Technical University of Denmark

Food waste prevention in Denmark

Identification of hotspots and potentials with Life Cycle Assessment

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Content

1. Introduction and background

The importance of food in Danish society is demonstrated with households spending over DKK 88,000 million a year on food (retrieved from dst.dk, FU5, 2013:2014), the agro-chain sector as a whole (from production to retail) having a turnover of around DKK 162,000 million a year (retrieved from dsk.dk, OMS5, 2015) and at the same time the Danish food production sector is the industrial sector with the largest greenhouse gas emissions after housing (with 7% of the total CO_2 emissions) (Ghosh et al., 2014). If this food is not consumed, resources (environmental and economic) are wasted.

The most recent and up-to-date European project on *food waste* (the “FUSIONS”; Östergren et al., 2014) defines food waste as “fraction of food, and inedible parts of food, removed from the food supply chain to be recovered or disposed (including composted, crops ploughed in/not harvested, anaerobic digestion, bio-energy production, co-generation, incineration, disposal to sewer, landfill or discarded to sea)”.”. This is different from *food losses* defined as “un-harvested crops (left in field), losses of livestock pre-slaughter (dead during breeding or dead during transport to slaughter) or losses of milk due to mastitis and cow sickness”. Similar definitions may be found in previous studies (Gustavsson et al., 2011; Stancu et al., 2015). Both *food losses* and *food waste* refer to food items intended for human consumption and include both avoidable and unavoidable waste. The avoidable food waste (in Danish *madspild*) is, instead, defined as “the food and drinks which at some point, prior to being thrown out, was edible” (Quested & Johnson 2009).

In Denmark, a number of studies have reported information about the amount of food waste generated at different levels of the Food Supply Chain (Halloran 2014; Mogensen et al., 2013a; Ettrup & Bauer 2002; Petersen et al., 2014b; Petersen et al., 2014a; Jensen 2011; Tønning et al., 2014), but actual primary data, i.e. based on experimental campaigns and observations, are very limited. Primary Danish data about the type of food items being wasted are only available for the case of the households sector (Petersen et al., 2014a,b). While knowing the food categories being wasted, through dedicated experimental campaigns and observations, is certainly crucial to quantify the resources associated with the food waste, some studies have nevertheless attempted to quantify these resources using different approaches and assumptions, justified by the lack of experimental data/observations (Kim et al., 2011; Martinez-Sanchez et al., 2016; Nahman et al., 2012; Bernstad Saraiva Schott & Andersson 2015; Nahman & de Lange 2013; Evans 2012; Venkat 2011; Vandermeersch et al., 2014; Eriksson et al., 2016; Kummu 2012; Buzby & Hyman 2012). All in all, regardless of the approach taken, the common message of these studies is that preventing food waste is beneficial economically and to the welfare of society. Environmental benefits may also be significant, assuming that monetary savings, due to unpurchased foods (because of prevention), are spent for environmentally sound activities and products (e.g. health care, education, culture; Martinez-Sanchez et al. 2016).

Food waste reduction may be achieved with different means, among which prevention (reduction at the source) has the highest priority as indicated in the waste hierarchy; this may be achieved by reducing food losses in the Food Supply Chain (including households) and, therefore, by decreasing the demand for food production/supply. A number of studies have looked into different prevention options, (Stenmarck et al., 2011; Schneider 2013; Cox et al., 2010; Sharp et al., 2010a; Sharp et al., 2010b; Gustavsson et al., 2011; Bernstad Saraiva Schott & Andersson 2015) but, to identify the prevention measures with the largest potentials, the causes of food waste have to be identified for each specific case. Food waste is caused by different reasons, e.g. quality or size standards (food items that do not fit with the required shape or appearance), food items damaged during transport, over/non-appropriate purchasing, as well as confusion between the terms ‘‘best before’’ or ‘‘use by’’ dates (CONCITO 2011). Alternatively, food waste reduction could be obtained by re-distributing excess (edible) food waste (sometimes referred to as “surplus food”) to other end-consumers, e.g. food banks or social supermarkets. Follows, in the hierarchy, the diversion of food waste (when applicable according to legislation) to animal feeding. These two reduction pathways follow prevention in the food waste hierarchy (Teuber & Jensen 2016).

The goal of this study is assessing the potential environmental savings that may be achieved by preventing the avoidable food waste in the individual sectors of the Danish Food Supply Chain (with the exception of the primary production sector due to lack of data, see later). To this purpose, the following steps are needed:

- Quantifying the flows of avoidable food waste in the Danish Food Supply Chain (i.e. where does this "avoidable" wastage occur? which food items are being wasted?)
- Quantifying the potential environmental savings achieved by preventing avoidable food waste in each sector of the Danish Food Supply Chain
- Quantifying potential environmental savings in the endeavour to meet international reduction targets

Due to the uncertainty associated with the data used for the assessment, this study should only be used as a preliminary LCA-screening for a first estimation of the potential environmental benefits from food waste prevention in each individual sector of the Danish Food Supply Chain. It should be borne in mind that the study does not focus on any specific prevention measures or actions. For a more robust quantification of the environmental benefits from prevention, further investigations are necessary, especially for obtaining better information on the food waste composition and on the potential indirect effects associated with monetary savings (e.g. due to unpurchased food by the consumers). Moreover, a thorough inclusion of the parameter and scenario uncertainties is beyond the scope of this LCA-screening.

2. Materials and method

2.1 Goal and Scope definition

This study generally follows the definitions given in the European project "FUSIONS" (Östergren et al., 2014) where *food waste* is defined as "fraction of food, and inedible parts of food, removed from the food supply chain to be recovered or disposed (including composted, crops ploughed in/not harvested, anaerobic digestion, bio-energy production, co-generation, incineration, disposal to sewer, landfill or discarded to sea)". Yet, for the case of Denmark no data are available for food disposed to sewer or discarded to sea. These waste flows are therefore not included in the analysis. Also, it should be noticed that the "Fusions" definition excludes from being considered as food waste all food/drink items used for animal feeding and/or valorised for production of biobased materials/chemicals. A*voidable food waste*, instead, is here defined as "food and drink items which at some point, prior to being thrown out, was edible" conformingly with the definition of Quested & Johnson (2009).

The functional unit of the study is the prevention of one tonne of avoidable food waste, as wet weight generated by each individual sector involved in the Danish Food Supply Chain, with the exception of the Primary Production sector (agriculture): A) Processing sector (food industry converting primary production into food products for final consumption), B) Wholesale and Retail sector (storing and distributing food to final consumers), C) Food Service sector (commercial kitchens, restaurants, schools, and hospitals), and D) Households sector. The Danish Food Service sector is assumed here to include hospitality sector as well as institutions such as schools and hospitals.

The system boundaries of the study include: agricultural production of food items, land use changes, packaging, transportation, cooking, storage/cooling and waste disposal. Cooking is assumed to apply only to Food Service and Households sector. The food waste associated with the production of the imported food and with the commercialization and use of the exported food are excluded from the assessment because the geographic scope of the study is Denmark.

For simplicity, the study uses five food categories (instead of several food items) as basis for the assessment: 1) Meat & Meat products, 2) Milk & Dairy Products, 3) Bakery Products, 4) Dry Products, and 5) Fruits & Vegetables. While this categorization is sufficient in order to establish a Material Flow Analysis, for the LCA it was instead necessary to represent each of these food categories by a set of proxies (i.e. food items composing the individual food category). This is further described in section 2.4. The assessment was performed using the LCA tool EASETECH (Clavreul et al., 2014). The following environmental impact categories were included in the assessment: Global Warming (Forster et al., 2007), Terrestrial Acidification (Seppälä et al., 2006), Eutrophication - Nitrogen (Struijs et al., 2009), Human Toxicity, carcinogenic (Rosenbaum et al., 2011), Ecotoxicity (Rosenbaum et al., 2011), and Resource Depletion, abiotic (van Oers et al., 2002).

2.2 System boundary

The boundary of the LCA, thus the processes included in the assessment, differ depending upon the sector of the Food Supply Chain considered (Figure 1A-D). The life cycle assessment of food waste prevention in the processing sector includes agricultural production of food (this may occur in Denmark or elsewhere due to import/trade, i.e. it is global), land use change implications (global, following the approach of Tonini et al., 2016), processing (in Denmark), associated waste management (Denmark), and required transport; all these life cycle stages are avoided when prevention is enforced; Figure 1A. The life cycle assessment of food waste prevention in the wholesale & retail sector includes agricultural production of food (this may occur in Denmark or elsewhere due to import/trade), land use change implications (global), processing (global), retail/sales (Denmark), associated waste management, and required transport; all these life cycle stages are avoided when prevention is enforced; Figure 1B. Finally, the life cycle assessment of food waste prevention in the food service or household sector includes agricultural production of food (global), land use change implications (global), processing (this may occur in Denmark or elsewhere due to import/trade), retail/sales (Denmark), cooking (Denmark), associated waste management (in Denmark), and required transport; all these life cycle stages are avoided when prevention is enforced; Figure 1C and D). It should be noticed that prevention measures implemented at processing, retail/wholesale, food service/household sector (Figure 1A-D) may incur environmental benefits in other countries due to the rather globalized import and trade of agricultural goods (i.e. it is clear that not all the processed/consumed food items in Denmark are actually produced within Danish borders). These benefits, occurring elsewhere (out of the Danish borders), are also accounted for in this assessment. Yet, only food waste generated within the Danish borders is considered in this assessment. This means that food produced in Denmark but then exported and wasted elsewhere is out of the scope of this study. Further, it should be noticed that any food removed from the Food Supply Chain and used for production of biomaterials/chemicals and for animal feeding (i.e. “valorised”) is not included in this assessment as it is not considered food waste conformingly with the most recent definitions given in the European project FUSIONS (see Figure 1A-D).

2.3 Land use changes (LUCs)

Land use changes refer to the conversion of land from one management type (e.g. forest, grassland, pasture, etc.) to another (e.g. arable land). Land use changes (LUCs) are responsible for ca. 12% of the global greenhouse gas (GHG) emissions, mainly because of the carbon emissions from forest loss (Herzog 2009). Any economic sector (timber, agriculture, etc.) demanding for land is a primary cause of LUCs at a global scale (IPCC 2014; IPCC 2006; Schmidt et al., 2015). Among these, agriculture (including pasture and cropping according to FAO definitions) plays an important role due to crop demand for feeding the increasing world population, satisfying dietary changes (switching to high-protein diets in many developing countries), and providing feedstock for the growing bioenergy/bioproducts industry. On this basis, it appears clear that including LUC impacts in LCAs is crucial in order to provide decision-makers with a full picture of the environmental consequences associated with agricultural systems involving demand/use of land. In LCA, typically, we distinguish between direct and indirect LUCs (dLUC/iLUC). Both dLUC and iLUC are caused by the use/occupation of land; following the definitions given in Schmidt et al. (2015), dLUC are defined as those changes that occur on the same land as the land use, while iLUC are defined as the upstream life cycle consequences of the land use, regardless of the purpose of the land use. In other words, iLUC could be considered as the environmental cost of demanding land, regardless of location and type of production, i.e. the upstream pressure caused on the global forest resources and on the global production intensification by the demand for arable land. On this basis, examples of dLUC include changes in soil carbon content due to changes from one type of cropping to another (e.g. changing from barley to wheat) while examples of iLUC are deforestation and production intensification (e.g. increased use of fertilizers). Typically, iLUC are much more important than dLUC, as the carbon losses (and other emissions) involved are much higher (Tonini et al. 2012; Hamelin et al. 2014). In this study, the impacts associated with LUCs were included conformingly with the approach of Tonini et al. (2016). In this, a deterministic modeling framework was developed to quantify iLUC impacts caused by demand for arable land (eventual dLUC impacts are not considered). The main assumptions of this model are: i) effects associated with the demand for land are global, given the global nature of agricultural commodity trading; ii) there is a cause-effect relationship between the demand for arable land and expansion/intensification effects; iii) there is full-elasticity of supply (short-term effects on prices and related price-elasticities are not modelled; Weidema et al., 2009).The model considers that additional crop production is ultimately supplied by: i) net expansion of arable land (25% of the total response) and ii) intensification of current cultivation practices (75% of the total response). The sum of the impacts from (i) and (ii) provides the total iLUC impact. In the model, intensification is considered as 100% input-driven (modelled as increases in N, P and K fertilizers). The detailed iLUC inventory may be found in Tonini et al. (2016).

