (28). 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 FW category prematurely (29).

FOOD LOSS AND WASTE QUANTIFICATION

Quantification of FLW is essential to allow development of reduction or valorisation strategies. The FLW Protocol is a partnership between multiple stakeholders, which launched in 2013 to provide standard tools for quantification of FLW. The quantification of FLW is facilitated by specifying what to measure and how to measure it (see Figure 1 for an overview of steps in developing an FLW inventory). The aim is to encourage consistency and transparency of the reported data and promote informed decisions about food loss and work on strategies to minimise FLW.

Figure 1: Overview of Steps in FLW Accounting and Reporting (30)



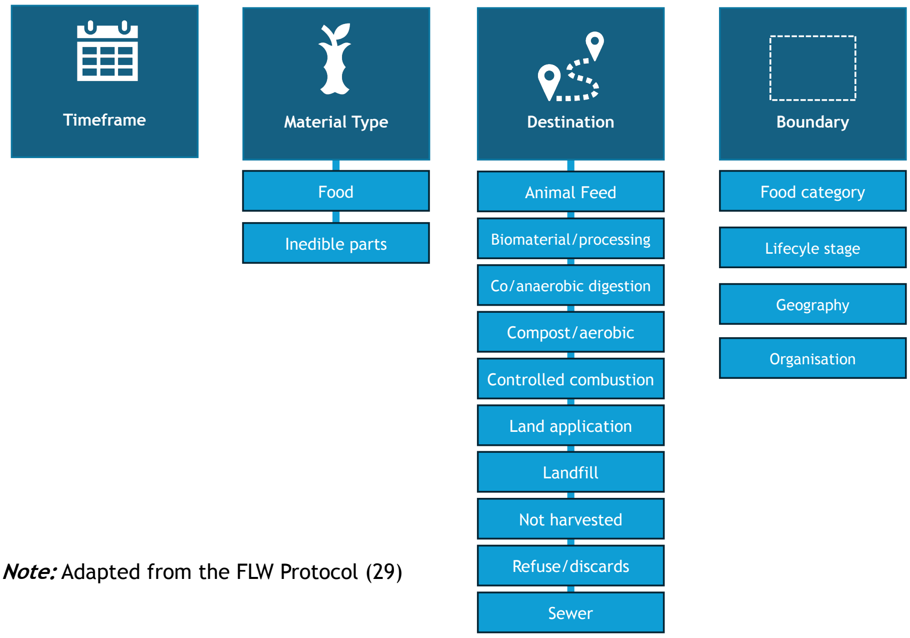
Note: Adapted from the FLW Protocol (29)

There are ten methods for quantifying FLW based on measuring or approximating (30).

1. **Direct Weighing:** This method uses scales to directly measure the amount of FLW. Weighing can be used alone or with other methods such as waste composition analysis. The main advantages of direct weighing are high accuracy and low uncertainty. However, weighing equipment generally needs to be transported to the location of quantification, causing logistical and cost impacts, otherwise a scale is needed at each location, which can be costly.
2. **Counting:** This method involves counting individual items to estimate the weight of FLW. Items can be similar (e.g., bananas) or contained (e.g., a can of soup or a bag of grain). The weight of one unit is multiplied by the number of units to get the total weight. Scanning and visual scales can also be used, increasing the cost.
3. **Assessing Volume:** This method is primarily used for quantification of liquid FLW but can also be applied to semi-solid or solid FLW. The volume occupied by the FLW is measured and then converted into its weight.
4. **Waste Composition Analysis:** This method involves physically separating FLW from the waste stream for weighing (for example separating packing). It helps understand how much different components weigh and the overall composition of the FLW is determined.
5. **Records:** Existing written records which are typically maintained for reasons other than quantifying, such as warehouse logs or waste transfer receipts, can be very useful for quantification of FLW.
6. **Diaries:** A regular log of FLW is kept. This approach is commonly applied in households or commercial kitchens. Diaries are often used to study social and market behaviour relating to food waste.
7. **Surveys:** The survey method uses structured questions to collect data on FLW. Responses are based on logical information, approximations, or visual estimations of FLW.
8. **Mass Balance:** This method calculates FLW by quantifying the inputs and outputs of a process, for example a food processing facility, accounting for changes in weight during food processing.
9. **Modelling:** The modelling method uses simulations and mathematical approaches to estimate FLW under various conditions.
10. **Proxy Data:** This approach is used to estimate FLW using data that is outside the scope of an entity’s FLW inventory. Example data sources are older data, data from another country or from another company. Proxy data can be used to infer FLW calculations when direct measurement is not feasible due to budget or accessibility constraints.

