



## Carbon footprint of supermarket food waste

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### ABSTRACT

Food waste is a major problem in modern society and carries considerable social, economic and environmental costs. Food production causes greenhouse gas emissions along the entire food supply chain and wasting food means that those emissions are produced in vain. There is consensus that food waste has to be reduced. For example, the EU and some of its member countries have set concrete targets to reduce the amount of waste. However, in order to achieve the overall goal of a more sustainable economy, not only quantitative but also environmental indicators have to be considered when pursuing waste reduction goals. This study analysed the discrepancies between the waste quantity and wastage carbon footprint (CF) profiles of perishable food products wasted in Swedish supermarkets.

The wastage CF, defined as the product CF from cradle up to and including delivery to the retailer times the amount of the product wasted at the store, was calculated for products in the meat, deli, cheese, dairy and fruit & vegetable departments of six Swedish supermarkets. The CF from cradle to retailer of the various products was determined based on existing life cycle assessment (LCA) literature. Emissions due to production and transportation were considered. Data on wasted mass of the products in the period 2010–2012 was provided by the Swedish retail chain Willys. Data on bread waste are mainly held by the bakeries, and were thus not included in the study.

Over a three-year period, 1570 t of fresh food (excluding bread) were wasted in the six supermarkets. The associated total wastage CF was 2500 t CO<sub>2</sub>e. The fruit & vegetable department contributed 85% of the wasted mass and 46% of the total wastage CF. The meat department contributed 3.5% of the wasted mass, while it accounted for 29% of the total wastage CF. The wastage CF of each department tended to be highly concentrated in certain products and thus halving the waste of the top three products in each department could save more than 25 t CO<sub>2</sub>e per store and year.

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## 1. Introduction

Globally, about 1.3 billion t of food are wasted every year ([Gustavsson et al., 2011](#)). Besides economic, ethic and social aspects, food wastage carries a considerable environmental burden. The provision of food causes emissions of greenhouse gases (GHG) at all stages along the food supply chain (FSC), from input generation through agricultural production, post-farm processing and distribution to final consumption and waste disposal.

In Europe, the consumption of food accounts for about 20–30% of GHG emissions from consumption of all products, with the agricultural stage in the FSC being the key factor ([Tukker et al., 2006](#); [Moll and Watson, 2009](#)). Agriculture is among the economic sectors with the highest environmental pressure intensities and resource use, and accounts for about 15% of direct GHG emissions from all

EU (EU-25) production ([Moll and Watson, 2009](#)). The main GHG emissions at farm level are CH<sub>4</sub> emissions from livestock and N<sub>2</sub>O emissions from soils and manure management ([Moll and Watson, 2009](#)). Globally, agriculture is the primary cause of increasing atmospheric concentrations of CH<sub>4</sub> and N<sub>2</sub>O and produces 10–12% of total anthropogenic GHG emissions ([Smith et al., 2007](#)). In addition, the production of inputs such as fertiliser and energy use on the farm and for post-farm activities (e.g. transportation, processing, storage, refrigeration) leads to food-related emissions ([Garnett, 2011](#); [Sonesson et al., 2010](#)).

Therefore, wasting food not only means that resources are wasted, but also that GHG emissions are produced in vain. According to [FAO \(2013\)](#) the global carbon footprint (CF) of annual food wastage is about 3.3 Gt CO<sub>2</sub> equivalents (CO<sub>2</sub>e).

In the EU, about 90 Mt of food are wasted every year ([Monier et al., 2010](#)). Recently, the European Commission developed a “Roadmap to a Resource Efficient Europe”. The food industry was identified as one of the key sectors and one of the milestones is for the amount of edible food waste in the EU to be halved by 2020

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(EC, 2011). So far, some individual countries have stipulated waste reduction targets which, however, partly still differ from the EU main goal. For example, Sweden aims to reduce food waste by 20% by 2020 compared with 2010 (SEPA, 2013), while the Netherlands has set a target of 20% by 2015 and France a target of 50% by 2025 (Rutten et al., 2013). All these targets refer to food waste in terms of mass.

Although food wastage occurs at all stages along the FSC, later stages such as households and the retail sector play a major role in industrialized countries (Gustavsson et al., 2011). In Sweden and other European countries, the retail sector is a highly concentrated industry (Axfod, 2012; Vander Stichele et al., 2006), which means that there are rather large supermarket chains instead of smaller, individual stores and therefore, food wastage is concentrated to certain locations. Moreover, the quality of the food wasted in stores is often still very high. Retailers are closely connected to other stages of the FSC and represent the link between producers and consumers. Therefore, addressing the retail sector is a key issue in order to reduce food wastage. Previous studies on food waste in the retail sector primarily focused on quantities of waste in terms of mass and identified fresh produce as the main contributor (e.g. Buzby et al., 2009). However, only evaluating wasted mass does not provide sufficient information about the environmental impact. In order to achieve the overall goal of a sustainable economy and to combat climate change, environmental indicators also have to be considered as regards food waste reduction goals. The aim of this study was to analyse wasted retail food in terms of GHG emissions, in order to obtain knowledge about the climate impact pattern of food waste in supermarkets. Specific objectives were to identify hotspots by determining the products and supermarket departments dominating the impacts and to quantify and illustrate the discrepancies between mass and CF profiles of the waste.

## 2. Material and methods

In order to analyse the climate impact pattern of retail food waste, the wastage CF was calculated for different food products wasted in six Swedish supermarkets. The wastage CF was defined as the specific CF value of a product, comprising emissions associated with the production and distribution up to delivery to the supermarket, multiplied by the total mass that was wasted in the stores of the respective product. Data on wasted mass were obtained as described in Section 2.1. The specific CF values were determined based on existing life cycle assessment (LCA) literature, as described in Section 2.2. For a detailed description of the background data see Scholz (2013).

The CF is expressed in terms of carbon dioxide equivalent (CO<sub>2</sub>e). Here, CO<sub>2</sub>, N<sub>2</sub>O, and CH<sub>4</sub> emissions were included where the global warming potential of N<sub>2</sub>O and CH<sub>4</sub> is expressed relative to CO<sub>2</sub> according to the IPCC (Solomon et al., 2007).