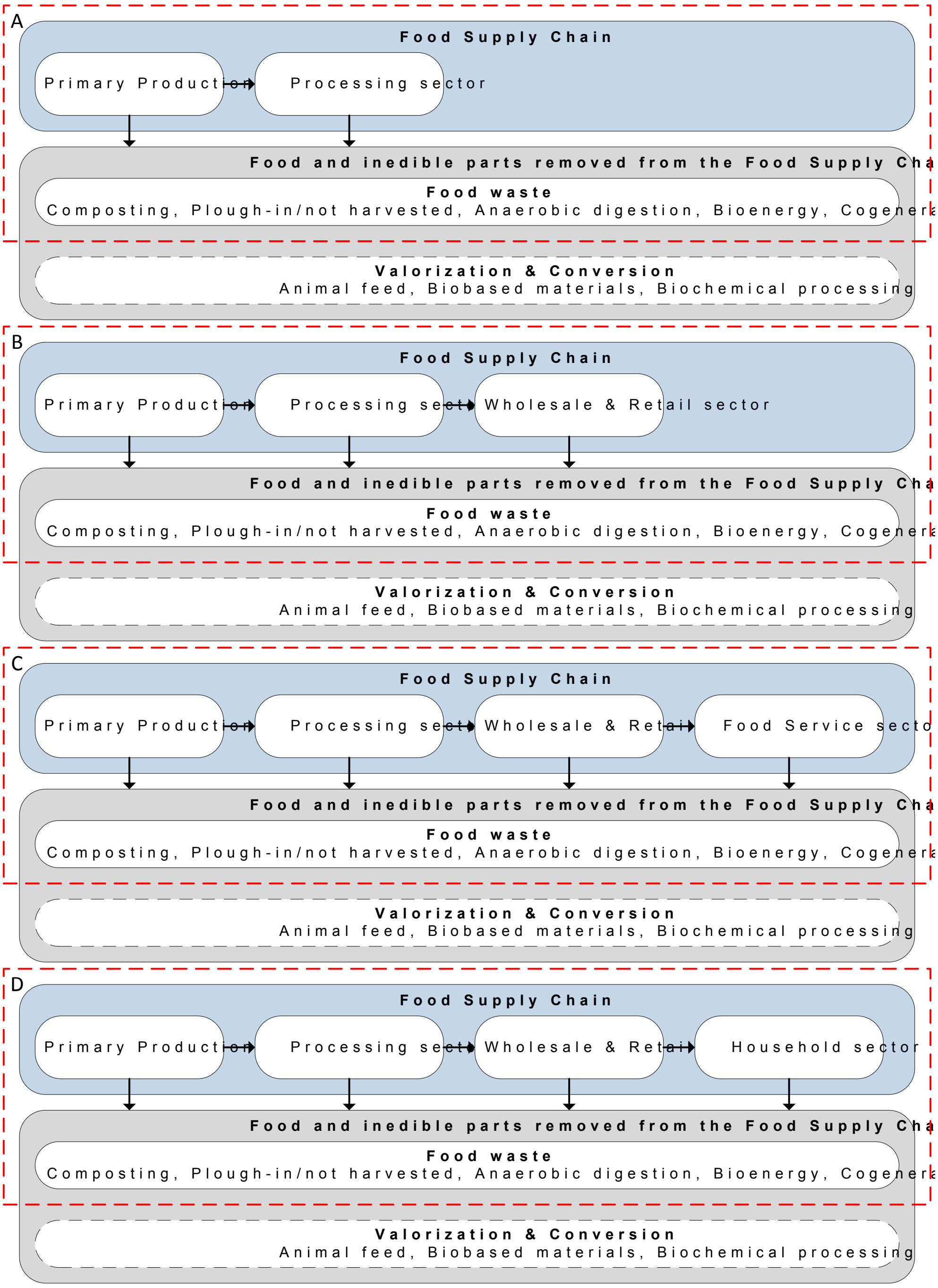

Figure 1: System boundary (red-dotted line) for the assessment of the life cycle impacts of avoidable food waste at the sector: A) Processing, B) Wholesale & Retail, C) Food Service, D) Households. Only food waste generated in Denmark was considered. Land use changes (as iLUC) following demand for arable land are also included in the as-

sessment.

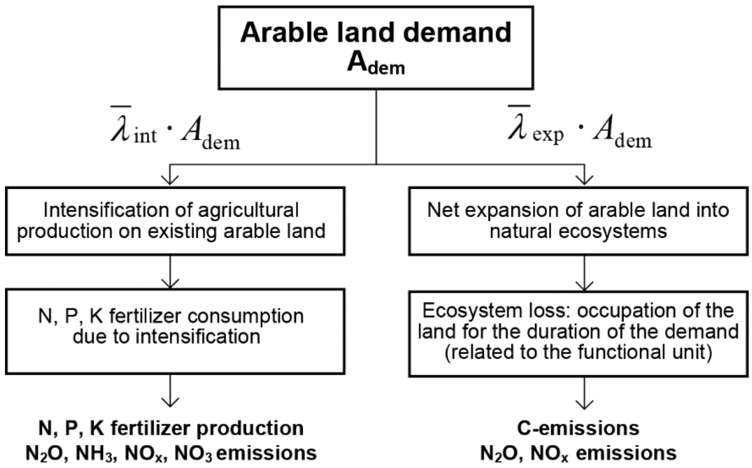

Figure 2: Processes and related emissions considered in the iLUC model (taken from Tonini et al., 2016). The term λ indicates the share of the supply obtained from intensification (λ_{int}=75%) and from expansion (λ_{exp}=25%). A_{dem}: Area of arable land demanded.

It should be noticed that, the environmental impacts quantified with this iLUC model also involve N-related categories (Acidification and Eutrophication – Nitrogen) additionally to Global Warming. This is because the model considers that, whenever there is a demand for crop production, a share of the corresponding supply is provided through production optimization (here assumed to be through intensification, i.e. increased fertilizers use). Such an increase in the use of N-fertilizers causes impacts because of the NPK-fertilizers production and because of the (mainly) nitrogen emissions (e.g. leaching of nitrates, NH_3, N_2O and NO_x emissions). These emissions contribute to the environmental categories of Global Warming (air emissions of N_2O, energy consumption for NPK-fertilizers production, etc.), Acidification (emissions of NH_3 and NO_x from N-fertilizer application), and Eutrophication – Nitrogen (nitrates leaching from N-fertilizer application). Moreover, it should noticed that NO_x and N_2O emissions also occur when arable land expands on forest due to land clearing (wood burning). An overview of the iLUC modelling approach is shown in Figure 2. For simplicity, from now onwards we will refer to iLUC with the more general term of LUC. Additional information on the LUC inventory established for this study and on how calculations were performed may be found in Annex 6.

2.4 Inventory data for Material Flow Analysis

This section describes the inventory data used to establish a Material Flow Analysis (MFA) of the avoidable food waste generated within the Danish Food Supply Chain. The purpose of the MFA is to quantify and illustrate the mass flows of the five food categories used in this study: 1) Meat & Meat products, 2) Milk & Dairy Products, 3) Bakery Products, 4) Dry Products, and 5) Fruits & Vegetables. The amount of food being wasted in each sector of the Danish Food Supply Chain was estimated using literature data. In respect to this, priority was given to available Danish data sources; when these were not available, other European data sources were used instead. For the Primary Production sector, no data on the composition of the avoidable food waste generated, i.e. on the specific food categories, could be found. For this sector, therefore, we only reported the total amount of avoidable food waste generated without further details on the food categories.

Table 1: Data reported by the study WRAP (2016) on the amount of food waste and of avoidable food waste in the UK processing (i.e. manufacturing) sector. The share (%) of the avoidable food waste is also reported. The last column to the right describes how the data were aggregated for use in this project. FW: food waste; av. FW: avoidable food waste.

Food category (WRAP study)	FW (t)	av. FW (t)	Share % (WRAP)	Food category (this study)
Meat, poultry and fish	540,000	160,000	18%	Meat & Meat Products
Dairy products	340,000	28,000	23%	Milk & Dairy Products
Ambient products	185,000	8,500	15%	Fruits & Vegetables
Alcoholic drinks	150,000	4,000	7%	Other - not included in this study
Fresh fruit and vegetable processing	140,000	55,000	12%	Fruits & Vegetables
Bakery, cake and cereals	110,000	67,500	10%	50% in Bakery Products 50% in Dry Products
Pre-prepared meals	83,000	20,000	7%	50% in Meat & Meat products 50% in Fruits & Vegetables
Soft drinks and fruit juices	77,000	7,500	3%	Other - not included in this study
Confectionery	49,000	1,000	3%	Other - not included in this study
Milling	35,000	10,000	1%	Dry Products
Sugar	2,000	1,000	<1%	Dry Products
Total			100%	

Table 2: Data reported by the study WRAP (2016) on the amount of food waste in the UK wholesale and retail sector. The last column to the right describes how the data were aggregated for use in this project. FW: food waste; av. FW: avoidable food waste.

Food category (WRAP study)	FW (t)	av. FW (t)	Share % (WRAP)	Food category (this study)
Meat, poultry and fish	12,000	12,000	6%	Meat & Meat Products
Dairy products	28,000	28,000	14%	Milk & Dairy Products
Ambient products	8,500	8,500	4%	Fruits & Vegetables
Alcoholic drinks	4,000	4,000	2%	Other - not included in this study
Fresh fruit and vegetable processing	55,000	55,000	27%	Fruits & Vegetables
Bakery, cake and cereals	67,500	67,500	33%	50% in Bakery Products 50% in Dry Products
Pre-prepared meals	20,000	20,000	10%	50% in Meat & Meat products 50% in Fruits & Vegetables
Soft drinks and fruit juices	7,500	7,500	4%	Other - not included in this study
Confectionery	1,000	1,000	0.5%	Other - not included in this study
Frozen	6,500	6,500	1%	Fruits & Vegetables
Total			100%	

2.4.1 Processing sector

The total amount of avoidable food waste generated in the processing sector was based on Mogensen et al. (2013a) and Jensen (2011) and equalled 133,000 t $year^{-1}$. Information regarding the type/composition of avoidable food waste in the Danish Food **Processing (PR)** sector has been reported in a number of Danish reports (Kjær & Werge 2010; Mogensen et al., 2013b; Halloran 2014; Jensen 2011). Yet, these studies are all based on data published in earlier investigations.

In respect to this, it appears that the primary data, on which these more recent studies were based, derive from a Miljøstyrelsen report dated 1998 (Andreasen et al., 1998) estimating organic residues from the Danish industry. This study does not actually report estimates on the avoidable food waste, but only on generic food waste. Because of this, it was decided to use instead the estimates from WRAP (WRAP 2016) as illustrated in Table 1, assuming that the Danish processing industry generates similar losses to the UK processing sector, in terms of type/composition. Norwegian estimates for avoidable food waste in the processing sector also exist (ForMat project, analysing years 2009-2014; Stensgård & Hanssen 2016; Stensgård & Hanssen 2014; Hanssen & Møller 2014). The latter estimates the avoidable food waste as percentage of the production of different food items. We applied these percentages to the Danish production volume based on Danish national statistics for food production in Denmark, as annual average of the years 2009-2015 to avoid fluctuations (ANI4, ANI5, ANI6, ANI7, VARER1, and GARTN1). See Annex 1 for further details on the calculation/background data. We used this alternative approach, based on Norwegian estimates, to test the sensitivity of the LCA results to the choice of the approach based on UK data (WRAP 2016).

2.4.2 Wholesale & Retail sector

Recent Danish studies (Halloran 2014; Mogensen et al., 2013b; Jensen 2011; Kjær & Werge 2010) have reported information on the amount of avoidable food waste in the **Wholesale & Retail** sector in Denmark. Yet, we considered the primary data in these reports to be obsolete and not up-to-date. Because of this, we used instead the primary data on the total amount of avoidable food waste obtained by ECONET (Petersen et al., 2014c). Based on this, the total amount of avoidable food waste in the Danish Wholesale & Retail sector equals 163,000 t year^{-1}. We then estimated the composition of the avoidable food waste (i.e. food categories) using data from WRAP (WRAP 2016) as illustrated in Table 2. Data on amount and composition of avoidable food waste in the Wholesale & Retail sector are also available from the Norwegian ForMat project for the Norwegian context (Stensgård & Hanssen 2016; Stensgård & Hanssen 2014; Hanssen & Møller 2014). Such data were used to test the influence of the choice of the UK data on the results (sensitivity analysis), similarly to the Processing sector. Yet, the Norwegian data, in order to be used for this project, needed to be combined with Danish statistics on sales from the Danish Wholesalers and Retailers (FIKS44), and with Danish prices, e.g. as reported in (Jensen 2011). See Annex 2 for further details.