An FLW Inventory contains information on the timeframe, material type, destinations, and boundary of the inventory. A sufficiently detailed scope, aligned with appropriate quantification and the commissioning entity’s goals, is important to ensure that an FLW inventory meets needs and allows identification of measures to reduce food waste (see Figure 2).

Figure 2: Scope of an FLW Inventory



Note: Adapted from the FLW Protocol (29)

Many food chains have been investigated to quantify the food waste arisings across the stages of the supply chain. Data on food loss and waste percentage occurring across different areas of the food supply chain, including agriculture, post-harvesting, processing, distribution and consumption, is presented in Table 1.

Table 1: Percentage of waste generated from each food category across different supply chains (31)

Food Category	Area of supply chain	Percentage of food waste generated in each stage of supply chain	References
Cereals	Agriculture Post-harvesting Processing Distribution Consumption	2% 3% 5% 2% 22%	(32; 33)
Roots and tubers	Agriculture Post-harvesting Processing Distribution Consumption	20% 7% 11% 4% 10%	(33; 34)
Oilseeds and pulses	Agriculture Post-harvesting Processing Distribution Consumption	10% 1% 5% 1% 4%	(33; 35)
Fruits and vegetables	Agriculture Post-harvesting Processing Distribution Consumption	20% 4% 1% 8% 13%	(33; 36)
Meat and poultry	Agriculture Post-harvesting Processing Distribution Consumption	2% 1% 5% 2% 10%	(33; 37)
Fish and seafood	Agriculture Post-harvesting Processing Distribution Consumption	9.6% 0.4% 5% 7% 8.5%	(33; 38)

Food Category	Area of supply chain	Percentage of food waste generated in each stage of supply chain	References
Dairy	Agriculture Post-harvesting Processing Distribution Consumption	2.5% 0.2% 1.8% 0.3% 6.7%	(33; 39)

FOOD LOSS & WASTE AND SUSTAINABILITY

As mentioned in the introduction, the food system is a major contributor to environmental impacts, including producing significant GHG emissions (40). The production of food requires extensive resources such as land, fertiliser, water etc. The expansion of food production globally, using modern agricultural practices including the extensive use of fertiliser and pesticides to ensure high yields, has increased land degradation. As food is produced and it travels through the supply chain, wastage can occur at several points. As food is wasted along the supply chain, it results in environmental impacts as all upstream activities and resources used in production are wasted. Furthermore, FLW causes water pollution and nitrogen loss. It is estimated that 12% of nitrogen is lost to the environment because of the production of food in the EU with 65% of the total nitrogen loss occurring as emission to water (41). Further, the intensive use of energy for storage, transportation, and food processing, causes emissions when the energy source is from fossil fuels. Studies estimate that 25% of energy usage in the agriculture sector in the US is associated with FLW (41).

Life Cycle Assessment (LCA) methodology has been used to estimate the environmental impacts of food production across its life cycle and allows quantification of the impact of FLW. Food waste impacts twice: when it is produced, and when it is disposed, as such, LCA studies have been applied in two distinct areas of the supply chain; the supply chain up to food production and the supply chain relating to food consumption (42). An LCA study of food waste from households in Denmark found that food wastage resulted in the emission of 1,200 kg CO2-eq per tonne of food waste. The carbon footprint from food waste in Swedish supermarkets is equal to 1,600 kg CO2-eq per tonne, while in Ireland it is equivalent to 5,600 kg CO2-eq per tonne (43).