### 2.1. Food waste data

Data of food products sold or wasted at retail level were provided by the Swedish supermarket chain Willys, which supplied data for six of its stores. Willys, which is wholly owned by Axfod, is Sweden's leading discount chain, with a total of 174 stores (Axfod, 2012). The six stores participating in the study were selected by the company head office and are located in the Uppsala-Stockholm region. The sales area of the selected stores is between 2300 and 4900 m<sup>2</sup> (Eriksson et al., 2012) and the stores were considered to represent an average store of the retail chain in terms of factors such as turnover, profit and percentage waste (Eriksson, 2012). Willys stores generally carry approximately 9000 products (Axfod, 2012). This study analysed data on products in the meat, deli, cheese, dairy and fruit & vegetable department,

i.e. the majority of the perishable products of the stores except bread and fresh fish. The bread department is managed separately by the supplier, while the fish department is relatively small and was not considered to contribute significantly to the food wastage. The departments are defined by the retail chain. The meat department sells fresh meat from terrestrial animals, mainly beef, pork and chicken, but also lamb and game meat. It also includes grilled chicken, raw sausages and some frozen meat. In the deli department, processed meat products such as sausages, meatballs and cold cuts, as well as black pudding and pâté, are sold. Besides dairy products such as milk, cream, butter and yoghurt, the dairy department also carries eggs, as well as drinks and juices based on fruit, vegetables and grain. The cheese department sells various cheeses, mainly hard or semi-hard cheese, soft cheese and cream cheese, but also tofu. The fruit & vegetable department sells a wide range of domestic and imported fresh produce.

Each store performs a daily waste recording routine where all products that are assumed to be unsellable, e.g. due to a passed best-before date, damage or colour change of the product, are collected. Where applicable, the European Article Number (EAN) code is scanned before the products are discarded, whereby the wasted mass is recorded. For unpacked fruit and vegetables, the estimated total mass or total number of items is entered manually. The items collected and discarded this way are referred to as in-store waste. The routine was already established by the stores before this study and is described in more detail by Eriksson (2012) and Åhnberg and Strid (2010). Unrecorded in-store waste and missing quantities as described by Eriksson et al. (2012) were not considered in this study.

However, some of the food discarded at Willys supermarkets is due to rejections upon delivery, which is defined as pre-store waste (Eriksson et al., 2012). Data on rejected products is logged into the supplier's accounting system manually every day and recorded in weekly reports. Since pre-store waste usually becomes physical waste at the retailer, it was included in this study. Data on pre-store waste was provided by the suppliers.

Data for the period 2010–2012 were analysed using Microsoft Excel 2010 and IBM SPSS Statistics 21. The wasted mass of a product or of a department was calculated as the sum of pre-store and in-store waste of all products belonging to the respective category. The wastage CF per year and store for each department was calculated as the mean of the six stores and the three years.

### 2.2. Carbon footprint of food products wasted in stores

The CF from cradle up to the delivery to the retailer of all products was calculated based on information from the literature. CF values as well as literature considered is listed in Tables 1–4. When more than one study on a specific product existed, the study that best represented the product at the store in terms of country of origin and production method and which used most current data was selected. Where the scope of the available literature did not exactly fit the purpose of the present study, assumptions or calculations were made as described in more detail in the following paragraphs. In general, all emissions associated with primary production, as well as emissions caused by processing and transportation up to the retailer, were considered. Emissions from land use change (LUC) were not included. Emissions associated with store operations and packaging were not included, since data availability was not sufficient and their impact was considered to be relatively low (Cederberg et al., 2009a; Stoessel et al., 2012).

#### 2.2.1. Meat department

The total wasted mass for the whole meat department and for different product categories was calculated, including all fresh meat belonging to the respective category, also including imported,

organic and frozen meat, unless otherwise indicated. In many LCA studies, the CF of meat production is presented per kilogram carcass weight (CW), which includes bones and fat. In this case, the CF of bone-free meat (BFM) was calculated based on the meat yield and all emissions were allocated to the meat; the conversion factor is 0.7 for beef (Cederberg et al., 2009c), 0.59 for pork (Sonesson et al., 2010), 0.77 for poultry (Sonesson et al., 2010) and 0.76 for lamb (Wallman et al., 2011).

Based on information from product labels, it was assumed that all marinated meat had a meat content of 90%.

The CF of meat varies widely due to different production systems and calculation methods. Here, the CF of Swedish pork, beef and chicken is based on results from Cederberg et al. (2009a, 2009b) since their scope fitted the present study (CF from cradle to retailer in Stockholm); the results are for the year 2005. There, Swedish meat production was analysed in a top-down national approach also including organic production systems and the results were therefore considered to be representative for the meat in the stores that was produced in Sweden. The CF of other meat, e.g. imported meat and meat from lamb or game is based on less comprehensive studies (see Appendix 1). However, 67% of the wasted mass in the meat department were beef, pork and chicken produced in Sweden.

## 2.2. Deli department

Products in the deli department are mainly processed meat products. Since no suitable LCA studies for specific deli products were available, the CF of the different products was estimated based on assumptions of meat content and energy requirements for processing.

It was assumed that the non-meat content of the products had no influence on the total CF of the product. For the meat content, the respective CF of meat produced in Sweden was used.

The meat content of the products in the retail stores was estimated based on information given on some product labels. In general, the meat content of sausages is between 35% (hot dogs) and 95%. Most sausages have a meat content of around 50–70%, while bratwurst and chorizo have a meat content of 75–95%. Here, an estimated average meat content of 35% was used for hot dogs, 85% for bratwurst and chorizo and 60% for most other sausages, e.g. wiener, chipolata or barbecue sausages. Meatballs usually have a meat content of about 70%, while for cured meat a general meat content of 90% was used. For dried sausages (e.g. salami) and dried ham, it was assumed that on average, 110 g of meat are required per 100 g product. When no specific information was available, it was assumed that the total meat content consisted of 90% pork and 10% beef. For meatballs, a ratio of 50% beef and 50% pork was assumed. These assumptions were made based on information from some product labels.

