# Food consumption and wasted food

# 11

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**Chapter Outline**



## 11.1 Introduction

An increasing global population, an evolution in consumers' needs, changes in consumption models, and considerable generation of food waste pose serious challenges to the overall sustainability of food production and consumption. About one third of the food produced for human consumption is currently wasted at the global scale (FAO, 2011). This reflects the high level of inefficiency of the food supply chain, which has significant economic, social, and environmental impacts. Besides being associated to relevant economic losses, food waste exacerbates food insecurity and malnutrition, and increases pressures on climate, water, and land resources contributing to natural resources depletion and environmental pollution (Godfray et al., 2010). In this context, the United Nations (UN) has proposed 17 Sustainable Development Goals (SDGs). Within SDGs, target 12.3 focuses on food waste reduction, requiring, by 2030, to: "halve per capita global food waste at the retail and consumer levels and reduce food losses along production and supply chains, including postharvest losses" (UN, 2017). The European Commission (EC) has also committed to achieve SDGs including the 12.3 (EC, 2016). In addition, EC has identified food waste as one of the priority areas of the European Circular Economy Action Plan (EC, 2015). This plan presents a set of actions to be implemented in

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Europe to facilitate and promote the transition towards circular economy, "where the value of products, materials and resources is maintained in the economy for as long as possible, and the generation of waste is minimized" (EC, 2015).

In the last years, food waste quantification has aroused considerable interest, reflected by the increasing availability of data on food waste generation along the food supply chain at various geographical scales. Corrado and Sala (2018) reviewed 10 studies focused on food waste. The reviewed studies reported that food waste generation along the supply chain ranged between 194 and 389 kg per person per year at the global level and between 158 and 290 kg per person per year when referring to the European scale. The latest estimate produced by Eurostat reported 149 kg per capita food waste in EU in 2014 (EC, 2018). The highest share of food waste was in most cases produced at the consumption stage, followed by the food manufacturing stage. However, it was also observed that estimations for different stages were quite uncertain and further in-depth analysis would be advisable. Caldeira et al. (2017) observed that the share of food waste generated in each stage varies according to the food waste definition adopted and the sources of data. For example, Bräutigam et al. (2014) and FAO (2011) reported a considerable amount of food waste generation at primary production and postharvest stages (43% and 47%, respectively) which was, instead, completely excluded by Monier et al. (2010), Tisserant et al. (2017), and Alexander et al. (2017), or only partly captured in van Holsteijn et al. (2017) and FUSIONS (2016). The distribution stage was found to generate a lower amount of food waste than other stages in all the analyzed studies.

When dealing with supply chains, Life cycle assessment (LCA) is a key methodology to assess environmental impacts of products taking into account all phases during their life cycle, from raw material extraction through processing, distribution, and use until the end of life (EoL). The use of LCA to assess environmental impacts of food has been increasing over time, aiming at assessing the sustainability of the food system (Sala et al., 2017a). Most of the studies available in the literature related to the environmental impacts of food consumption have been focused on climate change, acidification, and eutrophication impacts (McClelland et al., 2018). Other environmental impacts associated to the food production increasingly studied are water consumption (e.g., Lundqvist et al., 2008), land use (e.g., Meier et al., 2014), and biodiversity loss (Wolff et al., 2017; Crenna et al., 2019).

Current food production and consumption patterns are considered unsustainable. According to FAO (2010, p.10), "Sustainable diets are those diets with low environmental impacts which contribute to food and nutrition security and to healthy life for present and future generations". Sustainable diets are protective and respectful of biodiversity and ecosystems, culturally acceptable, accessible, economically fair and affordable, nutritionally adequate, safe, and healthy, while optimizing natural and human resources. Due to current concerns, dietary guidelines set by different national bodies are now including sustainability issues in their recommendations [e.g., the Nordic Nutrition Recommendations (Brugård Konde et al., 2015)].

Different food products have different environmental impacts and food waste rates, thus foods included in the diet and food waste generation among different food types have significant impact on the environmental impacts. Generally, meat has higher impacts compared with plant-based food due to the land and other inputs needed for feed production, but also due to enteric fermentation of beef cattle (Notarnicola et al., 2017). Thus, 1 kg of animal-based food waste has often higher environmental impact compared with 1 kg of plant-based food waste. Similarly, diets containing animal-based food have a higher environmental impact compared with a vegetarian diet (van Dooren et al., 2014). However, food waste rate is typically higher in plant-based food compared with animal-based food (FAO, 2011).

Food waste can be included in LCA studies using different approaches. Corrado et al. (2017) reviewed 100 studies aiming at identifying which approaches have been used to account for food waste in LCA applied on food products. According to Corrado et al. (2017), food waste has not been defined or included systematically in LCA studies. When included, different approaches have been adopted. For example, avoidable food waste at the processing stage was explicitly reported only in few studies. Conversely, possibly avoidable and unavoidable food waste at the processing stage were reported in a higher number of studies. Depending on the process, the amount of food waste can be relevant and the modeling approach adopted can considerably influence the LCA results.

Beretta et al. (2017) quantified environmental impacts of Swiss food consumption and environmental impacts of food waste along the food supply chain. They considered 33 food categories, which represent the whole food basket in Switzerland. They also included impacts of food waste treatment. In terms of climate change, the food waste related emissions were estimated to be 25% of the total emissions of consumed food. In addition, Beretta et al. (2017) observed that food waste at the end of the food value chain (households and food services) causes almost 60% of the total climate impact of food waste, because of large food waste quantities at this stage and higher accumulated impacts per kg of product.

Eberle and Fels (2016) assessed environmental burdens of food consumption and food waste in Germany. The German food basket was differentiated between in-house consumption and out-of-home consumption. Both baskets contained the same food items but in different quantities. Food waste along the food chain had a share of 15%–21% of environmental impacts of the food basket. Eberle and Fels (2016), however, did not made any distinction between avoidable and unavoidable waste. Results also showed that animal products, such as meat and dairy, cause most of the environmental burden of food consumption and food waste, although the share of plant products was higher regarding amounts of consumption and waste.

Scherhaufer et al. (2018) estimated the potential scale of food waste related impacts based on available food waste data on European level using nine indicator products (apple, tomato, potato, bread, milk, beef, pork, chicken, and fish). Food waste was considered as the edible or inedible part of food removed from supply chain and sent to food waste treatment and disposal facilities. The share of the food waste related impacts was from 15.1% to 15.7% of the overall food consumption impacts, depending on impact category. Most of the food waste related impacts derived from the primary production.

The aim of this chapter is firstly to calculate environmental impacts of food consumption of an average EU-28 citizen in 2015, taking into account the apparent consumption of food in EU-28 countries and food waste generation along the food chain. Secondly, the aim is to assess the environmental impacts of food waste, taking into account impacts from waste treatment of wasted food and additional food production, when part of the food is wasted. Moreover, scenarios for food waste reduction and alternative diets are defined, to assess the impact of food waste reduction and diet change when compared to the overall environmental impacts of food consumption.

## 11.2 Materials and methods

Materials and methods used in this study are presented in this section. First, the food products included in the study and their amounts are presented, then the LCA-based method to calculate the environmental impacts of food consumption in different life cycle stages, as well as the amount of food waste used in the study. Finally, different scenarios related to food waste reduction and dietary shift are illustrated.

### *11.2.1 Basket of representative food products*

In 2017, Notarnicola et al. (2017) published a study on the environmental impact of food consumption in Europe in 2010, focusing on a selection of food products covering 61% of food consumption. The reference flow was the amount of food consumed by an average EU-27 citizen in the reference year 2010. It consisted of a process-based life cycle inventory (LCI) model for a basket of products (BoP) that represented the most relevant food product groups, selected by importance in mass and economic value, to depict the average consumption for nutrition of EU citizens in 2010 (Notarnicola et al., 2017). The product groups in the original BoP were meat, dairy products, cereal-based products, sugar, oils, tubers, fruits, coffee, beverages, and pre-prepared meals.

The work done by Notarnicola et al. (2017) has been complemented with the new products in accordance to their relevance in terms of environmental impacts, for example, biodiversity and water use, even if their consumption amount was not so high. Also, products with high share of imports, and products representative of new trends in nutrition, for example, sources of vegetable proteins, nuts, and seeds, were added to the BoP food. In addition, the reference flow was updated to be the amount of food consumed by an average EU-28 citizen in the reference year 2015. The functional unit was defined as the average food consumption per person in the EU in terms of food categories.

The new product groups added to the basket were fish and seafood, eggs, vegetables, legumes, nuts and seeds, and confectionery products. Moreover, some products under existing products groups were added (rice, bananas, and tea). All products and their apparent consumption (=production + import−export) in 2015 are presented in Table 11.1 (Eurostat, 2018).