Figure 3 illustrates the loss of food which was not sold because it was graded below cosmetic requirements in the European Economic Area (EEA) in 2016 for different fresh fruit and vegetable crops, utilising the minimum, central and maximum grade out loss factor estimates (44). Figure 4 illustrates the GHG emissions produced by the grade-out losses of fresh fruit and vegetable crops in the EEA as a result of loss of food which was not sold (44).

Figure 3: Grade-out losses (in kt) of FFV crops for the EEA (44)

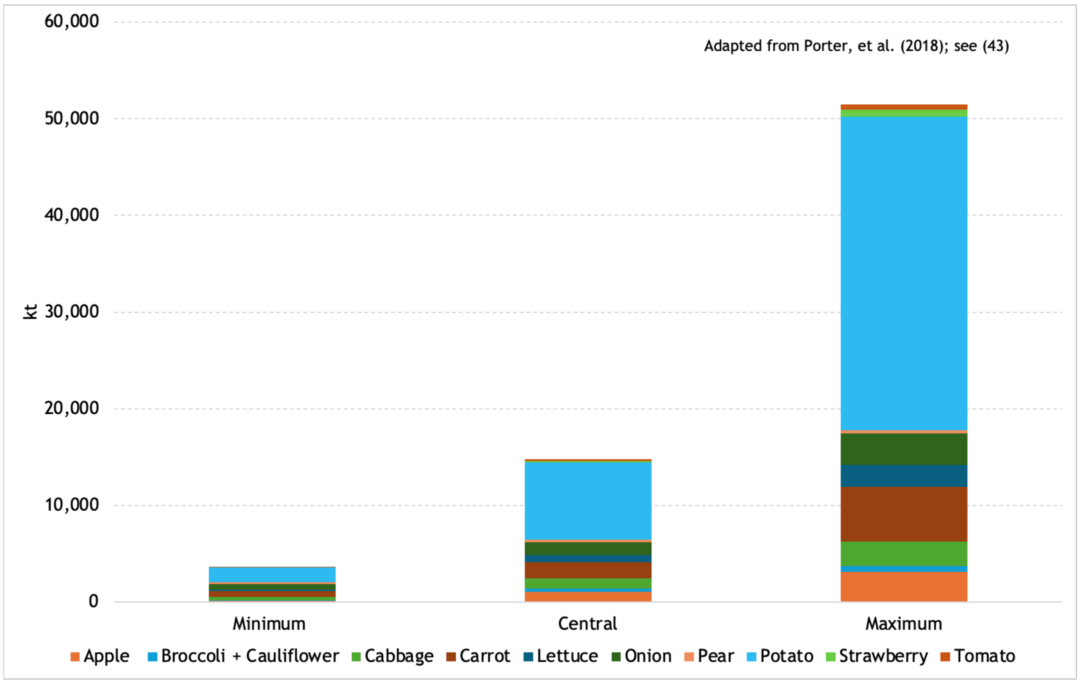
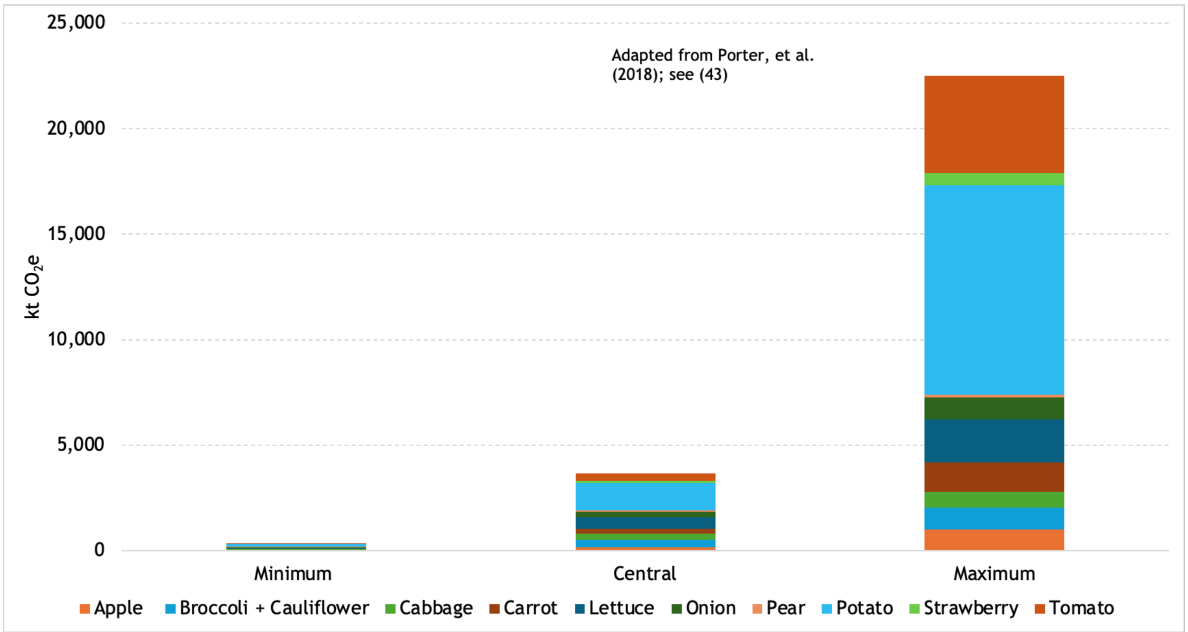