GHG emissions from energy use were calculated based on the assumption that the energy consumption of the meat processing industry consists of 40% electricity and 60% fossil fuels (diesel), with associated GHG emissions of 0.007 kg CO<sub>2</sub>e kWh<sup>-1</sup> electricity and 0.4 kg CO<sub>2</sub>e kWh<sup>-1</sup> fossil fuels, adapted from a Swedish study by Wallén et al. (2004). This resulted in 0.067 kg CO<sub>2</sub>e MJ<sup>-1</sup> for meat processing. The energy requirement for processing cooked and dried sausages is 4.4 and 16.9 MJ kg<sup>-1</sup>, respectively (Wiegmann et al., 2005), while the energy for meatball processing is 2.5 MJ kg<sup>-1</sup> (Sonesson et al., 2005). It was assumed that black pudding, head cheese and pâté have similar energy requirements to cooked sausages. Wallman and Sonesson (2010) showed that the energy use per kg product for slaughter and processing is about 4 MJ higher for smoked turkey than for raw fillet and this value was thus used for the processing phase of all cured and smoked meat.

In the LCA studies of meat consulted, all GHG emissions are allocated to the animal carcass at the slaughterhouse stage. Therefore, no GHG emissions were associated with blood or organ meat

production. However, to account for transportation from slaughterhouse to store, a CF of 0.05 kg CO<sub>2</sub>e kg<sup>-1</sup> was assigned to those products, based on an assumption of truck transport for 300 km.

## 2.2.3. Dairy and cheese department

Several studies have calculated the environmental impact of raw milk for different production systems and countries, including Sweden (Cederberg et al., 2009a). However, fewer studies have investigated the impact of different dairy products. Flysjö (2012) calculated the CF of various products produced at the dairy company Arla Foods, including fresh dairy products, various cheeses, butter and butter blends. Many of the dairy product CF values used in this study are based on the study by Flysjö. Arla Foods is one of the largest dairy companies in the world and has its production sites and raw material intake mainly in northern Europe (Flysjö, 2012). Sweden is the second largest market of Arla Foods. Moreover, there is a product delivery agreement between Arla and Axfood (Axfood, 2009). Therefore, products included in the study by Flysjö were considered to be representative for products at the studied Willyssstores. Moreover, raw milk intake is the crucial factor for the CF of dairy products (Flysjö, 2012). The CF used by Flysjö for raw milk is 1 kg CO<sub>2</sub>e kg<sup>-1</sup> milk and is well in line with findings on Swedish milk production (1 kg CO<sub>2</sub>e kg<sup>-1</sup> energy corrected milk (Cederberg et al., 2009a)).

The CF of fresh orange or apple juice was calculated to be about 1 kg CO<sub>2</sub>e kg<sup>-1</sup> juice (Beccali et al., 2009; Angervall and Sonesson, 2011). Angervall and Sonesson (2011) also calculated the CF of juice made from concentrate to be about 0.6 kg CO<sub>2</sub>e kg<sup>-1</sup> juice. These values were used for all fruit and vegetable juices. Fruit drinks generally have a fruit juice content of 10–50%. Here, the CF was calculated based on a juice content of 50% juice made from concentrate to account for the emissions associated with the production of juice and other ingredients. Based on CF studies of soy milk (Ecofys, 2009) and an oat drink (Dahllöv and Gustafsson, 2008), an average CF from cradle to retailer of 0.15 kg CO<sub>2</sub>e kg<sup>-1</sup> product was estimated for all soy and grain drinks.

A small part of the wasted products was processed cheese. However, no detailed LCA data or data on energy requirements for processing were available. Therefore, the CF of processed cheese was estimated based on the cheese content, which was about 40% in the products considered.

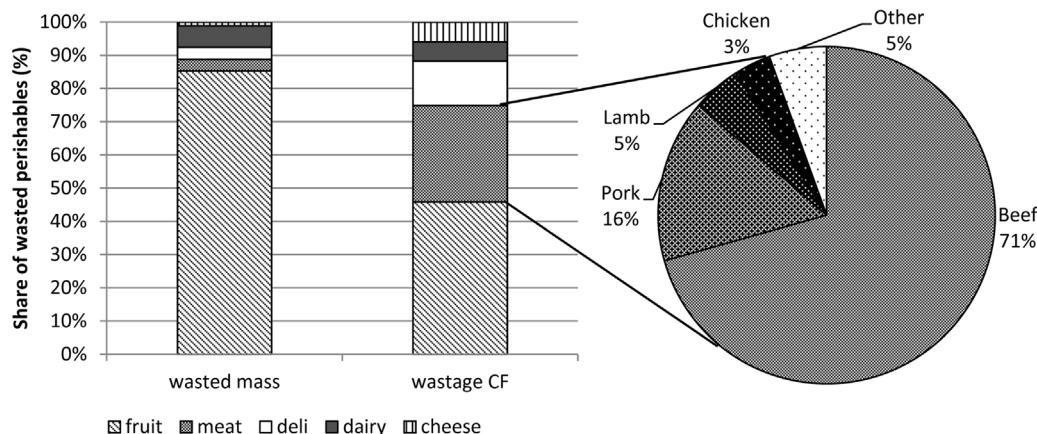
Reported CF values for tofu are between 0.9 (Muroyama et al., 2003) and 2 kg CO<sub>2</sub>e kg<sup>-1</sup> tofu (Blonk et al., 2008). Here, the Dutch value of 2 kg CO<sub>2</sub>e kg<sup>-1</sup> tofu (Blonk et al., 2008) was estimated to best represent Swedish products.

## 2.2.4. Fruit & vegetables

Many fruits and vegetables in the retail stores studied here are not produced in Sweden, but imported from other countries. Since the GHG emissions from production and transportation of food originating from different countries varies, the CF of the wasted products was calculated as the weighted average of GHG emissions associated with the product from its main countries of dispatch. Since exact data about the country of origin were not available for the wasted products, but only for the purchased products delivered to all Willyss stores in 2010 and 2011, these data was used to calculate the share (in terms of mass) of produce imported from a specific country or region. This factor was then used to calculate the weighted average CF of the wasted product.

In general, no distinction was made between different varieties of fruit or vegetables (e.g. different varieties of apples) when calculating the wasted mass and the wastage CF.

GHG emissions caused by production and transportation were considered. GHG emissions from production were estimated based on the existing literature; the CF values from cradle to farm



**Fig. 1.** Left: Relative distribution of wasted mass and wastage CF for the five supermarket departments studied. Right: Contribution of different animal meat types to the wastage CF of the meat department.

gate for different production countries are displayed in Appendix 1. GHG emissions from transport were added, as described below.