**Table 11.1** Composition of the BoP food in terms of product groups, representative products, and related quantities referred to the reference flow new products in the basket on top of those in Notarnicola et al., 2017 are marked with*

| Product group | Representative product | Per-capita consumption (kg/pers.[a]$yr^{-1}$) | Share from the whole basket (%) |
|---|---|---|---|
| Meat | Pork meat | 44.9 | 6.6 |
| | Beef meat | 15.2 | 2.2 |
| | Poultry meat | 26.3 | 3.9 |
| Fish and seafood | Cod* | 10.4 | 1.5 |
| | Salmon* | 3.5 | 0.5 |
| | Shrimp* | 1.5 | 0.2 |
| Dairy | Milk | 78.4 | 11.5 |
| | Cheese | 15.1 | 2.2 |
| | Butter | 4.4 | 0.6 |
| Eggs | Eggs* | 14.0 | 2.0 |
| Cereal-based products | Bread | 40.0 | 5.9 |
| | Pasta | 9.3 | 1.4 |
| | Rice* | 9.6 | 1.4 |
| Sugar | Sugar | 28.6 | 4.2 |
| Oils | Sunflower oil | 5.7 | 0.8 |
| | Olive oil | 4.7 | 0.7 |
| Tubers | Potatoes[a] | 68.5 | 10.0 |
| Vegetables | Tomatoes* | 14.5 | 2.1 |
| Legumes | Beans* | 2.8 | 0.4 |
| | Tofu[b]* | 4.3 | 0.6 |
| Fruits | Apples | 17.5 | 2.6 |
| | Oranges | 13.0 | 1.9 |
| | Bananas* | 11.5 | 1.7 |
| Nuts and seeds | Almonds[a]* | 0.6 | 0.1 |
| Coffee and tea | Coffee | 3.3 | 0.5 |
| | Tea* | 0.6 | 0.1 |
| Beverages | Beer | 70.0 L | 10.2 |
| | Wine | 26.0 L | 3.8 |
| | Mineral water | 122.3 L | 17.9 |
| Confectionery products | Biscuits* | 7.1 | 1.0 |
| | Chocolate* | 6.0 | 0.9 |
| Preprepared meals | Meat-based dishes | 3.4 | 0.5 |

[a]Based on 2013 data, since 2015 data was not available.
[b]Based on EFSA (2018).

### 11.2.2 Calculation of environmental impact of food consumption

Environmental impacts were calculated using LCA approach and modeled with SimaPro 8.5 software. Included life cycle stages were agriculture, industrial processing, packaging, logistics, retail, use, and EoL (Table 11.2). The same stages were

**Table 11.2** Summary of life cycle stages and related activities included in the BoP food

| Life cycle stage | Activities included |
|---|---|
| Agriculture/breeding | Cultivation of crops<br>Animal rearing<br>Food waste management |
| Industrial processing | Processing of ingredients<br>Slaughtering and processing<br>Chilled or frozen storage<br>Food waste management |
| Logistics | International transport of imports<br>Transport to processing<br>Transport to regional distribution center<br>Transport to retailer<br>Food waste management |
| Packaging | Manufacture of packaging<br>Final disposal of packaging |
| Retail | Storage at retail<br>Food waste management |
| Use | Transport of the products from retailer to consumer's home<br>Refrigerated storage at home<br>Cooking of the meal |
| EoL | Final disposal of food waste<br>Wastewater treatment and auxiliary processes due to human excretion |

also included in the original BoP food (Notarnicola et al., 2017). The most representative datasets for each product in the basket were identified from existing LCA literature. LCI data sources of the agriculture and production stages of the new products in BoP food are summarized in Table 11.3. Data sources for other stages can be found in the following sections. Data sources and LCI results of original products can be found in Notarnicola et al. (2017) and Castellani et al. (2017). All the agricultural datasets, taken from the literature or from databases, have been modified to adapt them to the method and assumptions reported in Notarnicola et al. (2017).

### *11.2.2.1 Agricultural stage*

Emissions from agriculture were calculated using methodology described in Notarnicola et al. (2017), that is, $N_2O$ emissions from managed soils, $CO_2$ emissions from lime and urea application, $NH_3$ emissions to air and nitrates leaching in the soil were estimated according to the IPCC guidelines (IPCC, 2006). It was assumed that all nitrogen that volatizes converts to ammonia, and all nitrogen that leaches is emitted as nitrate. It was also estimated that 5% of phosphorus applied through fertilizers is emitted to freshwater resources (Blonk Consultants, 2014). The emissions of pesticides during their use were also taken into account, assuming

**Table 11.3** Overview of LCI datasets relative to the agriculture and processing phase of new products in the BoP food

| Representative product | Activities | Geographical scope of the data source | References |
|---|---|---|---|
| Wild cod | • Fishing<br>• Processing of cod fillets | Sweden | Svanes et al. (2011) |
| Farmed salmon | • Salmon aquaculture<br>• Slaughtering<br>• Processing of salmon fillets | Norway | Pelletier et al. (2009), Ellingsen et al. (2009) |
| Shrimp | • Shrimp aquaculture<br>• Processing | China | Cao et al. (2011) |
| Eggs | • Laying hens | The Netherlands | Blonk Consultants (2014) |
| Rice | • Rice cultivation<br>• Rice processing | Italy | Blengini and Busto (2009), Water: Chapagain and Hoekstra (2010) |
| Tomatoes | • Tomato cultivation | Spain | Torrellas et al. (2012) |
| Beans (dry) | • Bean cultivation and drying | The Netherlands | Blonk Consultants (2014) |
| Tofu | • Soybean cultivation | Brazil, Argentina, and The United States | Blonk Consultants (2014) |
| | • Production of tofu | The United States (adapted to Europe) | Mejia et al. (2017) |
| Bananas | • Banana cultivation<br>• Postharvest handling | Ecuador | Iriarte et al. (2014), Water: Mekonnen and Hoekstra (2011), Dole (2011) |
| | • Ripening | Europe | Svanes and Aronsson (2013) |
| Almonds | • Almond cultivation<br>• Almond processing | Greece | Bartzas et al. (2017), Kendall et al. (2015) |
| Tea | • Tea cultivation<br>• Tea processing | Average of Kenya, India, and Indonesia, processing in the United Kingdom | Jefferies et al. (2012) |

(*Continued*)

**Table 11.3** (Continued)

| Representative product | Activities | Geographical scope of the data source | References |
|---|---|---|---|
| Biscuits | • Wheat cultivation and flour production<br>• Sugar beet cultivation and sugar production<br>• Oil palm cultivation and palm oil production<br>• Laying hens (producing eggs)<br>• Dairy cattle breeding and milk production | Europe and Indonesia (palm oil) | Blonk Consultants (2014) |
| | • Baking of biscuits | Europe | Noya et al. (2018) |
| Chocolate | • Cocoa bean cultivation<br>• Cocoa processing | Ghana | Ntiamoah and Afrane (2008) |
| | • Chocolate production | Italy | Recanati et al. (2018) |

that 100% of the active pesticide ingredient is emitted to soil (de Beaufort-Langeveld et al., 2003).

LCIs of the cultivation of new plant-based products are presented in Table 11.4. LCI results of original products in BoP food can be found in Notarnicola et al. (2017) and Castellani et al. (2017). The emissions from the combustion of diesel in agricultural machinery are not reported in Table 11.4, but are considered in the inventory according to data in the agri-footprint database (Blonk Consultants, 2014).

Table 11.5 shows the LCIs of the farming phase of salmon and shrimp aquaculture, and egg production. The table reports the feed used, the water consumed, and energy inputs as well as main emissions to the air and water. Economic allocation was used to allocate burdens between eggs and meat in the farming phase. Fish processing is also producing some coproducts, for example, heads and guts, which can be used as fish feed after processing. However, in this study, no burdens were