Figure 4: Embedded Production Phase GHG Emissions (kt CO_2e) in the EEA (44)



Figures 3 and 4 highlight the significant quantities of food that are wasted due to the application of cosmetic standards by retailers. This type of food waste is counted as avoidable food waste i.e. when foods are discarded because they are regarded as 'suboptimal', or when they pass their 'best-before' date, or due to product flaws. The production of this food will have caused environmental impacts, for example from application of fertilisers, creating direct emission of nitrous oxides from soil processes, and energy for planting, harvesting, transport. The later in the supply chain a product is wasted, the higher the environmental impacts. Tables 2 and 3 illustrate the global warming potential resulting from food wastage of specific food commodities and global warming potential related to food services and households, respectively (42).

Table 2: Global Warming Potential of specific food commodities. Adapted from Amicarelli, Lagioia, & Bux (2021) (see 42)

Product(s) considered	Environmental Impact	References
GHG emissions associated with food loss from farm production, delivery and refrigeration, retail sale, household consumption for four high value produces in California.	GWP kg CO2-eq per serving size: avocado = 0.022; celery = 0.014; lemon = 0.020; strawberry = 0.13.	(45)
Production-phase GHG emissions of California specialty crops considering on-farm food losses	GWP kg CO2-eq per kg of cultivated product: processing tomato = 4.86E-02; fresh tomato = 5.84E-02; lettuce heads = 1.05E-01; processing peach = 1.40E-01.	(46)
Environmental impacts associated with Belgian (BE) and New Zealand (NZ) apples.	GWP kg CO2-eq per product: NZ apples: 1.35 (of which distribution accounts for over 0.9); BE apples: 0.35 kg of CO2-eq (equal share along the food chain).	(47)
Environmental impacts of the various stages of the Swiss fresh potato supply chain.	Contribution of supply chain stages to GWP; Agricultural production 49% with fertilizer production (0.059 kg CO2-eq) and direct emissions (0.083 kg CO2-eq). Households 37% (0.176 kg CO2-eq).	(48)

Product(s) considered	Environmental Impact	References
Environmental impacts of wastage of five food commodities (ketchup, bread, milk, cheese, beef).	GWP g CO_2-eq per kg of food waste: ketchup = 790 bread = 610; milk = 950 cheese = 8500; beef = 14,000.	(49)

Table 3: Global Warming Potential related to food service and households. Adapted from Amicarelli, Lagioia, & Bux (2021) (see 42)

