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Life cycle assessment of supermarket food waste

Pedro Brancoli*, Kamran Rousta, Kim Bolton

Swedish Centre for Resource Recovery, University of Borås, Allégatan 1 501 90 Borås, Sweden

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ABSTRACT

Retail is an important actor regarding waste throughout the entire food supply chain. Although it produces lower amounts of waste compared to other steps in the food value chain, such as households and agriculture, it has a significant influence on the supply chain, including both suppliers in the upstream processes and consumers in the downstream. The research presented in this contribution analyses the impacts of food waste at a supermarket in Sweden. In addition to shedding light on which waste fractions have the largest environmental impacts and what part of the waste life cycle is responsible for the majority of the impacts, the results provide information to support development of strategies and actions to reduce of the supermarket's environmental footprint. Therefore, the food waste was categorised and quantified over the period of one year, the environmental impacts of waste that were generated regularly and in large amounts were assessed, and alternative waste management practices were suggested. The research revealed the importance of not only measuring the food waste in terms of mass, but also in terms of environmental impacts and economic costs. The results show that meat and bread waste contributes the most to the environmental footprint of the supermarket. Since bread is a large fraction of the food waste for many Swedish supermarkets, this is a key item for actions aimed at reducing the environmental footprint of supermarkets. Separation of waste packaging from its food content at the source and the use of bread as animal feed were investigated as alternative waste treatment routes and the results show that both have the potential to lead to a reduction in the carbon footprint of the supermarket.

1. Introduction

Food, during its life cycle, contributes to current global environmental challenges such as climate change, eutrophication, terrestrial and aquatic acidification, depletion of the stratospheric ozone layer, depletion of natural resources and loss of biodiversity (Garnett, 2013; Hertwich and Peters, 2009; Pretty et al., 2005). Furthermore, the global food demand is projected to increase by 70% by 2050 (FAO, 2009), which may well increase the environmental impact on the planet.

These issues are aggravated by the wastage of one third of all food produced for human consumption (Gustavsson et al., 2011), and raises ethical concerns since 795 million people suffer from undernourishment (FAO et al., 2015). According to the Food and Agricultural Organisation of the United Nations (FAO, 2013), the global food waste in 2007 was estimated to be 1.6 Gtonnes of primary product equivalents and the corresponding edible part was estimated as 1.3 Gtonnes.

Reduction of food waste is, therefore, important for food security and for reducing unnecessary economic costs. It will also reduce environmental impacts, and is less controversial than alternatives such as the reduction in consumption of some products like meat and dairy (Beretta et al., 2013; Gruber et al., 2015; Scholz et al., 2015).

Even though retail has lower amounts of food waste compared to other steps in the food value chain, (FAO, 2013; Naturvårdsverket, 2013), it has a significant influence on food waste generated throughout the supply chain. The European Commission (2013) reported that retailers have increased their bargaining power over other actors in the supply chain. Retailers also influence – and are influenced by – consumers that are downstream in the supply chain. For example, there is a large amount of waste in primary production due to the strict quality standards of consumers and retailers that define product classes. Food products that are classified as lower quality can yield lower profits, and it is therefore often not financially viable to harvest the product, even though it could be sold in supermarkets. For instance, each year 15% of lettuce grown in Sweden is not harvested (Livsmedelsverket, 2015).

Retailers are located towards the end of the supply chain, and hence a large environmental impact has already been generated

* Corresponding author.
E-mail address: pedro.brancoli@hb.se (P. Brancoli).

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from transportation, packaging and other processes before the food reaches the supermarkets. It also concentrates large quantities of waste at a few physical locations, which facilitates collection of the waste for further treatment as well as data of the waste fractions and quantities. Thus, supermarkets are potentially good targets to investigate food waste and subsequently implement measures for waste prevention. This would reduce the environmental impacts of the waste as well as economic losses suffered by the supermarkets (Scholz et al., 2015).

Statistics on the amount of food waste generated in the Swedish retail sector varies substantially depending on the source of the data. This is also true for the fraction of this waste that is avoidable, defined as "food that could have been eaten provided that it has been handled correctly and eaten by its use-by date" (Naturvårdsverket, 2013). For example, Naturvårdsverket (2013) reported that 70,000 t of food waste was generated by food retailers during 2012, of which 91% was avoidable. In a more recent report (Naturvårdsverket, 2016) they recalculate this figure to be 45,000 t. The reason for this large discrepancy is not clear, but may be due to differences in methods to obtain these figures. Of interest is that, using the newer method to calculate the food waste, there was a reduction from 45000 t in 2012–30000 t in 2014. Surprisingly, only 36% of this 30000 t was avoidable (compared to the value of 91% determined for 2012). Irrespective of this, there is substantial food waste in the Swedish retail sector.