**Table 11.4** Life cycle inventories of the cultivation of plant-based products or main ingredients used in new products added to the BoP food (per cultivated ha per year), excluding inventories of products based on agri-footprint database (i.e., inventories of beans and some ingredients used in modeling new products, e.g., soybeans)

| | Unit | Banana | Tomato | Rice | Cocoa beans | Almonds | Tea |
|---|---|---|---|---|---|---|---|
| Products | t | 32.8 | 166.7 | 7.0 | 25.5 | 3.3 | 1.7 |
| Coproducts (total weight) | t | 0 | 0 | 8.4 | 0 | 0 | 0 |
| **Inputs** | | | | | | | |
| N fertilizer | kg | 295 | 798 | 130 | 0 | 180 | 306 |
| P fertilizer | kg | 38 | 506 | 18 | 818 | 100 | 728 |
| K fertilizer | kg | 131 | 1562 | 135 | 670 | 200 | 128 |
| Lime | kg | 22 | 0 | 0 | 0 | 0 | 0 |
| Pesticides (total weight) | kg | 15 | 46.5 | 16.7 | 210 | 8.2 | < 0.1 |
| Irrigation water | $m^3$ | 3083 | 4748 | 4087[a] | 131 | 4650 | 136 |
| Diesel | kg | 108 | 0 | 95.5 | 0 | 539 | 14.3 |
| Heat | MJ | 0 | 0 | 4280 | 0 | 0 | 0 |
| Electricity | kWh | 10 | 6485 | 51 | 0 | 803 | 0 |
| **Outputs** | | | | | | | |
| ***Emissions to air*** | | | | | | | |
| $N_2O$ from fertilizers | kg | 6.1 | 16.6 | 2.7 | 0 | 3.7 | 6.4 |
| $NH_3$ from fertilizers | kg | 35.9 | 97.0 | 15.8 | 0 | 21.9 | 37.2 |
| $CO_2$ from fertilizers | kg | 9.5 | 0 | 80.1 | 0 | 0 | 0 |
| $CH_4$ from field | kg | 0 | 0 | 338 | 0 | 0 | 0 |
| ***Emissions to water*** | | | | | | | |
| $NO_3$ from fertilizers | kg | 88.6 | 239.4 | 39.0 | <0.1 | 54 | 91.8 |
| P from fertilizers | kg | 1.9 | 25.3 | 1.0 | <0.1 | 5.0 | 36.4 |
| ***Emissions to soil*** | | | | | | | |
| Chlorpyrifos | kg | 0 | 3.8 | 0.2 | 9.1 | 0 | 0 |
| Captan | kg | 0 | 0 | 0 | 0 | 4.1 | 0 |
| Glyphosate | kg | 2.8 | 0 | 0.8 | 0 | 0 | 0 |
| Mancozeb | kg | 6.2 | 28.5 | 0 | 142 | 0 | <0.1 |
| Diuron | kg | 0 | 0 | 0.1 | 0 | 0 | 0 |
| Bispyribac-sodium | kg | 0 | 0 | 0.3 | 0 | 0 | 0 |
| Pretilchlor | kg | 0 | 0 | 4.6 | 0 | 0 | 0 |

[a]Takes into account water uptake of the rice and available rainwater in the area. Although rice is usually cultivated in flooded field, part of this water can be captured and reused downstream (Chapagain and Hoekstra, 2010).

**Table 11.5** Life cycle inventories of the farming phase of animal-derived products

| | Unit | Salmon aquaculture | Shrimp aquaculture | Egg production |
|---|---|---|---|---|
| Products | kg | 1000 | 1000 | 1000 |
| Coproducts (total weight) | kg | – | – | 67.7 |
| ***Inputs*** | | | | |
| Compound feed | kg | 1103 | 1600 | 2162 |
| Water | $m^3$ | – | – | 3.5 |
| Heat from gas | MJ | 0.1 | – | – |
| Diesel | kg | 12.8 | – | – |
| Electricity | kWh | 20.1 | 2550 | 98.0 |
| ***Outputs*** | | | | |
| $CH_4$, biogenic | kg | – | – | 1.3 |
| $N_2O$ | kg | – | – | 0.4 |
| $NH_3$ | kg | – | – | 19.6 |
| N to water | kg | 41.1 | 66 | – |
| P to water | kg | 5.2 | 9 | – |

allocated to the coproducts of fish filleting, because according to other studies (e.g., Ellingsen et al., 2009) fish filleting coproducts have very small economic value. In addition, in the fish feed process, used as salmon feed, no burdens were allocated to raw material derived from fish coproducts.

### 11.2.2.2 Packaging, logistics, and retail

Table 11.6 reports the amounts of packaging inventoried for each product added to the BoP food [see inventories for original product in Notarnicola et al. (2017) and Castellani et al. (2017)]. Packaging types and amounts were mainly obtained from LCA studies presented in Table 11.3, with exception of beans and almonds, for which the information was not available. Thus, the package type and amount of beans and almonds were estimated according to other food products, assuming to be packed into plastic bags with the same weight as plastic package used in tofu packaging [according to Mejia et al. (2017)]. In addition, tomato packaging amount was based on Cellura et al. (2012) and egg packaging was based on Sonesson et al. (2008).

Logistics consists of international transportation from outside the EU, transport of raw materials to the processing site, and transport of processed goods from industry to retailing. The transport of imported products was assumed to occur from the capital of the exporting country to the city of Frankfurt, which was considered a central destination for the arrival of imports in Europe. For exporting countries directly connected to Europe by land, such as Switzerland or Belarus, only a transport by lorry was considered from the capital of the exporting country to the city of

**Table 11.6** Amounts of packaging per typology, grams per 1 kg packaged product

| Food product | Cardboard | Corrugated board box | Kraft paper | Cellulose fiber | Aluminum | LDPE | PS |
|---|---|---|---|---|---|---|---|
| Cod | 100 | – | – | – | – | – | – |
| Salmon | – | – | – | – | – | – | 25 |
| Shrimp | 135 | – | – | – | – | 10.5 | – |
| Eggs | 69 | – | – | – | – | – | – |
| Rice | 50 | | | | | 10 | |
| Tomatoes | – | 89.2 | – | – | – | – | – |
| Beans | – | – | – | – | – | 39 | – |
| Tofu | 93 | – | – | – | – | 39 | – |
| Bananas | – | 112.3 | – | – | – | 3.3 | – |
| Almonds | – | – | – | – | – | 39 | – |
| Tea | 260 | 280 | 440 | 10 | – | 42 | – |
| Biscuits | 170 | – | – | – | – | 5 | – |
| Chocolate | 118 | – | – | – | 18 | – | – |

Frankfurt. For the others, the transport was considered to be composed by a transport by lorry between the capital of the exporting country and the country's main port; a transport by ship from the port of the exporting country to the main European ports of goods (Rotterdam or Marseilles), and, finally, a transport by lorry between the port of destination and the city of Frankfurt. The distances were calculated by using http://www.sea-distances.org (transport by ship) and Google maps (transport by lorry). This transport was allocated to a percentage of the final product in the LCI model, corresponding to the share of imported goods out of the total apparent consumption of that kind of product. Distances and shares of imported products of new products are reported in Table 11.7. The same information for products originally in the BoP food can be found in Castellani et al. (2017).

The use of refrigerants (both load and leakage) was included in the inventory of refrigerated/frozen transportation and storage in retail phase when applicable (fish, shrimp, eggs, bananas, tomatoes). Refrigerant R404A was considered, as it is the most commonly used refrigerant in Europe. The LCA data for the production of the refrigerants were according to Bovea et al. (2007).

### *11.2.2.3 Use phase and end of life*

The use phase consists of transport of food to consumer home and domestic consumption. It was assumed that 30 products were bought in a single purchase, including food and nonfood products. The impact of transport was therefore allocated between the purchased products considering that each product is one of 30 items purchased (3.33% of the transport burden) (Vanderheyden and Aerts, 2014).

Refrigerated storage at home is included in the life cycle of salmon and tofu (2 days), and frozen storage for cod and shrimp (10 days). The electricity consumption of the domestic refrigerator was assumed to be 0.0023 kWh/L per day and the

**Table 11.7** Summary of the share of imported food products, sea transport distances and road transport distances for products added to the BoP food

| Product | Import (%) | Sea transport (tkm) per kg of product imported | Road transport (tkm) per kg of product imported |
|---|---|---|---|
| Fish (cod and salmon) | 66.9 | 4.62 | 0.57 |
| Shrimp | 64.7 | 10.42 | 1.12 |
| Eggs | 0.1 | 2.35 | 1.26 |
| Rice | 28.4 | 9.44 | 1.44 |
| Tomatoes | 7.7 | 1.87 | 0.53 |
| Beans | 16.5 | 3.76 | 0.84 |
| Soy beans for tofu | 92.8 | 7.13 | 2.16 |
| Bananas | 87.4 | 9.37 | 0.79 |
| Almonds | 35.8 | 6.27 | 0.68 |
| Tea | 100 | 10.48 | 1.46 |
| Wheat for biscuits | 4.2 | 2.19 | 0.29 |
| Palm oil for biscuits | 100 | 12.83 | 1.04 |
| Sugar for biscuits and chocolate | 4.5 | 0.43 | 0.10 |
| Cocoa beans for chocolate | 100 | 7.26 | 0.99 |

electricity consumption of the freezer was assumed to be 0.0042 kWh/L per day (Nielsen et al., 2003).

Regarding home preparation, the following specific energy consumptions were considered (Foster et al., 2006; Jefferies et al., 2012):

- Boiling of eggs: 2 MJ of natural gas per kg eggs (50% of eggs assumed to be boiled).
- Boiling of presoaked beans: 5.5 MJ of natural gas per kg beans.
- Boiling of rice: 1.7 MJ of natural gas per kg rice.
- Frying: 7.5 MJ of natural gas per kg product [fish, tofu, eggs (50% eggs assumed to be fried)].
- Boiling of tea: 49.5 MJ of natural gas per kg tea.