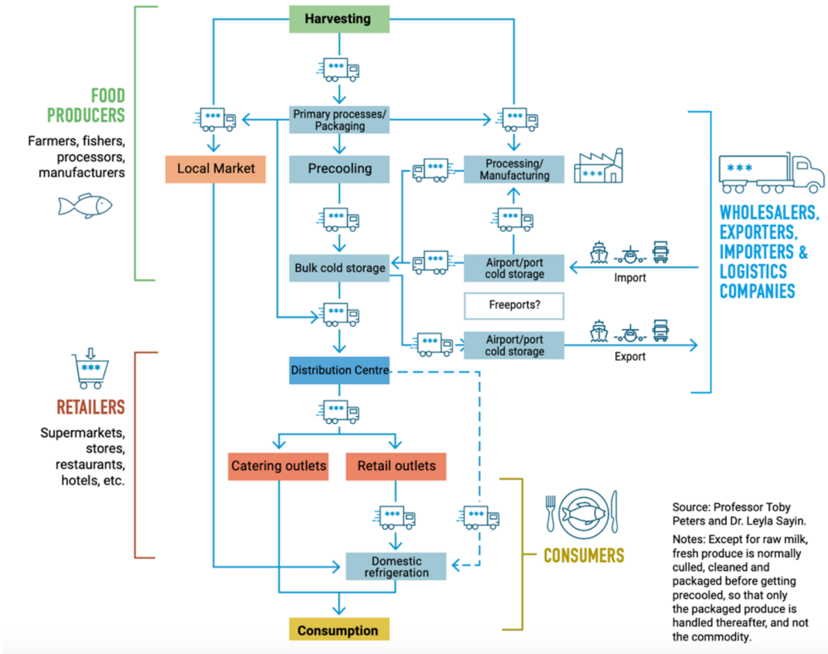
Food service considered	Environmental Impact	References
Environmental impact of a local food redistribution system intended as a service to redistribute food from emporium.	Net environmental benefits are over 1.87 kg CO_2-eq per kg of surplus food redistributed by each emporium.	(50)
Environmental impacts of food consumed and wasted in school canteens in Italy.	GWP of 1.31 kg CO_2-eq per average meal. The highest value was registered at primary winter schools (1.57 kg CO_2-eq), while the lowest at nursery summer schools (1.05 kg CO_2-eq).	(51)
GHG emissions of different waste disposal option for five core food types at UK supermarkets	Estimated net emissions in kg CO_2-eq are donation = −5583; animal feed = −347; anaerobic digestion = −314; composting = −31; incineration = −58; landfill = 2969.	(52)
GHG emissions of different treatment methods (incineration, composting,	One ton of food waste could generate, at composting	(53)

Food service considered	Environmental Impact	References
anaerobic digestion) under different decarbonization scenarios at UK households.	facilities, more than 74 CO2-eq, while anaerobic digestion and incineration could lead to −2400 kg CO2-eq and − 3000 kg CO2-eq.	
Environmental impacts related to landfill, incineration, composting, anaerobic digestion and bioconversion through insects at mass-retail sector	GWP in kg CO2-eq per ton of food waste: landfill = 1243; incineration = 822; composting = 99; biogas = 66 kg; bioconversion = 71.	(49)

COLD FOOD CHAINS

A cold food chain is an integrated temperature-controlled food distribution system that ensures that perishable produce and/or temperature-sensitive products are kept at their optimum temperature and environment, from source to destination (54), see Figure 5 below. It is important to maintain appropriate food storage conditions during transport of finished food products to distribution centres and to the retail stage, particularly for perishable food items, such as fruit and vegetables, that require controlled environments with specific temperature and humidity conditions. Maintaining appropriate storage conditions is essential to prevent food spoilage and minimise food loss as inefficient storage can accelerate the deterioration of food products, leading to losses in terms of quality and quantity (55). As such, time and temperature are critical variables in efficient cold chains to reduce loss (56). The lack of effective refrigeration in the food supply chain resulted in the loss of 526 million tonnes of food, or 12% of the global total, in 2017 (57).