Our own assumptions in the study were as follows. Cucumber, eggplant, garden radish, fresh herbs and peppers were assumed to be grown in greenhouses. When produced in the Netherlands or Spain, the same value as for Dutch and Spanish greenhouse tomato production was used, respectively, although for Dutch peppers the CF value was adjusted for yield. For fresh herbs and lettuce grown in greenhouses in Sweden, the same value as for Swedish greenhouse cucumber production was used. For all other fruit and vegetables, it was assumed that they are grown in the open field and on average cause emissions of 0.2 kg CO<sub>2</sub>e kg<sup>-1</sup> product (Röös, 2012). GHG emissions resulting from transportation were calculated based on the estimated distance and the mode of transportation. For its fresh produce, Axfood cooperates with the distributor Saba, which has its central warehouse in Helsingborg, Sweden (Nilsson, 2012). The transportation distance was estimated by using Google maps (Google, 2013) for road transport and by using a distance calculator for sea<sup>1</sup> freight or air<sup>2</sup> freight. For EU-internal trade, road transport is the dominant mode of transportation for agricultural goods (Huggins, 2009). It was assumed that within Europe, all produce is transported by heavy trucks to Helsingborg. Sea freight dominates goods transport in extra-EU trade (Huggins, 2009) and generally transportation by reefer ships was assumed for intercontinental transportation. However, some perishable goods are transported by air freight and this was determined using the "Shopper's guide" provided by Marriott (2005). Generally, the emission factors for transportation provided by the Network for Transport and Environment (NTM) were used except for reefer ships, where the value of 24 g CO<sub>2</sub>e t<sup>-1</sup> km<sup>-1</sup> was taken from Psaraftis and Kontovas (2009). It was assumed that all road transport used refrigeration. To account for increased emissions of chilled road distribution, 20% (Tassou et al., 2009) was added to the value provided by NTM, resulting in 148 g CO<sub>2</sub>e t<sup>-1</sup> km<sup>-1</sup> for heavy trucks. For air freight, NTM's value for continental freight aircraft of 1250 g CO<sub>2</sub>e t<sup>-1</sup> km<sup>-1</sup> was used for distances <5000 km, while for larger distances the value for intercontinental freight aircraft of 389 g CO<sub>2</sub>e t<sup>-1</sup> km<sup>-1</sup> was used (NTM, 2013). A list of the transportation distances, mode of transport and associated GHG emissions is presented in a background report by Scholz (2013).

### 3. Results

#### 3.1. Wasted mass and wastage carbon footprint

In total, 1570 t of perishable food (except bread) were wasted in the departments studied in the six retail stores during the three-year period (2010–2012). This is equal to about 90 t of food waste annually per store. The total CF of the wasted food was 2500 t CO<sub>2</sub>e, or 140 t CO<sub>2</sub>e yr<sup>-1</sup> per store.

When pre-store waste was included, the fruit & vegetable department contributed 85% of the wasted mass. The rest of the mass was distributed between the departments as follows: 6.4% dairy, 3.7% deli, 3.5% meat and 1.1% cheese (Fig. 1). Considering the total wastage CF, the fruit & vegetable department contributed about 46%, followed by the meat department (29%) and the deli department (13%). The dairy and cheese departments each contributed about 6% to the total wastage CF (Fig. 1).

##### 3.1.1. Meat department

In total, 54 t of meat were wasted during the study period and the total wastage CF of the meat department was 720 t CO<sub>2</sub>e, or 40 t CO<sub>2</sub>e year<sup>-1</sup> per store. This is mainly due to the wastage CF of beef (Fig. 1), which resulted from the high product specific CF of beef.

Considering individual products, minced meat was wasted most commonly. Minced meat from beef had the highest wastage CF, with a share of 19% of the department's wastage CF, followed by other beef products like cuts from the top round (7.2%) and short loin (6.3%). For those products, the share of the department's wastage CF was higher than the share of the wasted mass (Fig. 2). All beef products combined accounted for over 70% of the total CF of wasted meat (Fig. 1). For pork products, the share of the wasted mass was generally higher than the share of the wastage CF of the department. Poultry had the lowest wastage CF. The total wastage CF of all poultry products combined was in the range of that for beef sirloin and accounted for about 3.5% of the department's wastage CF, while all poultry products together accounted for about 20% of the mass of the department's food waste (Fig. 2).

##### 3.1.2. Deli department

During the three-year study period, 57 t of deli products were wasted in the six stores, accounting for emissions of 330 t CO<sub>2</sub>e. The yearly wastage CF of the deli department was therefore 18 t CO<sub>2</sub>e per store. The products with the highest wastage CF were meatballs, barbecue sausages and "varm" sausages, which contributed 8.8, 6.7 and 4.7%, respectively, to the total wastage CF of the deli department. The top 10 products with highest wastage CF are shown in Fig. 3.

<sup>1</sup> <http://www.searates.com/reference/portdistance/>.

<sup>2</sup> <http://www.airmilescalculator.com/>.

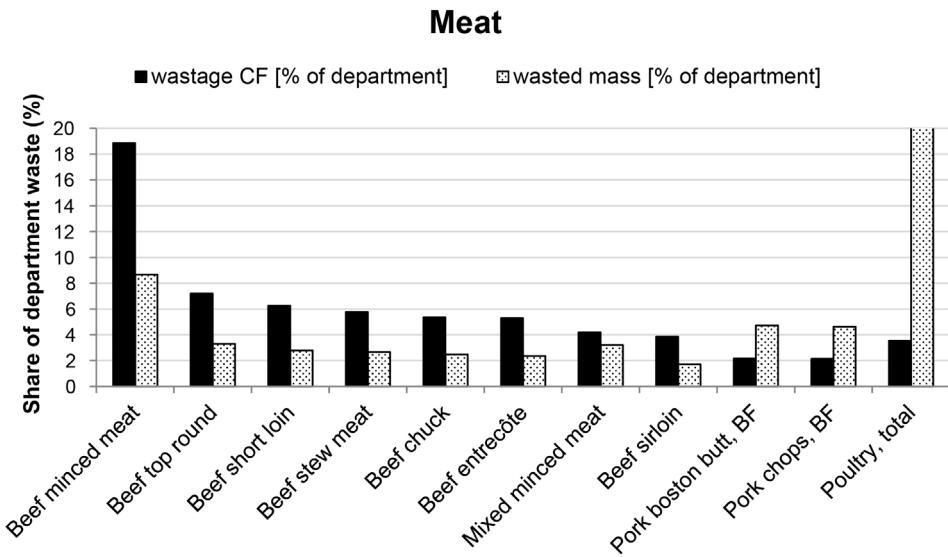


Fig. 2. Share of wastage carbon footprint (CF) and wasted mass of the meat department's total waste (BF = bone-free).