2.4.3 Food Service sector

The amount of avoidable food waste in the Danish **Food Service** sector was estimated using the figures reported by ECONET for Denmark 2014 (Tønning et al., 2014). Based on this, the total amount of avoidable food waste in the Danish Food Service sector equals 60,000 t year^{-1}. To estimate the composition of the avoidable food waste (i.e. the food categories) different sources were used for the different actors in the sector:

- Restaurants: an average of Swedish and Finnish data was used (Engström & Carlsson-Kanyama 2004; Silvennoinen et al., 2012).
- Canteens and catering: UK data were used (WRAP 2011).
- Hotels: UK data were used (WRAP 2013).
- Hospitals: an average of Portuguese, Spanish, and Wales data was used (Dias-Ferreira et al., 2015; Díaz & García 2013; Sonnino & McWilliam 2011).
- Nursing homes: American data were used (Nichols et al., 2002).
- Schools: an average of Swedish, Finnish, and UK data was used (WRAP 2011; Engström & Carlsson-Kanyama 2004; Silvennoinen et al., 2012).

Table 3 provides an overview of the data used as input to the Material Flow Analysis for the different actors of the sector. Annex 3 provides further details with respect to the background literature sources (i.e. prior to calculations of average values reported in Table 3).

2.4.4 Households sector

The amount and the composition of the avoidable food waste generated in the Danish **Households** sector was based on the findings of sampling campaigns (Petersen et al., 2014a,b; Petersen 2015). Based on these, the total amount of avoidable food waste in the Danish Households sector equals 260,000 t year^{-1}. For the scope of this study, the 46 material fractions reported in the results from Petersen (2015) were further aggregated into the 5 food categories used in this project (Meat & Meat products, Milk & Dairy Products, Bakery Products, Dry Products, and Fruits & Vegetables). An overview is presented in Table 4. For further details, refer to Annex 4.

Table 3: Overview of the data used to estimate the composition of the avoidable food waste generated by the different actors involved in the Danish Food Service sector.

Food category	Hotels[α]	Restaurants[β]	Canteens & Catering[γ]	Schools & kindergarden[δ]	Hospitals[ε]	Homes for the elderly[ζ]
Meat & Meat Products	10%	9%	10%	24%	22%	30%
Milk & Dairy Products	0%	3%	0%	2%	0%	23%
Bakery Products	20%	15%	20%	11%	8%	15%
Dry Products	11%	22%	11%	17%	25%	0%
Fruit & Vegetables	59%	50%	59%	47%	45%	32%
Total	100%	100%	100%	100%	100%	100%

α (WRAP 2013). β average of the figures provided in (Engström & Carlsson-Kanyama 2004; Silvennoinen et al., 2012); γ (WRAP 2011); δ average of the figures provided in (WRAP 2011; Engström & Carlsson-Kanyama 2004; Silvennoinen et al., 2012); ε average of the figures provided in (Dias-Ferreira et al., 2015; Díaz & García 2013; Sonnino & McWilliam 2011); ζ (Nichols et al., 2002).

Table 4: Overview of the data used to estimate the composition of the avoidable food waste generated by the Households sector.

Food category	Avoidable Food Waste	
	t year^{-1}	% Share
Meat & Meat Products	63,379	24%
Milk & Dairy Products	11,989	5%
Bakery Products	53,010	20%
Dry Products	25,022	10%
Fruits & Vegetables	106,601	41%
Total	260,000	100%

2.5 Other modelling assumptions for the LCA

2.5.1 Food items proxies

Since data on the specific composition of each food category (i.e. type of meat product, vegetables, dairy product, etc.) for each sector of the Danish Food Supply Chain were not available, it was necessary to define a set of proxies (i.e. specific food items) composing each food category. These proxies were estimated on the basis of the main food items produced (for the sector Processing) and consumed (for the sectors Wholesale & Retails, Food Service, and Households) in Denmark for each food category (see Table 5). For example beef, pork, and chicken were considered as food items proxy for the category “Meat & Meat Products”. The figures for beef, pork, and chicken thus represent the shares of their national production (for the sector Processing) or consumption (for the sectors Wholesale & Retail, Food Service, and Households) normalized to 100%. The same principle was then applied to the remaining food categories: “Milk & Dairy products”, “Bakery Products”, “Dry Products”, and “Fruits & Vegetables”. All the data regarding production and consumption were extracted from the Danish national statistics (Danish Statistics 2016a,b,c,d). Table 5 details the share of each food item in the avoidable food waste generated by each sector of the Danish Food Supply Chain. Regarding the life cycle inventory datasets for the production of the food items, we relied on the consequential inventory datasets from Ecoinvent v3.3, representing global markets for food production. For further details on the specific processes used in this study, please refer to Annex 5.

2.5.2 Packaging, cooking, cooling, and transport

The amount of packaging associated with the avoidable food waste at each stage of the Food Supply Chain was calculated based on the type of packaging used for each of type of food. On this basis, the amount of packaging may be different for each of the sectors of the Food Supply Chain (see details in Table 6).
It is assumed that all food items are refrigerated in Wholesale & Retails, Food Service, and Households sectors. Refrigerators in the household sector are assumed to be of energy class B. The related consumption of energy is calculated based on the enactment from European Commission number 1060/2010 (European Commission 2010) to be 193-263 kWh year^{-1} for a typical household refrigerator. From the Danish statistics the amount of food per person in Denmark is estimated to be about 1.5 kg per day. Also, from the statistics, if was found that 77% of the households consists of 1-3 persons. Knowing typical refrigerators consumption and the typical amount of persons living in Danish households, it derives that the interval of electricity consumption equals 0.11-0.46 kWh kg^{-1} food refrigerated in the household.
Data for energy used for cooling in the Wholesale & Retails and Food Service sectors were found in Gottfridsson (2013) to be 0.011 and 0.012 kWh kg^{-1} of food, respectively.
It was assumed that all food wasted in the Food Service and Households sectors is cooked. The related energy consumption for cooking was based on the average of the range provided in Schmidt Rivera et al. (2014) and equalled 2.93 kWh kg^{-1} food (0.2183-5.866).
The distances for transportation were based on the global average distances provided by Ecoinvent 3.3 database. For simplicity purposes, it was assumed that the transport distances from the Wholesale & Retail sector to the Food Service/Households were null.

Table 5: Food item proxies, representing each food category, used in this study. PR: Processing, WR: Wholesale & Retail, FS: Food Service; HH: Households.

Food category	Proxies	PR	WR	FS	HH
Meat & Meat Products	Pork	87%	45%	45%	45%
	Beef	6%	31%	31%	31%
	Chicken	7%	24%	24%	24%
	Total	100%	100%	100%	100%
Milk & Dairy Products	Milk	76%	80%	80%	80%
	Cheese and butter	24%	9%	9%	9%
	Yoghurt	-	11%	11%	11%
	Total	100%	100%	100%	100%
Bakery Products	Bread	100%	100%	100%	100%
Dry Products	Wheat flour and wheat products	19%	63%	63%	63%
	Rye flour and cereals products	81%	31%	31%	31%
	Rice	-	6%	6%	6%
	Total	100%	100%	100%	100%
Fruits & Vegetables	Potatoes	75%	33%	33%	33%
	Tomatoes	-	20%	20%	20%
	Carrots	14%	9%	9%	9%
	Onions	7%	7%	7%	7%
	Apples	4%	32%	32%	32%
	Total	100%	100%	100%	100%

Table 6: Data used for the assessment. PR: Processing, WR: Wholesale & Retail, FS: Food Service; HH: Households.

Processes	Unit	PR	WR	FS	HH
Packaging	kg kg^{-1}	-	0.025	0.025	0.027
Cooling of food (Wholesale & Retail)	kWh kg^{-1}	-	0.011	0.011	0.011
Cooling of food (Food Service)	kWh kg^{-1}	-	-	0.012	-
Cooling of food (Households)	kWh kg^{-1}	-	-	-	0.29
Cooking of food (Food Service)	kWh kg^{-1}	-	-	2.9	-
Cooking of food (Households)	kWh kg^{-1}	-	-	-	3.2
Transport from Primary Production/Processing to Wholesale & Retail	km	Ecoinvent v3.3 global data			
Transport from Wholesale & Retail to Food Service	km	Assumed to be zero			
Transport from Wholesale & Retail to Households	km	Assumed to be zero			
Transport of waste to Waste Management	km	20	20	20	20

3. Results

3.1 Material Flow Analysis

As illustrated in Figure 3, the Danish Food Supply Chain generates annually 716,000 t of avoidable food waste. Of this, 14% is generated by the Primary Production sector (100,000 t $year^{-1}$), 19% by the Processing sector (133,000 t $year^{-1}$), 23% by the Wholesale & Retail sector (163,000 t $year^{-1}$), 8.4% by the Food Service sector (60,000 t $year^{-1}$) and 36% by the Households sector (260,000 t $year^{-1}$).

On the basis of the assumptions taken in this study (see section 2), the composition of the avoidable food waste differs in each sector of the Danish Food Supply Chain. As displayed in Figure 3 (for further details, e.g. for the numerical results, refer to Annex 7):

- The avoidable food waste generated by the Processing sector is composed of: 25% Meat & Meat Products, 27% Milk & Dairy Products, 6% Bakery Products, 7% Dry Products, and 35% Fruits & Vegetables.
- The avoidable food waste generated by the Wholesale & Retail sector is composed of: 12% Meat & Meat products, 15% Milk & Dairy Products, 18% Bakery Products, 18% Dry Products, and 38% Fruits & Vegetables.
- The avoidable food waste generated by the Food Service sector is composed of: 15% Meat & Meat products, 3% Milk & Dairy Products, 15% Bakery Products, 16% Dry Products, and 51% Fruits & Vegetables.
- The avoidable food waste generated by the Households sector is composed of: 24% Meat & Meat Products, 5% Milk & Dairy Products, 20% Bakery Products, 10% Dry Products, and 41% Fruits & Vegetables.

Based on these results, and excluding the Primary Production sector, the following considerations for the remaining Food Supply Chain sectors can be drawn:

- All in all, Fruits & Vegetables appears to be the food category with the largest contribution to the avoidable food waste generated by Processing, Wholesale & Retail, Food Service, and Households sectors, followed by Meat & Meat Products and Bakery Products.
- Dry Products appears to be the food category with the lowest contributions to the avoidable food waste generated by all sectors. This may be because these products have long expiration date, typically.
- The amount of Milk & Dairy Products in the waste of Food Service and Households sectors may be underestimated due to two reasons: 1) a portion of the liquid dairy products may be disposed of through sewage and thus not accounted for in solid waste characterization studies and 2) when liquid dairy products are disposed of as solid waste, the liquid is typically “contained” in the solid material and thus (in waste characterization studies) accounted for as part of other food categories or other waste material fractions (in terms of wet weight) such as paper, plastic, packaging, cardboard, etc.
- The amount of Milk & Dairy Products in the waste of Processing and Wholesale & Retail sectors may be overestimated because of the approach taken (section 2.2), for which the share of each individual food category in the food waste is directly proportional to the national Danish production.