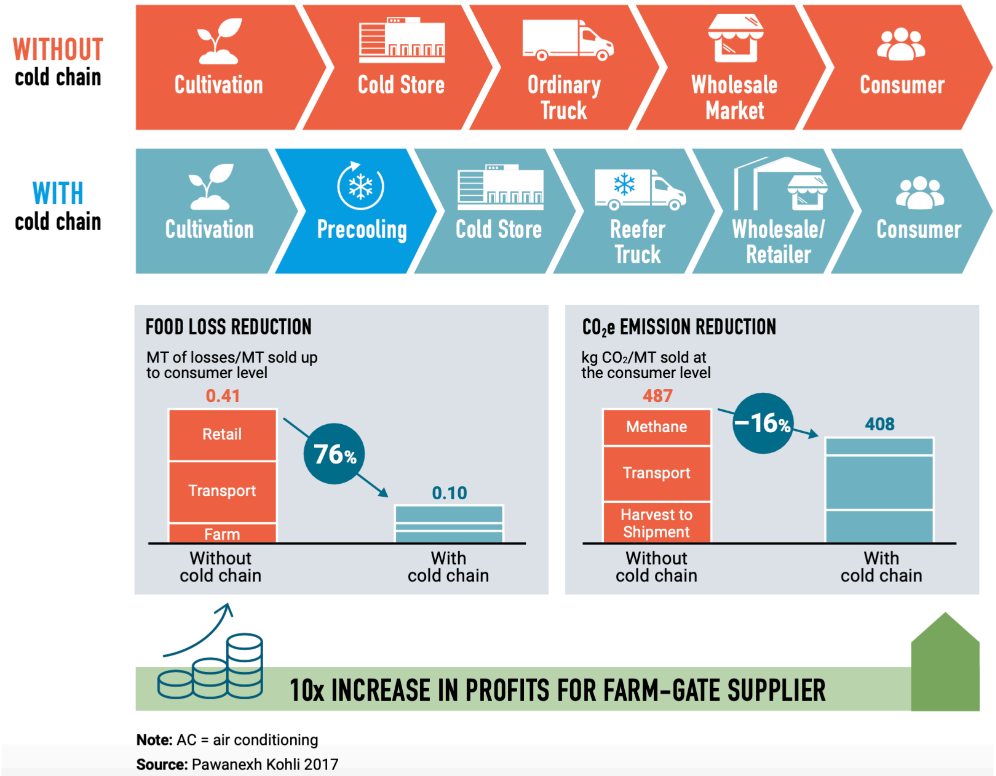
Figure 5: Typical food logistics cold chain steps and stakeholders (54)



The UNEP[3]/FAO report on Sustainable Cold Chains features a pilot case study from India measuring the impact of cold chain from farm-gate to terminal market across 2,500 kilometres, a 4–5-day journey by truck (54). The Kinnow fruit supply chain was carried both with cold chain and without the cold chain, over a four-month period. An overview of the pilot study is shown in Figure 6. The fruit, produced in the in the western Punjab area of India, without suitable cold chain facilities was only sold locally in nearby states, typically from January to mid-March. For the pilot study, the local farmer-aggregator invested in a precooling packhouse. The cold chain involved storing the precooled and packaged fruit in the available cold store, followed by transport by and a domestic transport company hired across 2,500 kilometres to an untried market in Bengaluru, in southern India. Multiple supplies to Bengaluru were carried out and studied, and there were multiple benefits from proper use of the cold chain; the addition of precooling extended the selling period by several months, the selling radius was extended, food losses declined 76%, adding to higher returns for farmers, and system-wide greenhouse gas emissions fell 16%, even when using diesel-powered transport refrigeration units and grid-based electricity (see Figure 6).