### 3.1.3. Dairy department

In the dairy department, 100 t of products were wasted during the three-year period. The total CF of the department's food waste was 140 t CO<sub>2</sub>e, or 8 t CO<sub>2</sub>e yr<sup>-1</sup> per store. The product with the highest wastage CF was cream, contributing 15% of the department's wastage CF, followed by yoghurt (8%) and semi-skimmed milk (7.7%) (Fig. 4). In terms of mass, semi-skimmed milk contributed the highest share of the department's food waste (11%), while cream contributed 4.1% (Fig. 4).

### 3.1.4. Cheese department

During the study period, 17 t of cheese were wasted in the six stores. The total wastage CF was 150 t CO<sub>2</sub>e, or 8 t CO<sub>2</sub>e yr<sup>-1</sup> per store. Semi-hard/hard cheese accounted for about 63% of the wastage emissions. Considering individual products, Herrgård, Gouda and Brie cheese had the highest wastage CF, contributing 7.7, 7.3 and 6.8% of the department's wastage CF, respectively (Fig. 5).

### 3.1.5. Fruit & vegetable department

In total, 1340 t of fresh fruit and vegetables were wasted in the six stores during the three-year period. The total wastage CF of the

department was 1140 t CO<sub>2</sub>e, or 60 t CO<sub>2</sub>e yr<sup>-1</sup> per store. Almost half (47%) of the department's wastage CF consisted of the wastage CF of the top three products: tomatoes (18%), peppers (17%) and bananas (12%) (Fig. 6).

Potatoes were wasted in large amounts, approx. 4 t yr<sup>-1</sup> per store, and contributed more than 5% of the wasted mass, but only about 0.7% to the wastage CF of the department.

## 4. Discussion

### 4.1. Wasted mass and wastage carbon footprint

There was a clear difference between the distribution of wasted mass and wastage CF of the different departments. While the meat department accounted for only 3.5% of the mass, it was responsible for 29% of the total wastage CF. On the other hand, the fruit & vegetable department contributed to the wasted mass by 85%, but only to 46% of the wastage CF. One German study (Göbel et al., 2012) analysed the contribution of different product groups to food waste and to the food wastage CF per capita in Germany. There, food waste along the entire FSC was considered. Fruit and

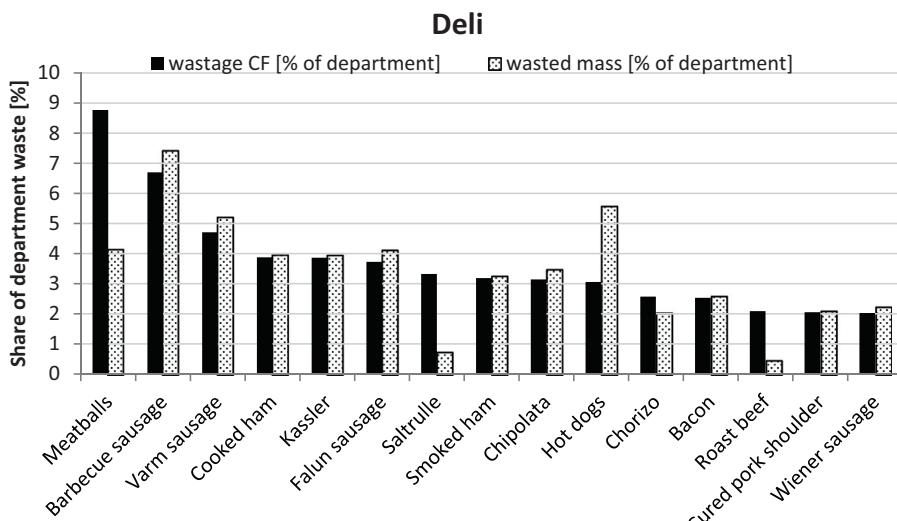
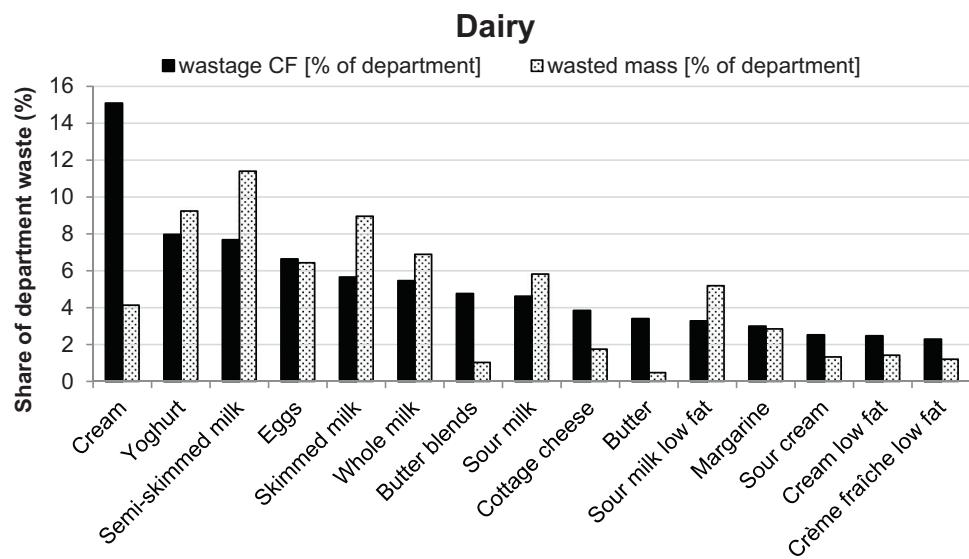
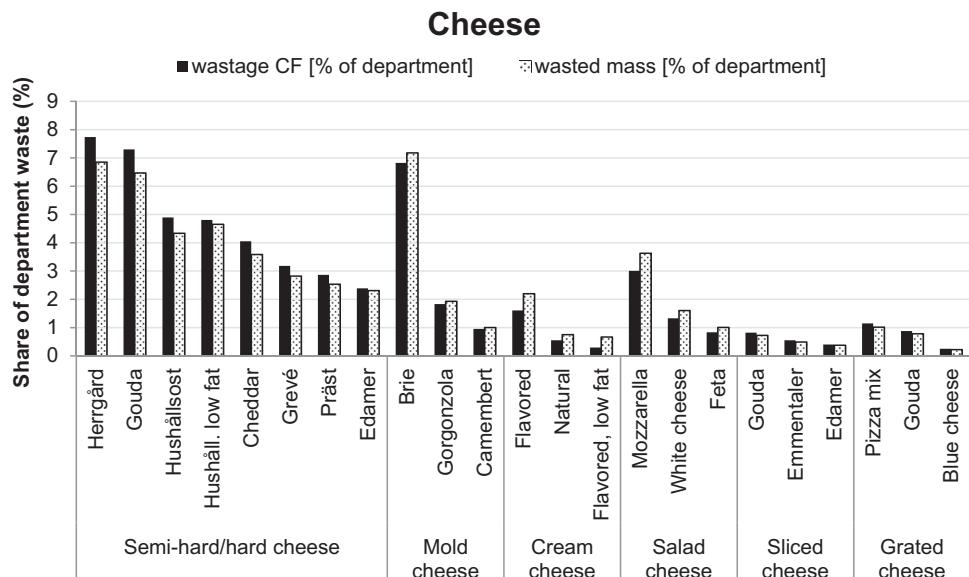