In addition, water consumption in cooking was taken into account when applicable (e.g., boiling of food) and related waste water treatment (e.g., waste water from bean cooking).

The EoL stage was modeled taking into account both burdens of waste management and benefits of recycling and reuse. The end-of-life phase includes packages, treatment of food scraps and unconsumed foods, together with the human metabolism, modeled according to the method of Muñoz et al. (2007). Specifically, each food product was considered in terms of its nutritional composition (e.g., fiber/carbohydrate/protein) to account for the impacts of human excretion (Ciraolo et al., 1998).

### 11.2.3 Food waste quantification

In this study, food waste was considered as food that is intended for human consumption but is not consumed, that is, avoidable food waste. The estimation of food waste generated in the different production stages was mainly based on FAO (2011). However, some LCA studies, used as data sources in this study, included also food waste generation from processing (Kendall et al., 2015; Pelletier et al., 2013; Noya et al., 2018), in this case these data were used also in this study. For eggs, chocolate and biscuits, the food waste amount from the household was not available in FAO (2011), instead WRAP (2014) data was used. In case of tofu, the food waste amount was not available at any stage, thus the waste generation was assumed to be equal to that for oilseed and pulses reported by FAO (2011). In case of tea and chocolate, food waste amount in processing and retail was not available, thus FAO (2011) values of cereals (tea) and oilseed and pulses (cocoa bean processing and chocolate retail) were used.

Amounts of the avoidable food waste used in the baseline modeling are presented in Table 11.8. In most of the products, the waste amount from agricultural phase is zero, because usually agricultural losses are taken into account already in estimating the yield, that is, the inputs used in cultivation are per yield that is harvested, but the real yield could be higher if part of the yield is left to the field or lost otherwise.

Emissions from food waste treatment were calculated assuming the average waste treatment scenario for Europe based on Eurostat data (Eurostat, 2014), where 8% of industrial food waste is sent to landfill, 5% is incinerated, and 87% is sent to other recovery treatments (composting and biogas production). In case of household wastes, 59.9% is sent to landfill, 33.3% to energy recovery, and 9.8% to other recovery than energy (Eurostat, 2014). In addition to emissions and benefits from waste treatment (e.g., energy recovery from biogas production), the food waste amount was also taken into account when calculating how much food was actually produced compared with apparent consumption in EU-28. Apparent consumption was assumed to be equal to food consumed in households, and this amount was increased according to amount of wasted food, that is, in the zero waste situation all food produced would be eaten, but when food is wasted along the food chain, the wasted amount increases the food production amount in previous phases. An example of an approach can be seen in Fig. 11.1.

### 11.2.4 Food waste reduction and dietary shift scenarios

In addition to the average food consumption in the EU, different scenarios were developed to assess the differences in the environmental impacts when the food waste amount is reduced or the diet is changed. The United Nations Sustainable Development Goals has the target 12.3 focusing on food waste reduction. The higher reduction target is on retail and consumer level (50% reduction by 2030), but the aim is to reduce food losses also in other phases (UN, 2017). The food waste reduction scenarios assessed in this study were:

**Table 11.8** Avoidable food waste used in the baseline modeling; processing phase includes also postharvest selection

| | Agriculture (%) | Processing (%) | Logistics and retail (%) | Household (%) |
|---|---|---|---|---|
| Meat | 0 | 5 | 4 | 11 |
| Fish and shrimp | 0 | 6 | 9 | 11 |
| Milk | 3.5 | 1.7 | 0.5 | 7 |
| Cheese and butter | 3.5 | 0 | 3.4 | 3.4 |
| Eggs | 0 | 1.1 | 4 | 6.5 |
| Bread | 0 | 5 | 2 | 25 |
| Pasta | 0 | 7 | 2 | 25 |
| Rice | 0 | 10 | 2 | 25 |
| Sugar | 0 | 0 | 0 | 17.2 |
| Sunflower oil | 10 | 6 | 1 | 4 |
| Olive oil | 0 | 0 | 0 | 13.6 |
| Potatoes | 0 | 0 | 7 | 17 |
| Tomatoes | 0 | 5 | 10 | 19 |
| Legumes | 0 | 5 | 1 | 4 |
| Apples | 0 | 15 | 10 | 19 |
| Oranges | 0 | 20 | 10 | 19 |
| Bananas | 0 | 5 | 10 | 19 |
| Almonds | 0 | 7.5 | 2 | 4 |
| Coffee | 0 | 0 | 0 | 32 |
| Tea | 0 | 10.5 | 2 | 33.3 |
| Beer | 0 | 0 | 0 | 10 |
| Wine | 0 | 0.3 | 1 | 10 |
| Mineral water | – | 0 | 0 | 10 |
| Biscuits | 0 | 2.3 | 2 | 4.3 |
| Chocolate | 0 | 5 | 1 | 4.4 |
| Meat-based dishes | 0 | 3.1 | 1 | 24 |

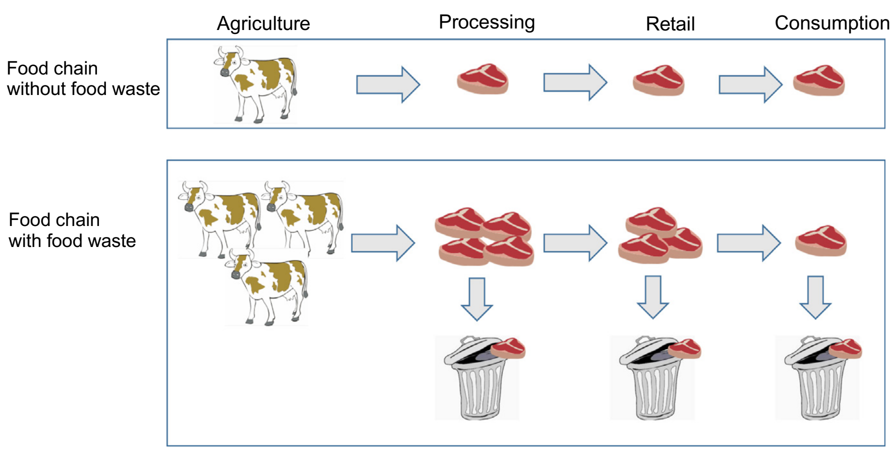


**Figure 11.1** Example of the approach used in this study to calculate environmental impacts of food consumption and food waste of an average EU-28 citizen.

1. linear reduction in all phases and all product groups (food waste −50% in all products and all phases),
2. food waste reduction in retail and households (food waste −50% in retail and household phases of all products),
3. food waste reduction in animal-based products (food waste −50% in all phases of all animal-based products), and
4. food waste reduction in plant-based products (food waste −50% in all phases of all plant-based products).

Different diets were selected to see how changes in food products consumed would affect the environmental impact of diet and food waste, because different foods have different food waste intensities and different environmental impact (e.g., meat vs plant proteins). Dietary change scenarios were defined according to literature based on:

1. Swedish nutrition recommendations, which take into account both nutritional value and sustainability aspects of food (Brugård Konde et al., 2015),
2. Mediterranean diet containing less meat and more fish, fruits, and vegetables compared to other diet in Europe (van Dooren et al., 2014), and
3. Vegetarian diet without meat and fish but including eggs and dairy products (van Dooren et al., 2014).

In some cases, it was necessary to adjust the original diet proposals to keep different diets at a reasonable level in terms of energy, protein, fat, and carbohydrate intake, and because representative products included in the BoP food did not cover all recommended food. Due to nature of the different diets, the purpose was not to have exactly the same protein, fat, and carbohydrate intakes with different diets, but to keep them at a reasonable level, for example, to make sure that fat intake from food is not too high related to all food consumed, or that the amount of carbohydrates is high enough.

Swedish nutrition recommendations are based on Nordic Nutrition Recommendations, which set maximum amounts for red meat (max 500 g per week), sugar (max 10% of energy), and alcohol (max 5% of energy), and minimum amounts for fruits and vegetables without potatoes (min 500 g per day) (Brugård Konde et al., 2015). These amounts were used in this study under the assumption that equal amounts of fruits and vegetables are consumed, 250 g per day both. There are also recommended amounts for dairy products (2−5 dL per day), fish (2−3 times per week), and nuts and seeds (couple of tablespoon per day), when amount of milk and cheese was assumed to be 350 g per day (average from recommendation), fish amount 300 g per week (three times 100 g), and almonds 30 g per day. In addition, there is recommendation to use whole-grain pasta and rice, and unsweetened dairy products, which could not be included in our study, because BoP food includes only traditional pasta and rice, and all dairy products are already unsweetened. Recommendation to use healthy oils, for example, rapeseed oil, was included by removing butter from the diet. Amount of vegetable oils was not increased because energy intake from fat was already at the level it should be (35% from total energy intake). The amount of sugar was decreased by 50% compared with the baseline to achieve the target that only 10% of energy intake is from sugar. After decreasing sugar, the carbohydrate and energy intake was very low. Because of that, the amounts of bread and pasta were increased by 50%. Amount of drinks and preprepared food was kept the same as the average diet.