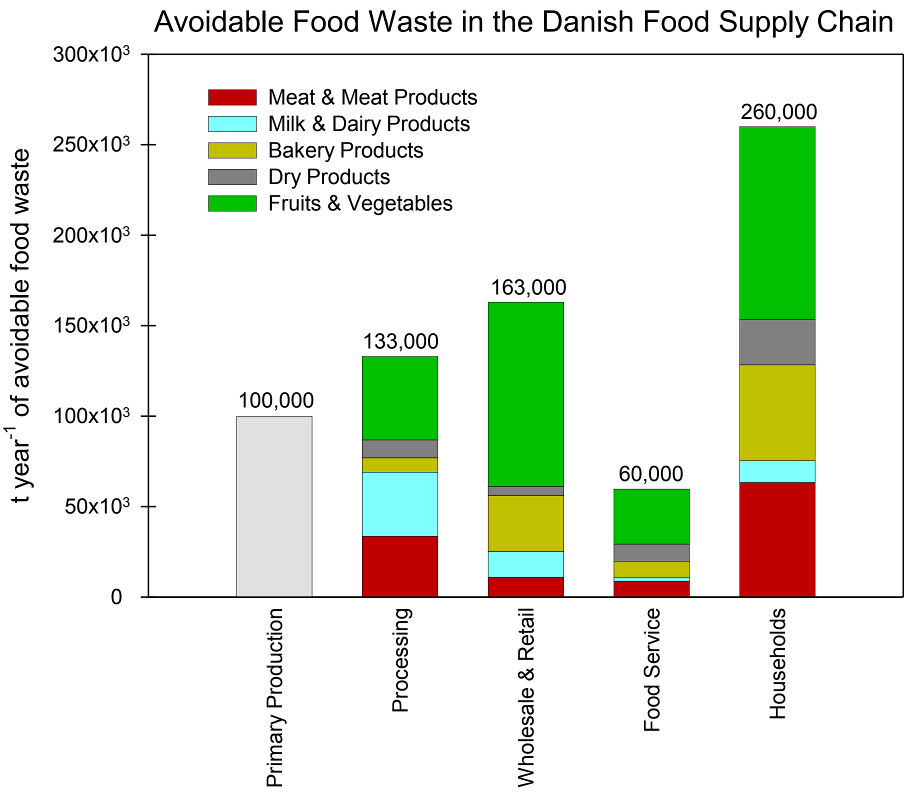

Figure 3: Breakdown of the avoidable food waste flows generated in the Danish Food Supply Chain: five food categories are considered, with the exception of the Primary Production sector (in grey) for which only the total is presented.

3.2 Life Cycle Assessment (LCA)

The results of the LCA are reported in terms of:

1. Characterized environmental impacts following prevention of one tonne of avoidable food waste in each sector of the Danish Food Supply Chain, each sector having its own specific waste composition as displayed in Table 5. The focus here is on the overall benefits obtained when preventing one tonne of avoidable food waste including all the (prevented) activities otherwise involved in the life cycle of the food. This may be found in section 3.2.1. Note that, these environmental benefits do not account for potential detrimental effects due to the use of monetary savings (derived from the unpurchased food) for purchasing other goods/activities (that may incur environmental burdens). These are called indirect or rebound effects; Martinez-Sanchez et al., 2016).
2. Breakdown of the contribution from the five food categories to the environmental impact associated with the agricultural production of one tonne of avoidable food waste, in each sector of the Danish Food Supply Chain, with the exception of the Primary Production sector. The focus here is on the relative importance of the individual food categories. This may be found in section 3.2.2.
3. Sensitivity analysis of the baseline results (point I above). The focus here is to illustrate the variation of the results relative to the baseline (point I above) when using the Norwegian data (ForMat project) for estimating the waste composition of the sectors Processing and Wholesale & Retail in place of the data from WRAP (2016). This may be found in section 3.2.3.

Figure 4-6 show the results of the LCA. The results are reported as characterized impacts. This means that the total impact on the selected environmental category (e.g. Global Warming) is obtained as the sum of the characterized impacts of all the emissions (e.g. CO_2, N_2O, CH_4, etc.) contributing to the impact on the given category. The characterized impact is calculated according to Eq. (1) below. The contributors to the impact are here distinguished as: Land Use Changes, Food Production (including agriculture/animal farming and industrial processing, when applicable), Transport, Packaging, Cooking/Cooling, Waste Management (including waste collection). Any value above the zero line (i.e. positive values) is intended as an environmental burden, while any value below the zero line (i.e. negative values) is intended as an environmental saving. “Total” is the net sum of burdens and savings. For further details on the numerical values, refer to Annex 8.

$$EP(j) = \sum_i EP(j)_i = \sum_i Q_i \cdot EF(j)_i \qquad \text{Eq.(1)}$$

EP(j): total characterized impact for the environmental impact category *j*
$EP(j)_i$: characterized impact of the emission *i* for the environmental impact category *j*
Q_i: quantity of the emission *i* released to the environment
$EF(j)_i$: equivalency factor of the emission *i* for the environmental impact category *j*

3.2.1 Importance of prevention in each sector of the Food Supply Chain

As expected, prevention of (avoidable) food waste showed environmental savings in all the impact categories considered. The magnitude of these savings was, in general, comparable across the different sectors of the Food Supply Chain. For the environmental category Global Warming, the GHG savings following prevention of one tonne of avoidable food waste (Figure 4) ranged between ca. 2,300 (for prevention in Wholesale & Retail sector) and ca. 4,300 (for prevention in the Households sector) kg CO_2-eq. per tonne of avoidable food waste prevented.

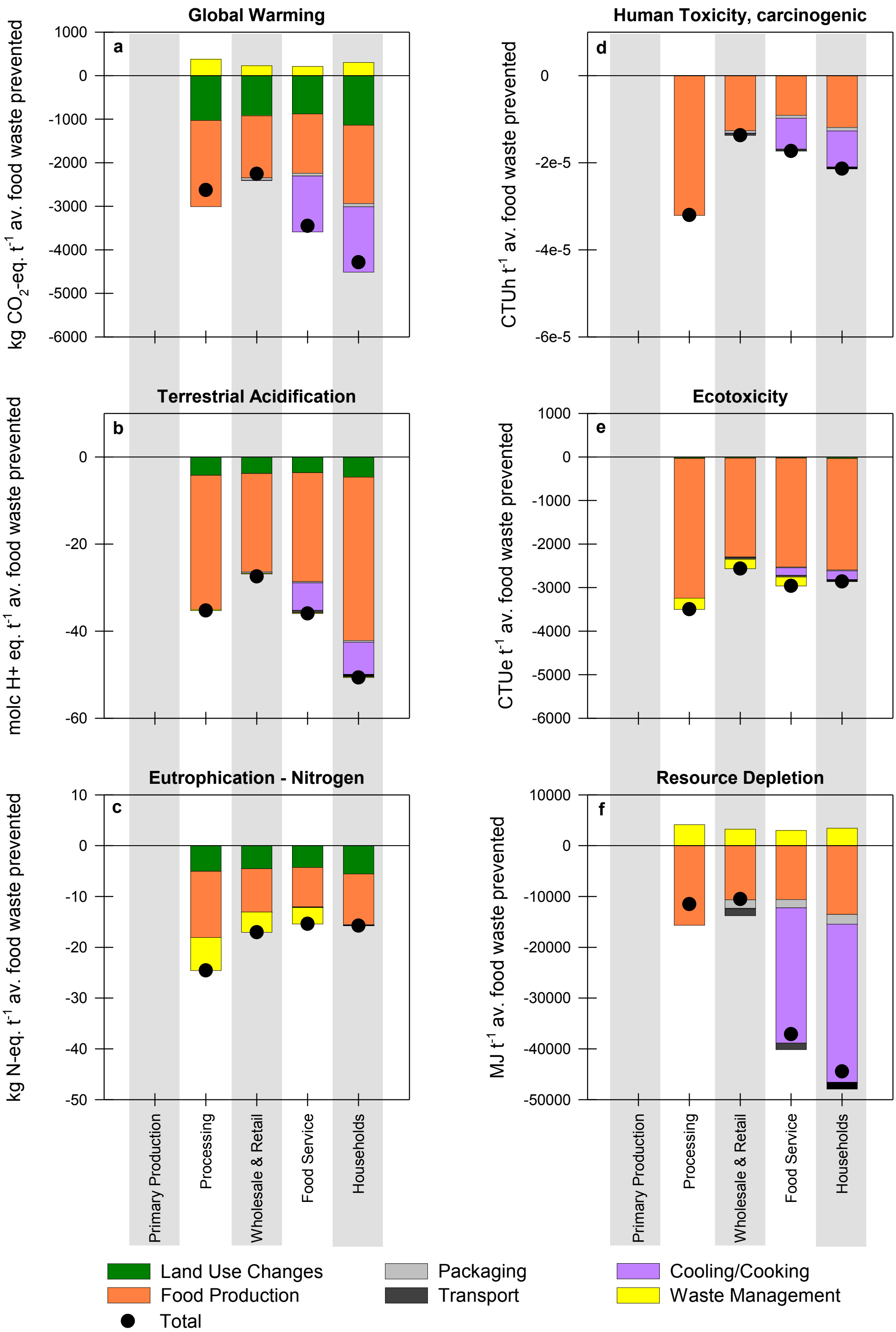

Figure 4: Environmental impacts following prevention of one tonne of avoidable food waste generated in each sector of the Danish Food Supply Chain, with the exception of the Primary Production sector. Food Production, in orange, includes primary production and eventual processing.

Food Service and Households sector highlighted the largest potential savings owing to the impact from cooking/cooling activities, which were assumed not to be part of the remaining Food Supply Chain sectors. As illustrated in Figure 4, Food production (including agriculture/animal farming and industrial processing, in red colours), Land Use Change (in green), and Cooking/Cooling (in purple) were the most important contributors to the Global Warming savings. This is because these activities are avoided when food waste is prevented. As opposite to this, Waste Management (including collection, treatment, and energy/products generation with substitution of conventional fossil products; in orange) appeared as a burden, with an impact ranging between ca. 216 and 379 kg CO_2-eq. kg CO_2-eq. per tonne of avoidable food waste prevented (see Annex 8). This is because by preventing food to become waste the handling of the waste is avoided (i.e. prevented). By avoiding incineration or anaerobic digestion of the food waste, all the related savings from energy recovery and substitution of conventional means of production (mainly relying on fossil fuels) are also cancelled off. In other words, this corresponds to a "lost opportunity" for energy generation and substitution of conventional energy sources. The impacts from Transport and Packaging were minor compared with Food Production, Land Use Changes, and Cooking/Cooling as highlighted in Figure 4. The savings on the category Terrestrial Acidification reflected those seen for Global Warming. Again the magnitude of the savings was comparable across the different sectors of the Food supply Chain. Land Use Changes, Food Production, and Cooking/Cooling were the most important contributors to the impact on this category, similarly to Global Warming. This is because of the NO_x and SO_x emissions associated with production and use of NPK fertilizers (involved in Land Use Changes and Food Production) and with production and use of energy carriers for cooking and cooling activities (Cooking/Cooling). Households and Food Service sectors showed the highest benefit from prevention, per unit of waste prevented, mainly because of the cooking/cooling activities assumed to be involved in these sectors.

In the category Eutrophication - Nitrogen, the largest potential savings were observed for those sectors currently sending the food waste for anaerobic digestion treatment, i.e. biogas production (Processing, Wholesale & Retail, and Food Service). This is because anaerobic digestion comes along with generation of a residual digestate to be applied on agricultural land. It is acknowledged that application of organic digestates induces higher nitrogen leaching compared with the alternative mineral nitrogen fertilizers (Nielsen et al., 2016; Yoshida 2014; Bruun et al., 2006); such impact is illustrated in Figure 4 with the impact of Waste Management, in yellow colour. On this basis, preventing food waste to go through anaerobic digestion decreases the potential for eutrophication of water bodies.

The categories Human Toxicity (carcinogenic) and Ecotoxicity highlighted that Food Production (agricultural practices) is by far the main responsible for toxicity-related impacts on ecosystems and humans. Expectedly, a decreased demand for food would induce savings in these environmental compartments owing to reduction in use of herbicides and pest-control. The results for the category Resource Depletion reflect the avoided use of resources (mainly fossil energy resources due to their scarcity) for production and consumption of the food when this is prevented. Such impact mirrors that seen for Global Warming, being this majorly caused by combustion of fossil energy resources; because this category is strictly related to the use (and thus depletion) of fossil resources, the contribution from cooking/cooling activities appeared very important as evident from Figure 4.

3.2.2 Importance of the individual food categories

In the sectors Wholesale & Retail, Food Service, and Households the food category "Meat & Meat Products" showed the largest contribution on the impact related to food production in all the environmental categories considered (Figure 5), even though the share of this category in the waste was not the largest, as previously displayed in Figure 3 and described in section 3.1.