[3] UNEP: United Nations Environment Programme

Figure 6: Impacts of a pilot cold chain project in India (54)



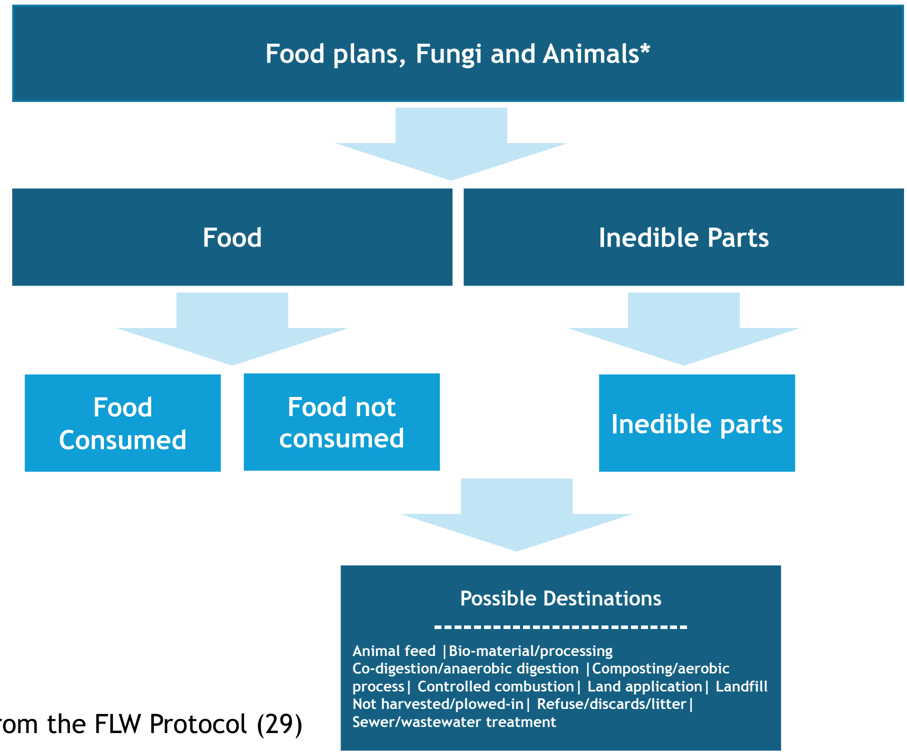
Identifying conditions leading to food spoilage and acting before food is wasted is an efficient way to avoid FLW. Temperature- and humidity-sensitive sensors can be deployed across the cold chain to enable prompt identification of potential for food spoilage allowing an intervention to be made to save the food from going to waste by acting before microbial damage can occur (58).

FOOD WASTE MANAGEMENT

Globally, the main food waste management methods are landfilling, incineration, AD and composting. Food waste is predominantly disposed of in landfills, posing significant environmental and economic challenges due to the emission of greenhouse gases such as methane (CH4) and unpleasant odours from nitrogen and sulphur compounds (59-61). Composting is also frequently used and produces nutrient-rich fertiliser which can offset conventional fertiliser, improving soil health and reducing GHG emissions. However, composting can emit unpleasant odours, release harmful by-products and contribute to secondary pollution (62; 63).

However, food waste contains valuable materials, such as carbohydrates, lipids and amino acids, and is a promising feedstock for producing value-added chemicals and fuels. Food waste valorisation involves converting waste materials into more useful products such as chemicals, materials and fuels (64). There are currently several valorisation routes for food waste in which can be split into three broad categories: thermal (direct combustion and incineration), thermo-chemical (torrefaction, gasification and pyrolysis) and biochemical (composting, anaerobic digestion and ethanol fermentation) (64). See Figure 7 below for an overview of FW material types and valorisation routes. Environmental impacts of different waste management strategies for food waste, including avoidance, composting, anaerobic digestion (AD) and incineration have been considered using LCA. An avoidance strategy for wasted food showed the best environmental performance, while AD resulted in the lowest environmental impact for unavoidable food residues and minimal food waste (65). Anaerobic digestion produces methane-rich biogas for energy, and digestate which can be returned to the agricultural system through its use as a fertiliser (66). AD of FW is more challenging compared to conventional feedstocks such as energy crops (e.g. maize) and animal wastes due to high moisture content, high organic carbon content and high biodegradability of FW (67). These properties lead to a rapid hydrolysis, which may cause acidification of the digester and inhibition of methanogenic bacteria activity.

