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Carbon footprint of retail food wastage

a case study of six Swedish retail stores

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Abstract

Globally, about 1.3 billion tons of food are wasted every year. Besides economic, ethic and social aspects, food wastage bears a considerable environmental burden. The production of food causes greenhouse gases (GHG) at all stages along the food supply chain. Especially for animal products, the agricultural stage is crucial with CH_4 and N_2O emissions being of major importance. Agriculture was estimated to be the cause of 10-12 % of global anthropogenic GHG emissions and 15 % of production related emissions at EU level. Other steps like processing and transportation of food also cause GHG emissions. Therefore, wasting food not only means that resources are wasted but also that GHG emissions have been caused in vain.

Although wastage of food occurs at all stages along the food supply chain (FSC), later stages like households and the retail sector play a major role in industrialized countries. In Sweden and other European countries, the retail sector is a highly concentrated industry which means that food wastage is also concentrated to certain locations. Moreover, the quality of the food wasted in stores often is still very high. Retailers are closely connected to other stages of the FSC and present the link between producers and consumers. Therefore, addressing the retail sector is a key issue in order to reduce food wastage. Reduction measures have to be economical feasible which means that priority areas have to be identified. Previous studies on food waste in the retail sector have primarily focused on quantities of waste in terms of mass and have identified fresh produce as main contributor. However, only evaluating wasted mass does not give sufficient information about the environmental impact. The aim of this study was to analyze the wasted food in terms of GHG emissions including CO_2, CH_4 and N_2O in order to gain knowledge about the climate impact of food waste and its reduction potential. Therefore, the wastage carbon footprint (CF) of all products wasted in the stores was calculated. The wastage CF was defined as the CF from cradle up to delivery to the retailer for the total amount of retail waste of a certain product. To determine the CF from cradle to retailer of the various products an extensive literature review especially of LCA studies was conducted. In general, emissions associated with the production and transportation of food were considered. Data on wasted food products was provided by six Swedish retail stores belonging to the discount chain Willys. Products of the meat, deli, cheese, dairy, and fruit & vegetable department were analyzed.

In total, 1565 t of food were wasted in the six stores over a three-year period. The associated total wastage CF was 2500 t of CO_2e or 830 t of CO_2e/yr. The average CF per ton of food waste was therefore 1.6 t of CO_2e. 85 % of the wasted mass consisted of fruit and vegetables, followed by wasted products of the dairy (6.4 %), deli (3.7 %), meat (3.5 %) and cheese (1.1 %) department. Comparing the wasted mass to the wastage CF, there was a clear shift between the different departments. With 46 % of the total wastage CF, the fruit & vegetable department still had the largest share. However, the meat department was responsible for about 29 % of the total wastage CF; the deli department contributed 13 % while the dairy and cheese department each had a share of about 6 %. Beef meat has the highest CF and all beef of the meat department combined had a share of 21 % of the overall wastage CF of the six stores. Moreover, the analysis showed that the wastage CF of a department tends to be highly concentrated in certain products. In the fruit & vegetable department, tomatoes, peppers and bananas account for 47 % of the department's wastage CF. Beef minced meat had a share of 19 % of the wastage CF of the meat department. Halving the waste of the three products with the highest wastage CF in each department could save more than 150 t of CO_2e per year in the six stores.

Popular Science Summary

In recent years, publications on increasing atmospheric greenhouse gas (GHG) concentrations and the experience of unusual weather phenomena have raised the discussion about global climate change in the public. The global climate is determined by the energy of the incoming solar radiation and its interaction with the earth's atmosphere and surface. GHGs in the atmosphere play a crucial role in making our planet inhabitable due to the natural greenhouse effect. A change in GHG concentrations, however, can lead to an alteration of the energy balance of the climate system.

Atmospheric CO_2 concentrations and other GHGs have been observed to increase over the last decades and in comparison to estimated historic values. Emissions caused by human activities have been identified as the main cause. For example energy generation, transportation and industrial activities are causing emissions, but agricultural production, livestock rearing and deforestation are also contributing.

To evaluate the environmental performance of a product its so called carbon footprint (CF) can be determined. The CF comprises all CO_2 emissions that are associated with a certain product or service over its whole life cycle, and can also include other GHGs like methane (CH_4) or nitrous oxide (N_2O). Emissions associated with food provision are caused at all stages along the food supply chain – from farming to processing, distribution and storing, as well as preparation and waste disposal. Therefore, wasting food does not only mean that resources are wasted, but also that GHG emissions have been caused in vain.

Recently, it was estimated that globally we waste about one third or 1.3 billion tons of our food every year. In industrialized countries, especially later stages of the supply chain play a major role. In the EU, about 40 % of the food waste occurs in households and the retail sector is still responsible for about 5 %. Since the stores present the link between consumers and producers, addressing the retail sector is crucial to reduce food waste.

This study determined the CF including CO_2, N_2O and CH_4 emissions of various food products that are wasted in supermarkets based on the existing literature. Emissions that were caused by the production and distribution of the wasted food were considered. Subsequently, the product's CF was multiplied with the corresponding wasted amount resulting in the wastage CF values for all products. The values were also summarized department wise.

Data on food waste was provided by six Swedish supermarkets; products of the meat, deli, dairy, cheese and fruit & vegetable department were analyzed.

The results showed that over a period of three years 1565 t of food were wasted and this was associated with the emissions of about 2500 t of CO_2e. To put this in relation, a rather fuel efficient car emits about 150g of CO_2 per kilometer[1]. In this case, the emissions caused by the wasted food are equivalent to driving about 16,600,000 km.

Furthermore, the results showed a clear shift of the distribution of the share of wasted mass and wastage CF between the different departments. The fruit & vegetable department was responsible for 85 % of the wasted mass, but only for about 46 % of the wastage CF. Especially tomatoes and bananas contributed to both, wasted mass and wastage CF of the department. Meat accounted for only about 4 % of the wasted mass, but was responsible for 29 % of the emissions. Of the analyzed food products, beef has the highest CF and all beef meat wasted in the stores has caused 510 t of CO_2e in vain. Reducing food waste is crucial to minimize the climate impact of our food system and looking at the wastage CF can provide a tool to identify priority targets for reduction measures.

[1] http://www.energy.eu/car-co2-emissions/

Zusammenfassung

Jedes Jahr werden weltweit etwa 1.3 Milliarden Tonnen an Lebensmitteln verschwendet. Die Verschwendung von Lebensmitteln birgt neben sozialen, ethischen und ökonomischen Aspekten auch eine beachtliche Auswirkung auf die Umwelt. Die Produktion von Lebensmitteln führt zur Emission von Treibhausgasen (THG) wie CO_2, N_2O und CH_4 auf nahezu jeder Stufe der Wertschöpfungskette. Vor allem für Produkte tierischer Herkunft spielt die landwirtschaftliche Produktion eine maßgebliche Rolle bei der THG-Bilanzierung. Die Landwirtschaft ist weltweit für etwa 10-12 % aller menschlich verursachten THG und für etwa 15 % aller produktionsbedingten THG der EU verantwortlich. Aber auch andere Prozesse wie die Weiterverarbeitung und der Transport von Lebensmitteln führen zu THG-Emissionen.

Entlang der gesamten Wertschöpfungskette gehen Lebensmittel verloren oder werden weggeworfen. Vor allem in Industrieländern entstehen viele Lebensmittelabfälle am Ende der Wertschöpfungskette, also im Handel und in Haushalten. Lebensmittel, die im Groß- oder Einzelhandel weggeworfen werden sind oft von noch hoher Qualität. Darüber hinaus stellen Händler die Verbindung zwischen Produzenten und Konsumenten dar und können einen Einfluss auf die Entstehung von Lebensmittelabfällen auf vor- oder nachgeschaltete Stufen der Wertschöpfungskette haben. Um die Verschwendung von Lebensmitteln zu verringern ist es deshalb wichtig, sich mit dem Handelssektor zu befassen.

Existierende Studien zur Untersuchung von Lebensmittelabfällen im Handelssektor haben sich vor allem damit befasst, die weggeworfenen Mengen an Lebensmitteln zu erfassen. Mengenangaben alleine geben jedoch nicht ausreichend Information über die ökologischen Auswirkungen. Deshalb war das Ziel der vorliegenden Studie die Menge an THG zu ermitteln, die durch Produktion und Vertrieb von in Supermärkten verschwendeten Lebensmitteln verursacht wurden. Hierfür wurde für alle Produkte die zu Lebensmittelabfällen beitragen der sogenannte „wastage carbon footprint“, also der ökologische Fußabdruck des Abfalls, berechnet. Der ökologische Fußabdruck eines Produktes wurde anhand der existierenden Literatur ermittelt; einbezogen wurden CO_2-, N_2O- und CH_4-Emissionen die entlang der Schöpfungskette von der ursprünglichen Produktion bis zur Anlieferung beim Händler verursacht wurden. Anschließend wurde der ökologische Fußabdruck eines Produktes mit der entsprechenden Menge an entstandenem Abfall multipliziert um den ökologischen Fußabdruck des Lebensmittelabfalls zu erhalten.

Daten von verschwendeten Lebensmitteln wurden von sechs Läden der schwedischen Discounter-Kette Willys zur Verfügung gestellt. Produkte der Fleisch-, Delikatessen-, Käse-, Molkerei-, und Obst & Gemüse-Abteilung wurden analysiert.

Insgesamt wurden in den sechs Läden während einem Zeitraum von 3 Jahren (2010-2012) 1565 t an Lebensmitteln weggeworfen. Der ökologische Fußabdruck des Lebensmittelabfalls war insgesamt 2500 t CO_2e oder 830 t CO_2e pro Jahr. Der durchschnittliche ökologische Fußabdruck pro Tonne Lebensmittelabfall war somit 1.6 t CO_2e. 85 % der weggeworfenen Menge waren frisches Obst und Gemüse, gefolgt von Produkten aus der Molkerei- (6.4 %), Delikatessen- (3.7 %), Fleisch- (3.5 %) und Käse-Abteilung (1.1 %). Betrachtet man den ökologischen Fußabdruck des Lebensmittelabfalls der verschiedenen Abteilungen im Vergleich zur weggeworfenen Menge konnte eine klare Umverteilung der Beiträge beobachtet werden. Die Obst & Gemüse-Abteilung hatte mit 46 % den größten Anteil am ökologischen Fußabdruck des gesamten Lebensmittelabfalls. Die Fleischabteilung trug hier 29 % bei. Die Delikatessen-Abteilung hatte einen Anteil von 13 %, während die Käse- und die Molkerei-Abteilung jeweils für etwa 6 % der Emissionen verantwortlich waren. Von den untersuchten Lebensmitteln hatte Rindfleisch den größten ökologischen Fußabdruck und trug 21 % zum ökologischen Fußabdruck des gesamten Lebensmittelabfalls bei. Die Ergebnisse der Untersuchung zeigten außerdem, dass meist wenige Produkte für einen Großteil des ökologischen Fußabdrucks des

gesamten Lebensmittelabfalls einer Abteilung verantwortlich waren. So war Rinderhackfleisch allein für 19 % des ökologischen Fußabdrucks des Lebensmittelabfalls der Fleischabteilung verantwortlich und Tomaten, Paprika und Bananen zusammen für 47 % der Obst & Gemüse-Abteilung. Eine Reduzierung des Abfalls der drei Produkte mit dem höchsten Beitrag zum ökologischen Fußabdruck des Lebensmittelabfalls jeder Abteilung um die Hälfte könnte mehr als 150 t CO_2e pro Jahr in den sechs Läden einsparen.

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Abbreviations

BF	Bone free
BFM	Bone-free meat
CF	Carbon footprint
CH_4	Methane
CO_2	Carbon dioxide
CO_2e	CO_2-equivalent
CW	Carcass weight
EAN	European Article Number
EU	European Union
FSC	Food supply chain
GHG	Greenhouse gas
GWP	Global warming potential
IPCC	Intergovernmental Panel on Climate Change
kg	Kilogram
kWh	Kilowatt hour
LCA	Life cycle assessment
LCI	Life cycle inventory analysis
LCIA	Life cycle impact assessment
LUC	Land-use change
MJ	Megajoule
Mt	Megatonne (10^9 kg)
N_2O	Nitrous oxide
t	Tonne (metric ton, 10^3 kg)
yr	Year
THG	Treibhausgas (greenhouse gas)

1. Introduction

1.1. Climate change and greenhouse gas emissions

During the last decades one topic has increasingly gained the attention not only of researchers but also of the general public: climate change and its relation to anthropogenic greenhouse gas (GHG) emissions. Unusual warm years, more intense and longer droughts, increases in heavy precipitation events and decreases in snowpack and snowcover have been observed worldwide [Solomon et al., 2007]. According to the IPCC [Solomon et al., 2007] the average global surface temperature has experienced a warming of 0.74°C ± 0.18°C over a period from 1906 to 2005. Meanwhile, an increase in atmospheric GHG concentrations has been documented. For example atmospheric CO_2 concentrations can be measured very precisely and since the industrialization, the amounts of CO_2 in the atmosphere have increased by 38 % to 385 ppm in 2008 [Le Quéré et al. 2009]. This increase is mainly caused by human alteration of the carbon cycle, especially due to emissions caused by the combustion of fossil fuels and land-use changes (LUC) like deforestation and intensive cultivation [Solomon et al., 2007]. Other GHGs like methane (CH_4) and nitrous oxide (N_2O) also show increasing trends in atmospheric concentrations [Solomon et al., 2007]. Anthropogenic non-CO_2 emissions have increased over the last decades and this is expected to continue [EPA, 2012]. Human activities contributing to those emissions are for example energy generation, waste disposal, as well as agriculture, where especially the use of nitrogen fertilizer, livestock farming (enteric fermentation of ruminants; manure management) and rice cultivation are causing CH_4 and N_2O emissions [EPA, 2012].

As pointed out by the IPCC [Le Treut et al., 2007], GHGs have been identified as main drivers of the global climate.