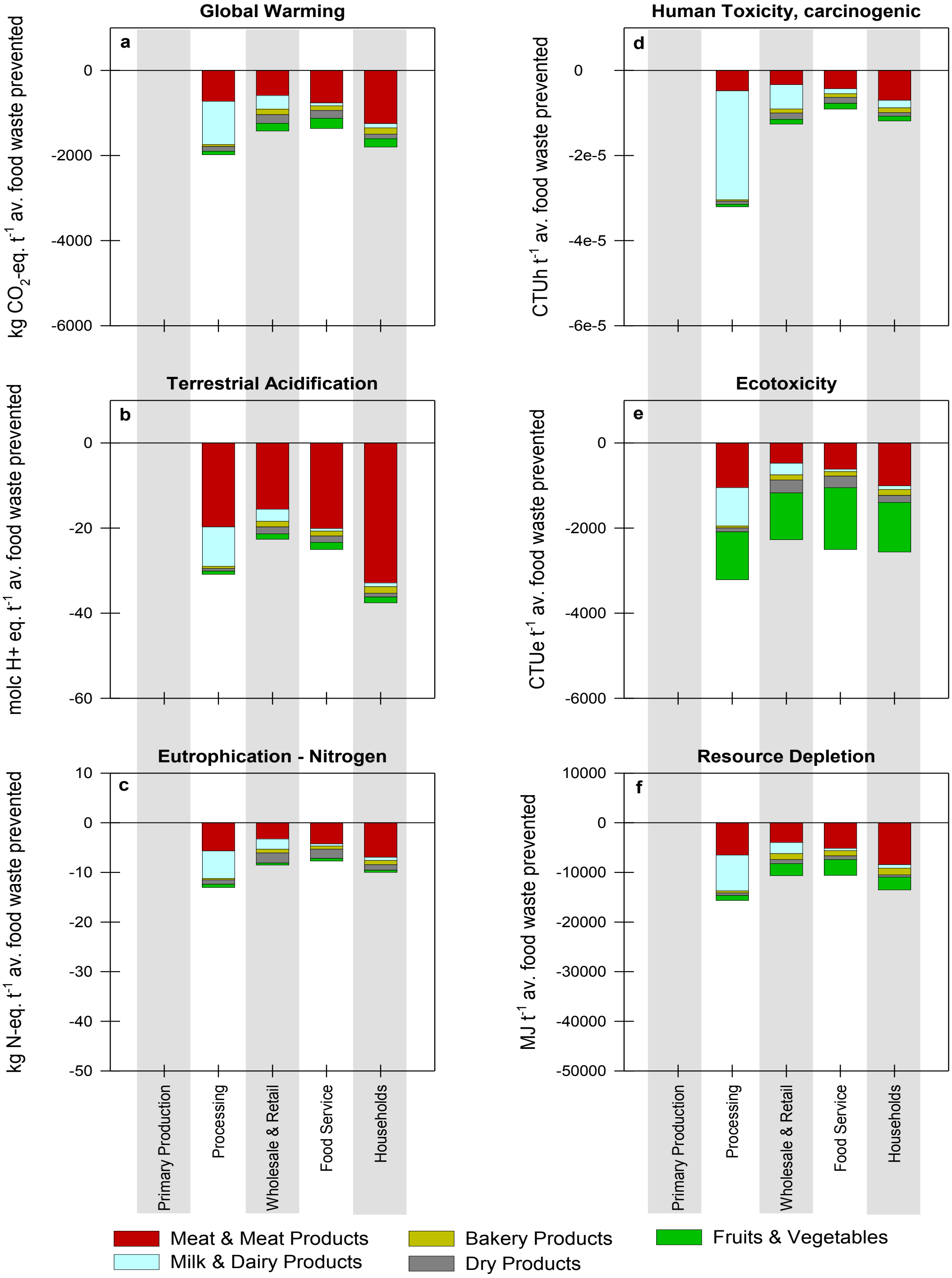

Figure 5: Breakdown of the contribution of the five food categories to the environmental impact associated with Food Production (including agriculture/animal farming and industrial processing) for one tonne of avoidable food waste generated in each sector of the Danish Food Supply Chain (except for the Primary Production sector).

This is because of the higher environmental footprint of meat products compared with the other food items, as highlighted in a multitude of available studies (among the most recent: Martinez-Sanchez et al., 2016; Nemecek et al., 2016). This is further documented in Annex 5, which displays the footprint of the individual food items on the environmental compartments considered in this study, per unit (kg) of food. Meat products, especially from swine and cattle, and cheese have by far the highest environmental footprint in most of the categories. The impacts of these food products in the energy-related environmental categories (Global Warming, Terrestrial Acidification, and Eutrophication - Nitrogen) are about two orders of magnitude higher than those of Fruits & Vegetables.

In the Processing sector, instead, the environmental impacts were mainly associated with the categories “Meat & Meat Products” and “Milk & Dairy Products”, the latter owing to the significant share taken by this category in the whole waste from the Processing sector, as earlier illustrated in Figure 3. It should be kept in mind that these shares have been calculated based on the assumption that the shares of the food items in the food waste from the Processing sector are directly proportional to the shares in the Danish production, due to lack of reliable observations (measured/primary data).

The impact from the food category Fruits & Vegetables on the energy-related environmental categories (Global Warming, Terrestrial Acidification, and Eutrophication - Nitrogen) and on Human Toxicity were minor compared with meat and dairy items, because of the significantly lower environmental impact of Fruits & Vegetables production on these environmental categories, per unit of food product (see Annex 5). Conversely, the impact of Fruits & Vegetables appeared more prominent on Ecotoxicity and Resource Depletion, owing, respectively, to the use of pest control (herbicides, pesticides, etc.) and to the consumption of energy resources for agricultural practices (operation, fuels, fertilizers and seed production, etc.). While the impact of Fruits & Vegetables on Ecotoxicity and Resource Depletion is still lower compared to Meat and Dairy Products on a food-unit basis (see Annex 5), the total impact on the overall food waste generated in each sector becomes comparable to meat/dairy products owing to the high share taken by the category Fruits & Vegetables (as evident from Figure 5).

3.2.3 Sensitivity analysis using Norwegian data

Figure 6 illustrates the results of the LCA when using Norwegian data (ForMat project) instead of those from WRAP (WRAP 2016). The total environmental impact obtained when using the data from WRAP is also displayed (white circle) for the purpose of comparison. As illustrated by Figure 6, this different assumption did not change the overall trend of the results compared to the baseline results (trend is here intended as the relative ranking of the of the Danish Food Supply Chain sector with respect to their environmental performance). Yet, when using Norwegian data the environmental savings of prevention were decreased compared with the baseline in the Processing (reduction between 8% and 16% depending upon the environmental category) and Wholesale & Retail sector (reduction between 5% and 34% depending upon the environmental category considered). The decrease in savings was more evident in the case of the Wholesale & Retail sector. For example, in this sector the Global Warming savings decreased from 2,300 to 1,600 kg CO_2-eq. per tonne of avoidable food waste prevented (i.e. by ca. 30%). Similar reductions could be observed in the environmental categories Terrestrial Acidification, Eutrophication - Nitrogen, and Human Toxicity. Such a decrease in the environmental savings was a consequence of the different composition of the waste in the Norwegian data compared with the WRAP: the Norwegian data have lower shares of meat and dairy food products and corresponding larger shares of fruits and vegetables compared with WRAP (2016); Annex 2.

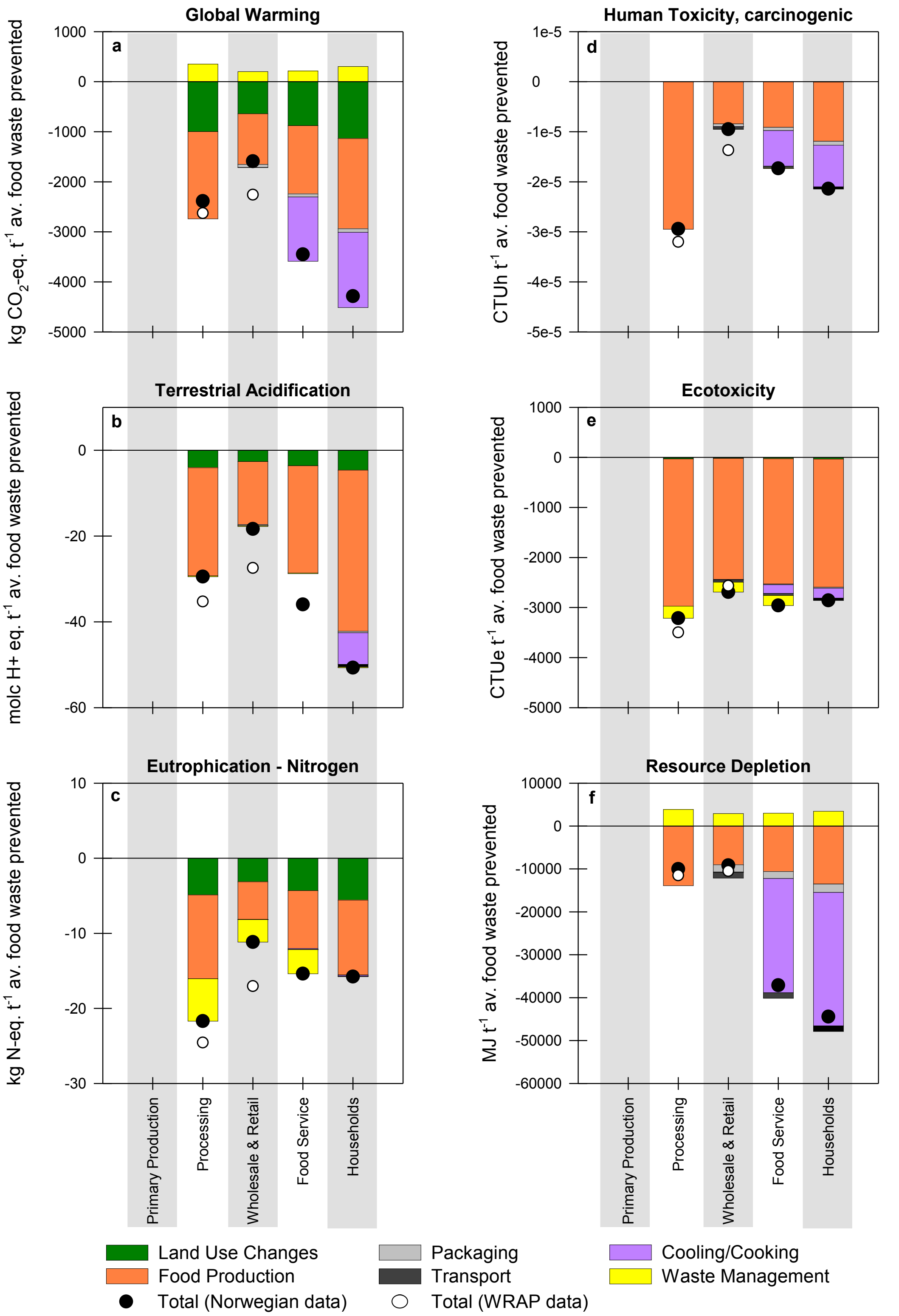

Figure 6. Sensitivity analysis: results of the LCA when using Norwegian data (ForMat project) in place of WRAP (2016) for estimating the waste composition of Processing and Wholesale & Retail sector. The "Total" environmental impact quantified for the baseline (with WRAP data) is also displayed for comparison.

3.2.4 Annual potential savings from prevention

By combining the total amount of avoidable food waste generated by each sector of the Food Supply Chain (Figure 3) with the environmental impacts quantified per tonne of avoidable food waste (Figure 4), it is possible to estimate the annual potential environmental savings following prevention. This is true under the assumption that monetary savings, due to unpurchased foods (because of prevention), are spent for environmentally sound activities and products (e.g. health care, education, culture; Martinez-Sanchez et al., 2016). This, in other words, means that the consumers will not invest such monetary savings in products/activities that may generate environmental burdens, which may ultimately reduce (or cancel off) the environmental benefits of prevention. Table 7 reports the results for each sector of the Danish Food Supply Chain for all the environmental impact categories considered. The results are presented both as characterized impacts (see Eq. (1)) and as normalized impacts. Normalized impacts are calculated from the characterized impacts according with Eq. (2). The normalization references used for such calculation were taken from the specific assessment methods selected for this study (Global Warming: 8100 kg CO_2-eq. person-eq^{-1} year^{-1}; Terrestrial Acidification: 49.6 molc H+ eq. person-eq^{-1} year^{-1}; Eutrophication - Nitrogen: 9.38 kg N-eq. person-eq^{-1} year^{-1}; Human Toxicity, carcinogenic: 5.42E-05 CTU_h person-eq^{-1} year^{-1}; Ecotoxicity: 665 CTU_e person-eq^{-1} year^{-1}; Resource Depletion, abiotic: 6.24E+04 MJ-eq. person-eq^{-1} year^{-1}). The normalization references represent the average impact of a European citizen in the environmental impact category considered. Normalization is used for two purposes: i) to present the results in a form suitable for comparing the magnitude of the impacts across different environmental categories (otherwise having different characterized units, e.g. kg CO_2-eq. vs kg N-eq.); ii) to provide an impression of the magnitude of the environmental impacts, which might be useful for decision making.