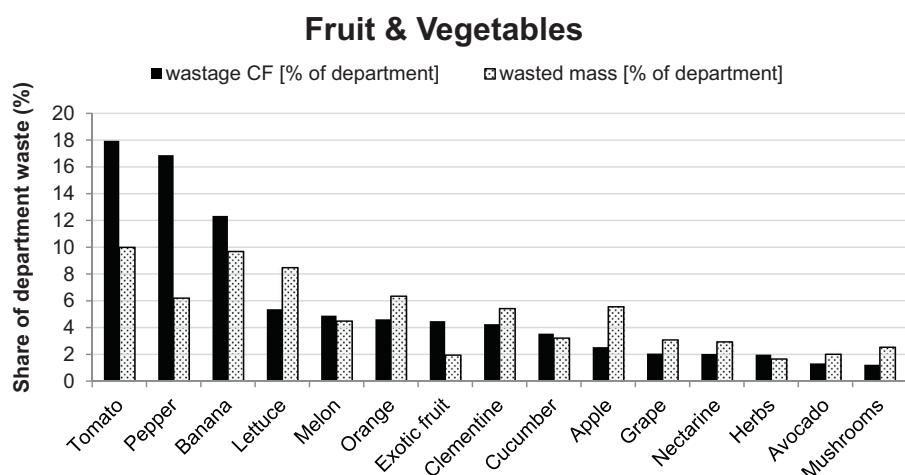
Fig. 3. Share of wastage carbon footprint (CF) and wasted mass of various deli products as a percentage of total waste in the deli department.



**Fig. 4.** Share of wastage carbon footprint (CF) and wasted mass of different dairy products as a percentage of total waste in the dairy department.



**Fig. 5.** Share of wastage carbon footprint (CF) and wasted mass of cheese as a percentage of total waste in the cheese department.



**Fig. 6.** Share of wastage carbon footprint (CF) and wasted mass of fruit and vegetables as a percentage of total waste in the fruit & vegetable department.

vegetables contributed to 43% of the wasted mass and to 18% of the wastage CF, while meat products (incl. deli) accounted for 10% of the mass and 43% of the emissions (Göbel et al., 2012). The results are not directly comparable since many more stages of the FSC are included, and since Göbel et al. also included grain products. The trends of shifting the share between wasted mass and wastage CF for the different categories, however, is the same. Other studies addressing food waste in the retail sector mainly focused on quantifying wasted mass, in which case fruit and vegetables were identified as the most important contributors (Stenmarck et al., 2011; Eriksson, 2012). Eriksson (2012) and Eriksson et al. (2012, 2014) analysed food waste quantities in the same six Willys-stores and presented results per type of product in terms of mass. Compared to these studies, there is a clear shift of products at the top end for most departments, since the present study ranked the products after their wastage CF instead of mass. The direct comparison of the share of the wasted mass and of the wastage CF of different products in this study clearly shows the discrepancies between the two parameters (see Figs. 2–6).

This emphasizes the importance to not only measure food waste in terms of mass but also to relate it to environmental indicators. Therefore, calculating the wastage CF provides a tool to better assess the potential environmental impact of food waste and should be considered when pursuing waste reduction goals. The carbon footprint also makes the results comparable to other activities associated with greenhouse gas emissions. To make a rough comparison the CF of the food wasted in one store during one year ( $140 \text{ t CO}_2\text{e yr}^{-1} \text{ store}^{-1}$ ) corresponds to the CF of driving a fully loaded (15 t) heavy truck (assumed Euro 3 and 0.33 l/km diesel consumption) 71,000 km (NTM, 2013), a distance close to two laps around the earth at the equator.

#### 4.2. Potential areas for reduction measures

To reduce the climate impact associated with wasted food most efficiently, it is crucial to focus on products which have both a large amount of waste and a high specific CF, which together leads to a high wastage CF. This study showed, that the total wastage CF of a department tends to be highly concentrated within a few products with the highest wastage CF. The top three products of the deli, cheese, and dairy department account for 20%, 22% and 31% of the department's emissions. Beef minced meat alone has a share of 19% of the wastage CF of the meat department or 5.5% of the wastage CF of the five investigated departments. All wasted beef products combined have caused the emission of  $28 \text{ t CO}_2\text{e year}^{-1} \text{ store}^{-1}$ , corresponding to 21% of the total wastage CF of the five investigated departments.