In general, the energy balance of the climate system is determined by the incoming solar radiation and the properties of the earth and its atmosphere. The surface attributes and the abundance of GHGs and aerosols in the atmosphere determine how much of the incoming radiation is absorbed, transmitted or reflected. About 30 % of the energy of the sun reaching the earth's atmosphere is reflected back to space. The rest is absorbed by the earth and to keep the energy balance re-emitted as longwave radiation, which would lead to a surface temperature of around -19°C. However, due to the presence of GHGs part of the longwave radiation emitted by the earth is radiated back from the atmosphere towards the earth's surface thereby increasing the global surface temperature. [Le Treut et al., 2007]

Therefore, a change in atmospheric GHG concentrations leads to a change in the energy balance and according to the IPCC [Solomon et al., 2007] it is very likely that most of the observed increase in global average temperatures since the mid-20th century is due to anthropogenic GHG emissions.

To determine the extent to which certain actions contribute to GHG emissions the carbon footprint (CF) of a product or service is calculated. Wiedmann and Minx [2007] define the carbon footprint as "the exclusive total amount of carbon dioxide emissions that is directly and indirectly caused by an activity or is accumulated over the life stages of a product" and refer to CO_2 emissions only. However, for some products other GHGs like CH_4 and N_2O are of significant importance [Sonesson et al., 2010; Carlsson-Kanyama and González, 2009] and are therefore often included in the total CF, especially of food products. The Joint Research Center of the European Commission for example describes the carbon footprint as the total amount of CO_2 and other GHG emissions that are associated with goods and services [EC, 2007].

Depending on their properties, the potential climate impact of the different emissions varies. Of the three GHGs discussed, CO_2 is the most abundant GHG in the atmosphere while CH_4 and

N_2O have a much higher climate impact due to higher radiative efficiencies. A way to assess the climate response of different GHGs is to express their global warming potential (GWP) relative to CO_2. This is related to a specific period of time to account for differences in the atmospheric lifetime of the gases. The GWP of different agents is, however, no fixed number, but is updated according to current research and new findings. For example, the values for CH_4 presented by the IPCC in 1995 were lower than the most current values while the values for N_2O have decreased [Solomon et al., 2007]. The GWP of CO_2, CH_4 and N_2O over a given time horizon is presented in Table 1.

Table 1 GWP of different GHGs relative to CO_2 for a given time horizon as reported in the IPCC Second (SAR, 1995) and Fourth Assessment Report (AR4, 2007) [Solomon et al., 2007]

GHG	GWP_{SAR}, 100 yr	GWP_{AR4}, 100 yr	GWP_{AR4}, 20 yr
CO_2	1	1	1
CH_4	21	25	72
N_2O	310	298	289

1.2. LCA

One common method to evaluate the environmental impact of products is the Life-Cycle Assessment (LCA). LCA is an ISO standardized method which aims to analyze the impact a product (i.e. any good or service) causes during its entire life cycle from "cradle to grave". This means that all life cycle stages from the extraction of raw materials through processing, manufacturing, distribution, use, recycling and final disposal are investigated to determine the use of resources and energy, as well as the amount of emissions. Therefore, a LCA study can provide information on the CF (often expressed as potential of climate change or GWP) as well as on other potential environmental impacts of different products.

A LCA compromises of four phases: goal and scope definition, inventory analysis, impact assessment, and interpretation.

In the goal and scope definition, the reason for conducting the study as well as the intended application should be stated. Furthermore, it serves to define the functional unit and the system boundary and to indicate any assumptions, allocation procedures and the limitations of the study.

During the life cycle inventory analysis (LCI) the relevant inputs and outputs of the studied system are quantified by means of data collection and calculations.

In the impact assessment phase (LCIA), the LCI data is categorized into different environmental impact categories in order to better understand and to evaluate the contribution to these impacts. This also provides the information for the last phase, the interpretation.

By considering the results of the previous steps, the interpretation should provide conclusions and recommendations that are consistent with the scope and goal of the study. [ISO, 2006]

1.3. Greenhouse gas emissions from food production

The provision of food causes emissions of GHGs at all stages along the food supply chain (FSC), from the input generation through agricultural production, post-farm processing and distribution to the final consumption and waste disposal. The production of inputs like fertilizer mainly causes CO_2 emissions, while CH_4 and N_2O are the main GHGs emitted at the agricultural stage [Sonesson et al., 2010]. Fossil fuel use on the farm and for post-farm activities like transportation, processing and refrigeration or energy consumption by processing plants, retail stores and consumers also lead to food related emissions [Garnett, 2011; Sonesson et al., 2010]. Finally, food waste and by-products ending up in landfills also release GHG emissions [Sonesson et al. 2010]. However, food waste ending up in landfills has been reduced significantly within the EU due to several waste management requirements. In Sweden for example, a landfill ban on organic waste was introduced in 2005 [Avfall Sverige, 2012].

In Europe, the consumption of food accounts for about 20-30 % of the GHG emissions from consumption of all products due to emissions arising at all stages along the FSC with the production step being the key factor [Tukker et al., 2006; Moll and Watson, 2009]. Agriculture is among the economic sectors with 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 the farm level are CH_4-emissions from livestock and N_2O-emissions from soils and manure management [Moll and Watson, 2009]. Globally, agriculture is the primary cause of increasing atmospheric concentrations of CH_4 and N_2O and it causes 10-12 % of the total anthropogenic GHG emissions [Smith et al., 2007].

Indeed, many studies on the environmental impact of individual food products have shown that the production at the farm is the main contributor to the product's CF with CH_4 and N_2O playing a major role [Cederberg et al., 2009a,b; Flysjö, 2012; Davis et al., 2011]. Different food products have different environmental impacts and even within one product category there can be large variations depending on the specific production system. However, some broad generalizations can be made. Animal products tend to have a higher environmental burden than plant-based products with meat from beef and other ruminants being at the top end [Sonesson et al., 2010]. GHG emissions from beef and dairy production are dominated by CH_4 emissions due to direct emissions from enteric fermentation [Cederberg et al., 2009a,c]. Emissions caused by pork and poultry production are less than for beef with N_2O and CO_2 being relatively more important [Cederberg et al., 2009a].

Fruit and vegetables are generally considered to have a low environmental impact. However, emissions from soils and from the use of fertilizer as well as the use of fossil fuels for machinery operation, manufacturing of agrochemicals, greenhouse heating and transportation may contribute significantly to the CF of produce. Among the EU member states there is a large variation of geographic and climatic conditions. Nevertheless, the production is seasonally limited and some fruits or vegetables are not grown within the EU. Due to the consumer's demand for year round availability and high variation and quality of produce, the EU is the largest importer of fruit and vegetables [Kelch, 2004]. Furthermore, within the EU the production of some produce is highly concentrated in only a few countries which leads to EU-internal trade. For example oranges are mainly produced in the Mediterranean region [EC, 2011] and northern countries like Sweden depend on imports. Fruit and vegetables tend to be perishable and therefore need to be shipped in a proper way. Air fright is especially carbon intense and energy use for refrigeration also releases GHG emissions.

Animal products also require transportation, but due to generally higher emissions associated with primary production, the relative impact on the CF tends to be lower than for produce. The overall environmental impact of a product depends on the specific production system and the mode of transportation.

Improving production systems along the entire supply chain is crucial to reduce the environmental impact of food. Moreover, a sustainable consumption behavior is needed including reducing the amount of waste. Wasting food products not only means that resources are wasted but also that GHG emissions were caused in vain.

1.4. Food wastage

A recent study by Gustavsson et al. [2011] indicates that globally about 1.3 billion tons or one third of food produced for human consumption is wasted. The report points out, that besides environmental costs, wastage of food also bears economic and social impacts; it affects food availability and food prices and therefore also food security.

Food wastage occurs at all stages of the FSC. Gustavsson et al. [2011] analyzed global food wastage considering the following stages within the FSC: agricultural production, postharvest handling and storage, processing, distribution (including waste in the market system, e.g. the retail sector), and consumption (household level). They found that the share of the initial production wasted is within the same range for industrialized and developing countries but food waste per capita is much higher in Europe and North-America than for example in sub-Saharan Africa or South/Southeast Asia. Moreover, in low-income countries food waste mainly occurs in early stages of the FSC due to a lack of infrastructure and technology while the share of food wasted in later stages of the FSC is higher in industrialized countries. According to Gustavsson et al. [2011], in the latter food is commonly wasted at the retail or household level. High quality standards, cultural attitude or a lack of knowledge about the impact of food waste as well as on how to buy, store and use food efficiently have for example been identified as causes [Gustavsson, 2011; Monier et al., 2010]. Food waste occurring at later stages in the FSC is loaded with a higher environmental burden since more processing and transportation steps have been performed. It has been estimated that overall the food wastage in the EU (EU-27) causes emissions of 170 Mt CO_2e/year considering the whole life cycle of the wasted food [Monier et al., 2010]. This is based on estimated average emissions per kg food at different stages of the FSC and a food waste generation of 89 Mt/year. Since this estimation was done using available statistics and there were no clear reporting requirements or definition of food waste, it can also include inedible food waste like bones or egg shells. In the same study, wastage at the household level was estimated to contribute the highest fraction (42 %) of the total EU-27 food waste in terms of mass. While the share of the retail sector is estimated to be 5 %, it still represents about 4.4 Mt of food waste [Monier et al., 2010]. On a national level, food waste quantities were estimated for example in Germany [Göbel et al., 2012] or the UK [Lee et al., 2010]. Göbel et al. [2012] estimated that 13 % of the initial production are lost along the FSC and about 3 % or 310,000 t/yr of this wastage occurs in the retail sector.

Retail stores are the link between producers and consumers and are closely connected to other stages of the FSC. Gustavsson et al. [2011] for example point out that quality standards determined by retailers are responsible for the major part of food losses in the agricultural stage. Decisions at the retail level can therefore have an impact on other parts upstream or downstream in the FSC. Another consideration is that the quality of the food wasted in retail stores often is still very high. Moreover, addressing the retail sector can be rather efficient since it is a highly concentrated industry. Food waste of this sector is therefore also concentrated at certain sites. In 2002, the market share of the top five food retailers was 69.2 % in the EU member states (EU-15) [Vander Stichele et al., 2005]. In Sweden, the top three retail groups alone have a market share of 87 % [Axfood, 2012]. One of the groups is Axfood, which accounts for about 20 % of the market, and which owns among others the Willys chain [Axfood, 2012].

Only a limited number of studies have focused on food waste in the retail sector and usually food waste is assessed in terms of mass or value [Eriksson, 2012; Gustavsson and Stage, 2011; Stenmarck et al., 2011; Buzby et al., 2009].

An in-depth study on the quantities and causes of food wastage within six retail stores of the Willys chain has been conducted by Eriksson [2012]. The study revealed that the fruit & vegetable department had by far the largest share of the analyzed food waste in terms of mass. However, only analyzing the quantities of wasted food products does not give sufficient information on the environmental aspects, since the potential environmental impact of each product varies. Therefore, the amount of waste of different products has to be related to the product's specific environmental performance.

There is an urgent need for tackling the problem of food wastage. In order to implement waste reduction measures most efficiently, priority target areas have to be identified and more knowledge is needed to base the decisions on.

1.5. Objective

The goal of this study was to investigate the climate impact pattern of food wasted in retail stores. In particular, the aim was to identify hotspots by determining the products and the department with dominating impacts, to quantify and illustrate the discrepancies between mass and CF profiles of the waste and to establish a CF value per ton of retail food waste. The underlying purpose was to gain knowledge on the potential to reduce the climate impact of food wastage.

2. Material & Methods

2.1. Food wastage carbon footprint

In order to analyze the climate impact pattern of retail food waste, the wastage CF was calculated for different food products wasted in six Swedish retail stores. The wastage CF was defined as the specific CF value of a product, comprising of emissions associated with the production and distribution up to the delivery to the stores, multiplied with the total wasted mass of the respective product (Figure 1). Data on wasted mass was obtained as described in chapter 2.2. The specific CF values were determined based on the existing literature and this is described in chapter 2.3. For fruit and vegetables, emissions associated with transportation from farm-gate to retail were newly calculated.

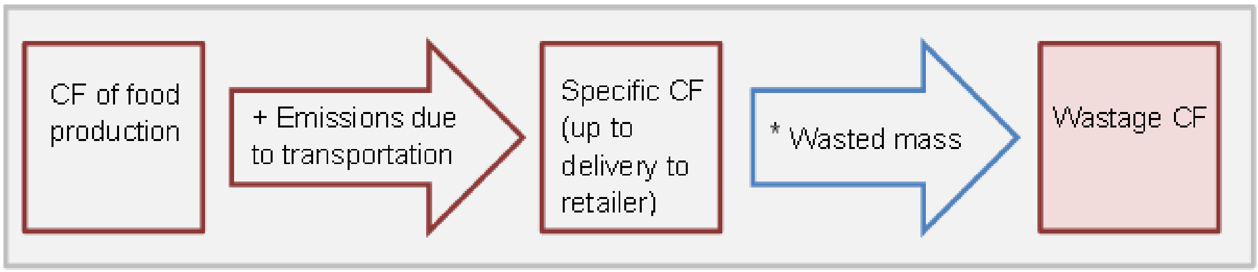

Figure 1 Determining the wastage CF.

Unless otherwise indicated, the wasted mass and the wastage CF of food products was calculated as the sum for six stores during the three year period from 2010-2012.

2.2. Food waste data

Data of food products wasted at the retail level was provided by the Swedish retail chain Willys, which gave data of six stores. With a total of 174 stores Willys is Sweden's leading discount chain, which is wholly owned by Axfood [Axfood, 2012]. The six stores participating in the study have been selected by the company head office and they are located in the Uppsala-Stockholm region. The sales area of the selected stores is between 2300 and 4900 m² [Eriksson et al., 2012]. Willysstores carry in general approximately 9000 products [Axfood, 2012]. In this study, data of products in the meat, deli, cheese, dairy, and fruit & vegetable department were analyzed. 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 like sausages, meatballs or cold cuts, but also black pudding and pâté are sold. Besides dairy products like milk, cream, butter and yoghurt, the dairy department also carries eggs as well as fruit, vegetable, or grain drinks and juices. The cheese department comprises 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 color 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. An estimated total mass or total number of items is entered manually for unpacked fruit and vegetables. This is 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 & Strid [2010]. Unrecorded in-store waste as described by Eriksson et al. [2012] was not considered in this study.