This study analyses the food waste at a supermarket in Sweden in terms of product type, mass, environmental impacts and economic costs. The supermarket is located in the city of Borås, and has a sales area of approximately 410 m^2. It is therefore a typical mid-size urban supermarket (Gómez-Suárez and Martínez-Ruiz, 2016). The results presented here are therefore expected to be relevant for many Swedish supermarkets, and perhaps even for retailers in other developed countries. In addition, the information obtained in this study can be used to support the development of strategies and actions aimed to reduce supermarket food waste and to identify alternative waste treatment routes that reduce the supermarket's environmental footprint.

This study is divided into three parts:

(i) The categorisation and quantification of food waste in the supermarket over a one year period.
(ii) The results from the waste categorisation and quantification revealed which waste fractions were large and generated often. The environmental impacts of these waste fractions were assessed.
(iii) The results from the waste categorisation and quantification together with the life cycle assessment (LCA) supported the design of alternative waste treatment routes. The change in the environmental footprint for each alternative was quantified.

2. Material and methods

2.1. Waste categorisation and quantification

The type and amount of food waste at the supermarket was gathered from October 2014 to September 2015. Products that were considered unsellable due to defects or that have expired shelf-life were scanned by a bar code reader and the data was saved in the supermarket's database. Products that were sold without a bar code, such as fruits and vegetables, were weighed, and the mass of the waste was entered manually into the database. After the data collection, the food products were categorized. This study does not differentiate between avoidable and unavoidable food waste. It is assumed that the waste was edible at or before the time that it was disposed of, or that an excessive amount of products was ordered and that this led to waste.

The economic analysis is limited to the costs incurred by the supermarket and it includes the purchase costs of the wasted products and the disposal costs (including fetching the waste from the supermarket). Other costs borne by the supermarket, e.g., salaries, were not included. This analysis was incorporated as a secondary goal in this study since economic losses are important for motivating change in the retail sector.

Pre-supermarket waste, which is waste that is rejected upon delivery, is not included in this study since it was not recorded in the supermarket's database. Pre-supermarket waste consists of items that do not satisfy the quality requirements of the supermarket (Eriksson et al., 2012). According to Eriksson (2015) pre-supermarket waste can represent significant quantities of waste, particularly for fruits and vegetables, where it can correspond to three times the amount of waste in the supermarket.

2.2. LCA of the supermarket food waste

Food waste fractions that were generated often (high frequency) and in large amounts were included in the LCA. The frequency of waste generation was assessed as the number of days in the year that the product was disposed of. This parameter was used to avoid waste that was generated due to a single or infrequent occurrence, such as a breakdown of equipment. Waste fractions that occur in frequent and large amounts are of more interest than those that are generated in small amounts and less often since they are statistically more meaningful (they are more likely to represent annual waste fractions and quantities over several years).

2.2.1. Goal and scope definition

Based on the criteria discussed in the previous paragraph, the waste fractions that were selected for the LCA were beef, pork, chicken, bread, strawberries, bananas, tomatoes, lettuce, potatoes, carrots, cabbage and apples. Dairy waste was not included in the main LCA due to the large variety of wasted products and the lack of available data to accurately model all impact categories.

The functional unit for this study is the waste generated by the supermarket from October 2014 to September 2015 for the selected products, which corresponds 11.4 t from the total of 22.5 t of food waste generated during that period. This is similar to that used in comparable LCAs (Scholz et al., 2015), and was used since the aim was to compare the environmental impacts of different food waste fractions generated during an entire year. Impacts per kg of food waste are presented in Section 2.2 of the Supplementary material.

2.2.2. System boundaries

Fig. 1 shows the simplified flow chart of the waste fractions that were analysed and includes some of the relevant processes used to model each product. The life cycle was modelled from the cradle to the grave. It includes processes from the agricultural production, packaging production, transportation, retail and end of life treatment. The bakery stage is also included for bread waste. The city of Borås, Sweden was the geographical reference for the retail and for the waste treatment. A global dataset that is based on the average global data was used for the agricultural production. The current waste management practice in the city is to use the food waste for anaerobic digestion. The waste treatment is explained in more detail in Section 2.3. More details of the data and assumptions made for the life cycle modelling are available in Section 2, Supplementary material.