In the fruit & vegetable department, tomatoes, peppers and bananas combined accounted for 47% of the department's wastage CF. While for example potatoes, carrots and apples also belong to commonly wasted products, their wastage CF is relatively low due to low production-related emissions and transportation distances. When developing measures for reducing the fruit and vegetable waste, it is important to ensure that the waste is not only moved to another actor. Eriksson (2012) showed that a decrease in in-store waste over time coincided with an increase in pre-store waste over the same period, implying that it was possibly simply shifted to pre-store waste.

Animal products, especially beef products, tend to have relatively higher impacts, and it is therefore important to focus on the prevention of wastage of animal products. One average kg wasted fruit and vegetable equals about  $0.9 \text{ kg CO}_2\text{e}$ , while one average kg wasted meat/deli/cheese equals  $9 \text{ kg CO}_2\text{e}$ , thus they differ by a factor of about 10. Since the volumes of wasted animal products are small compared to wasted fruits and vegetables and usually consist

of products with a relatively high value, this can be economically feasible, as estimated in a study by Eriksson and Strid (2013).

Reduction measures may bear trade-offs between reduction of food waste and loss of profit for the stores. For example, Åhnberg and Strid (2010) showed that the ordering practice is a crucial factor determining the amount of food waste in a store while it represents a trade-off between well-filled shelves, to stimulate sales, and low waste of food. In other cases, tossing away food that is still good for consumption might be easier or faster and therefore appear cheaper to the store than sorting it or to invest time for donating it to charity. Therefore, in order to be economical feasible, not all products can be addressed. Prioritizing products with a high wastage CF can provide a way to reduce the climate impact of food waste most efficiently. Halving the food waste of just the top three products in each department could save more than  $25 \text{ t CO}_2\text{e}$  per year per store.

Waste reduction measures, that also have the potential to prevent shifting the problem along the supply chain, are for example to sell minced meat as frozen instead of chilled; to freeze meat shortly before it expires and sell it on a second hand market; to donate food to charity; to increase the activity with the ordering system; or to ban promotions on fresh fruits and vegetables (see Eriksson and Strid, 2013).

#### 4.3. Data quality

The six stores included in this study were selected by the company. Since there could be a fear of presenting high amounts of food waste resulting in a negative image of the chain, there might be a bias towards stores with lower waste percentages. Moreover, the stores were all located within the same geographical area. However, according to Eriksson et al. (2012) the six selected stores were among stores with amounts of food waste from the bottom to the top 25% of all Willys stores in 2010 and may therefore represent an average store. Since the Willys chain is a discount chain it is expected to have relatively low waste due to the low price policy and the stores might therefore represent an average or lower than average Swedish retailer.

The waste records are based on a long established waste recording routine (Åhnberg and Strid, 2010). Nevertheless, some uncertainties remain since mistakes can be made when logging in a product into the database. Moreover, for unpacked products or when the EAN code is broken in most cases an average estimated mass is assigned to the product. Eriksson et al. (2012) analysed un-recorded waste of the fruit & vegetable department which was about 0.3% of the total mass flow of fruit & vegetables mainly due to non-recording or estimating a wrong mass, while recorded waste (pre-store and in-store) was 4%. Since the present study only used recorded waste the results could be expected to represent only 90% of the actual wasted fruits and vegetables, in accordance with findings of Eriksson et al. (2012).

The CF of the wasted food products was mainly calculated based on the existing literature of LCA studies. Although the LCA methodology is ISO standardized, the choice of some aspects like the exact system boundary, functional unit, allocation method, or use of emission factors is slightly open. Therefore, the results for the same product can vary and in general the results of different studies are not directly comparable. Moreover, for agricultural products the chosen production system as well as the production country is crucial. Here, most effort was put into getting the necessary background information and to evaluate the CF that is most representative for the wasted products. However, in some cases rather broad assumptions had to be made.

The CF of the different deli products was calculated based on assumptions on meat content and energy requirements. Although information about the total meat content of the products was

generally available, mostly no information about the exact content of meat type was given. Since most products contain beef and pork to some extent and the CF of beef is almost five times larger than the CF of pork this could have a significant impact on the results. Moreover, the meat content of individual products can vary for example between different brands. The meat content was generalized for different product categories and it was considered that the deviations were balanced on average. It was assumed that the non-meat content does not have any impact on the overall result since other ingredients are usually products with a much lower CF than meat like for example water or potato starch and the relative impact is low.

Estimating the CF of processed dairy products is difficult since milk intake and other activities and the associated emissions can be allocated to different products. For example butter fat can be seen as a by-product from cheese production (Cederberg et al., 2009b). Here, the wastage CF of most dairy products including milk and other fresh dairy products, butter, butter blends and cheese was calculated based on results from a study by Flysjö (2012) where total emissions associated with dairy production of a large dairy company were allocated in a top-down approach to the different products; milk intake was calculated for the different products based on the weighted value of fat and protein. Only a limited number of other studies on processed products was available (e.g. (semi-hard) cheese was assessed by Berlin (2002) and Cederberg et al. (2009b)).

Processed food like cheese spreads and different deli products need to be analysed in more detail to establish more accurate CF values. When analysing meat products it should be considered to develop a method to estimate the impact of different meat cuts as well as by-products like organ meats.

Overall, the results have to be considered with care. LCA studies always bear uncertainties (e.g., Röös et al., 2010, 2011), and for some products broad assumptions had to be made. Nevertheless, the results of this study are considered to give a good picture of the potential climate impact of food waste in the studied stores and to reveal the differences between different product groups. Differences between product groups have been verified in e.g., Röös (2013), who presented a graph based on a literature review of a large number of LCAs.

Food production affects the environment in many ways. Here, only the climate impact in terms of GHG emissions was addressed. Measuring the environmental impact of food waste in terms of other impact categories like resource use, toxic effects or biodiversity indicators could lead to a shift in the results of products with the highest wastage impact. However, in a study on meat production by Röös et al. (2013), the risk of jeopardizing other environmental targets when acting on the carbon footprint of food was concluded to be small, at least for acidification, eutrophication and land use. This study has evaluated the CF of the food waste according to its lifecycle production cost up to delivery at the retail level.