Some of the food discarded at the supermarkets is also due to rejections upon delivery, which was defined as pre-store waste [Eriksson et al., 2012]. Data is logged into the accounting system manually every day and recorded in weekly reports. Since pre-store waste usually becomes physical waste at the retailers it was included in this study. Moreover, Eriksson [2012] showed that a change in in-store waste can mean that it was simply shifted to pre-store waste.

In addition, the amount of each product that is sold is recorded. This data as well as data on the value of the sold and of the wasted products was collected and analyzed together with the waste data. Data for the years 2010 through 2012 was analyzed 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. Pre-store and in-store waste is also presented separately for the different departments.

2.3. Carbon footprint data based on literature review

To estimate the environmental impact of the food wasted in the retail stores, the CF including CO_2, CH_4 and N_2O emissions for the different products was researched.

Many LCA and CF studies on various products including food items have been performed worldwide. Here, an extensive review of various studies was conducted in order to estimate the most suitable value for GHG emissions associated with specific food items produced for and distributed to Swedish retail stores. The criteria therefore were:

- Suitable goal and scope (preferable scope: from cradle to retail store in Sweden)
- Studied system representative for the producing country (Sweden, or exporting countries)
- Detailed description of input and output flows
- Up-to-date data; most recent publication

The CF from cradle up to the delivery to the retailer of all products was calculated based on information from the literature. Where the scope of the available literature did not fit exactly the purpose of the present study, own assumptions or calculations have been 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 LUC are not included. Emissions associated with store operations and packaging were not included since data availability was not sufficient and its impact was considered to be relatively low [Cederberg et al., 2009b; Stoessel et al., 2012]. Moreover, the impact of packaging highly depends on the specific material and also on its waste management [Flysjö, 2012], which can vary even for the same product, thus determining the packaging for all products was not possible in the scope of the present study.

2.3.1. Meat

The total wasted mass for the whole department as well as for different product categories was calculated including all meat belonging to the respective category including also imported, organic and frozen meat unless otherwise indicated. Swedish names of specific products and meat cuts were translated based on information from Judge [1989] and the Swedish meat producer Scan[2]. A list with the translations can be found in Appendix 1.

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) has been calculated based on the meat yield and all emissions were allocated to the meat; the conversion factors used are listed in Table 2. However, some of the meat cuts at the retailers still contain bones. For pieces of chicken that still contain bone the same CF value as for the whole carcass was used. For beef and pork it was assumed that meat cuts with bones in general contain 15 % bones, while cuts from the ribs contain 40 % bones.

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

In the considered studies, at the slaughterhouse stage all GHG emissions are allocated to the animal carcass. Therefore, no GHG emissions are associated with blood or organ meat production. To account for the transportation from the slaughterhouse to the stores, a CF of 0.05 kg CO_2e/kg was assigned to those products.

Table 2 Meat yield factors for meat products from different animals

	Conversion factor CW to BFM
Beef	0,7 [1)]
Pork	0,59 [2)]
Chicken	0,77 [2)]
Lamb	0,76 [3)]

1) Cederberg et al., 2009 2) Sonesson et al., 2010 3) Wallman et al., 2011

Meat produced in Sweden

Cederberg et al. [2009b] estimated the CF of Swedish beef, pork and chicken meat up to delivery to a retailer in Stockholm using the CF values from cradle to farm-gate obtained in a detailed LCA study based on a top down national average system analysis [Cederberg et al., 2009a]. Since the scope fits the purpose of the present study, the values presented in the study by Cederberg et al. [2009b] were chosen.

To account for the grilling process of grilled chicken, 0.04 kg of CO_2e per kg CW [Nilsson, 2012] was added to the CF of chicken. Grilled chicken is sold as whole or half, including bones.

Turkey meat accounts for a rather small part of the meat department. Wallman and Sonesson [2010] analyzed turkey production and the CF was found to be slightly higher than for chicken. In this study, a value of 3.6 CO_2e per kg raw filet without packaging was used.

2 http://www.scan.se/kottguiden

GHG emissions associated with raw sausages were calculated based on the meat content which was 50 %. It was assumed, that the meat content consisted of Swedish pork or beef (90 % pork and 10 % beef if no further information was available) and that other ingredients had no significant impact on the total CF.

The CF of lamb is based on the LCA by Wallman et al. [2011]. There, the lamb production on 10 sheep farms in southern Sweden including 4 organic systems was assessed. The calculated CF of lamb includes emissions associated with packaging. However, all emissions from post-farm activities (transport, processing at slaughterhouse and packaging) combined contributed only about 1 % to the CF.

For game meat the value is taken from the Food-climate-list (Mat-Klimat-Listan) [Röös, 2012]. Since game is considered part of the natural ecosystem, no GHG emissions were associated with primary production, but 0.5 kg CO_2e are attributed to game meat due to necessary transportation and processing steps. This is a rather rough estimate. However, game meat consumption is generally relatively low and game meat contributed only a small fraction to the total amount of the department's food waste.

The CF of different meat products produced in Sweden is listed in Table 3.

Imported meat

Based on the information available from the retailer and national statistics, beef is imported from EU countries, mainly Ireland, or South America while Denmark is the main country of dispatch for imported pork and chicken meat [FAO, 2013]. Cederberg et al. [2009b] estimated the CF of beef produced in other EU countries and imported to Sweden, including its distribution to a retailer in Stockholm. In the same study, the CF of pork and chicken produced in Denmark and imported to Sweden was estimated and this value was used for imported pork and chicken meat. The production and transportation of beef produced in Brazil was analyzed by Cederberg [2009c] and the resulting CF value was considered representative for imported beef from South America.

It was assumed that lamb meat is imported from New Zealand or Ireland. Wallman et al. [2011] point out, that Swedish lamb production is less efficient than in other countries. Other studies indicate that emissions of imported meat from New Zealand are lower or in the range of other European systems even when transportation from New Zealand is included [Williams et al., 2008; Ledgard et al. 2011]. Ledgard et al. [2011] calculated the GHG emissions of 19 kg CO_2e/kg meat for the entire life-cycle of lamb meat produced in New Zealand and transported to Europe. About 12 % of the reported emissions are due to consumer-related components. Therefore, a value of 17 kg of CO_2e/kg meat for the life-cycle from cradle to retailer was estimated for imported lamb.

The CF of meat products imported to Sweden is listed in Table 3.

Table 3 CF of meat produced in or imported to Sweden

	CF per kg CW [kg CO_2e]	CF per kg BFM [kg CO_2e]
Beef	20	29
Beef-EU	20.5	29
Beef-South America	28.2	41
Pork	3.54	6
Pork-imported	3.82	6.5
Chicken	2.15	2.8
Grilled chicken	2.19	
Chicken-imported	2.9	3.7
Turkey		3.6
Lamb	16	21
Lamb-imported		17
Game		0.5

2.3.2. *Deli*

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.

For the production of sausages often low value meat cuts, as well as meat trimmings and organs are used. Due to the lack of more specific data, the general CF of meat produced in Sweden was taken. It was assumed that the non-meat content of the products had no influence on the total CF of the product.

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 chorizos 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, like wiener, prince or barbecue sausages. The Swedish product “varmkorv” also translates into “hot dog”, but has generally a higher meat content than the products labeled as “hot dogs” in the store. Therefore, “varmkorv” was treated as general sausage and is referred to as “hot dog$_{60\,\%}$”, while hot dogs are referred to as “hot dogs$_{35\,\%}$”. 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 for 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.

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 with associated GHG emissions of 0.007 kg CO_2e/kWh of energy from electricity and 0.4 kg CO_2e/kWh of energy from fossil fuels [Wallén et al., 2004], resulting in 0.067 kg CO_2e/MJ (1 kWh = 3.6 MJ). Energy required for processing of cooked and dried sausages is 4.4 MJ/kg and 16.9 MJ/kg respectively [Wiegmann et al., 2005], while the energy for meatball processing is 2.5 MJ/kg [Sonesson et al., 2005]. It was assumed that black pudding, head cheese and pâté have similar energy requirements as 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 filet and this value was used for all cured and smoked meat.

The CF of some common products is listed in Table 4. A detailed list with all products and the respective assumptions is included in Appendix 2.

Table 4 CF of deli products

Product	CF [kg CO_2e/kg]	Meat content per 100 g product [g]
Meatballs	12	70 (50 % beef, 50 % pork)
Cooked sausages	5.2	60 (10 % beef, 90 % pork)
Dried sausages	10	110 (10 % beef, 90 % pork)
Cured pork	5.7	90
Black pudding	0.34	Blood
Pâté	0.94	10 (pork), 30 (liver)
Head cheese (pork)	3.3	50 (pork)

2.3.3. *Dairy*

It was assumed that all eggs wasted at the studied retail stores were produced in Sweden and the associated GHG emissions of egg production are taken from Cederberg et al. [2009b].

Several studies have been performed to calculated the environmental impact of raw milk for different production systems and countries [e.g. Gerber et al., 2010; Haas et al., 2001], including Sweden [Cederberg et al., 2009a]. However, fewer studies investigated the impact of different dairy products. Flysjö [2012] calculated the CF of various products produced at the dairy company Arla Foods from cradle to grave including fresh dairy products, butter and butter blends. The CF of the products is presented in detail, including input generation (raw milk and other ingredients), processing, packaging, transportation and contributions from retail and consumer. Here, the calculated CF up to the retail level without emissions associated with packaging was considered. The CF was calculated for a limited number of products with specific protein and fat contents. However, for the products wasted at the retailer, only the fat content was known and in some cases it did not match exactly the given fat content on which the CF calculation was based. Products wasted at the retailers that did not exactly match the products presented in the study by Flysjö were assigned to the product category considered to be the best match. It was assumed that sour milk has the same CF as milk; sour cream and Turkish yoghurt were assigned the same CF as low fat crème fraîche and the CF of desserts was assumed to be comparable to that of yoghurt.

Nilsson et al. [2010] analyzed different margarine products and the CF was between 1.1 and 1.6 kg CO_2e/kg product. Here, in accordance with the Food-climate-list [Röös, 2012], a value of 1.5 kg CO_2e/kg margarine was used.

The CF of fresh orange or apple juice was calculated to be about 1 kg CO_2e/kg juice [Beccali et al., 2009; Angervall and Sonesson, 2011; Engel et al. 2012]. Angervall and Sonesson [2011] also calculated the CF of juice made from concentrate which is about 0.6 kg CO_2e/kg 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 the CF studies of soy milk [Ecofys, 2009] and an oat drink [Dahllöv and Gustafsson, 2009] an average CF from cradle to retailer of 0.15 kg CO_2e/kg product was estimated for all soy and grain drinks.
Yeast has a CF of 0.73 kg CO_2e/kg product [Cofalec, 2012].

Table 5 shows the CF of different products of the dairy department.

2.3.4. *Cheese*

In the same study analyzing fresh dairy products and butter, Flysjö [2012] calculated the CF of yellow, white, mold and cream cheese, as well as of low fat yellow and low fat cream cheese. The various products wasted at the retailers were assigned to the different products as considered best suitable.

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

Reported CF values for tofu are between 0.9 [Muroyama et al., 2003] and 2 kg of CO_2e/kg tofu [Blonk et al., 2008]. Here, a value of 1.5 kg of CO_2e/kg tofu was used.

The CF of different products sold in the cheese department is listed in Table 5.

Table 5 CF of products sold in the dairy and cheese departments

Product	CF per kg product [kg CO_2e]
Eggs	1.47
Milk, whole	1.13
Milk, semi-skimmed	0.96
Milk, skimmed	0.9
Cream	5.2
Cream, low fat	2.5
Yoghurt	1.2
Yoghurt, low fat	1.0
Crème fraîche	4.8
Crème fraîche, low fat	2.7
Cottage cheese	3.1
Butter	10
Butter blends	6.6
Margarine	1.5
Yeast	0.73
Juice	1
Juice made from concentrate	0.6
Fruit drinks	0.3
Soy and grain drinks	0.15
Yellow cheese	9.6
Yellow cheese, low fat	8.8
White cheese	7.0
Mold cheese	8.1
Cream cheese	6.2
Cream cheese, low fat	3.8
Processed cheese	3.8
Tofu	1.5

2.3.5. Fruit & Vegetable

Many fruits and vegetables in the studied retail stores are not produced in Sweden but imported from other countries. Since the GHG emissions of 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. Unfortunately, exact data about the country of origin was not available for the wasted products. However, it was possible to get this information for the purchased products delivered to all Willysstores in 2010 and 2011. Therefore, the share (in terms of mass) of produce imported from a specific country or region was calculated for the delivered products and this factor was used to calculate the weighted average CF of the wasted product.

GHG emissions caused by the production and transportation were considered. GHG emissions from production were estimated based on the existing literature as described in the paragraphs later on, GHG emissions resulting from transportation were calculated based on the estimated distance and the mode of transportation. Unfortunately, no exact data on the mode of transportation or the exact routes was available. For its fresh produce Axfood cooperates with the distributor Saba which has its central warehouse in Helsingborg, Sweden [Nilsson, 2012]. It was assumed that the products were transported from a point within the main production area of a country to Helsingborg. The distance was estimated using google maps [Google, 2013] for road transport and a distance calculator for sea[3] freight or air[4] 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. However, no data for reefer ships was available and this value was taken from Psaraftis & 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. For air freight, NTM's value for continental freight aircraft was used for distances <5000 km while for larger distances the value for intercontinental freight aircraft was used [NTM, 2013].

The emission factors for the different modes of transportation are summarized in Table 6.

Table 6 GHG emissions of different transportation modes

Mode of transportation	Emission factor [g CO_2e/t/km]
Road, heavy truck	148
Sea, reefer ship	24
Air, continental freight aircraft	1250
Air, intercontinental freight aircraft	389

To account for transportation from the farm to the main point of distribution, as well as for the distribution within Sweden, values calculated by Davis et al. [2011] were used for transportation of Swedish produce and added to the values for transportation of imported produce. For products not included in their study it was assumed that the distribution of the products within Sweden to the retailers caused on average the emission of 0.05 kg of CO_2e per kg product.

A detailed list with the calculated distances and associated GHG emissions from transportation can be found in Appendix 3.

The existing literature of impact assessments of fruit and vegetables does not cover all products carried in the retail stores. Furthermore, the existing studies usually focus on a specific production site and the results for the same product vary. It was not possible to find assessments based on national averages for the different products and countries.