The fruits and vegetables sold in the supermarket come from different countries and some of products even have several countries of origin. Representative countries for each waste fraction were chosen to model the transportation routes. For each waste frac-

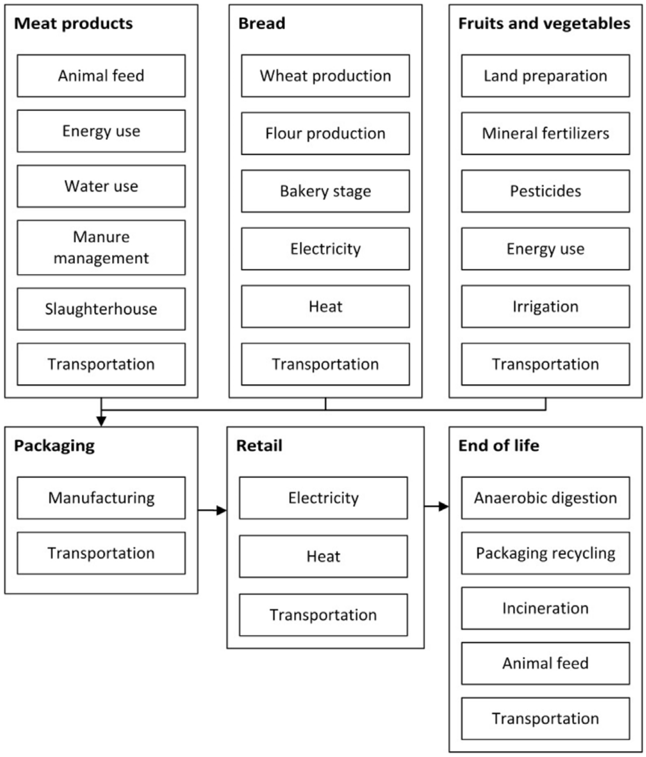

Fig. 1. Simplified flow chart of the LCA for the different waste fractions. Only a few processes are shown for the sake of clarity.

tion, the representative country is the country of origin for most products in this fraction at the supermarket (see Table 2, Supplementary material). No distinction was made between varieties of the same fruit or vegetable. Meat waste was assumed, for simplification of the model, as waste arising from fresh meat. For sausages and minced meat, the meat content was allocated to the relevant meat fraction (beef, pork or chicken). The transportation distances are given in Table 2 of the Supplementary material.

2.2.3. *Inventory analysis*

The inventory analysis was based on datasets that are relevant to the different waste fractions. Details are given in Section 2 of the Supplementary material.

2.2.4. *Impact assessment*

The life cycle impact assessment method that was used is the international reference life cycle data system (ILCD) for midpoint indicators (European Commission, 2011). This method is recommended by the European Commission to ensure quality and consistency of life cycle data (Wolf et al., 2012). The categories included in this study are climate change, ozone depletion, particulate matter, photochemical ozone formation, acidification, eutrophication, freshwater ecotoxicity, and resource depletion.

2.3. *Life cycle assessment of alternative waste treatment scenarios*

2.3.1. *Goal and scope*

In order to identify opportunities to reduce the carbon footprint at the supermarket, two alternative waste management scenarios (Sc. II and Sc. IV) were compared with the current practice at the supermarket (Sc. I and Sc. III). This gate-to-grave study includes the waste treatment scenarios for the food waste. The waste is assumed to enter the system burden-free and the co-products generated were considered to substitute other products on the global market.

2.3.1.1. *System description of scenarios I and II.* The functional unit for Scenarios I and II is the waste fractions described in Section 2.2.1, as well as those from dairy and ready meal products, generated from October 2014 to September 2015. The inclusion of the aforementioned products was possible on this assessment since the waste is assumed to enter the system burden-free. Thus the lack of data regarding primary production for dairy and ready meal products (that prevented the modelling of these products in the LCA done in Section 2.2) does not restrict the assessment on this section. The description of the packaging data is available in Table 4 of the Supplementary material.