$$NP(j) = \frac{EP(j)}{R(j)} \qquad \text{Eq. (2)}$$

NP(j): normalized impact for the environmental impact category *j*
EP(j): total characterized impact for the environmental impact category *j*
R(j): normalization reference for one year for the environmental impact category *j*

For Global Warming, it was estimated that more than 2 million tonne of CO_2 equivalent could be saved with food waste prevention under the assumption that 100% of the avoidable food waste is prevented and that monetary savings are spent in environmentally sound activities/products as highlighted earlier (e.g. health care, education, culture; Martinez-Sanchez et al., 2016). This, for the purpose of comparison, is equal to the Global Warming impact of about 252,000 person-eq. or to the Global Warming impact of extracting and burning ca. 770,000 tonne of coal (assuming 1 t coal = 2.64 t CO_2-eq.) or, alternatively, to about 3.8% of the total GHG emissions of Denmark in 2014 (ca. 54 million t CO_2-eq.; Eurostat 2016). Fulfilling the 50% reduction target in food waste (here considering for the calculation only the avoidable food waste) proposed by United Nations for 2030 (corresponding to the goal #12 of the sustainable development document from UN; http://www.un.org/sustainabledevelopment/sustainable-development-goals/) may therefore bring a reduction of more than 1 million tonne of GHG emissions, under the same assumptions regarding consumer's behaviours with respect to monetary savings. Likewise, important environmental savings were also highlighted in the remaining impact categories considered: these ranged from ca. 273,000 person-eq. (Resource Depletion, abiotic) to ca. 2.7 million person-eq. for the case of Ecotoxicity, assuming 100% prevention. The latter is a consequence of the avoided use of pest-control (pesticides, herbicides, insecticides, etc.) in the agricultural sector following decreased demand for food, thus decreased production. A similar argument applies to Eutrophication – Nitrogen, where significant benefits were highlighted thanks to the reduced use of N-fertilizers owing to the decrease in food demand and production.

Table 7. Annual potential savings from prevention, assuming 100% and 50% of the avoidable food waste is prevented. PP: Primary Production; PR: Processing, WR: Wholesale & Retail, FS: Food service; HH: Households.

Environmental impact category	Sector	100% prevention		50% prevention*	
		Annual savings (characterized)	Annual savings (normalized)	Annual savings (characterized)	Annual savings (normalized)
Global Warming	PP	0	0	0	0
Characterized unit: t CO_2-eq. year^{-1}	PR	-349,396	-43135	-174,698	-21,568
Normalized unit:	WR	-367,825	-45411	-183,913	-22,705
person-eq.	FS	-205,596	-25382	-102,798	-12,691
	HH	-1,114,531	-137,596	-557,265	-68,798
	Total	**-2,037,348**	**-251,524**	**-1,018,674**	**-125,762**
Terrestrial Acidification	PP	0	0	0	0
Characterized unit: molc H+ eq. year^{-1}	PR	-4,688,934	-94,535	-2,344,467	-47,267
Normalized unit:	WR	-4,473,539	-90,192	-2,236,770	-45,096
person-eq.	FS	-2,142,043	-43,186	-1,071,021	-21,593
	HH	-13,165,807	-265,440	-6,582,904	-132,720
	Total	**-24,470,322**	**-493,353**	**-12,235,161**	**-246,677**
Eutrophication – Nitrogen	PP	0	0	0	0
Characterized unit: kg N-eq. year^{-1}	PR	-3,265,580	-348,143	-1,632,790	-174,071
Normalized unit:	WR	-2,777,545	-296,114	-1,388,773	-148,057
person-eq.	SI	-916,725	-97,732	-458,362	-48,866
	HH	-4,096,697	-436,748	-2,048,349	-218,374
	Total	**-11,056,547**	**-1,178,736**	**-5,528,274**	**-589,368**
Human Toxicity	PP	0	0	0	0
Characterized unit: molc H+ eq. year^{-1}	PR	-4	-78,545	-2	-39,273
Normalized unit:	WR	-2	-41,171	-1	-20,586
person-eq.	FS	-1	-19,050	-1	-9,525
	HH	-6	-102,496	-3	-51,248
	Total	**-13**	**-241,263**	**-7**	**-120,631**
Ecotoxicity	PP	0	0	0	0
Characterized unit: CTU_e year^{-1}	PR	-465,277,385	-699,665	-232,638,692	-349,833
Normalized unit:	WR	-418,107,734	-628,733	-209,053,867	-314,367
person-eq.	FS	-176,393,823	-265,254	-88,196,911	-132,627
	HH	-743,730,333	-1,118,391	-371,865,167	-559,196
	Total	**-1,803,509,275**	**-2,712,044**	**-901,754,637**	**-1,356,022**
Resource Depletion, abiotic	PP	0	0	0	0
Characterized unit: MJ-eq. year^{-1}	PR	-1,529,184,790	-24,506	-764,592,395	-12,253
Normalized unit:	WR	-1,711,858,910	-27,434	-855,929,455	-13,717
person-eq.	FS	-2,212,380,728	-35,455	-1,106,190,364	-17,727
	HH	-11,559,549,378	-185,249	-5,779,774,689	-92,625
	Total	**-17,012,973,805**	**-272,644**	**-8,506,486,903**	**-136,322**

*This reflects the 50% reduction target in food waste generation proposed by United Nations for 2030 (corresponding to the goal #12 of the sustainable development document: http://www.un.org/sustainabledevelopment/sustainable-development-goals/); yet, for the calculation, we here only consider the avoidable share of the total food waste.

3.2.5 Perspectives for further research

The results of this study highlights that the environmental savings (or impacts) of food waste prevention (or generation) are mainly related to agricultural food production and to the associated land use change implications. This also means that the specific composition of the food waste, in terms of food items composing the mix (type of meat products, dairy products, fruit, vegetables, etc.) is of critical importance to the assessment results, as the food items have significantly different environmental impacts (e.g. the environmental impact of beef is much higher than chicken and way higher than fruits/vegetables).

Only for the case of the Households sector, primary data (obtained as a result of waste characterization campaigns) were available on the type of food items wasted (e.g. vegetables, fruit, meat, etc.) albeit these represent a still limited sample of cities/areas in Denmark. As opposite to this, no (or obsolete/outdated/non reliable) primary data (intended as results of observations, measurements, campaigns) are available for the composition of the avoidable food waste for the case of the Primary Production, Processing, Wholesale & Retail, and Food Service sectors. It is therefore recommended that future research focuses on obtaining more information from these sectors, for which little is currently available. Possibly, compositional data should be gathered with a higher level of detail compared to current practice, where the waste composition is typically divided into vegetal and animal food, packaging, and paper/cardboard. For example, further dividing vegetables from fruits and the different types of meat (e.g. beef, chicken, and pork) may be envisioned. By doing so, a more detailed information on the type of food items composing the food waste will be achieved, this being a critical factor to increase the robustness and accuracy of the environmental assessment, thus to better document the potential benefits of prevention.

The land use changes (LUC) modelling approach also represents a critical factor to the assessment results. In this study, the framework approach developed in Tonini et al. (2016) was followed to derive LUC impacts. Such a model only includes the so-called indirect LUC impacts (i.e. direct LUC impacts were excluded). The model assumes that: i) effects associated with the demand for land are global, given the global nature of agricultural commodities trading; ii) there is a cause-effect relationship between the demand for arable land and expansion/intensification effects; iii) there is full-elasticity of supply (short-term effects on prices are not modelled). Further, the model considers that additional crop production is ultimately supplied by: i) net expansion of arable land (25% of the total response) and ii) intensification of current cultivation practices (75% of the total response). The so derived LUC impact represents a global LUC factor which is attributable to any crop regardless of type and location. This means that crop production in Europe and in other parts of the world are considered equally responsible for the global LUC emissions (e.g. regarding deforestation), owing to the global nature of agricultural commodities trading. However, other approaches to quantify LUC exist. These, for example, could be based on the results of *ad-hoc* studies using global/partial economic equilibrium models which address short-term effects on prices and related price elasticities (e.g. Marvuglia et al., 2013; Igos et al., 2015; Vazquez-Rowe et al., 2014). Yet, these models may be more suitable for short-term policy or scenario analyses rather than for LCA studies, as suggested in Schmidt et al. (2015). LUC models could, alternatively, follow a rather “country-centric” approach. This approach focuses on the direct land use changes (dLUC) occurring within the national borders of the countries. Because of this, this approach tends to punish with LUC impacts only the crops produced in geographic areas involved with on-going deforestation processes. This could be the case of palm fruit in South-East Asia or of soybean in Brazil (e.g. Ecoinvent 3.3). This approach, compared with that used in this study, may lead to significantly lower LUC impacts as only specific crops (and supplying regions) are heavily punished with LUC impacts.

4. Conclusions and Recommendations

The Danish Food Supply Chain generates annually about 716,000 t of avoidable food waste: Of this, 14% is generated by the Primary Production sector (100,000 t per year), 19% by the Processing sector (133,000 t per year), 23% by the Wholesale & Retail sector (163,000 t per year), 8.4% by the Food Service sector (60,000 t per year) and 36% by the Households sector (260,000 t per year).

All in all, fruits and vegetables appear to be the food products with the largest contribution to the avoidable food waste generated by the Danish Food Supply Chain, followed by meat and bakery products. Dry Products such as grains and flours appear to be the food items with the lowest contribution to the avoidable food waste generated by the Food Supply Chain. The reason for this may be because these products have long expiration date, typically.

Prevention of avoidable food waste may generate important savings in all the environmental compartments, from Global Warming to the depletion of resources. The findings of this study highlight that, per unit of food waste prevented, the environmental benefits may be comparable across all the sectors of the Food Supply Chain. With respect to Global Warming, prevention may generate GHG emissions savings ranging between ca. 2,300 kg CO_2-eq. per tonne (prevention in the Wholesale & Retail sector) and ca. 4,300 kg CO_2-eq. per tonne (prevention in the Households sector). All in all, Households and Food Service sector have the highest GHG emissions saving potential, per unit of food waste prevented. This is a consequence of the fact that these sectors are placed at the end of the Food Supply Chain, thus also involving additional cooking/cooling activities on top of food production and land use change implications, which are common to all sectors.

Results further highlighted that food production, mainly in relation to agricultural practices, and associated land use change impacts are the major contributors to the overall Global Warming impact. Such impact is totally related to the type of food items found in the waste. This means that the specific composition of the food waste (in terms of share of meat, dairy products, fruits, vegetables, etc. composing the mix) is of fundamental importance to the final climate impact. This also applies to the remaining impact categories, where food production (mainly because of agricultural practices) and associated land-use changes are again the major contributors to the total environmental impact.

On an annual basis, the potential environmental savings achievable with prevention of avoidable food waste are significant for all the environmental categories investigated. For example, more than 2 million tonne of GHGs may be saved if 100% of the avoidable food waste was prevented, corresponding to the GW potential of ca. 770,000 tonne of coal. Alternatively, this corresponds to about 3.8% of the total GHGs emission of Denmark (in 2014). Fulfilling the 50% reduction targets proposed by the United Nations may therefore lead to a reduction of more than one million tonne of GHGs emission. Yet, it should be borne in mind that the environmental savings quantified in this study do not consider potential detrimental effects due to the use of monetary savings (derived from the unpurchased food) for purchasing other goods and/or activities (that may also incur environmental burdens). These are called indirect or rebound effects, and their implications should be specifically investigated when studying the implementation of prevention campaigns or policies.

All in all, the results of this study show that the environmental savings obtained with prevention of food waste mainly derive from avoiding food production (agriculture) and associated land use change implications. On this basis, a more robust quantification of the environmental benefits from prevention is much dependent upon a deeper and more solid knowledge of the food waste composition (i.e. food items composing the mixed food waste) generated by each individual sector of the Danish Food Supply Chain. This study highlights that this is particularly needed for the sectors: Primary Production, Processing, Wholesale & Retail, and Food Service. Moreover, while a thorough inclusion of the uncertainties is beyond the scope of this LCA-screening, it is nonetheless envisioned for future investigations to further assess input-data (hence results) uncertainties, in order to provide decision makers with more robust figures. The same applies for the inclusion of the potential indirect (rebound) effects arising from the use of eventual monetary savings.

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Annex 1. Processing

Table 8: Calculation of "Avoidable Food Waste (% Production) from Food Waste Norway 2013/2014/2015.