[3] http://www.searates.com/reference/portdistance/

[4] http://www.airmilescalculator.com/

Generally, a main distinction for the CF of produce is whether the product was grown in the open field or in a protected system since the emissions from the production of short-lived protecting systems adds significantly to the CF of produce. Moreover, the use of auxiliary heating and its source of energy is a very important factor.

Eriksson [2012] showed that the top wasted products in the fruit & vegetable department were tomatoes, lettuce, potatoes, peppers, bananas, oranges, apples, and clementines. Together they contributed almost 70 % of the departmental food waste. Therefore, primary focus was put on those products.

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

Tomatoes

Tomatoes delivered to Willysstores were mainly imported from the Netherlands (57 %), Spain (28 %) or Morocco (9 %). The share of Swedish tomatoes was 3.6 %. Tomatoes from other countries (Israel, Belgium, Poland and the Palestinian Territory) contributed less than 1 % each. The life cycle of tomato production has been analyzed in several studies and the results vary depending on the studied system, the specific methods and system boundaries.

In the Netherlands and in Sweden, tomatoes are mainly produced in heated greenhouses. However, Dutch greenhouses are mainly heated using natural gas [CBS, 2012] while in Sweden a large share of renewable energy sources is used [Jordbruksverket, 2012]. In the Netherlands, combined heat and power (CHP) plants are commonly used to produce electricity in addition to heat for the greenhouse.

Antón et al. [2012] calculated the CF of tomato production in a Dutch greenhouse using a CHP plant; the resulting CF of 2 kg CO_2e/kg tomatoes based on energy allocation was considered to be representative for all tomatoes imported from the Netherlands.

In Spain, tomatoes are mainly produced in the South in protected systems without additional heating. The CF of tomatoes grown in greenhouse tunnels in the South of Spain is 0.25 kg CO_2e/kg tomato [Torrellas et al., 2012].

No data for GHG emissions associated with tomato production in Morocco was found and therefore similar values as for Spanish production were assumed.

Swedish tomatoes have a CF of 0.66 kg CO_2e/kg tomatoes [Davis et al., 2011].

Including transportation, the weighted CF for tomatoes wasted at the retailer was calculated to 1.5 kg CO_2e/kg tomatoes.

Peppers

All peppers were imported and the major countries of origin were the Netherlands (48 %), Spain (41 %) and to a smaller extent Turkey (6 %), Israel (2 %) and Hungary (2 %).

In the Netherlands, peppers are grown like tomatoes in greenhouses. However, the yields are much lower than for tomatoes. Since no LCA study for Dutch peppers was found, the CF result for Dutch tomatoes was used, but adjusted for yield.

The CF of tomatoes was calculated based on a yield of 56.5 kg/m^2 [Antón et al., 2012]. The yield of peppers is 32 kg/m^2 [Gołaszewski et al., 2012]. Assuming the same inputs per square meter, this leads to a CF of 3.5 kg CO_2e/kg pepper grown in the Netherlands and this value was also used for peppers from Hungary. Cellura et al. [2012] calculated the CF of pepper grown in Italy. There, pepper grown in a greenhouse without the use of auxiliary heating was analyzed and the CF up to the farm-gate is about 0.48 kg CO_2e/kg. This value was used for all other pepper. Including transportation, the average weighted CF of pepper is 2.3 kg CO_2e/kg.

Cucumbers

Cucumbers delivered to the stores were mainly produced in Sweden (60 %) or Spain (40 %). In Sweden, cucumbers are mainly grown in greenhouses [Jordbruksverket, 2012] and the associated CF up to the farm-gate is 1.05 kg CO_2e/kg [Davis et al., 2011]. For Spanish production, the same value as for tomatoes, 0.25kg CO_2e/kg, was assumed. In total, cucumbers have a weighted average CF of 0.94 kg CO_2e/kg product.

Lettuce

This category includes all salad greens. Lettuce delivered to the stores originated mainly from Spain (42 %) or Sweden (40 %). For about 10 % no information about the country of origin was available while the remaining 8 % were from different European countries. Therefore, the CF was calculated based on the assumption that 50 % originated from Spain and 50 % from Sweden.

In Sweden, iceberg lettuce is grown in the open field and the CF at the farm-gate is 0.14 kg CO_2e/kg product [Davis et al. 2011]. It was assumed that other lettuce in Sweden is grown in the greenhouse with similar conditions as cucumber with a CF of 1.05 kg CO_2e/kg product [Davis et al., 2011]. For Spanish production it was assumed that all lettuce varieties are cultivated in the open field. The CF at the farm-gate was estimated to be 0.26 kg CO_2/kg product [Hospido et al., 2009]).

The total weighted average CF of lettuce delivered to the stores was assigned to 0.54 kg CO_2e/kg product.

Potatoes

96 % of the potatoes were produced in Sweden. The CF of potatoes grown in Sweden and distributed to a retailer in Stockholm is about 0.12 kg CO_2e per kg product [Röös et al. 2010] and this value was used for all potatoes.

Apples

The CF of apples up to the farm-gate is 0.13 kg CO_2e/kg [Davis et al., 2011]. Apples were mainly delivered from Italy (40 %) and other western European countries, but also from South America (14 %), China (2 %) and New Zealand (2 %). The CF of apples delivered to the store is therefore 0.39 kg CO_2e/kg.

Bananas

The CF of bananas from Costa Rica delivered to a Willys store was calculated by Nilsson [2012]. Overall, the CF of bananas without packaging is 1.1 kg CO_2e/kg.

Oranges

The main countries of dispatch for oranges were Greece (30 %), Spain (22 %), Israel (17 %) and South Africa (12 %). The CF of oranges grown in Spain is 0.25 kg CO_2e/kg [Sanjuan et al., 2005] and it was assumed that the production systems in other countries are similar. The weighted average CF of transportation is 0.37 kg CO_2e/kg and therefore, the total CF of oranges at the store is 0.62 kg CO_2e/kg.

Melon

This category includes varieties of watermelon and muskmelon. The main countries of dispatch were Spain, Costa Rica, Hungary (only watermelons) and Brazil. It was assumed that all melons in Costa Rica and Brazil as well as watermelons in all countries are cultivated in the open field. The CF of melon grown in the open field was calculated for different scenarios by Brito de Figueirêdo et al. [2012]. The CF up to the farm-gate without emissions from packaging or LUC in their study was about 0.3 kg CO_2e/kg. Cellura et al. [2012] analyzed melon cultivation in a greenhouse in Southern Italy. In that study, the CF at the farm-gate was about 1 kg CO_2e/kg and this value was assumed to best represent muskmelon from Spain. Including transportation, the weighted average CF of melon at the stores was 0.93 kg CO_2e/kg.

Table 7 summarizes the weighted average CF of different products that were estimated in more detail as described above. A list with products and their product specific CF from cradle to farm-gate according to country of origin is included in Appendix 3.

Other fruit and vegetables – assumptions for CF up to the farm-gate

Citrus fruit: the same CF as for oranges was assumed (0.25 kg CO_2e/kg).

Greenhouse production: chili peppers, eggplant, garden radish, and fresh herbs were assumed to be grown in the greenhouse. When produced in the Netherlands or Spain, the same value as for Dutch (2 kg CO_2e/kg) respective Spanish tomato production (0.25 kg CO_2e/kg) was used, while for chili peppers the same values as for peppers was used. For fresh herbs grown in Sweden the same value as for Swedish cucumbers was used (1.05 kg CO_2e/kg).

Fruit and vegetables, other: for all other fruit and vegetables it was assumed that they are grown in the open field and on average cause the emission of 0.2 kg CO_2e/kg.

Table 7 Weighted average CF of produce delivered to Swedish retailers

Product	CF per kg product [kg CO_2e]
Tomato	1.5
Lettuce	0.54
Potatoes	0.12
Peppers	2.3
Banana	1.1
Orange	0.62
Apples	0.39
Clementine	0.67
Melon	0.93
Cucumber	0.94

2.4. Sensitivity analysis: Wastage CF of meat using economic allocation to assign specific CF values for different meat cuts

The environmental impact of livestock production has been analyzed in various studies and the CF of meat has been calculated usually as an average for the whole animal or carcass. However, the carcass is divided up further after slaughtering so that at the retail level different meat cuts with specific qualitative characteristics are offered. The demand for different meat cuts varies and it is not necessarily in accordance with the availability of the specific meat cut per carcass. Therefore, the environmental burden of meat production should be allocated to specific meat cuts in accordance with the consumption pattern driving the production. However, this is a very complex task and there have been little attempts to do a specific allocation.

The different meat cuts can be seen as co-products from a joint production and there are generally no alternative production routes to get a specific meat cut. According to Weidema [2003] in this case an economic allocation reflects how a change in demand for one product influences the production volume of the joint production since the market prices are ideally set so that all products combined drive the production. In the present study, the total CF of different meat cuts delivered to the retail stores has been allocated to the different meat cuts based on the total value of the considered meat cuts, i.e. the price per kg times the total mass delivered to the six stores over a three-year period (2010-2012). Delivered products were estimated as the sum of sold and wasted products. The ingoing prices of the retailers were used since they were thought to have less variation due to for example promotions. Only conventional products were considered since organic products are not present in all categories. Organic products tend to have higher production costs and the price of organic products often includes premiums [Michelsen et al., 1999] which is not in line with the assumption of demand and supply driven market prices that determine the production volume. The CF per kg product is presented in Table 8 for some of the products wasted in the stores. Economic allocation was only done for beef and pork produced in Sweden, since the emissions associated with meat production vary between different countries. Moreover, only certain meat cuts might be imported and prices of imported meat might also be influenced by other factors. It was assumed that Swedish beef and pork products reflect best the overall availability of different meat cuts.

Initially, the goal was to calculate the wastage CF of the meat department by using specific CF values for different meat cuts. However, due to the complexity of the topic and insufficient data availability it was considered to comprise too many uncertainties. Here the results of the wastage CF of the meat department (Swedish beef and pork) using specific CF values with and without economic allocation of the emissions between different meat cuts were compared.

Table 8 CF of different meat cuts of Swedish beef and pork based on economic allocation

Meat cut		CF of meat cut [kg CO_2e/kg]	Meat cut		CF of meat cut [kg CO_2e/kg]
Beef	BFM without economic allocation	29	Pork	BFM without economic allocation	6.0
Beef	Tenderloin	107	Pork	Tenderloin	9.0
	Top loin	61		Pork chop BF	6.8
	Entrecôte	56		Top loin	6.3
	Short loin	51		Pork chop	6.3
	Sirloin	50		Fresh ham	6.3
	Top Round	47		Boston butt BF	5.2
	Stew meat	29		Loin ribs	5.1
	Chuck	27		Boston butt	5.1
	Minced meat	24		Picnic Shoulder	4.7
	Organ meat	14		Stew meat	4.5
	Blood	8		Spare ribs	4.2
				Minced meat	3.9
				Organ meat	3.1

3. Results

3.1. Wasted mass and wastage carbon footprint

In total, 1565 t of food were wasted in the analyzed departments of the six retail stores during the three year period (2010-2012). The total CF of the wasted food was 2484 t of CO_2e or 828 t CO_2e/yr.

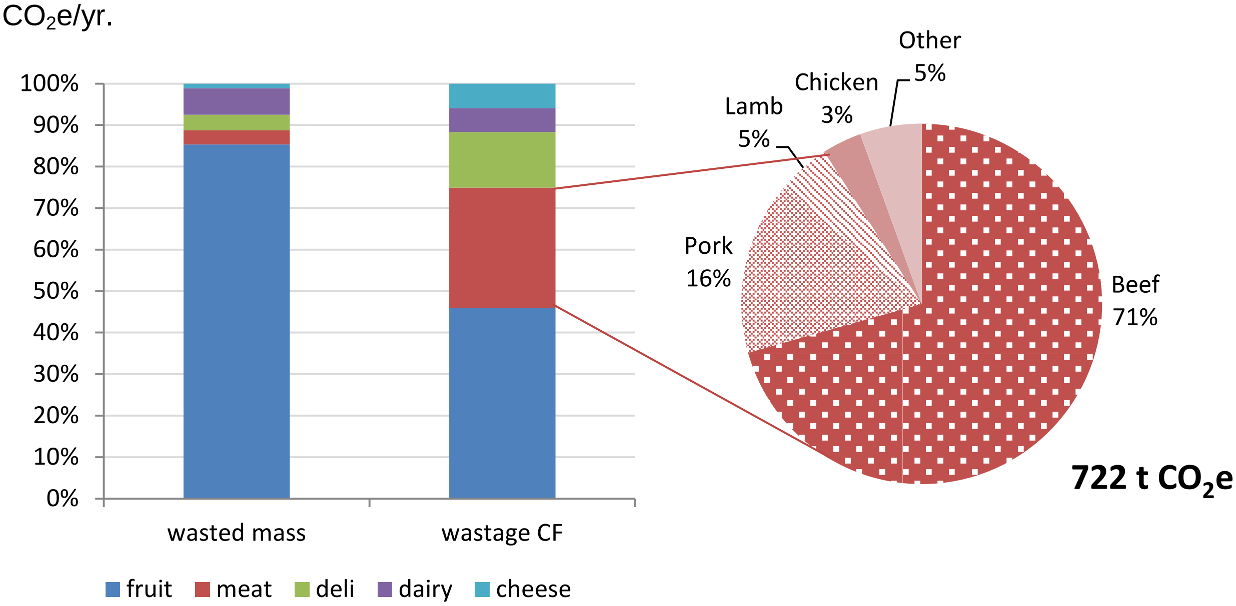

Figure 2 Left: Share of wasted mass and wastage CF of the five departments in percent of the total food waste of six retail stores during a three-year period. Right: Share of the wastage CF of different animal meat products in percent of the wastage CF of the whole meat department.

When pre-store waste is included, the fruit & vegetable department contributed 85 % to 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 (Figure 2). Considering the total wastage CF, the fruit & vegetable department contributed about 46 %, followed by the meat department with a share of 29 % and the deli department with a share of 13 %. The dairy and cheese department each contributed about 6 % to the total wastage CF (Figure 2).

The wastage CF of the different departments for each year from 2010-2012 can be seen in Figure 3. A detailed list with wasted mass and wastage CF of different products and the different departments is included in Appendix 4. For all departments, except for the fruit & vegetable department, the in-store waste contributed the major part to the total waste and therefore also to the wastage CF (Figure 3).