(Sc. I) This scenario is the current waste treatment method in the city, where food waste is treated using anaerobic digestion. Anaerobic digestion is the most common method of treating food waste in Sweden (Avfall Sverige, 2014), and hence the results presented here are expected to be relevant to many Swedish supermarkets. The food waste is sent to an anaerobic digestion plant for co-digestion with manure. The food waste is not separated from its packaging before arriving at the plant, and pretreatment at the plant is required. The pre-treatment consists of optical sorting, a drum sieve, magnetic sorting of metal and a mechanical filter where most of the food waste is washed from non-food waste using water (Rousta et al., 2015). The slurry is sent to a biological reactor for biogas production. The remaining part, consisting of the rejected material from the pre-treatment, contains food and non-food waste (mainly the food packaging). Measurements made at the plant show that 44% by mass of the food waste is rejected with the non-food waste. This rejected material is too contaminated to be sent for material recycling of the packaging, and is instead used for incineration with energy recovery.

(Sc. II) This scenario models source separation of the food waste from its packaging at the supermarket. This would enable the packaging to be recycled at a material recovery facility (MRF), and for the food waste to enter the anaerobic digestion plant with less pre-treatment. This pre-treatment requires less energy compared to the mixed waste line in Sc. I, since there are fewer pre-treatments steps compared to Scenario I. Also, there is less food waste in the rejected material (modelled as no waste in this study), meaning that, in comparison with Sc. I, more food waste is used for anaerobic digestion, instead of incineration. The packaging material and sizes, shown in Table 4 of the Supplementary Material, were assessed by measurements made at the supermarket and represent packaging of different products.

2.3.1.2. *System description of scenarios III and IV.* The functional unit for Scenarios III and IV is the bread waste produced from October 2014 to September 2015, which corresponds to 6.7 t. As discussed below, the results from the waste quantification and impact assessment indicate that bread is an important product both in terms of the total waste produced and in terms of the environmental impacts. Therefore, these results support the decision to model a scenario specifically for bread waste.

(Sc. III) This scenario assumes that the bread waste is treated using the current waste management practice, i.e., it is not sorted from the packaging and that the mixed food-packaging fraction is sent to the anaerobic digestion plant, where a fraction of the bread goes through anaerobic digestion and the rest is lost in the pre-treatment mixed with non-food materials and is incinerated, as in Sc. I.

(Sc. IV) This scenario assumes that the bread waste is separated from other food fractions and its packaging at the supermarket, and that the bread waste is used as animal feed and the packaging is recycled.

2.3.2. System boundaries

The system boundaries considered for all scenarios are illustrated in Fig. 2. It contains the main mass flows and the substituted products (dashed lines).

The environmental impacts of the products from the waste treatment scenarios (i.e., energy feedstock, secondary materials and animal feed) were assessed using system expansion. That is, these products are considered as alternatives to other products on the global market that are used to generate energy, the secondary products and animal feed. The heat and electricity produced at the incineration plant and at the anaerobic digestion plant were assumed to substitute the production of these products for the Swedish national energy matrix. The digestate produced at the anaerobic digestion plant was assumed to be used as organic fertilizer and substitute the use of mineral fertilizer. The nutrient content for nitrogen, phosphorus and potassium was retrieved from typical values for co-digestion anaerobic plants (WRAP, 2012). The mineral fertilizer that was substituted was assumed to be urea, diammonium phosphate and potassium chloride (Martinez-Sanchez et al., 2016; Tonini et al., 2015). The greenhouse gas emissions for the secondary production of materials were retrieved from a previous study (Hillman et al., 2015).

The bread waste used for animal feed (Sc. IV) is assumed to substitute wheat, a conventional feed for the energy fraction in pig feed (Federation of Swedish Farmers, 2015). Bread has a low protein content of ~9% (Danish Food Composition Databank, 2016), lower than the protein content of wheat (Feedipedia, 2016), and much lower than that of soya meal, which is typically used as the protein fraction in animal feed (Tonini et al., 2015). In this study, 1.0 kg of bread waste replaced 0.4 kg of wheat owing to its nutrient composition and the suggested maximum inclusion rate of bread in a pig diet (Boggess et al., 2008; Dalgaard et al., 2008; Danish Food Composition Databank, 2016; Kumar et al., 2014). The bread waste is assumed to be transported 200 km for use as animal feed. This distance is the average distance from the city of Borås to the south region of Sweden, where the majority of pig farms are located (Marquer, 2010). According to Scherhaufer and Schneider (2011), EU Regulation No. EC/1069/2009 allows bread waste to be used as pig feed.

2.3.3. Inventory analysis

The inventory analysis was based on datasets that are relevant to the different waste fractions and its packaging. Details are given in Section 3 of the Supplementary material.