Figure 7: An overview of FW material types and valorisation routes (30)



Note: Adapted from the FLW Protocol (29)

CONSUMER

The consumption stage is the final stage in the food supply chain where the food products are purchased, prepared, and consumed by individuals or households. In this stage, consumer choices play a crucial role minimising food waste. Food is usually thrown away due to overbuying, expiring beyond the best-before date and being leftover. By making conscious choices and reducing unnecessary food waste, consumers can contribute to a more sustainable and efficient food system (68). In 2019, it is estimated that 931 million tonnes or 17% of total food available to consumers was wasted (69).

A systematic literature review (2000-2018) found that behaviour which leads to food waste is influenced by socio-economic, social, psychological, situational and demographic factors and impacts on both the consumer food management and the buyer decision processes[4] (70). A study in the US examining the drivers of food waste reduction in households found that emotions such as anticipated guilt regarding contribution to food waste, awareness of consequences of food waste and environmental knowledge were positively associated with reducing, reusing and recycling processes (71), thus pointing to the complex influential role of social, cognitive and emotional factors in consumer behaviour. In addition, lack of knowledge and misunderstanding of food date labels may also result in unnecessary food waste (72).

Initiatives such as campaigns which focus on social norms and behaviours of others (73) and educational campaigns aimed at improving consumers' knowledge and skills in cooking and food storage have been recommended to tackle food waste (70). Interventions which used 'nudges' regarding social norms as well as reminders were found to be more effective in changing food waste behaviours in comparison to initiatives which solely focussed on information on the environmental cost of food waste (74). There is an increasing body of literature which explores determinants of consumer food waste behaviour, however more research on the relationship between food waste and consumer behaviour and how this is impacted by daily routines and social food practices would further extend the evidence on the necessary initiatives to change behaviour (75).

Consumer behaviour is likely to be influenced by associated attitudes towards food waste. A study in Ireland, found that consumer attitudes towards food waste are associated with the amount of food waste that is generated (76). Similarly to studies focussing on behaviour, educational campaigns which focus on consumer generated food waste and its impact on the environment may help in changing attitudes towards food waste (76).

In addition to food waste, food packaging can also contribute to food waste, however there is a paucity of research on consumer attitudes towards food packaging and this relates to food waste (77). Considering water footprint and scarcity in relation to food production, consumption and waste is also an important consideration in the broader waste cycle (78). Literature on food waste is dominated by research carried out in Europe, greater focus on other regions would be beneficial to ensure that any recommended food waste interventions consider country-specific factors as well as economic and cultural characteristics (79).

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[4] Consumer food management process includes planning, provisioning, storing, preparing, consuming, disposal and the *buyer decision process involves* planning, pre-acquisition, acquisition, preparation, consumption, disposition. See reference number (11) for more information.

CONCLUDING REMARKS

Significant volumes of food waste are generated globally, across the food supply chain, resulting in significant environmental, economic and social impacts. Globally, efforts are being made to reduce food waste with Sustainable Development Goal 12 specifically relating to food waste. Quantification of food loss and waste across the supply is essential for planning interventions to reduce avoidable food waste and to valorise unavoidable food waste. The cold food chain has an important role in reducing food loss and waste in perishable food supply chains. However, food loss and waste should be considered from an environmental, economic and social viewpoint to provide a holistic understanding of the challenges and potential solutions.

Current treatment methods are suboptimal, including landfilling, incineration, composting and anaerobic digestion, each of which has environmental impacts. Food waste contains valuable materials, such as carbohydrates, lipids and amino acids, and is a promising feedstock to produce value-added chemicals and fuels. It is important to characterise food waste to identify optimal valorisation routes, extracting higher value from food waste while reducing impacts.

Consumer related food waste generated in households, restaurants, retail and other food services plays a significant role in the total amount of food waste that is produced globally. There is a growing body of literature which focusses on exploring consumer behaviours and attitudes towards food waste, however further studies which explore how daily routines, habits and social food practices impact on overall behaviours and attitudes are needed. Greater focus on initiatives needed to reduce waste, while taking into account country-specific factors, economic and cultural characteristics would also significantly benefit the task of reducing food waste on a global scale.

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