Mediterranean and vegetarian diets were adapted from van Dooren et al. (2014), making some small adjustments as follows. Diets reported in van Dooren et al. (2014) did not include any sugar, biscuits, chocolate, almonds, coffee, or tea, so the amount of those was mainly kept the same as in the baseline. In addition, amount of alcohol and beverages was kept constant to keep different diets more comparable. However, the energy intake was much higher in Mediterranean and vegetarian diets, so the amount of sugar, biscuits, and chocolate was halved in the end. Even after that, energy content of the Mediterranean diet was higher compared with other diets.

In the data sources of all additional diet scenarios (van Dooren et al., 2014; Brugård Konde et al., 2015), the data was not divided between different meat, fish, oils, and fruits as it was done in BoP food. The division between different meat, fish, oil, and fruits was done according to division in average EU consumption, for example, 40.8% of fruits were assumed to be apples, 27.6% oranges, and 31.6% bananas as was in the baseline diet. In addition, tomato was the only vegetable included in the BoP food, although tomatoes represent only 9.5% of vegetables eaten in the EU. The amount of tomatoes was upscaled to represent all vegetable consumption, because in diet scenarios vegetables have a significant role. Energy content of tomatoes is lower compared with many other vegetables, so also the total energy content of whole diets can be slightly lower compared with real diet with varying vegetables. Food amounts, energy, protein, fat, and carbohydrate intakes, as well as energy from sugar and alcohol related to each diet, are presented in Table 11.9.

Total mass of consumed food is very low in the baseline diet, because quite a big part of energy comes from sugar (17%). Energy intake is also lower compared with other diets, but difference from the Swedish recommended diet and vegetarian diet is not very big. Contrarily, the protein intake is highest in the baseline. In fact, protein intake is higher than recommended protein intake, 0.8 g protein per kg of weight, which means 60 g protein per day if the weight is 75 kg (Pendick, 2015), in all other diets except in vegetarian diet, where protein intake is 59.4 g per day. Fat intake is at the same level in all diets, being little higher in the Swedish recommended diet. Carbohydrate intake is much higher in the Mediterranean and the vegetarian diets compared with the other two diets.

## 11.3 Results

LCIs of BoP food were characterized using EF 2017 midpoint life cycle impact assessment method (Sala et al., 2017b; EC, 2017). This section represents the characterized results of the average EU-28 citizen food consumption as baseline results, and then the results of different scenarios compared with baseline results, related to either food waste reduction or dietary shift.

**Table 11.9** Differences between the diet scenarios tested in this study, in terms of amounts per food product. At the end of the table the energy, protein, fat, and carbohydrate intakes as well as the percentage of energy deriving from sugar and from alcohol are reported.

| Representative product | Unit | Baseline | Swedish recommendations | Mediterranean diet | Vegetarian diet |
|---|---|---|---|---|---|
| Pork meat | g/day | 99.6 | 37.1 | 15.6 | 0 |
| Beef meat | g/day | 33.7 | 12.6 | 5.3 | 0 |
| Poultry meat | g/day | 58.4 | 21.7 | 9.1 | 0 |
| Cod | g/day | 21.1 | 28.9 | 25.0 | 0 |
| Salmon | g/day | 7.1 | 9.7 | 8.4 | 0 |
| Shrimp | g/day | 3.0 | 4.2 | 3.6 | 0 |
| Milk | g/day | 187.5 | 292.2 | 300 | 450 |
| Cheese | g/day | 37.1 | 57.8 | 15 | 30 |
| Butter | g/day | 10.8 | 0 | 0 | 0 |
| Eggs | g/day | 33.9 | 33.9 | 29 | 29 |
| Bread | g/day | 74.5 | 111.8 | 210 | 210 |
| Pasta | g/day | 16.8 | 25.2 | 50.4 | 30.7 |
| Rice | g/day | 16.6 | 16.6 | 49.6 | 30.3 |
| Sugar | g/day | 64.9 | 32.4 | 32.4 | 32.4 |
| Sunflower oil | g/day | 12.3 | 12.3 | 23.7 | 23.7 |
| Olive oil | g/day | 11.1 | 11.1 | 21.3 | 21.3 |
| Potatoes | g/day | 142.6 | 142.6 | 25 | 117 |
| Tomatoes | g/day | 276.0 | 250 | 300 | 200 |
| Beans | g/day | 6.9 | 6.9 | 75 | 11 |
| Tofu | g/day | 10.6 | 10.6 | 4 | 43 |
| Apples | g/day | 26.8 | 102 | 102 | 81.6 |
| Oranges | g/day | 18.2 | 69 | 69 | 55.2 |
| Bananas | g/day | 20.8 | 79 | 79 | 63.2 |
| Almonds | g/day | 1.4 | 30 | 1.4 | 1.4 |
| Coffee | g/day | 6.1 | 6.1 | 6.1 | 6.1 |
| Tea | g/day | 1.1 | 1.1 | 1.1 | 1.1 |
| Beer | g/day | 172.6 | 172.6 | 172.6 | 172.6 |
| Wine | g/day | 63.2 | 63.2 | 63.2 | 63.2 |
| Mineral water | g/day | 301.6 | 301.6 | 301.6 | 301.6 |
| Biscuits | g/day | 17.8 | 17.8 | 8.9 | 8.9 |
| Chocolate | g/day | 14.7 | 14.7 | 7.4 | 7.4 |
| Meat-based dishes | g/day | 6.7 | 6.7 | 0 | 0 |
| Total mass | Kg/day | 1.78 | 1.98 | 2.01 | 1.99 |
| Total energy | Kcal/day | 1948 | 2046 | 2348 | 2097 |
| Proteins | g/day | 84.2 | 80.7 | 77.8 | 59.4 |
| Fat | g/day | 76.7 | 79.8 | 73.8 | 75.7 |
| Carbohydrates | g/day | 204 | 222 | 312 | 272 |
| Energy from sugar | % | 17 | 10 | 7 | 8 |
| Energy from alcohol | % | 6 | 6 | 5 | 6 |

### 11.3.1 Baseline results

Characterized baseline results are presented in Table 11.10 divided into the emissions due to food consumption without any food waste (actual food consumption) and emissions caused by avoidable food waste. Emissions caused by food waste include both emissions and benefits from food waste treatment, and emissions due to additional production of food because part of the food is wasted. Emissions due to food waste generation are between 15% and 21% of the total emissions of food consumption of EU average citizen in the year 2015, depending on impact category. The lowest share is in the impact category human toxicity noncancer effect and the highest share is in mineral and metal resource use.

Meat consumption is the biggest contributor in almost all impact categories included in the study, except for human toxicity noncancer effect, ionizing radiation, water use, and mineral and metal resource use (Fig. 11.2). Highest contribution to the human toxicity noncancer effect is due to the consumption of dairy products, especially due to production of feeds. Drinks, including alcoholic and nonalcoholic drinks, coffee, and tea, have the highest contribution to water use, and mineral and metal resource use, because the consumed amount of drinks is high, so the amount of water in drinks and amount of materials used for packaging are also high. In addition, drinks have the highest contribution to ionizing radiation and quite high impact on fossil resource use due to high-energy consumption in the processing. In general, cereal-based products, fish, vegetables, oils, and fruits have low share of impacts in all impact categories. However, ozone depletion potential of fruits can be identified as a hotspot due to the refrigerants used in the transportation and storage of fruits. In case of fish, photochemical ozone formation and freshwater eutrophication have higher share of the impacts compared with other impact categories. High photochemical ozone formation potential is due to the high fuel consumption in cod fishing, and high eutrophication potential is due to the nutrient emissions from salmon aquaculture. Water use of cereal-based products is the second highest after drinks due to the high water consumption in rice cultivation.

In case of environmental impacts of the food waste, agriculture has the highest contribution to most of the impact categories (Fig. 11.3) because there is a need to produce more food when part of the food is wasted. In case of ozone depletion, retail has the highest contribution due to the refrigerants used in the storage of the cold or frozen products. Processing has high contribution to the ozone depletion, ionizing radiation, and resource use impacts due to the additional energy needed for the production of wasted food. In addition, packaging has quite high impact on resource use. EoL impacts, namely the treatment of the wasted food, has very low impact compared with other life cycle phases moreover, the EoL phase takes into account also benefits, for example, energy recovery from biogas process. EoL phase has the highest share in climate impact, 9% of the total climate impact of the wasted food.