**Table 1**  
Carbon footprint (CF) values of meat products.

Product	CF per kg CW [kg CO <sub>2</sub> e]	CF per kg BFM [kg CO <sub>2</sub> e]	Based on
Beef	20	29	Cederberg et al. (2009b)
Beef-EU	20.5	29	Cederberg et al. (2009b)
Beef-South America	28.2	41	Cederberg et al. (2009c)
Pork	3.5	6	Cederberg et al. (2009b)
Pork-imported	3.8	6.5	Cederberg et al. (2009b)
Chicken	2.2	2.8	Cederberg et al. (2009b)
Chicken-imported	2.9	3.7	Cederberg et al. (2009a)
Turkey		3.6	
Lamb	16	21	Wallman and Sonesson (2010)
Lamb-imported		17	Wallman et al. (2011)
Game		0.5	Ledgard et al. (2011)
			Röös (2012)

CW: carcass weight; BFM: bone-free meat.

This can be seen as a first estimation of the size of the problem we are facing. The marginal effect of reduced food wastage is however a complex issue involving marginal food production, food consumption on other markets, waste valorization, etc., why these figures may not reflect the final effect of reducing the food waste to zero. Though, this was not within the scope of the study.

## 5. Conclusions

In the six investigated stores, 1570 t of food were wasted during a three-year period. The results of this study show that due to this food wastage about 2500 t of CO<sub>2</sub>e have been caused in vain. The average CF per tonne of food waste of the stores was 1.6 t CO<sub>2</sub>e. Fresh fruit and vegetables were responsible for 85% of the wasted mass, amounting to 74 t per store and year. The associated wastage CF was 60 t of CO<sub>2</sub>e yr<sup>-1</sup> store<sup>-1</sup> corresponding to 46% of the overall wastage CF of the stores. Tomatoes, peppers and bananas accounted for 47% of the wastage CF of the fruit & vegetable department. Products wasted in the meat department contributed less than 4% to the total wasted mass. However, the meat department was responsible for 29% of the total wastage CF. This was mainly due to the waste of beef products, which was associated with the emissions of 28 t of CO<sub>2</sub> yr<sup>-1</sup> store<sup>-1</sup>.

The results clearly show a difference between the distribution of wasted mass and wastage CF of different products. Although quantifying food waste in terms of mass or value can be done more accurately, it does not provide sufficient information about potential environmental impacts. The availability of CF values for food production is increasing and gets more available with summarizing studies like this one. Therefore, analysing food waste in terms of both wasted mass and wastage CF provides a better tool to identify priority targets in order to establish efficient waste reduction measures.

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## Appendix 1.

See Tables 1–4.

**Table 2**

Meat content, energy requirements and carbon footprint (CF) of deli products.

Category	Total meat content [g/100 g]	Type of meat	Processing energy [MJ/kg]
Cooked sausage	60	90% pork, 10% beef	4.4 <sup>a</sup>
Cooked sausage	35	90% pork, 10% beef	4.4
Cooked sausage	85	90% pork, 10% beef	4.4
Cooked sausage	60	Chicken	4.4
Cooked sausage	60	Beef	4.4
Dried sausage	110	90% pork, 10% beef	16.9 <sup>a</sup>
Dried ham	110	Pork	16.9
Cured pork	90	Pork	4
Cured turkey	90	Turkey	4 <sup>b</sup>
Cured beef	90	Beef	4
Meatballs	70	50% pork, 50% beef	2.5 <sup>c</sup>

<sup>a</sup> Wiegmann et al. (2005).<sup>b</sup> Wallman and Sonesson (2010).<sup>c</sup> Sonesson et al. (2005).**Table 3**

Carbon footprint (CF) of products in the dairy and cheese departments.

Product	CF per kg product [kg CO <sub>2</sub> e]	Based on
Eggs	1.5	Cederberg et al. (2009b)
Milk, whole	1.1	Flysjö (2012)
Milk, semi-skimmed	1	Flysjö (2012)
Milk, skimmed	0.9	Flysjö (2012)
Cream	5.2	Flysjö (2012)
Cream, low fat	2.5	Flysjö (2012)
Yoghurt	1.2	Flysjö (2012)
Yoghurt, low fat	1.0	Flysjö (2012)
Crème fraîche	4.8	Flysjö (2012)
Crème fraîche, low fat	2.7	Flysjö (2012)
Cottage cheese	3.1	Flysjö (2012)

**Table 4**

Cradle to farm-gate carbon footprint (CF) of produce.

Product	Country of origin	CF cradle to farm gate [kg CO <sub>2</sub> e]	Based on
Apple	Sweden	0.13	Davis et al. (2011)
Apple	Other countries	0.13	Same as in Sweden <sup>a</sup>
Banana	Costa Rica	0.14	Nilsson (2012)
Carrot	Sweden	0.08	Davis et al. (2011)
Cucumber	Sweden	1.05	Davis et al. (2011)
Cucumber	Spain	0.25	<sup>a</sup>
Eggplant	Spain	0.25	<sup>a</sup>
Eggplant	Netherlands	2	<sup>a</sup>
Garden radish	Netherlands	2	<sup>a</sup>
Herbs	Sweden	1.05	<sup>a</sup>
Lettuce	Sweden, greenhouse	1.05	<sup>a</sup>
Lettuce	Sweden, open field	0.14	Davis et al. (2011)
Lettuce	Spain	0.26	Hospido et al. (2009)
Melon	Spain, greenhouse	1	Based on Cellura et al. (2012) <sup>a</sup>
Melon	Brazil	0.3	Brito de Figueirêdo et al. (2012)
Melon (watermelon)	Other countries, open field	0.3	Same as Brazil <sup>a</sup>
Orange	Spain	0.25	Sanjuan et al. (2005)
Orange	Other countries	0.25	Same as Spain <sup>a</sup>
Other citrus fruit	all	0.25	Same as Oranges <sup>a</sup>
Pepper	Spain	0.48	Based on Cellura et al. (2012) <sup>a</sup>
Pepper	Netherlands	3.5	<sup>a</sup>
Potato	Sweden	0.12	Röös et al. (2010)
Tomato	Netherlands	2	Antón et al. (2012)
Tomato	Morocco	0.25	Same as in Spain <sup>a</sup>
Tomato	Spain	0.25	Torreillas et al. (2012)
Tomato	Sweden	0.66	Davis et al. (2011)
Other vegetables	All, open field	0.2	<sup>a</sup>
Other fruit	All	0.2	<sup>a</sup>

<sup>a</sup> Own assumptions.

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