Food category	2009	2010	2011	2012	2013	2014	Average	Reference
Meat & Meat products	1.5%	1.7%	1.5%	1.5%	1.0%	1.1%	1.38%	Food Waste Norway 2013/2014/2015
Milk & Dairy products		1.9%			3.4%	3.3%	2.88%	Food Waste Norway 2013/2015
Bakery Products	13.0%	13.0%	12.0%	11.0%	13.6%	-	12.52%	Food Waste Norway 2013/2014/2015
Dry Products	3.2%	7.8%	2.1%	2.0%	3.4%	3.4%	3.65%	Food Waste Norway 2013/2014/2015
Fruits & Vegetables	2.0%		10.0%	14.0%			8.67%	Food Waste Norway 2013
The data for dairy was divided for 2014 into milk and cheese:								
Milk products (flytende meieri)					4.10%	4%	4.05%	76% (share in the mix)
Cheese (fast meieri)					1.30%	1.30%	1.3%	24% (share in the mix)

Table 9: Application of Norwegian figures calculated above to the Danish Processing sector. *Production was based on the Danish statistics (dst.dk).

Food category	Danish Production* t year^{-1}	Avoidable Food waste % Production	Avoidable Food waste t year^{-1}	Avoidable Food waste Share %	Avoidable Food waste t year^{-1} (recalculated based on total Danish amount)
Meat & Meat products	2,238,643	1.38%	30,968	18%	23,928
Milk & Dairy products	1,492,990	2.88%	43,072	25%	33,281
Bakery Products	227,789	12.52%	28,519	17%	22,036
Dry Products	198,474	3.65%	7,244	4%	5,597
Fruits & Vegetables	719,144	8.67%	62,326	36%	48,158
TOTAL	4,877,039		172,129	100%	133,000

Annex 2. Wholesale & Retail

Table 10: Composition of the avoidable food waste in Denmark elaborated on the basis of Norwegian data and DK sales statistics. Sales data on Wholesale and Retail in Denmark are from dst.dk (FIKS44). Prices from Table 1 of the study from Jensen (2011).

Food categories		2013 (MDKK)	2014 (MDKK)	Price (DKK kg^{-1})	Average production (t $year^{-1}$)	Food waste, sales (%)	Food waste (t $year^{-1}$)	Share of Food waste (%)
Wholesale	Meat & Meat products	14,259	13,131	24.1	568,257	0.06%	341	2%
	Milk & Dairy products	8,323	8,812	5.66	1,513,693	0.15%	2,271	13%
	Bakery Products	-	-	3.54	-	0.09%	-	0%
	Dry Products	6,132	6,369	3.54	1,765,678	0.05%	795	4%
	Fruits & Vegetables	11,614	10,653	7.94	1,402,204	1.05%	14,653	81%
Retail	Meat & Meat products	1,872	1,792	39.57	46,298	3.10%	1,435	18%
	Milk & Dairy products	-	-	13.42		0.90%	-	0%
	Bakery Products	1,286	1,073	20.38	57,875	8.60%	4,977	61%
	Dry Products	-	-	20.38	-	0.50%	-	0%
	Fruits & Vegetables	487	471	12.59	38,046	4.45%	1,693	21%

Annex 3. Food Service

Table 11: Data on the amount of avoidable Food Waste amounts in the Danish Food Service sector, taken from DEPA (2014).

Food Sector activity	Avoidable Food Waste (t $year^{-1}$)	Total (t $year^{-1}$)	Rounded total (t $year^{-1}$)	Comments	Source in DEPA (2014)
Total Hotels and restaurants		28,500	29,000		
Hotels	8,400			±25%	Table 5.3
Restaurants	20,100			±25%	Table 6.3
Institutions and "storkøkkener"		31,200	31,000		
Canteens and catering	10,200			±10%	Table 8.5
Institutions	21,000			±50%	Table 7.4
Folkeskoler	10,700				
Hospitaler	1,100			114 kg $patient^{-1}$ $year^{-1}$	
Plejehjem	3,700				
Børneinstituitioner	5,500				
Total		59,700	60,000		

Table 12: Data on the composition of edible food waste, taken from literature. We used data for the specific type of institutions when possible, and when this was not possible (for hotels and canteens) we applied the general composition found by WRAP for the UK Hospitality sector.

	RESTAURANTS			GENERAL	HOSPITAL			NURSING HOME	SCHOOL			
	Engstrom & Carlsson-kanyama (2004) Sweden		Silvennoinen et al 2012	WRAP 2011d	Dias-Ferreira et al (2015) Portugal	Diaz & Garcia (2013) Spain	Sonnino & McWilliam (2011) Wales	Nichols et al (2002) US	Engstrom & Carlsson-kanyama (2004) sweden	WRAP 2011b (Primary school)	WRAP 2011b (secondary school)	Silvennoinen et al 2012
Meat & Meat Products	15%	5%	11.3%	10%	28%	23%	27%	30%	20%	8%	7%	63.0%
Milk & Dairy Products			3.8%					23%		2%	3%	
Bakery Products			17.5%	20%	9%			15%		12%	15%	3.0%
Dry Products	18%	33%	23.3%	11%	28%	30%			33%	10%	13%	12.5%
Fruits & Vegetables	67%	62%	44.2%	59%	36%	47%	73%	32%	47%	68%	61%	17.5%
Total	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	96%
Assumptions	The study aggregates potatoes, rice and pasta in one category. We have assumed that potatoes makes 1/3 of this category and have place them together with Fruits & Vegetables.		The study aggregates potatoes, rice and pasta in one category. We have assumed that potatoes makes 1/3 of this category and have place them together with Fruits & Vegetables. Main Course Meat = Meat & Meat Products		The main dish is assumed to be: 1/3 meat, 1/3 pasta, 1/3 vegetables. Soup was taken out of the % because: 1) it does not fit the categories, and 2) it is a liquid that it is disposed of through the sewage		Roasted Lamb + 1/2 Cottage pie = M&MP; Creamed potatoes + Roast potatoes+ Broad beans + Diced swede+ 1/2 Cottage pie = Fruits & Vegetables	It was assumed that starches was bread (shredded wheat cereals)	We have assumed that potatoes makes 1/3 of this category and have place them together with Fruits & Vegetables.			We have assumed that potatoes makes 1/3 of this category and have place them together with Fruits & Vegetables.

Table 13: Resulting composition, estimated for the Danish Food Service sector.

Food category	Hotels		Restaurants		Canteens/Catering		Schools/kindergarten		Hospitals		Homes for the elderly		Avoidable Food Waste	
	%	t $year^{-1}$	%	t $year^{-1}$	%	t $year^{-1}$	%	t $year^{-1}$	%	t $year^{-1}$	%	t $year^{-1}$	%	t $year^{-1}$
Meat & Meat Products	10%	826	9%	1,834	10%	1,003	24%	3,851	22%	247	30%	1,107	15%	8,868
Milk & Dairy Products	0%	-	3%	660	0%	-	2%	291	0%	-	23%	864	3%	1,815
Bakery Products	20%	1,652	15%	3,081	20%	2,007	11%	1,766	8%	84	15%	553	15%	9,143
Dry Products	11%	964	22%	4,382	11%	1,170	17%	2,728	25%	275	0%	-	16%	9,519
Fruits & Vegetables	59%	4,957	50%	10,143	59%	6,020	47%	7,564	45%	494	32%	1,176	51%	30,354
Total	100%	8,400	100%	20,100	100%	10,200	100%	16,200	100%	1,100	100%	3,700	100%	59,700

Annex 4. Households

Table 2-2 ECONET (2015) Madspildets TOP10-rapport		Multi-family houses t year^{-1}	Single-family houses t year^{-1}	Total t year-^{1}	Food Category assigned	Assumptions
Ej forarbedet, vegetabilsh mad-spild	Fresh fruits	10340	12037	22377	F&V	
	Fresh carrots	2526	2015	4541	F&V	
	Fresh potatoes	2740	6469	9209	F&V	
	Salad	2107	1013	3120	F&V	
	Cabbage	1998	2159	4157	F&V	
	Other fresh vegetable	5216	7508	12724	F&V	
	Bread with date - mark	13067	16073	29140	BP	
	Cake with date - mark	801	1845	2646	BP	
	Bread from bakery - bake off	3198	2928	6126	BP	
	Cake from bakery - bake off	530	804	1334	BP	
	Breakfast products	120	1335	1455	BP	100% bread
	Rice or pasta (no cooked)	78	377	455	DP	
	Flour, sugar, salt & *"krydderier"*	1510	6374	7884	DP	
	Other dry products	5359	4358	9717	DP	
	Preserved food	1307	1434	2741	F&V	
	Margarine	28	270	298	F&V	
	Oil, mayonnaise, ketchup	908	3415	4323	F&V	
	Juice and soft drinks	753	479	1232	F&V	
	cereals, whole prepared	0	1874	1874	F&V	
	ready dishes and spreads	1276	321	1597	F&V	
	Other	11	349	360	F&V	
Forarbedet, vege-tabilsh madspild	Rice and cereals products	2184	1110	3294	DP	
	Pasta	1869	1785	3654	DP	
	Potatoes and vegetables	7244	13066	20310	F&V	
	Pizza and crusts	0	603	603	BP	100% bread
	Processed bread	794	2896	3690	BP	
	Vegetarian lunch dish	3045	4707	7752	F&V	100% vegetables
	Processed vegetables	4124	2720	6844	F&V	100% vegetables
	Other	2200	865	3065	F&V	
Ej forarbedet madspild med animalsk indhold	Fresh eggs - not cooked	1081	914	1995	M&MP	
	Fresh and Frozen meat	4800	3418	8218	M&MP	
	Yoghurt	3533	1303	4836	M&DP	
	Butter and blends	156	230	386	M&DP	
	Cheese	1216	2809	4025	M&DP	
	Other dairy products	1339	1394	2733	M&DP	
	Spreadings of fish and meat	3512	6680	10192	M&MP	100% meat
	preserved meat food	0	486	486	M&MP	100% meat

	ready meat dishes (no opened)	224	488	712	M&MP	100% meat
	Other	0	58	58	M&MP	
Forarbedet madspild med animalsk indhold	Lunch rest - meat	10710	17830	28540	M&MP	100% meat
	ready meat dish (opened)	390	516	906	M&MP	100% meat
	take away meal	3206	1025	4231	M&MP	100% meat
	Cooked eggs	177	647	824	M&MP	No category
	bread with spreading	3054	4924	7978	BP	100% bread
	clean meat preparation	2047	5124	7171	M&MP	100% meat
	other	0	0	0	M&MP	No category
Total		110778	149035	260000		
Excluded catego-ries	*"Ørvirgt vegetabilsk madaffald"*	58298	115051	Unavoidable		
	"Ørvirgt madspild med animalsk indhold"	9924	19915	Unavoidable (bones, pet food…)		
Total		179000	284001			

Table 14: Original data from Petersen (2015), further elaborated for this study. F&V: Fruits & Vegetables; M&MP: Meat & Meat Products; BP: Bakery Products; DP: Dry Products; M&DP: Milk & Dairy Products.

Annex 5. Food datasets

Table 15: Datasets used to model the production (agriculture and processing) of the food items included in this study. GW (Global Warming): kg CO_2-eq kg^{-1}; TA (Terrestrial Acidification): kg SO_2-eq kg^{-1}; EN (Eutrophication – Nitrogen): kg N-eq. kg^{-1}; HTc (Human Toxicity, carcinogenic): CTU kg^{-1}; ET (Ecotoxicity): CTU kg^{-1}; RD (Resource Depletion, abiotic): MJ-eq. kg^{-1}; PR: Processing; WR: wholesale & Retail; FS: Food Service; HH: Households. The processes called "market" include agricultural production, eventual processing, and transport to processing. The processes called "production" only include agricultural production and eventual processing. They are used to model the environmental impacts of food production (an exception to this is chicken and cattle, for which we used the market dataset due to lack of data). All datasets from Ecoinvent 3.3 have been manipulated in order to delete the emissions related to LUCs (e.g. CO_2 from/to soil due to land transformation) to avoid double counting with the LUC inventory used in this study. Values are rounded.