### 11.3.2 Scenario results: food waste reduction

Results of the food waste reduction scenarios compared with the baseline scenario are presented in Fig. 11.4. Food production amount could be almost 10% lower if

**Table 11.10** Characterized baseline results of the food consumption of an average EU-28 citizen in 2015 and share between impacts due to food consumption and impacts attributable to avoidable food waste

| Impact category | Unit | Impacts due to actual food consumption | | Impacts due to avoidable food waste | | Total impacts due to food consumption including food waste | |
|---|---|---|---|---|---|---|---|
| | | **Value** | **%** | **Value** | **%** | **Value** | **%** |
| Climate change | kg $CO_2$ eq. | 1.90E + 3 | 82 | 4.08E + 2 | 18 | 2.31E + 3 | 100 |
| Ozone depletion | kg CFC-11 eq. | 2.71E−3 | 80 | 6.89E−4 | 20 | 3.40E−3 | 100 |
| Human toxicity, noncancer | CTUh | 1.45E−3 | 85 | 2.59E−4 | 15 | 1.71E−3 | 100 |
| Human toxicity, cancer | CTUh | 2.16E−5 | 83 | 4.44E−6 | 17 | 2.61E−5 | 100 |
| Particulate matter | Disease incidence | 1.94E−4 | 83 | 3.92E−5 | 17 | 2.33E−4 | 100 |
| Ionizing radiation | kBq $U^{235}$ eq. | 4.02E + 1 | 80 | 9.86E + 0 | 20 | 5.01E + 1 | 100 |
| Photochemical ozone formation | kg NMVOC eq. | 3.31E + 0 | 81 | 7.83E−1 | 19 | 4.09E + 0 | 100 |
| Acidification | molc $H^+$ eq. | 2.66E + 1 | 83 | 5.39E + 0 | 17 | 3.19E + 1 | 100 |
| Eutrophication, terrestrial | molc N eq. | 1.12E + 2 | 83 | 2.25E + 1 | 17 | 1.35E + 2 | 100 |
| Eutrophication, freshwater | kg P eq. | 5.40E−1 | 81 | 1.27E−1 | 19 | 6.67E−1 | 100 |
| Eutrophication, marine | kg N eq. | 1.27E + 1 | 82 | 2.77E + 0 | 18 | 1.55E + 1 | 100 |
| Ecotoxicity, freshwater | CTUe | 5.42E + 3 | 82 | 1.20E + 3 | 18 | 6.62E + 3 | 100 |
| Land use | Pt | 1.75E + 5 | 82 | 3.73E + 4 | 18 | 2.12E + 5 | 100 |
| Water use | $m^3$ water eq. | 4.16E + 3 | 81 | 9.89E + 2 | 19 | 5.15E + 3 | 100 |
| Resource use, fossils | MJ | 1.17E + 4 | 81 | 2.77E + 3 | 19 | 1.45E + 4 | 100 |
| Resource use, minerals and metals | kg Sb eq. | 2.14E−3 | 79 | 5.52E−4 | 21 | 2.69E−3 | 100 |

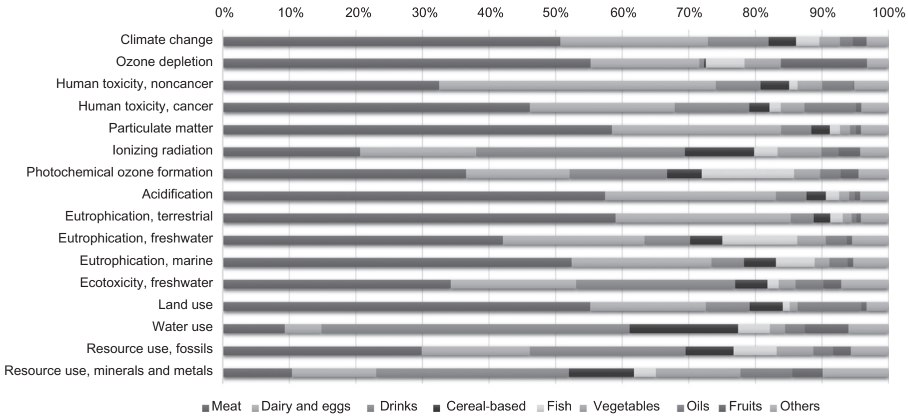


**Figure 11.2** Environmental impacts of food consumption of EU-28 average citizen with the breakdown of the contribution of the different product groups.

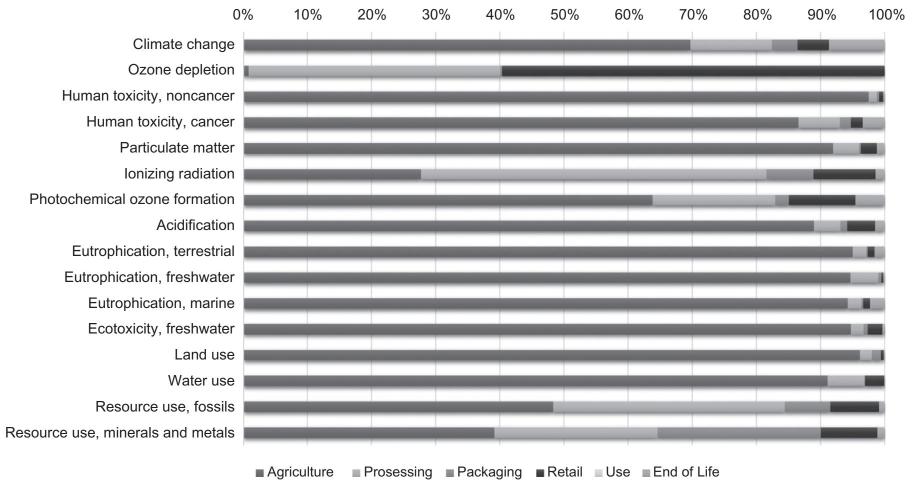


**Figure 11.3** Contributions of different life cycle phases to the environmental impacts of food waste.

food waste would be reduced 50% in all product groups and all phases. If the food waste amount would be reduced 50% only in retail and consumer phases, the food production amount could be decreased 8%. Similarly, if food waste is reduced only in animal-based products, the food production amount could be only around 3% lower, whereas if the reduction of food waste is in plant-based products, the food production amount could be decreased by 7%, because plant-based products have in general higher food waste amount along the whole supply chain. Environmental impacts of food consumption by average EU-28 citizen could be decreased from 7% to almost 10%, depending on impact category, by decreasing 50% of avoidable

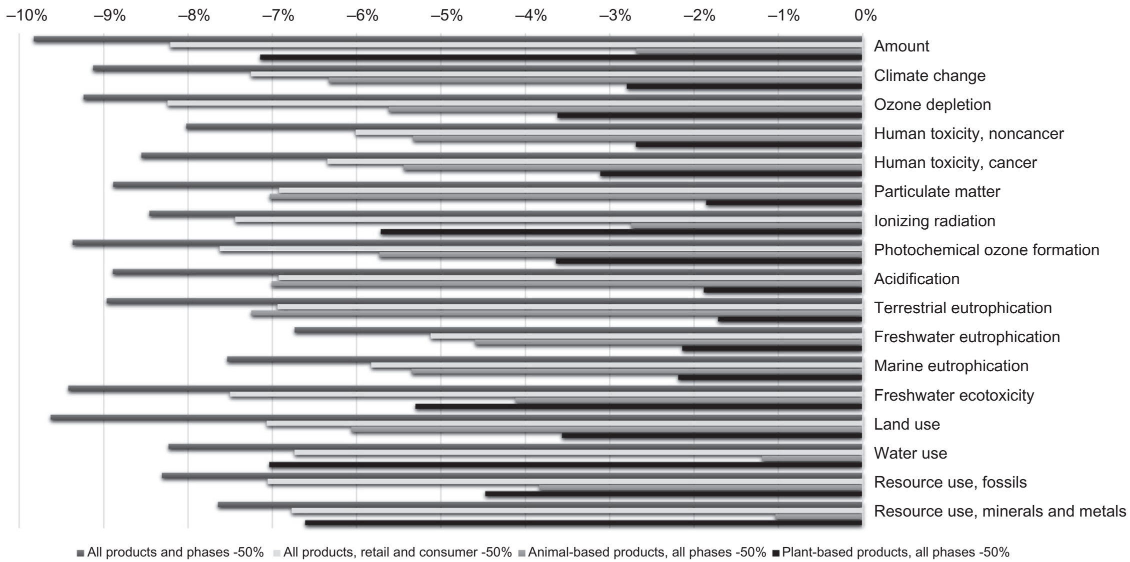


**Figure 11.4** Environmental impact reduction compared with baseline when 50% of food waste is reduced under different assumptions: (i) reduced in all life cycle stages of all products; (ii) reduced in the retail and consumption phases of all products; (iii) reduce in all stages of animal-based products; (iv) reduced in all stages of plant-based products.

food waste of all products in all phases of food supply chain, and 5%−8% if the reduction is only in retail and consumer phases of all products. Highest reductions can be achieved in land use, freshwater ecotoxicity, and photochemical ozone formation.