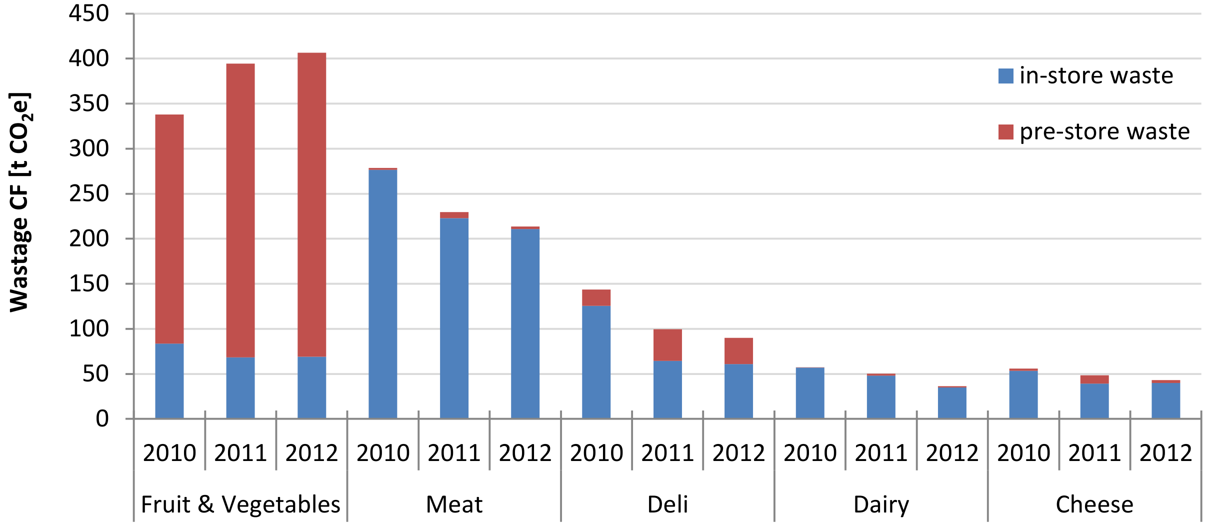

Figure 3 Total wastage CF of six Swedish retail stores for each department and year.

3.1.1. *Meat*

In total, 54.2 t of meat were wasted during the studied period and the total wastage CF of the meat department was 722 t CO_2e or 240 t CO_2e/yr mainly due to the wastage CF of beef (Figure 2).

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 (Figure 4). All beef products combined accounted for over 70 % of the total CF of wasted meat (Figure 2). For pork products, generally the share of the wasted mass was 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 beef sirloin and accounted for about 3.5 % of the department while all poultry products together accounted for about 20 % of the mass of the department’s food waste (Figure 4).

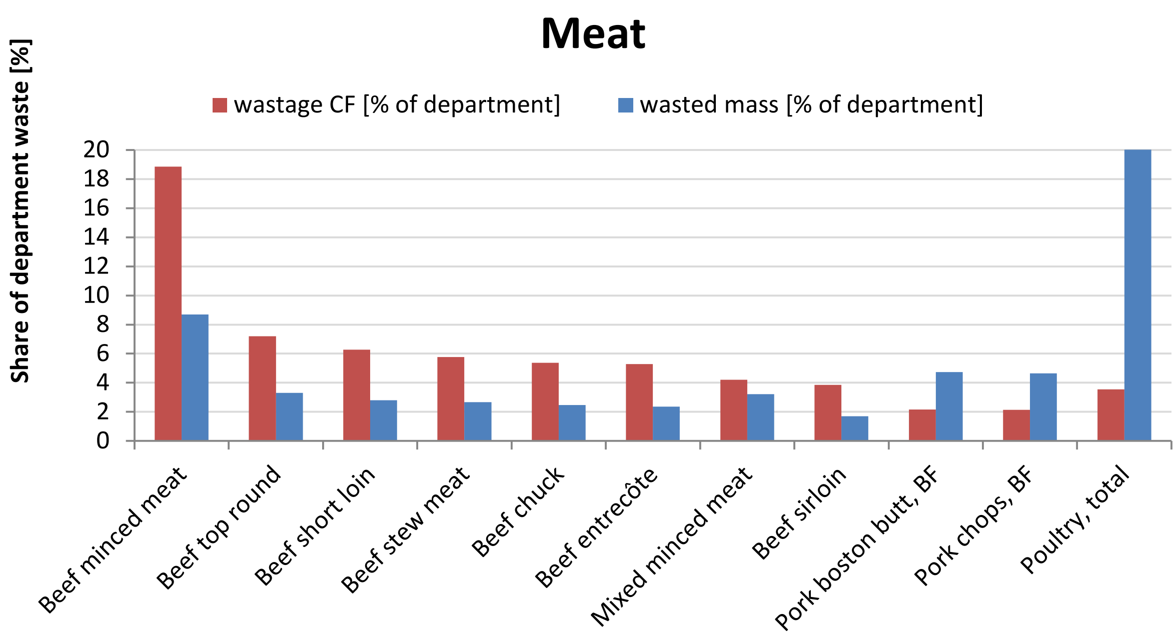

Figure 4 Share of wastage CF and wasted mass of the meat products with the highest wastage CF in percent of the meat department's total. All products of the meat department of six stores during a three-year period were considered. (BF = Bone free).

3.1.2. Deli

During the three years, 57.4 t of deli products were wasted in the six stores accounting for the emission of 333 t of CO_2e. The yearly wastage CF of the deli department is therefore 111 t CO_2e/yr. The products with the highest wastage CF were meatballs, barbecue sausages and hot dogs$_{60\,\%}$, which contributed 8.8 %, 6.7 % and 4.7 % respectively to the total wastage CF of the department (Figure 5).

3.1.3. Dairy

In the dairy department, 101 t of products were wasted during the three year period. The total CF of the department's food waste was 144 t of CO_2e or 48 t CO_2e/yr. The product with the highest wastage CF was cream with a share of 15 % of the department's wastage CF, followed by yoghurt (8 %) and semi-skimmed milk (7.7 %) (Figure 6). Considering mass, semi-skimmed milk had with 11 % the highest share of the department's food waste; cream had a share of 4.1 % of the wasted mass (Figure 6).

3.1.4. Cheese

During the studied period, 17.3 t of cheese were wasted in the six stores. The total wastage CF was 147 t CO_2e or 49 t CO_2e/yr. Semi-hard/hard cheese accounted for about 63 % of the emissions. Considering individual products, Herrgård, Gouda, and Brie cheese had the highest wastage CF with a share of the department's wastage CF of 7.7 %, 7.3 %, and 6.8 % respectively (Figure 7).

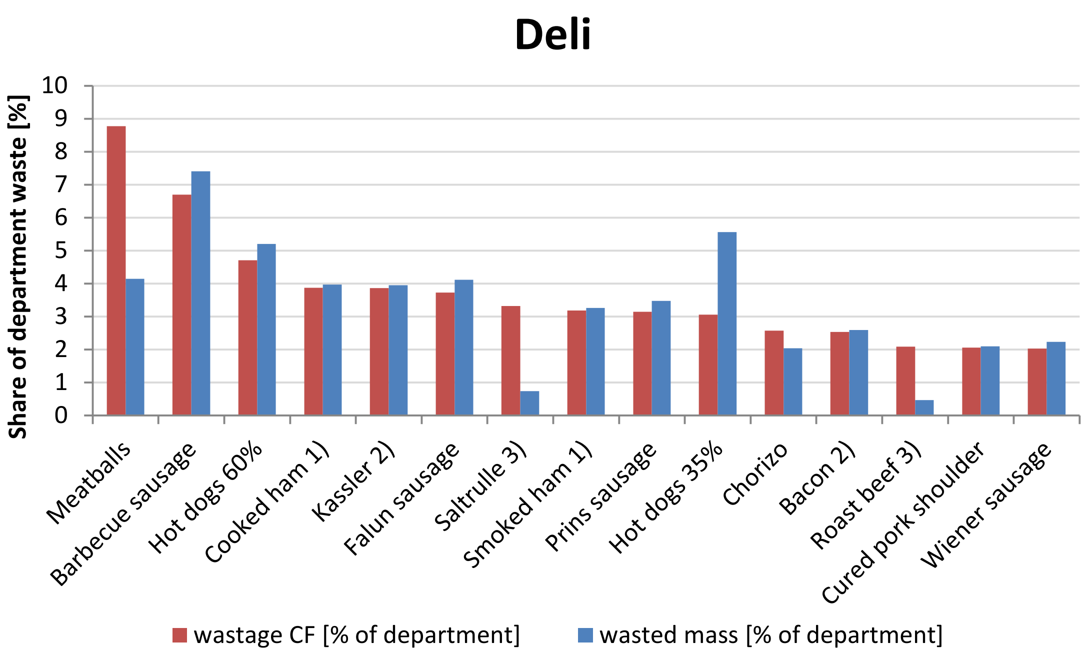

Figure 5 Share of wastage CF and wasted mass of various deli products in percent of the total waste of the deli department. (1) Sliced sandwich meat, pork 2) Pork 3) Sliced sandwich meat, beef.)

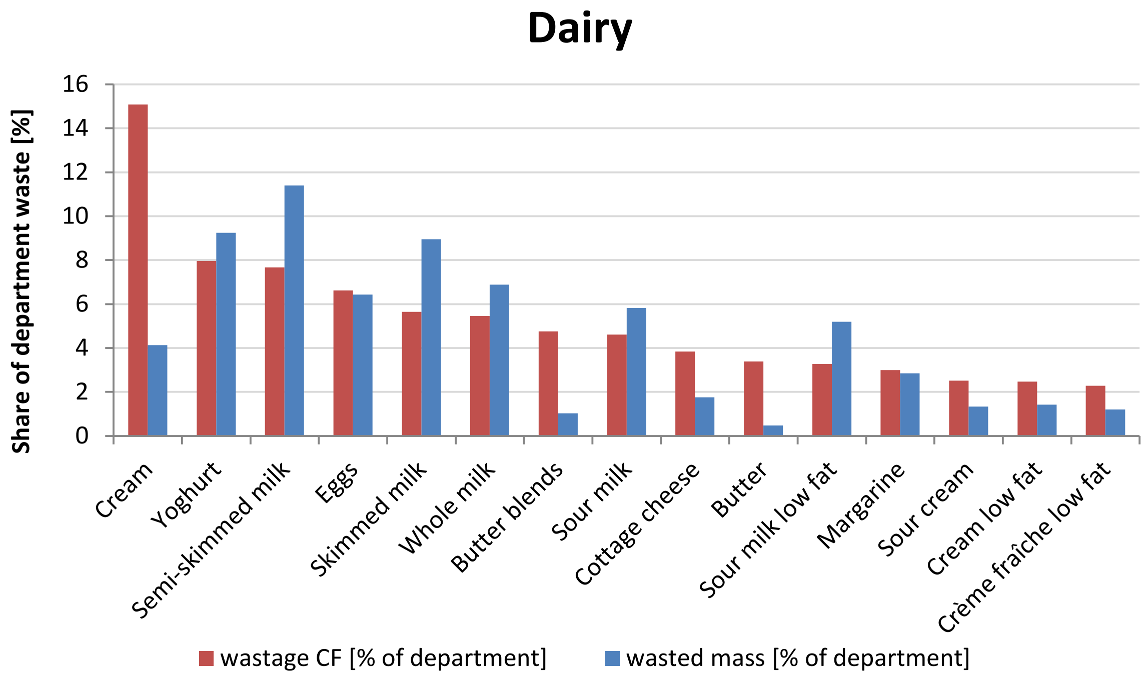

Figure 6 Share of wastage CF and wasted mass of different dairy products in percent of the department's total.

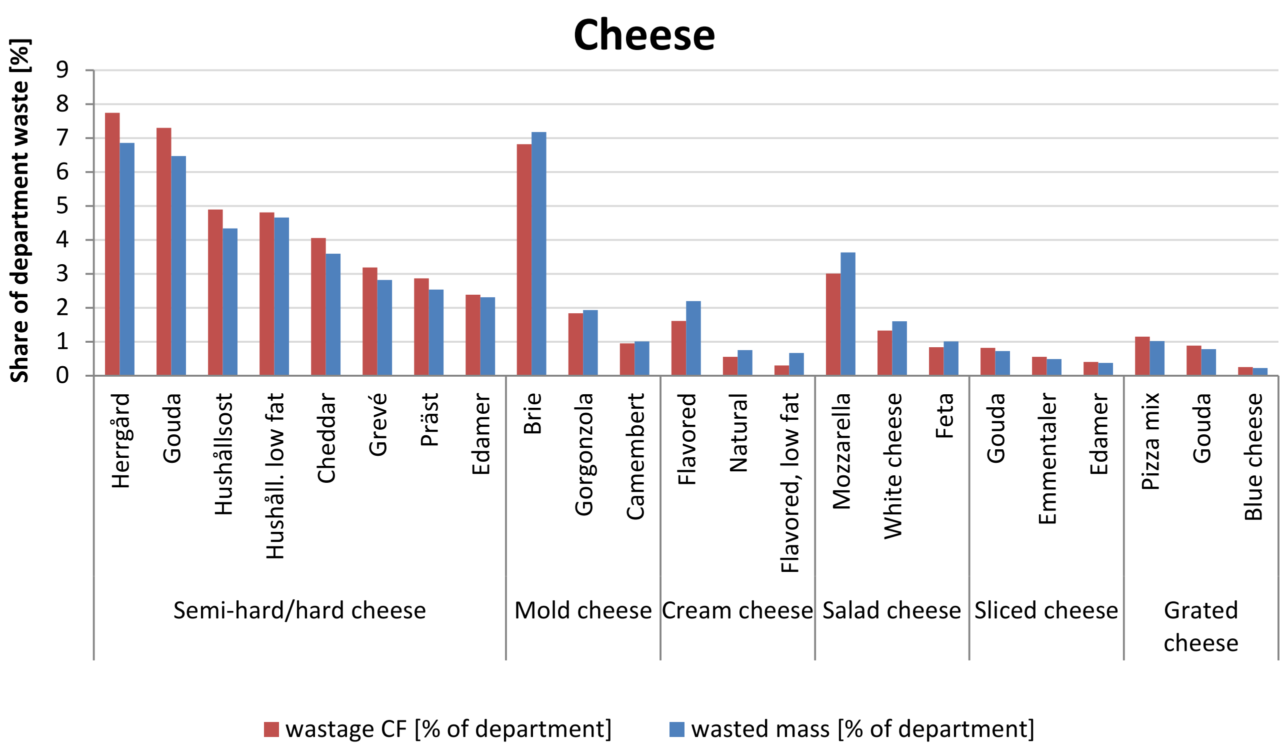

Figure 7 Share of wastage CF and wasted mass of cheese in percent of the total of the cheese department.