Process name	Source	GW	TA	EN	HTc	ET	RD
market for chicken for slaughtering, live weight; GLO	Ecoinvent v3.3	2.1	6.1E-02	2.0E-02	1.4E-08	4.1	21.7
cattle for slaughtering, live weight to generic market for red meat, live weight; GLO	Ecoinvent v3.3	8.6	2.7E-01	4.3E-02	1.3E-08	3.2	26.3
swine production; GLO	Ecoinvent v3.3	6.9	1.2E-01	2.8E-02	8.0E-08	5.9	74.6
milk production, from cow; RoW	Ecoinvent v3.3	1.2	9.8E-03	1.0E-02	5.3E-09	1.0	7.4
cheese production, soft, from cow milk; GLO	Ecoinvent v3.3	11.8	1.1E-01	5.4E-02	3.8E-07	10.9	87.9
Yogurt production, from cow milk; GLO	Ecoinvent v3.3	1.8	1.7E-02	7.8E-03	5.3E-08	1.6	13.8
Wheat bread, conventional, fresh production	LCA food DK*	0.7	7.8E-03	4.4E-03	5.6E-09	0.7	6.9
Wheat flour production	LCA food DK*	1.0	1.1E-02	6.3E-03	7.9E-09	1.0	9.6
Rye flour production	LCA food DK*	0.1	7.3E-04	1.6E-02	2.5E-09	3.3	-15.2
rice production; RoW	Ecoinvent v3.3	2.0	1.0E-02	1.1E-02	1.2E-08	0.6	13.1
potato production; RoW	Ecoinvent v3.3	0.2	2.1E-03	2.2E-03	1.3E-09	3.9	2.1
carrot production; RoW	Ecoinvent v3.3	0.4	2.5E-03	8.6E-04	3.0E-09	0.5	5.3
tomato production; GLO	Ecoinvent v3.3	1.4	8.2E-03	4.6E-04	5.7E-09	0.5	17.7
onion production; RoW	Ecoinvent v3.3	0.4	3.1E-03	1.3E-03	3.3E-09	1.0	5.9
apple production; GLO	Ecoinvent v3.3	0.3	2.0E-03	4.2E-04	2.4E-09	4.5	4.2

*The model from LCA food DK has been adapted using consequential process-data from Ecoinvent v3.3, to assure as much as possible consistency with the consequential approach used for the remaining datasets.

Annex 6. LUC inventory

LUC impacts (as iLUC – see section 2.3) were calculated according with Eq. (3):

iLUC impact $_{ij}$ = *Arable land demanded* $_{i}$ · *iLUC impact* $_{j}$ Eq. (3)

Where:
iLUC impact ij: impact, due to iLUC, of the food product *i* on the environmental impact category j; the impact is based upon the life-cycle inventory provided in Tonini et al. (2016); see Table 16 herein for details.
Arable land demanded $_{i}$ = area of arable land required for the life-cycle of the food product *i;* see Table 17 herein.

Table 16: Final aggregated inventory for (indirect) land-use change impacts, iLUC (unit: one hectare of arable land demanded for cropping). Taken from Tonini et al. (2016).

Expansion	**Emissions to air**		
	CO_2	2.2	t CO_2 ha^{-1}_{dem} y^{-1}
	N_2O	0.22	kg N_2O ha^{-1}_{dem} y^{-1}
	NO_x	1.8	kg NO ha^{-1}_{dem} y^{-1}
Intensification: NPK fertilizer production	**Materials**		
	N-fertilizer	125	kg N ha^{-1}_{dem} y^{-1}
	P-fertilizer	52	kg P_2O_5 ha^{-1}_{dem} y^{-1}
	K-fertilizer	35	kg K_2O ha^{-1}_{dem} y^{-1}
Intensification: N-emissions	**Emissions to air**		
	N_2O (dir + ind)*	3.4	kg N_2O ha^{-1}_{dem} y^{-1}
	NH_3	3	kg NH_3 ha^{-1}_{dem} y^{-1}
	NO_x	4.5	kg NO_2 ha^{-1}_{dem} y^{-1}
	Emissions to water		

	NO_3-N	25	kg NO_3-N $ha^{-1}{}_{dem}$ y^{-1}

* Sum of direct and indirect N_2O.

Table 17: Life-cycle arable land demanded, in $m^2 \cdot y\ kg^{-1}$ ww. Rounded values.

Name	Amount	Unit	Source	Comment
Market for chicken for slaughtering, live weight; GLO	2.4	$m^2 \cdot y\ kg^{-1}$ ww	Ecoinvent 3.3	Total land needed for transformation + occupation*
Cattle for slaughtering, live weight to generic market for red meat, live weight; GLO	10.0	$m^2 \cdot y\ kg^{-1}$ ww	Ecoinvent 3.3	Total land needed for transformation + occupation*
Swine production; GLO	5.9	$m^2 \cdot y\ kg^{-1}$ ww	Ecoinvent 3.3	Total land needed for transformation + occupation*
Cow milk production; GLO	1.3	$m^2 \cdot y\ kg^{-1}$ ww	Ecoinvent 3.3	Total land needed for transformation + occupation*
Cheese production, soft, from cow milk; GLO	9.0	$m^2 \cdot y\ kg^{-1}$ ww	Ecoinvent 3.3	Total land needed for transformation + occupation*
Yogurt production, from cow milk; GLO	1.3	$m^2 \cdot y\ kg^{-1}$ ww	Ecoinvent 3.3	Total land needed for transformation + occupation*
Wheat bread, conventional, fresh, production	2.2	$m^2 \cdot y\ kg^{-1}$ ww	Ecoinvent 3.3 & LCA food DK	Total land needed for transformation + occupation*
Wheat flour production	3.1	$m^2 \cdot y\ kg^{-1}$ ww	Ecoinvent 3.3 & LCA food DK	Total land needed for transformation + occupation*
Rye flour production	1.4	$m^2 \cdot y\ kg^{-1}$ ww	Ecoinvent 3.3 & LCA food DK	Total land needed for transformation + occupation*
Rice production; GLO	0.006	$m^2 \cdot y\ kg^{-1}$ ww	Ecoinvent 3.3	Total land needed for transformation + occupation*
Potato production; GLO	0.54	$m^2 \cdot y\ kg^{-1}$ ww	Ecoinvent 3.3	Total land needed for transformation + occupation*
Tomato production; GLO	0.19	$m^2 \cdot y\ kg^{-1}$ ww	Ecoinvent 3.3	Total land needed for transformation + occupation*
Carrot production; GLO	0.14	$m^2 \cdot y\ kg^{-1}$ ww	Ecoinvent 3.3	Total land needed for transformation + occupation*
Onion production; GLO	0.18	$m^2 \cdot y\ kg^{-1}$ ww	Ecoinvent 3.3	Total land needed for transformation + occupation*
Apple production; GLO	0.36	$m^2 \cdot y\ kg^{-1}$ ww	Ecoinvent 3.3	Total land needed for transformation + occupation*

*For the calculation in Eq. (3), the figure needed is the total land demanded (i.e. occupation + transformation) per each food product. This is because, in Tonini et al. (2016), the iLUC inventory is given per unit of land (i.e. ha) demanded. The impact is then given as a combination of intensification (occupying existing arable land, with optimized production; 75% of the response to the initial demand for 1 hectare) and transformation (expansion into virgin land, e.g. forest and grassland; 25% of the response to the initial demand for 1 hectare).

Annex 7. MFA results

Table 18: Numerical results of the Material Flow Analysis of the avoidable food waste, estimated for the Danish Food Supply Chain. PP: Primary Production; PR: Processing; WR: wholesale & Retail; FS: Food Service; HH: Households. The unit is wet tonne of avoidable food waste per year (t av. FW year^{-1}). Eventual discrepancies with the figures provided in the text are due to rounding.

Food category	PP	PR	WR	FS	HH
Meat & Meat Products	17,991	33,648	11,065	8,868	63,379
Milk & Dairy Products	25,023	35,419	14,145	1,815	11,989
Bakery Products	16,568	7,969	31,007	9,143	53,010
Dry Products	4,209	9,917	4,950	9,519	25,022
Fruits & Vegetables	36,209	46,045	101,833	30,354	106,601
TOTAL	100,000	133,000	163,000	59,700	260,000
% Share of each sector	14%	19%	23%	8%	36%

Annex 8. LCA results

Table 19: LCA results (numerical values). PP: Primary Production; PR: Processing; WR: wholesale & Retail; FS: Food Service; HH: Households.

Environmental Impact category	Process contributor	PP	PR	WR	FS	HH
Global Warming (kg CO_2-eq. t^{-1} av. food waste prevented)	Land Use Changes	-	-1026	-922	-877	-1136
	Agricultural Production	-	-1980	-1422	-1364	-1799
	Packaging	-	0	-58	-61	-73
	Cooling/Cooking	-	0	-5	-1285	-1502
	Transport	-	0	-82	-78	-81
	Waste Management	-	379	232	216	305
	Total	-	-2627	-2257	-3450	-4287
Terrestrial Acidification (molc H+ eq. t^{-1} av. food waste prevented)	Land Use Changes	-	-4.2	-3.8	-3.6	-4.6
	Agricultural Production	-	-30.9	-22.6	-25.0	-37.5
	Packaging	-	0.0	-0.3	-0.3	-0.4
	Cooling/Cooking	-	0.0	0.02	-6.3	-7.4
	Transport	-	0.0	-0.6	-0.6	-0.6
	Waste Management	-	-0.2	-0.2	-0.2	-0.2
	Total	-	-35.3	-27.4	-35.9	-50.6
Eutrophication - Nitrogen (kg N-eq. t^{-1} av. food waste prevented)	Land Use Changes	-	-5.0	-4.5	-4.3	-5.6
	Agricultural Production	-	-13.0	-8.5	-7.7	-10.0
	Packaging	-	0	-0.01	-0.01	-0.01
	Cooling/Cooking	-	0	-0.001	-0.1	-0.2
	Transport	-	0	-0.02	-0.02	-0.02
	Waste Management	-	-6.5	-4.0	-3.2	-0.02
	Total	-	-24.6	-17.0	-15.4	-15.8
Human Toxicity, carcinogenic (CTUh t^{-1} av. food waste prevented)	Land Use Changes	-	-3.3E-08	-2.9E-08	-2.8E-08	-3.6E-08
	Agricultural Production	-	-3.2E-05	-1.3E-05	-9.1E-06	-1.2E-05
	Packaging	-	0	-5.6E-07	-6.6E-07	-8E-07
	Cooling/Cooking	-	0	-2.6E-08	-7.1E-06	-8.3E-06
	Transport	-	0	-4.7E-07	-4.3E-07	-4.3E-07
	Waste Management	-	7.4E-08	-1.1E-08	-3.8E-08	3.4E-08
	Total	-	-3.2E-05	-1.4E-05	-1.7E-05	-2.1E-05
Ecotoxicity (CTUe t^{-1} av. food waste prevented)	Land Use Changes	-	-29	-26	-25	-32
	Agricultural Production	-	-3214	-2269	-2502	-2562
	Packaging	-	0	-12	-16	-19
	Cooling/Cooking	-	0	-1	-172	-201
	Transport	-	0	-44	-43	-46
	Waste Management	-	-256	-213	-202	0
	Total	-	-3498	-2565	-2960	-2861
Resource Depletion, abiotic (MJ t^{-1} av. food waste prevented)	Land Use Changes	-	0	0	0	0
	Agricultural Production	-	-15640	-10630	-10580	-13500
	Packaging	-	0	-1675	-1626	-1943
	Cooling/Cooking	-	0	-99	-26630	-31120
	Transport	-	0	-1356	-1291	-1353
	Waste Management	-	4142	3258	3007	3456
	Total	-	-11498	-10502	-37120	-44460

Food waste prevention in Denmark

Prevention of avoidable food waste may generate important savings in all environmental impact categories, from global warming to the depletion of resources. The findings of this study highlight that, per unit of food waste prevented, the environmental benefits may be comparable across all the sectors of the Food Supply Chain. With respect to Global Warming, prevention may generate GHG emissions savings ranging between ca. 2,300 kg CO2-eq. per tonne (prevention in Wholesale & Retail) and ca. 4,300 kg CO2-eq. per tonne (prevention in Households). All in all, Households and Food Service sector have the highest GHG emissions saving potential, per unit of food waste prevented.

Results further highlighted that food production, mainly in relation to agricultural practices, and associated land use change impacts are the major contributors to the overall Global Warming impact. Such impact is totally related to the type of food items found in the waste.

On an annual basis, the potential environmental savings achievable with prevention of avoidable food waste are significant for all the environmental categories investigated. For example, more than 2 million tonne of GHGs may be saved if 100% of the avoidable food waste was prevented, corresponding to about 3.8% of the total GHGs emission of Denmark (in 2014).

Yet, it should be borne in mind that the environmental savings quantified in this study do not consider potential detrimental effects due to the use of monetary savings (derived from the unpurchased food) for purchasing other goods and/or activities (that may also incur environmental burdens).

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