In the majority of the impact categories, the higher impact reduction can be achieved reducing food waste in animal-based products instead of plant-based products (5%−8% and 2%−7%, respectively, depending on impact category), because in the majority of impact categories the animal-based products are the main drivers of environmental impacts. However, in case of ionizing radiation, freshwater ecotoxicity, water use, and resource use (both fossil, and minerals and metals), higher impact reduction potential is achieved when food waste is reduced in plant-based products, because in these impact categories plant-based products are the major drivers of environmental impacts. For example, in case of water use, rice and wine contribute 45% of water use impact of the average food consumption in the EU. For ionizing radiation, the highest share of impact is due to coffee consumption, in particular energy consumption in processing of coffee. In case of resource use, potatoes, wine, and beer have a high share of impacts, but also coffee and animal-based food in case of fossil resources. In case of animal-based products, the highest reduction can be achieved in ozone depletion potential due to cold or frozen storage of all animal-based products.

### 11.3.3 Scenario results: diet shift

Results of the different dietary scenarios compared with the baseline results are presented in Table 11.11. Environmental impacts in the majority of the impact categories are lower compared with the baseline results when alternative diets are applied. In case of all diet scenarios, the impact on ionizing radiation, water use, and mineral and metal resource use are higher compared with the baseline. In case of the recommended diet in Sweden and the Mediterranean diet, water use impact is 90% and 39% higher, respectively, compared with the average diet in EU. Almond cultivation has high water consumption, and almond consumption is much higher in the Swedish diet compared with the other diets. Rice cultivation has also quite high water use, and rice consumption is higher in the Mediterranean and the vegetarian diets compared with the average diet. Higher mineral and metal resource use in the Mediterranean and the vegetarian diets is mainly due to higher sunflower and olive oil consumption compared with the baseline, when pesticide production associated to agricultural stage of sunflower oil and olive oil packaging are the main contributing processes. Pasta and milk also have quite high resource use impacts, whose consumption amounts are also higher in all alternative diet scenarios. Ionizing radiation is higher in all diet scenarios compared with the baseline due to higher bread consumption (electricity consumption in baking of bread).

When applying the diet according to the Swedish nutrient recommendations, there is also a small increase in photochemical ozone formation, freshwater eutrophication, and fossil resource use. Increase in photochemical ozone formation is due to the higher consumption of wild cod, diesel consumption in cod fishing being

**Table 11.11** Impacts due to the different diet scenarios and comparison with the baseline impacts

| Impact category | Unit | Swedish dietary recommendations | | Mediterranean diet | | Vegetarian diet | |
|---|---|---|---|---|---|---|---|
| | | Value | Diff. to baseline (%) | Value | Diff. to baseline (%) | Value | Diff. to baseline (%) |
| Climate change | kg $CO_2$ eq. | 1.95E + 3 | −15 | 1.57E + 3 | −32 | 1.43E + 3 | −38 |
| Ozone depletion | kg CFC-11 eq. | 3.35E−3 | −1 | 2.41E−3 | −29 | 2.24E−3 | −34 |
| Human toxicity, noncancer | CTUh | 1.50E−3 | −12 | 1.18E−3 | −31 | 1.37E−3 | −20 |
| Human toxicity, cancer | CTUh | 2.13E−5 | −18 | 1.96E−5 | −25 | 1.89E−5 | −28 |
| Particulate matter | Disease incidence | 1.78E−4 | −24 | 1.34E−4 | −43 | 1.19E−4 | −49 |
| Ionizing radiation | kBq $U^{235}$ eq. | 5.52E + 1 | +10 | 5.35E + 1 | +7 | 5.13E + 1 | +2 |
| Photochemical ozone formation | kg NMVOC eq. | 4.21E + 0 | +3 | 3.67E + 0 | −10 | 2.89E + 0 | −29 |
| Acidification | molc $H^+$ eq. | 2.46E + 1 | −23 | 1.87E + 1 | −41 | 1.64E + 1 | −49 |
| Eutrophication, terrestrial | molc N eq. | 1.01E + 2 | −25 | 7.53E + 1 | −44 | 6.56E + 1 | −51 |
| Eutrophication, freshwater | kg P eq. | 6.95E−1 | +4 | 6.38E−1 | −4 | 4.79E−1 | −28 |
| Eutrophication, marine | kg N eq. | 1.29E + 1 | −17 | 1.14E + 1 | −26 | 9.26E + 0 | −40 |
| Ecotoxicity, freshwater | CTUe | 6.48E + 3 | −2 | 5.67E + 3 | −14 | 5.24E + 3 | −21 |
| Land use | Pt | 1.72E + 5 | −19 | 1.65E + 5 | −22 | 1.43E + 5 | −32 |
| Water use | $m^3$ water eq. | 9.79E + 3 | +90 | 7.16E + 3 | +39 | 5.95E + 3 | +15 |
| Resource use, fossils | MJ | 1.50E + 4 | +4 | 1.38E + 4 | −5 | 1.26E + 4 | −13 |
| Resource use, minerals and metals | kg Sb eq. | 3.14E−3 | +17 | 3.13E−3 | +16 | 2.93E−3 | +9 |

the main contributing process. Increase in freshwater eutrophication impact is due to higher amount of salmon consumption (nutrient emissions from salmon aquaculture), and increase in fossil resource use is due to higher cheese consumption (energy consumption in cheese processing and in compound feed production).

In general, the vegetarian diet has the highest impact reduction potential compared with other diet scenarios in almost all impact categories. However, in case of human toxicity noncancer effect, the highest reduction, 31%, can be achieved with the Mediterranean diet, due to lower consumption of cheese compared with other diets. Related to the impact categories, whose impacts are higher in alternative diets than in the baseline, the increase of impacts is lower with the vegetarian diet compared with the other two diet scenarios.

When comparing environmental impacts of avoidable food waste in different diets, it can be noted that the share of food waste of total environmental impacts of the food consumption is highest in the Mediterranean diet (Fig. 11.5). This is because the food waste amount is highest for fruit (over 40% along the whole supply chain), and vegetables, bread, pasta, and rice (over 30% along the whole supply chain). Fruit, vegetables, bread, pasta, and rice have higher share in the Mediterranean diet compared with the baseline. These are also mainly higher in the Mediterranean diet compared with other diet scenarios, except fruit consumption amount is the same as the recommended diet in Sweden, and bread consumption amount is same as the vegetarian diet.

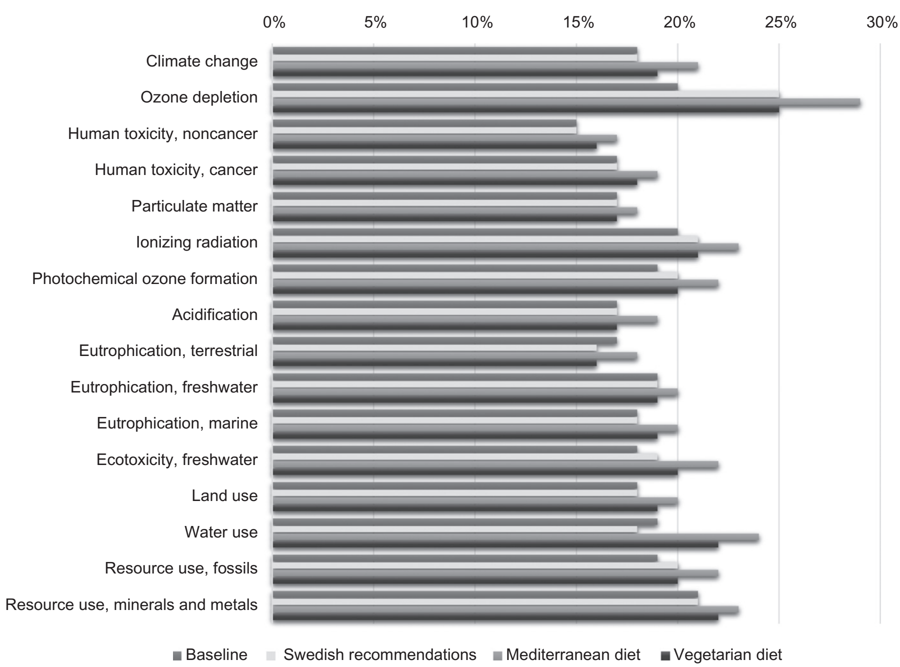


**Figure 11.5** Percentage of environmental impacts due to avoidable food waste over the total environmental impacts of food consumption with different diets.