3.1.5. *Fruit & Vegetable*

In total, 1335 t of fresh fruit and vegetables were wasted in the six stores during the three-year period. The total wastage CF of the department is 1139 t of CO_2e or 380 t CO_2e/yr. 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 %) (Figure 8).

Potatoes were wasted in large amounts and contributed more than 5 % to the wasted mass, but only about 0.7 % to the wastage CF of the department.

The category exotic fruit includes different exotic fruit, mainly pineapple, fig, mango and sharon.

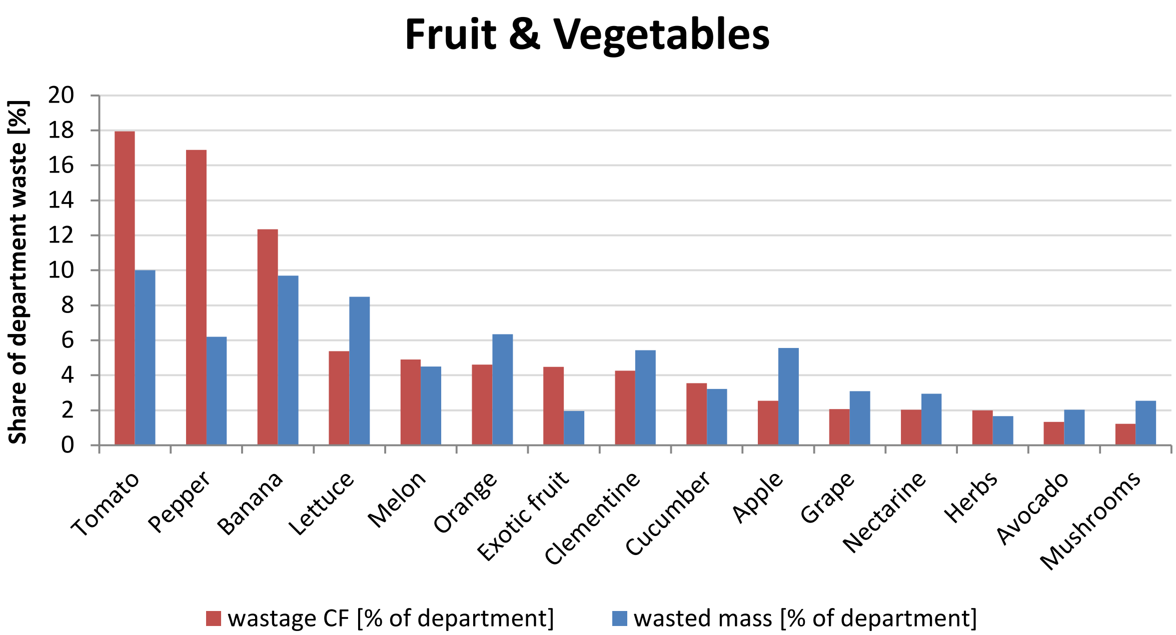

Figure 8 Share of wastage CF and wasted mass of fruit and vegetables in percent of the department's total.

3.2. *Sensitivity analysis: Wastage CF of meat using economic allocation to assign specific CF values for different meat cuts*

In the LCA methodology there is some freedom about how to allocate emissions between different co-products. Cederberg et al. [2009a] allocated all emissions from meat production to the whole carcass and therefore there is no differentiation between different meat cuts and no emissions were allocated to by-products like blood or organ meats.

Here, the effect of assigning specific CF values to the different meat cuts based on their economic value on the wastage CF of the meat department was analyzed. Only Swedish beef and pork was included. The result of the sensitivity analysis is shown in Figure 9. Tenderloin is the most expensive meat cut of both beef and pork and has therefore the highest product specific CF. The wastage CF of all Swedish beef and pork combined was 372 t CO_2e for the six stores during three years. In comparison, when the CF was not allocated between different meat cuts based on economic allocation, the wastage CF of the considered products was 293 t of CO_2e. This is explained by the fact that more expensive meat cuts are wasted at a relatively higher ratio than the cheaper details, such as minced meat. Compared to other cuts of beef, minced meat has the lowest specific CF, but is still the product with the highest wastage CF (Figure 9).

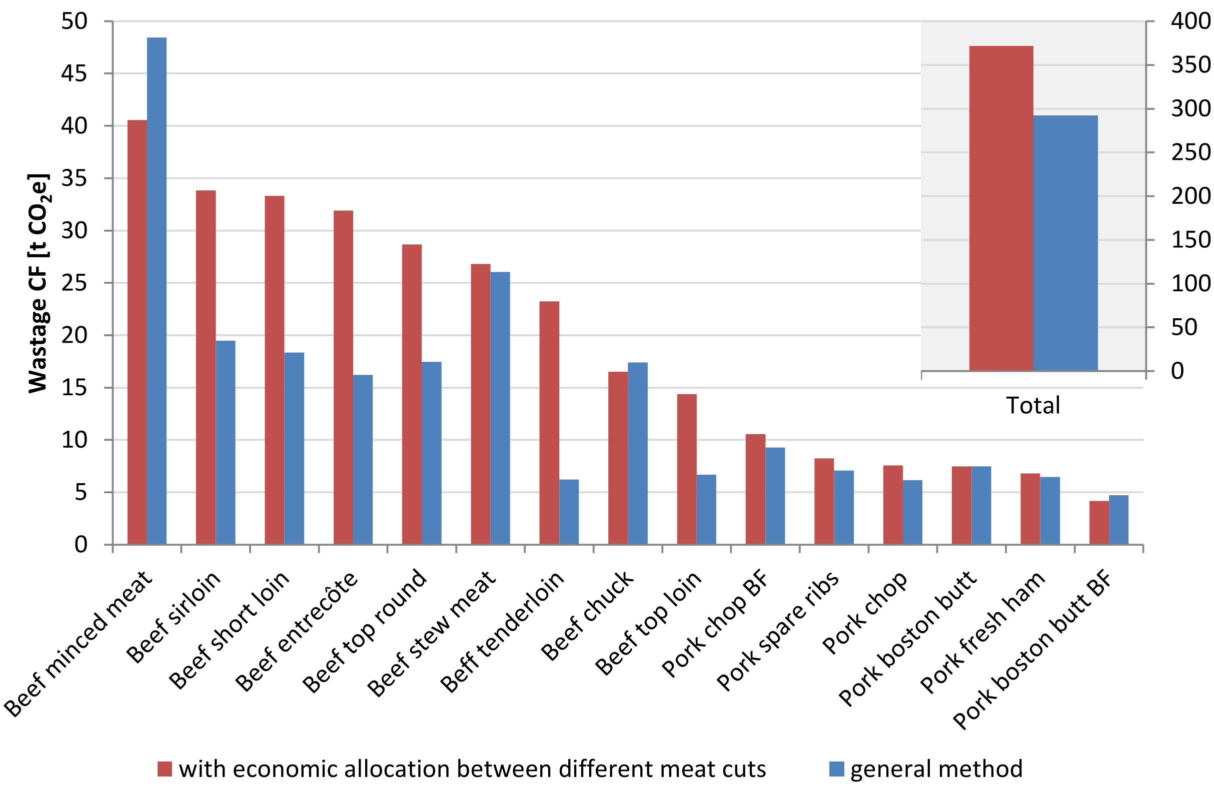

Figure 9 The wastage CF of different meat cuts of beef and pork calculated with and without specific CF based on economic allocation. (BF = Bone free).

4. Discussion

4.1. Wasted mass and wastage carbon footprint

The aim of this study was to assess the pattern of the CF of food wasted in retail stores in order to gain knowledge about its climate impact and to identify priority areas that should be addressed in order to reduce it most efficiently. The results show that in the six stores 1565 t of food were wasted during the studied period and that therefore 2484 t CO_2e were caused in vain. The average GHG emissions per t of food waste are therefore about 1.6 t CO_2e. This includes emissions caused along the life-cycle from cradle up to the delivery to the retailer for the wasted products analyzed in the present study. Bread and other bakery products were not included. Monier et al. [2010] calculated the average environmental impact of food waste based on different studies and the results for the distribution and retail sector lay between 1.35 t and 3.2 t of CO_2e per t of food waste. However, those were average estimates over the whole food sector and no data on the wastage CF of individual products or product categories within different sectors was found.

Here, the food wastage CF was analyzed in more detail for a case study on the retail level. Products of the meat, deli, dairy, cheese and fruit & vegetable department were analyzed.

Over the three years, the wastage CF decreased due to a reduction in wasted mass for all departments except the fruit & vegetable department. The overall turnover of all departments has also decreased over the years and this could be a possible explanation. Rising awareness of food waste generation due to the reporting for this study project might also have increased the focus on reducing food waste in the stores. The rise of food waste and wastage CF in the fruit & vegetable department was mainly due to an increase in the rejections upon delivery (pre-store waste).

The fruit & vegetable department contributed most to both, the wasted mass (85 %) and the wastage CF (46 %). However, 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. One short study [Göbel et al., 2012] analyzed 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 vegetables contributed 43 % to the wasted mass and 18 % to the wastage CF, while meat products accounted for 10 % of the mass and 43 % of the emissions [Göbel et al., 2012]. The results are not directly comparable since different stages of the FSC are included. Furthermore, Göbel et al. [2012] also included grain products while their category "meat products" also includes deli 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] analyzed food waste quantities in the six Willysstores and presented the results also for individual products in terms of mass. In the present study, the focus was on wastage CF and for most departments there is a clear shift of products at the top end compared to the results provided by Eriksson [2012]. The study by Eriksson is based on data from 2010-2011, while the present study also includes data from 2012 so the shift could be caused by a change in the amount of wasted products during 2012. However, the direct comparison of the share of the wasted mass and of the wastage CF of different products in this study also shows the differences between the two parameters. 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.

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.

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 leads to a high wastage CF. This study showed, that the total wastage CF of a department tends to be highly concentrated in the top products. 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 whole stores and all beef products wasted during three years have caused the emission of 510 t of CO_2e corresponding to 21 % of the total wastage CF of the six stores.

In the fruit & vegetable department, tomatoes, peppers and bananas combined accounted for 47 % of the department's wastage CF. While for example potatoes and apples also belong to commonly wasted products, their wastage CF is relatively low due to low production-related emissions and transportation distances.

Reduction measures have to be economical feasible, which means that 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 economically. Halving the food waste of the top three products in each department could save more than 150 t of CO_2e per year in the six stores.

4.2. Economic allocation of CF between different meat cuts and by-products

Using an economic base instead of the weight for allocating the GHG emissions between the different meat cuts resulted in notable differences of the wastage CF of the meat cuts especially for beef. Beef tenderloin is the most expensive meat cut and the value is about 4.5 times higher than the cheapest beef meat, which was minced meat. The total wastage CF of beef and pork (produced in Sweden) was about 27 % higher when the CF was allocated between the different meat cuts based on economic allocation. Since the allocation was based on all products delivered to the store, the increase in the total wastage CF indicates that the more expensive meat cuts have a relatively higher share of the waste than of the delivered products. This emphasizes the importance to differentiate between different products.

The allocation was done based on the economic value of the meat cuts delivered to the retailers. This method is adequate only if the share of different meat cuts in the stores is representative for the overall meat production or what is sold at the farm. Here, almost 80 % of the delivered mass of beef meat was minced meat representing about 65 % of the total value. Since this is also among the cheapest meat, the specific CFs of the meat cuts are relatively high. Although the production of minced meat can be adjusted to some extent (different meat parts can be processed into minced meat) 80 % seems rather high to be representative for the overall production. It is likely that the studied stores carry a rather high share of minced meat since they belong to a discount chain where cheaper meat cuts might be more popular. More expensive meat cuts might be sold from the farms/processing industry to other stores or restaurants which then carry a comparatively higher share of other meat cuts. Moreover, only the CF per animal carcass was known. Therefore, the total CF of the meat delivered to the stores was calculated based on the assumption, that 70 % and 59 % of the carcass of beef respective pork is BFM, while it was assumed that meat cuts with bone still include 15 % bones. Only the quantities and the value of products sold at the stores was known, i.e. there was no information on the exact amount of cut out fat or bones and its value.

Ideally, economic allocation should be done at the slaughter-house, including all meat cuts as well as by-products like bones, meat trimmings and organ meats. Differentiating between different meat cuts based on the economic value must be considered with care, since for example the demand for a certain cut of beef might be influenced by the availability of other meat products like pork or lamb. Moreover, trade between different countries adds another factor since specific meat products might be sold to different markets.

Nevertheless, an economic allocation of the emissions between different meat cuts and by-products can facilitate the understanding of the environmental burden provoked by the wasted amounts of different products.

4.3. Data quality and methodology

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 Willysstores 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 & 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] analyzed un-recorded waste of the fruit & vegetable department which was about 0.3 % of the total mass flow mainly due to non-recording or estimating a wrong mass, while recorded waste (pre-store and in-store) was 4 %.

The CF of the wasted food poducts 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. Moreover, the GWP of different GHGs in relation to CO_2 suggested by the IPCC has changed over time and therefore especially older studies might use different conversion factors than the most resent publications or different studies might use different time horizons. Therefore, the results for the same product can vary and in general the results of different studies for different products are not directly comparable.

One question concerning system boundaries has recently gained attention: whether to include emissions from LUC or not and how they should be allocated to the products. Here, emissions from LUC were not included since data availability was limited. Many LCA studies did not include emissions from LUC, and reports where it was included usually present the results with and without the emissions associated with LUC. There is no clear methodology on how to account for emissions due to LUC and therefore large variations and uncertainties are associated with LUC-related emissions [Flysjö et al., 2012]. However, especially for animal products it was shown to have a considerable impact [Flysjö et al., 2012; Cederberg et al., 2011] and therefore a common methodology should be agreed on to include LUC in LCA studies.