## 11.4 Discussion

According to this study, a considerable amount of total environmental impacts of food consumption is due to the food waste that could be avoided, ranging between 15% and 21% of the total impact of food consumption. Also Eberle and Fels (2016) and Scherhaufer et al. (2018) reported impacts in simlar ranges, 15%−21% and 15.1%−15.7% of the total food consumption, respectively. However, Eberle and Fels (2016) accounted both in-house and out-of-home food waste, whilst in this study only in-house food wast is accounted for. Environmental impacts due to only in-house food waste were between 11% and 17% in the Eberle and Fels (2016) study, being lower than impacts due to the out-of-house waste or impacts in this study. Beretta et al. (2017) reported 25% climate impact of the consumed food due to the food waste, which is significantly higher compared with this and other published studies: 18% in this study, 15.7% in Scherhaufer et al. (2018), and 15% in Eberle and Fels (2016). Comparison of shares of impacts due to food waste in the different impact categories are reported in Table 11.12. Discrepancies in the results can be due to many factors:

1. different food waste definition and thus different amounts of food waste used in the studies,
2. food products selected for running the study, which may imply different impacts, and
3. differences in the per-kg emissions of the same food products, depending on system boundaries, allocation methods, and used data sources.

**Table 11.12** Share of the food waste impact from total impact of the food consumption in different studies

| Impact category | This study | Eberle and Fels (2016) | Scherhaufer et al. (2018) |
|---|---|---|---|
| Climate impact (%) | 18 | 15 | 15.7 |
| Ozone depletion (%) | 20 | 11 | – |
| Particulate matter (%) | 17 | 15 | – |
| Photochemical ozone formation (%) | 19 | 11 | – |
| Acidification (%) | 17 | 17[a] | 15.1 |
| Eutrophication, freshwater (%) | 19 | 11 | 15.2[b] |
| Eutrophication, marine (%) | 18 | 17 | |
| Land use (%) | 18 | 15 | – |
| Water use (%) | 19 | 16[c] | – |
| Resource use, fossils (%) | 19 | 12[d] | – |
| Resource use, minerals and metals (%) | 21 | 15[e] | – |

[a]Terrestrial acidification.
[b]Eutrophication, not specified.
[c]Only agricultural water use.
[d]Fossil depletion.
[e]Metal depletion.

In case of environmental impacts of the food waste, agriculture has the highest contribution to the most of the impact categories, because there is a need to produce more food when part of the food is wasted. This is also due to the fact that agriculture is the life cycle stage with higher contributions in most of the impact categories in food LCA (Castellani et al., 2017). Also, according to EEA (2016), agricultural activities for production of food, fibers, and fuel in Europe account for 90% of ammonia emissions, 80% of methane emissions, and 50%−80% of nitrogen load in freshwater bodies. EoL impacts, that is, treatment of the wasted food, have very low contribution compared with other life cycle phases, but the EoL phase also takes into account benefits, for example, energy recovery from biogas process. Consequently the contribution could be higher without benefits.

Food production amount could be almost 10% lower, if food waste would be reduced 50% in all product groups, which is especially important when land resources are limited due to constantly growing population and pressures to use land area also for biofuel production. Similarly, environmental impacts of food consumption by the average EU-28 citizen could be decreased from 7% to almost 10% by decreasing 50% of food waste in all phases of the food supply chain. The highest reduction can be achieved in land use, photochemical ozone formation, and freshwater ecotoxicity. In the majority of the impact categories, the higher impact reduction could be achieved by reducing food waste in animal-based products instead of plant-based products, because animal-based products are the main source of environmental impacts in the majority of the impact categories, although the food waste generation rate is mainly higher with plant-based products (FAO, 2011). This can also be seen in higher reduction in food production amount if the food waste reduction is applied to plant-based products (7% reduction) instead of animal-based products (less than 3% reduction).

In the majority of impact categories, the environmental impacts are lower compared with baseline results when alternative diets are applied. However, ionizing radiation, water use, and mineral and metal resource use are lower with the average diet compared with alternative diet scenarios. In fact, the water use impact of diet according to Swedish dietary recommendations is 90% higher compared with the average diet. This is due to the fact that nutrient recommendations in Sweden contain a considerable amount of nuts and seeds. Only almonds were included in the basket, representing all nuts and seeds included in the diet. However, environmental impacts of different nuts and seeds are different. All nuts and seeds have high water consumption, as was the case with almonds, but for almonds it can be slightly higher (Barilla, 2016). This could have caused an overestimation to the water use impact of diet according to Swedish recommendations, which contains nuts and seeds 30 g per day, while average consumption in EU is only 1.4 g per day.

In general, the vegetarian diet had the highest impact reduction potential compared with other diet scenarios in almost all impact categories, except human toxicity noncancer effects, because the vegetarian diet did not include any meat-based food or fish, which are among the food products contributing most to the environmental impacts of food consumption. Contrarily, the share of avoidable food waste is not lower with the vegetarian diet compared with the baseline, because the vegetarian diet includes significant amounts of fruit and other plant-based food with high food waste amount. In fact, the average diet has the lowest or similar share of impacts with alternative diets due to the food waste in majority of the impact categories, except in water use impact.

Limitations of this study are mainly related to representative products included in the basket. In addition to almonds already discussed to represent all nuts and seeds and thus potentially affecting overestimation on water use impact of diet according to the Swedish recommendations, tomatoes were the only vegetable included in the basket. Tomatoes have the highest consumption among vegetables, but still the share of tomatoes is only 9.5% of all vegetables consumed. For example, share of carrots is 7.5% and share of onions 7.3%. However, all vegetables have in general quite low environmental impacts, but some vegetables can have specific hotspot impact areas that are not covered when using only tomatoes to represent all vegetables. Pesticide usage in the cultivation of tomatoes, in turn, can be higher compared with some other vegetables, which can cause overestimation in ecotoxicity impacts.

There are also limitations related to the accuracy of food intake and the food waste amounts. The food intake was calculated according to apparent consumption in EU-28 (production + import−export) and food waste amounts along the food supply chain. Apparent consumption was assumed to be the consumed food amount, that is, food waste amounts were added as additional food that has to be produced. However, food waste amounts were based on different studies, which includes uncertainty.

Selected data sources and assumptions made in the assessment also influences the results. Data used in the assessment were based on the literature that was assessed to be the most reliable and representative in terms of data quality and geographical scope. For example, the study by Blengini and Busto (2009) was selected as a data source on rice cultivation representing rice cultivation in Italy, which has the highest rice production in Europe. In that study, water use was 19,800 $m^3$/ha, based on average from different studies and reusage rate of 28%, thus rice is cultivated in flooded field and part of this water can be reused. This was much higher compared with the study by Chapagain and Hoekstra (2010), which takes into account water uptake of the rice and available rainwater in the area, that is, amount of rainwater was deducted from the irrigation water needed. Thus, the assumption of Chapagain and Hoekstra (2010) was that all “additional” water, which is not taken up by the plant, can be reused later somewhere else. According to that, water consumption was 4087 $m^3$/ha. The latter approach was used also in this study. This selection has clear impact on the water use results.

The main purpose of this study was to assess how much environmental impacts of food consumption will change with different dietary habits, when the amount of food waste is changing, because food waste amount of different food products is different. The potential next step would be to find the most favorable diet in terms of food waste amount, environmental impact, and nutrient intake, that is, optimization of diet related to three different factors.

## 11.5 Conclusions

According to this study, between 15% to 21% of total environmental impact of food consumption is due to avoidable food waste. Food production amount could be decreased by almost 10%, if food waste would be reduced 50% within all product groups and all phases of the food supply chain. Similarly, environmental impacts of food consumption by the average EU-28 citizen could be decreased from 7% to almost 10%, depending on the impact category, by decreasing 50% of the food waste in all phases. The highest reduction can be achieved in land use, photochemical ozone formation, and freshwater ecotoxicity potential. In the majority of the impact categories, the higher impact reduction could be achieved by reducing food waste in animal-based products instead of plant-based products, since in the majority of impact categories the animal-based products are the main sources of environmental impacts.

In the majority of impact categories, the environmental impacts are lower compared with the baseline results when alternative diets are applied. Environmental impacts in some impact categories (ionizing radiation, water use, and mineral and metal resource use) are higher with alternative diet scenarios. Water use impact is especially high with the diet according to the Swedish dietary recommendations, which contains a high amount of nuts and seeds which are related to an high demand of water for irrigation. In general, the vegetarian diet has the highest impact reduction potential compared with other diet scenarios in almost all impact categories, because the vegetarian diet did not include any meat-based foods, which have high environmental impacts per kg of food. Contrarily, the share of avoidable food waste is not lower with the vegetarian diet compared with the baseline, because the vegetarian diet includes significant amounts of fruit and other plant-based food with high food waste rate. In fact, the average diet had mainly lower or similar environmental impacts with alternative diets due to avoidable food waste.

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