For some products wasted at the studied retailers, several LCA studies exist and in that case the study considered most suitable was used. In other cases, the results presented here were dependent on the only existing study, on less detailed CF studies or on own assumptions. The main studies used and how they compare to the results of other studies, as well as how own assumptions and calculations were included is discussed in more detail in the following paragraphs.

Meat

Pork, beef and chicken are the most important meat products at the retailers and accounted together for about 90 % of the wasted mass of the department. Beef and pork production has been analyzed in various studies and the results vary depending on the production system and the chosen method. For example, some beef meat produced comes from the dairy sector. Since there the cows produce both milk and calves for meat production, the beef meat is associated with less emissions. Nguyen et al. [2010] calculated the CF of beef from different European production systems and the results for beef from different dairy systems were between 16 and 20 kg CO_2e/kg CW while the CF of beef from a suckler cow-calf system was about 27 kg CO_2e/kg CW.

Leip et al. [2010] calculated the CF of beef for all European countries based on a model using national statistics and the results range from 14-44 kg CO_2e/kg CW. There, emissions from LUC were included which together with different production efficiencies was responsible for the large country-specific variation. The average European beef CF was calculated to be 22.2 kg CO_2e/kg CW. Without LUC-related emissions, the CF of beef was 23.5 kg CO_2e/kg CW when produced in Sweden and 18.8 kg CO_2e/kg CW when produced in Ireland [Leip et al., 2010]. Both results from Nguyen et al. [2010] and Leip et al. [2010] are considering the CF up to the farm-gate. In comparison, the cradle to farm-gate CF of beef produced in Sweden was 19.8 kg CO_2e/kg CW according to Cederberg et al. [2009a]. The figure used in the present study was 20 kg CO_2e/kg CW or 29 kg CO_2e/kg BFM also including post farm-gate emissions up to the delivery to the stores.

Values (cradle to farm-gate) for pork were in the range of 4.7 and 20.3 kg of CO_2e/kg CW for EU countries when LUC-related emissions are included [Leip et al., 2010]. Without emissions from LUC, the CF of pork was 4.4 and 5 kg CO_2e/kg CW for Sweden and Denmark respectively.

González et al. [2011] report a CF of 20 kg CO_2e for beef and 7.2 kg CO_2e for pork. Both values are per kg bone-free carcass produced in Sweden and transportation from the farm to the entry port of Gothenburg is included. However, not very many details of the calculations are given.

The CF of Swedish pork, beef and chicken presented here is based on results from Cederberg et al. [2009a,b] 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 analyzed in a top-down national approach also including organic production systems and the results should therefore be representative for the meat in the stores that was produced in Sweden. The CF of imported meat and meat from lamb and game is based on less detailed data. However, 67 % of the wasted mass in the meat department were beef, pork and chicken produced in Sweden.

At the slaughter house stage, Cederberg et al. [2009a,c] allocated all emissions to the carcass, i.e. no emissions were associated with hides, blood or organ meats. The results were presented per kg CW, i.e. still including some fat, tendons, bones and in the case of pork also the skin. However, the meat in the stores contains no or a comparable small amount of fat and bone. Therefore, to calculate the CF of this meat the factors described in chapter 2.3.1 were applied. This bears some uncertainties since the meat yield factor depends on the animal breed and slaughter method. This also means that all emissions were allocated to the meat.

Deli

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. It is not clear to which extent this is true, however other ingredients are often products with a much lower CF than meat like for example water or potato starch so the relative impact is probably very low.

Dairy and cheese

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]. 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]). In the study by Flysjö [2012] total emissions associated with dairy production of the dairy company Arla Foods were allocated in a top-down approach to the different products. 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 Willysstores. 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_2e/kg milk and is well in line with findings on Swedish milk production (1.02 kg CO_2e/kg ECM [Cederberg et al., 2009a]). Milk intake was calculated for the different products based on the weighted value of fat and protein.

The fat content of most products wasted in the stores was known, but did not always exactly match the fat content on which the calculation of CF was based. For example Flysjö [2012] calculated the CF of cream with a fat content of 40 % and 15 %. However, cream at the stores had a fat content between 5-40 %; cream with a fat content of 5-20 % was considered low fat, while the rest (27-40 %) was considered normal cream. For crème fraîche, the fat content of different products in the stores was 28-34 % and for low fat crème fraîche 5-20 %.

The CF of yellow cheese up to the retailer was 9.6 kg CO_2e/kg [Flysjö, 2012]. This compares to 8.7 kg CO_2e/kg estimated in the study by Berlin [2002], who used older GWP factors, or 10.8 kg CO_2e/kg estimated by Cederberg et al. [2009b], who also accounted for imported cheese. Some of the cheese in the stores is also imported. However, which products or how big the share was could not be determined and for example extra emissions due to transport are thus not considered in this study.

For some of the products like desserts or processed cheese no exact CF data was available and the specific CF was estimated based on own assumptions. However, the share of those products of the department's wasted mass was very low (desserts: 1.8 % of dairy department; processed cheese: 3.8 % of cheese department).

Fruit and vegetables

LCA studies on the production of fruit and vegetables often address only one or a few production sites so the results are specific for the particular system. Since produce is often imported into Sweden from other countries, the wastage CF was calculated based on the share of the product from its different countries of dispatch. Therefore, the focus was to find LCA studies for the countries' typical production systems which was not always possible. To give a picture about variations of the product's CF, some products and related LCA studies are discussed in the following.

Tomatoes mainly originated from the Netherlands and Spain. There is consensus that most tomatoes are grown in greenhouses and for the CF it is crucial whether or not auxiliary heating is used and, if so, based on what source of energy. For example the CF of tomatoes grown in a heated greenhouse in Sweden was estimated to be 2.7 [Biel et al., 2006] or even 3.7 kg CO_2e/kg [González et al., 2011] while according to Davis et al. [2011] the average CF is 0.66 CO_2e/kg due to an increasing use of biofuels in greenhouse heating. Reported values for Dutch production were between 0.78-2 kg CO_2e/kg [Antón et al., 2010] and 2.9 kg CO_2e/kg [Biel et al., 2006]. Here, the value of 2 kg CO_2e/kg estimated by Antón et al. [2010] was chosen since it was considering the use of a CHP plant which is common in Dutch greenhouses. The lower value (0.78 kg CO_2e/kg) presented in the same study by Antón et al. [2010] was calculated when electricity produced by the CHP plant was considered an avoided product. This reflects more a consequential approach that was not used for any other product and there are some uncertainties in determining which electricity production is avoided. For Spanish production, the values range from 0.05 (production in the open field, [Muñoz et al., 2007]) to 2.64 kg CO_2e/kg (baby plum tomatoes in heated greenhouse, [William et al., 2008]). Here, it was assumed that all tomatoes were grown in an unheated greenhouse tunnel.

No distinction was made between different tomato varieties. William et al. [2008] showed that for example vine tomatoes are associated with higher emissions due to lower yields. From the available data on food waste in the stores it was not always clear what kind of tomato it was. However, at least 77 % were considered classic loose (bulk) tomatoes.

The CF of peppers grown in Dutch greenhouses was estimated based on the yield assuming same growing conditions as for tomatoes resulting in 3.5 kg CO_2e/kg. This is a rather rough estimate. However, the only reported value for pepper grown in a heated greenhouse was for Sweden with 10 kg CO_2e/kg [González et al., 2011] which seemed rather high and no detailed background data was given.

The GHG emissions caused by banana production were estimated for Dole Food Company; the results were adjusted by Nilsson [2012] to represent bananas delivered to a Willysstore. Oversea transportation was included and contributed 0.69 kg of CO_2e to the total CF, which is a rather high value compared to own calculated emissions from transportation (about 0.3 kg CO_2e/kg product from Costa Rica to Sweden).

As described in the materials and methods (chapter 2.3.5), fruit and vegetables not described in more detail were assigned an average estimated CF from cradle to farm-gate of 0.2 kg CO_2e/kg. Considering processes up to the farm-gate most results for different fruit and vegetables grown in the field lay between about 0.05 and 0.45 kg CO_2e/kg product, for example onion: 0.05 kg CO_2e/kg [Davis et al., 2011]; beetroot: 0.11 kg CO_2e/kg [González et al., 2011]; leek: 0.15 kg CO_2e/kg [Davis et al., 2011]; pineapple: 0.19 kg CO_2e/kg [Ingwersen, 2012]; strawberries: 0.21 kg CO_2e/kg [Davis et al., 2011]; broccoli: 0.45 kg CO_2e/kg [Davis et al., 2011]. Therefore, on a product level this might lead to slight over- or underestimations. However, those products were less relevant for the department's waste generation and on the departmental level it was considered to give valuable results.

Here, for most imported produce the emissions due to transportation were calculated based on the distance and the mode of transportation. However, the exact transportation route or vehicle was not known. The range of emissions for different modes of transport is very large. For example, estimated emissions for different trucks are between 0.06 (truck+semitrailer) and 0.25 kg CO_2e/t/km, while emissions associated with sea transport are in the range of 0.01 and 0.06 kg CO_2e/t/km and 0.39-1.9 kg CO_2e/t/km for air freight [NTM, 2013]. Especially on long distances like from New Zealand or China to Sweden the choice of emission factor can have a significant impact. Here, the calculations were based only on direct routes and generally one type of vehicle. Stop-overs or transition of goods for example from ship to trucks for part of the route can add to the total emissions caused by transportation of imported produce. Moreover, emissions per kg of product also depend on its characteristics and packing requirements, since for example bulky products with a low density might not be able to use the full loading capacity.

Therefore, more research is needed to assess exact shipping routes and emission factors to calculate GHG emissions associated with food transport.

Overall, the results have to be considered with care. LCA studies always bear uncertainties 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. Animal products tend to have a relatively higher impact and it is therefore important to focus on the prevention of wastage of animal products. 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.

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. Therefore, analyzing food waste and presenting the results in terms of both, wasted mass and wastage CF, might provide a good solution.

In order to make the data on environmental impacts more reliable and comparable, it is crucial that CF studies are up-to date and the methodology is further harmonized. The results and the used method of LCA/CF studies should be highly transparent. Moreover, processed food like cheese spreads and different deli products need to be analyzed in more detail. When analyzing 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. In order to gain an overall picture of the environmental impact of food waste, other impact categories like water and land use, eutrophication, eco-toxicity and biodiversity should also be addressed.

5. Conclusions

This study focused on food waste in six Swedish retailers in terms of GHG emissions caused by the production and distribution of the wasted food products. The calculation of the wastage CF provided further information on the climate impact of different food products wasted in the stores.

Over a three-year period, 1565 t of food were wasted in the five departments of the studied stores. The results of this study show that due to this food wastage about 2500 t of CO_2e have been caused in vain. The average CF per t food waste of the stores was 1.6 t CO_2e. Fresh fruit and vegetables were responsible for 85 % of the wasted mass. The associated wastage CF was 1140 t of CO_2e 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 were associated with the emissions of 510 t of CO_2e.

The results clearly show a difference between the distribution of wasted mass and wastage CF of different products. Therefore, looking at food waste in terms of wastage CF provides better information on the potential environmental impact of food wastage and can help to identify priority targets for waste reduction measures.

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Appendix 1

Glossary

Cradle to grave	including the entire life-cycle of a product from primary input generation to final consumption and waste management.
Cradle to retailer	including the life-cycle stages of a product up to the delivery to the store.
Cradle to farm-gate	including the life-cycle stages of a product until it leaves the farm/production site.
Carbon Footprint	total amount of CO_2, CH_4 and N_2O emissions associated with a product.
Wastage CF	Carbon footprint (here: cradle to retailer) associated with the total amount of (retail) waste of a product.

Meat	**Kött**
Minced meat	Färs
Stew meat	Grytbitar
Tenderloin	Filé
Top loin	Ytterfilé
Beef	**Nöt**
Chuck	Högrev
Round	Fransyska, Rulle, Ytterlår
Short loin	Ryggbiff, Biff
Shoulder	Bog
Sirloin	Rostbiff, Rostas
Tenderloin	Oxfilé
Top Round	Lövbiff
Pork	**Fläsk**
Boston butt	Karré
Fresh ham	Skinkstek, Skinkschnitzel
Ham	Julskinka
Loin ribs	Kamben
Picnic shoulder	Picnicbog
Pork chop	Kotlett
Shank	Fläsklägg
Side pork	Sidfläsk, Fläskstek
Spare ribs	Revben, Revbensspjäll
Deli	**Chark**
Barbecue sausage	Grillkorv
Black pudding	Blodpudding
Breakfast sausage	Frukostkorv
Cold cuts	Medwurst, Mortadella, Onsalakorv, Jaktkorv
cured	rimmad/rökt
Falun sausage	Falukorv
Head cheese	Sylta
Hot dog	Varmkorv, Hot dog
Lunch sausage	Lunchkorv
Meatballs	Köttbullar
Pâté	Pastejer, Patéer
Prins sausage	Prinskorv
Salami	Salami, Ölkorv, Gyulaer
Salisbury steak	Pannbiff
Sandwich meat	Smörgåsmat
Wiener sausage	Wienerkorv, Wienerpölser
Cheese	**Ost**
semi-hard/hard cheese	hårdost mild/mellan/lagrad

Appendix 2

CF of Deli Products

Table 9 CF of deli products and related assumptions

Category	Total meat content [%]	Type of meat	Processing energy [MJ/kg]	CF [kg CO_2e/kg]	Products
Cooked sausages	60	90% pork, 10% beef	4.4	5.3	Barbecue-, Wiener-, Prince-, Falun-, Breakfast-, Lunch sausage, Hot dogs (Varmkorv), Cold cuts
Cooked sausage	35	90% pork, 10% beef	4.4	3.2	Hot dogs
Cooked sausage	85	90% pork, 10% beef	4.4	7.3	Bratwurst, Chorizo, Salsiccia
Cooked sausage	60	chicken	4.4	2	Chicken sausages
Cooked sausage	60	beef	4.4	17	Beef sausages
Dried sausage	110	90% pork, 10% beef	16.9	10	Salami
Dried ham	110	pork	16.9	7.7	Black Forest ham, Jamón Serrano
Cured pork	90	pork	4	5.7	Smoked ham, cooked ham, bacon, cured shank and other pork cuts, Kassler
Cured turkey	90	turkey	4	3.5	Smoked or grilled turkey breast
Cured beef	90	beef	4	26	Roast beef, sliced sandwich meat of beef
Meatballs	70	50% pork, 50% beef	2.5	12	Meatballs, Salisbury steak, Cevapcici
Pâté	10	pork + 30% liver	4.4	0.9	Different pâtes
Black pudding	blood		4.4	0.3	Black pudding
Head cheese	50	pork	4.4	3.3	Head cheese pork
Head cheese	50	veal	4.4	14	Head cheese veal

Appendix 3

CF of Fruit and Vegetables: Production and Transportation

Table 10 CF of fruit and vegetables according to country of origin

Product	Country of origin	CF cradle to farm-gate [CO_2e/kg]	Source
Apple	Sweden	0.13	Davis et al., 2011
Apple	other countries	0.13	*)
Banana	Costa Rica	0.138	Nilsson, 2012
Carrot	Sweden	0.08	Davis et al., 2011
Cucumber	Sweden	1.05	Davis et al., 2011
Cucumber	Spain	0.25	*)
Eggplant	Spain	0.25	*)
Eggplant	Netherlands	2	*)
Garden radish	Netherlands	2	*)
Herbs	Sweden	1.05	*)
Lettuce	Sweden, greenhouse	1.05	*)
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
Melon	Brazil	0.3	Brito de Figueirêdo et al., 2012
Melon (watermelon)	other countries, open field	0.3	*)
Orange	Spain	0.25	Sanjuan et al., 2005
Orange	other countries	0.25	*)
Other Citrus fruit	all	0.25	*)
Pepper	Spain	0.48	*) based on Cellura et al., 2012
Pepper	Netherlands	3.5	*)
Potato	Sweden	0.12	Röös et al., 2010
Tomato	Netherlands	2	Antón et al., 2010
Tomato	Morocco	0.25	*)
Tomato	Spain	0.25	Torrellas et al., 2012
Tomato	Sweden	0.66	Davis et al., 2011
other vegetables	all, open field	0.2	*)
other fruit	all	0.2	*)

*) own assumptions

Table 11 Countries of origin of produce, estimated distances and associated GHG emissions

Country	Point of origin	Assumed distance [km]	Mode of transport	Emission factor [CO2e/kg/km]	CO2e / kg product [kg CO2e]
Spain	Almería	2940	road	1.48E-04	0.49
Italy	Rome	1960	road	1.48E-04	0.34
Portugal	Lisboa	3000	road	1.48E-04	0.49
France	Bourges	1520	road	1.48E-04	0.27
Netherlands	Amsterdam	840	road	1.48E-04	0.17
Denmark	Vejle	285	road	1.48E-04	0.09
Germany	Leipzig	640	road	1.48E-04	0.14
Greece	Athens	2830	road	1.48E-04	0.47
Israel	Tel-Aviv	7120	boat	2.40E-05	0.22
Israel	Ben Gurion Airport	3300	plane (exotic)	1.25E-03	4.17
Poland	Warsaw	1050	road	1.48E-04	0.21
Belgium	Brussels	970	road	1.48E-04	0.19
United Kingdom	London	1300	road	1.48E-04	0.24
Hungary	Budapest	1360	road	1.48E-04	0.25
Cyprus	Limassol	6800	boat	2.40E-05	0.21
Chile	Valparaiso	14700	boat	2.40E-05	0.40
Chile	Santiago	13100	plane (berries)	3.89E-04	5.15
China	Shanghai	20200	boat	2.40E-05	0.53
Argentina	Buenos Aires	12600	boat	2.40E-05	0.35
Argentina	Buenos Aires	12600	plane (berries)	3.89E-04	4.95
Brazil	Pecém	8400	boat	2.40E-05	0.25
Brazil	São Paulo	10900	plane (exotic)	3.89E-04	4.29
New Zealand	Auckland	21900	boat	2.40E-05	0.58
South Africa	Port Elizabeth	13000	boat	2.40E-05	0.36
South Africa	Johannesburg	9600	plane (exotic)	3.89E-04	3.78
Costa Rica	Puerto Limon	10100	boat	2.40E-05	0.29
Costa Rica	San José	9700	plane (exotic)	3.89E-04	3.82
Canada	Vancouver	7400	plane (cherries)	3.89E-04	2.93
Cote d'ivoire	Abidjan	7700	boat	2.40E-05	0.23
Colombia	Bogotá	9700	plane (exotic)	3.89E-04	3.82
Algeria	Algiers	2800	plane (exotic)	1.25E-03	3.54
Ecuador	Quito	10400	plane (exotic)	3.89E-04	4.10
Egypt	Alexandria	6800	boat	2.40E-05	0.21
Egypt	Cairo	3400	plane (beans, exotic)	1.25E-03	4.29
India	Jawaharlal Nehru Port	12700	boat	2.40E-05	0.35
India	Delhi	5600	plane (exotic, minimajs)	3.89E-04	2.23
Kenya	Nairobi	7000	plane (green beans, exotic)	3.89E-04	2.77
Morocco	Casablanca	3350	boat	2.40E-05	0.13
Madagascar	Toamasina	13600	boat	2.40E-05	0.38
Macedonia	Skopje	2160	road	1.48E-04	0.37
Mexico	Veracruz	10100	boat	2.40E-05	0.29
Mexico	Mexico City	9600	plane (berries, asparagus, chili)	3.89E-04	3.78
Malaysia	Port Kelang	15800	boat	2.40E-05	0.43
Malaysia	Kuala Lumpur	9400	plane (exotic)	3.89E-04	3.71
Peru	Callao	12400	boat	2.40E-05	0.35
Peru	Lima	11500	plane (exotic, asparagus)	3.89E-04	4.52
Thailand	Bangkok	8300	plane (exotic, minimajs)	3.89E-04	3.28
Tunisia	Tunis	4800	boat	2.40E-05	0.17
Turkey	Antalya	6600	boat	2.40E-05	0.21
Turkey	Ankara	3140	road	1.48E-04	0.51
Tanzania	Dar es Salaam	7600	plane (berries)	3.89E-04	3.01
Uganda	Entebbe	6800	plane (chili)	3.89E-04	2.70
US	Seattle	17300	boat	2.40E-05	0.47
US	Miami	8250	boat	2.40E-05	0.25
US	Detroit	6600	plane (cherries, cranberry)	3.89E-04	2.62
Uruguay	Montevideo	12400	boat	2.40E-05	0.35
Uruguay	Montevideo	12500	plane (berries)	3.89E-04	4.91
Vietnam	Tan Son Nhat	8900	plane (exotic)	3.89E-04	3.51
Zimbabwe	Harare	8700	plane (exotic)	3.89E-04	3.43

Appendix 4

List of wasted mass and wastage CF

Table 12 Wasted mass and wastage CF of the whole stores and of the different departments

Department	Product	wasted mass [t]	wastage CF [t CO_2e]	wastage CF [% of department]	wastage CF [% of total]
Total	(five departments of six stores; 2010-2012)	1565	2484		
Meat	total	54.2	721.9		29.1
	Beef	17.58	509.87	70.6	20.5
	Pork	20.33	112.85	15.6	4.5
	Lamb	1.82	33.76	4.7	1.4
	Poultry	10.94	25.60	3.5	1.0
	Other (mixed minced meat, raw sausages, game meat)	3.52	39.79	5.5	1.6
	Beef minced meat	4.71	136.14	18.9	5.5
	Beef top round	1.79	52.03	7.2	2.1
	Beef short loin	1.51	45.23	6.3	1.8
	Beef stew meat	1.45	41.70	5.8	1.7
	Beef chuck	1.34	38.73	5.4	1.6
	Beef entrecôte	1.28	38.20	5.3	1.5
	Mixed minced meat	1.74	30.36	4.2	1.2
	Beef sirloin	0.93	27.88	3.9	1.1
	Pork boston butt, BF	2.56	15.65	2.2	0.6
	Pork chops, BF	2.51	15.51	2.1	0.6
	Veal minced meat	0.50	14.26	2.0	0.6
	Beef tenderloin	0.43	13.52	1.9	0.5
	Beef round (fransyska)	0.36	10.51	1.5	0.4
	Pork spare ribs	2.55	9.30	1.3	0.4
	Hamburger (Beef, 80% meat)	0.36	8.33	1.2	0.3

Department	Product	wasted mass [t]	wastage CF [t CO_2e]	wastage CF [% of department]	wastage CF [% of total]
Deli	total	57.4	332.8		13.4
	Meatballs	2.38	29.19	8.8	1.2
	Barbecue sausage	4.25	22.30	6.7	0.9
	Hot dogs (Varmkorv)	2.99	15.67	4.7	0.6
	Cooked ham (sliced sandwich meat, pork)	2.28	12.91	3.9	0.5
	Kassler (cured pork)	2.27	12.85	3.9	0.5
	Falun sausage	2.36	12.40	3.7	0.5
	Saltrulle (sliced sandwich meat, beef)	0.43	11.06	3.3	0.4
	Smoked ham (sliced sandwich meat, pork)	1.87	10.61	3.2	0.4
	Prince sausage	1.99	10.46	3.1	0.4
	Hot dogs	3.19	10.19	3.1	0.4
	Chorizo	1.17	8.56	2.6	0.3
	Bacon (pork)	1.49	8.43	2.5	0.3
	Roast beef (sliced sandwich meat, beef)	0.27	6.95	2.1	0.3
	Cured pork shoulder	1.21	6.84	2.1	0.3
	Wiener sausage	1.28	6.75	2.0	0.3
Dairy	total	100.6	143.6		5.8
	Cream	4.16	21.67	15.1	0.9
	Yoghurt	9.30	11.44	8.0	0.5
	Semi-skimmed milk	11.47	11.01	7.7	0.4
	Eggs	6.48	9.52	6.6	0.4
	Skimmed milk	9.01	8.11	5.6	0.3
	Whole milk	6.93	7.83	5.5	0.3
	Butter blends	1.04	6.83	4.8	0.3
	Sour milk 3%	5.86	6.62	4.6	0.3
	Cottage cheese	1.76	5.51	3.8	0.2
	Butter	0.48	4.87	3.4	0.2
	Sour milk 0.5%	5.22	4.70	3.3	0.2
	Margarine	2.86	4.29	3.0	0.2
	Sour cream	1.34	3.61	2.5	0.1
	Cream low fat	1.43	3.54	2.5	0.1
	Crème fraîche low fat	1.21	3.27	2.3	0.1

Department	Product	wasted mass [t]	wastage CF [t CO_2e]	wastage CF [% of department]	wastage CF [% of total]
Cheese	total	17.3	146.9		5.9
Semi-hard/ hard cheese	Herrgård	1.18	11.37	7.7	0.5
	Gouda	1.12	10.73	7.3	0.4
	Hushållsost	0.75	7.19	4.9	0.3
	Hushåll. low fat	0.80	7.07	4.8	0.3
	Cheddar	0.62	5.95	4.1	0.2
	Grevé	0.49	4.68	3.2	0.2
	Präst	0.44	4.21	2.9	0.2
	Edamer	0.40	3.51	2.4	0.1
Mold cheese	Brie	1.24	10.02	6.8	0.4
	Gorgonzola	0.33	2.69	1.8	0.1
	Camembert	0.17	1.40	1.0	0.1
Cream cheese	Flavored	0.38	2.36	1.6	0.1
	Natural	0.13	0.81	0.6	0.0
	Flavored, low fat	0.12	0.43	0.3	0.0
Salad cheese	Mozzarella	0.63	4.42	3.0	0.2
	White cheese	0.28	1.95	1.3	0.1
	Feta	0.17	1.23	0.8	0.0
Sliced cheese	Gouda	0.13	1.21	0.8	0.0
	Emmentaler	0.08	0.81	0.6	0.0
	Edamer	0.06	0.59	0.4	0.0
Grated cheese	Pizza mix	0.18	1.68	1.1	0.1
	Gouda	0.13	1.29	0.9	0.1
	Blue cheese	0.04	0.37	0.3	0.0

Department	Product	wasted mass [t]	wastage CF [t CO_2e]	wastage CF [% of department]	wastage CF [% of total]
Fruit & Vegetable	total	1335.1	1138.8		45.8
	Tomato	133.56	204.35	17.9	8.2
	Pepper	82.85	192.22	16.9	7.7
	Banana	129.43	140.56	12.3	5.7
	Lettuce	113.33	61.20	5.4	2.5
	Melon	59.95	55.75	4.9	2.2
	Orange	84.78	52.56	4.6	2.1
	Exotic fruit	26.11	51.04	4.5	2.1
	Clementine	72.40	48.51	4.3	2.0
	Cucumber	43.03	40.45	3.6	1.6
	Apple	74.25	28.96	2.5	1.2
	Grape	41.19	23.48	2.1	0.9
	Nectarine	39.31	23.19	2.0	0.9
	Herbs	22.22	22.59	2.0	0.9
	Avocado	26.95	15.09	1.3	0.6
	Mushrooms	33.96	13.92	1.2	0.6
	Pear	34.53	13.81	1.2	0.6
	Eggplant	8.68	13.72	1.2	0.6
	Lemon	19.35	12.97	1.1	0.5
	Summer squash	10.87	11.85	1.0	0.5
	Peach	18.61	10.79	0.9	0.4
	Onion	29.58	8.87	0.8	0.4
	Potato	71.35	8.56	0.8	0.3
	Garden radish	3.92	8.51	0.7	0.3
	Broccoli	10.80	6.80	0.6	0.3
	Cauliflower	16.68	6.67	0.6	0.3
	Beans	2.86	6.07	0.5	0.2
	Plum	9.80	5.68	0.5	0.2
	Kiwi	9.46	5.20	0.5	0.2
	Asparagus	2.30	4.87	0.4	0.2
	Strawberries	11.99	4.43	0.4	0.2
	Grapefruits	8.17	4.09	0.4	0.2
	Cherries	4.19	3.52	0.3	0.1
	Carrot	26.17	3.40	0.3	0.1
	Berries	2.42	3.32	0.3	0.1
	White cabbage	6.91	2.21	0.2	0.1

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