2.3.4. Impact assessment

Due to lack of data for the recycling processes for other impact categories, the only impact category assessed in this part of the study was climate change, using the ILCD assessment recommended method (European Commission, 2011).

3. Results

3.1. Waste categorisation and quantification

The supermarket wasted 22.5 t of food from October 2014 to September 2015. The waste was categorized into the following fractions: bread, meat, fruits, vegetables, pastry, ready meals, dairy and other. The bread fraction consists of different types of bread produced at the supermarket bakery or from external suppliers. The meat fraction includes waste such as beef, pork, chicken, lamb and processed meat (e.g., sausages). The fruits and vegetables fractions

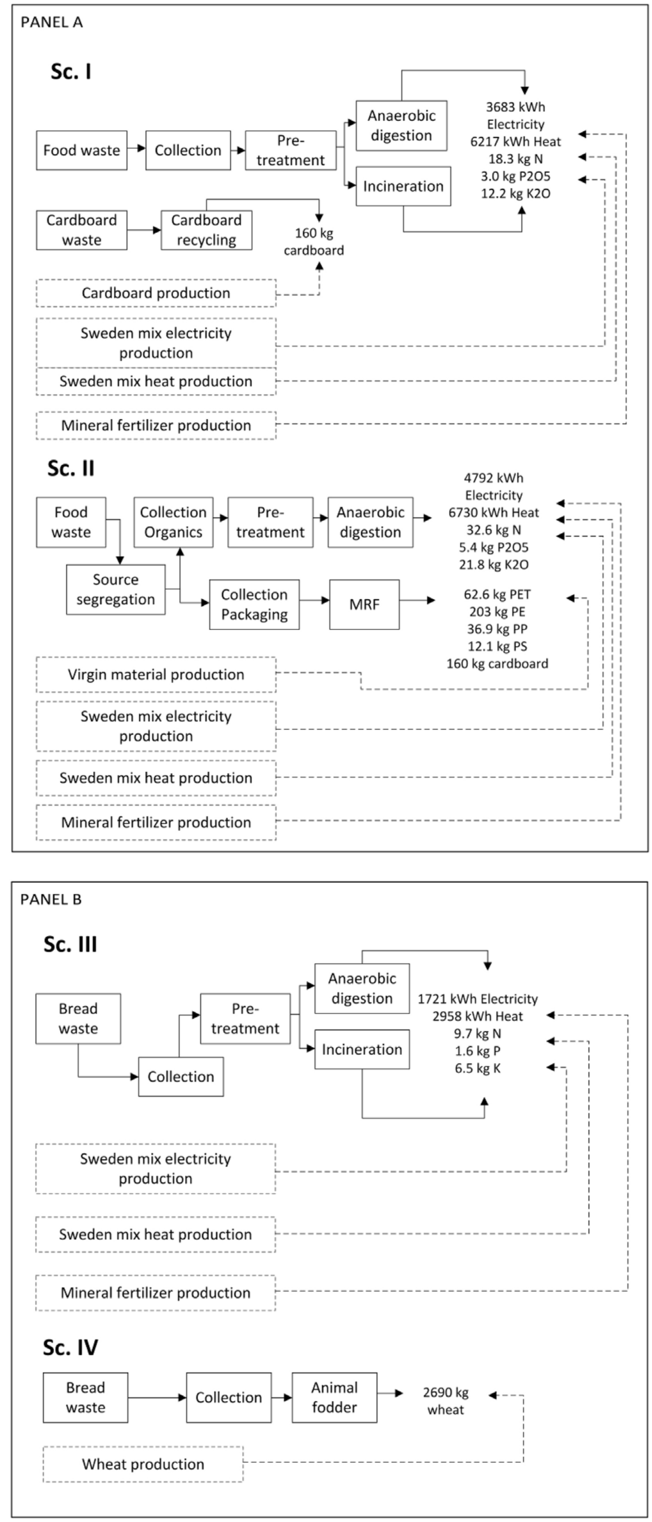

Fig. 2. Overview of the waste treatment scenarios assessed in this study. Scenarios I and II (Panel A) are for all waste fractions included in this LCA and Scenarios III and IV (Panel B) include only the bread waste fraction. Scenarios I and III model the current treatment in Borås city, and the alternative scenarios II and IV require separation of food waste from its packaging at the supermarket. Two comparisons are made in this part of the study. The first is between Scenarios I and II (Sc. I and Sc. II) and the second between Scenarios III and IV (Sc. III and Sc. IV).

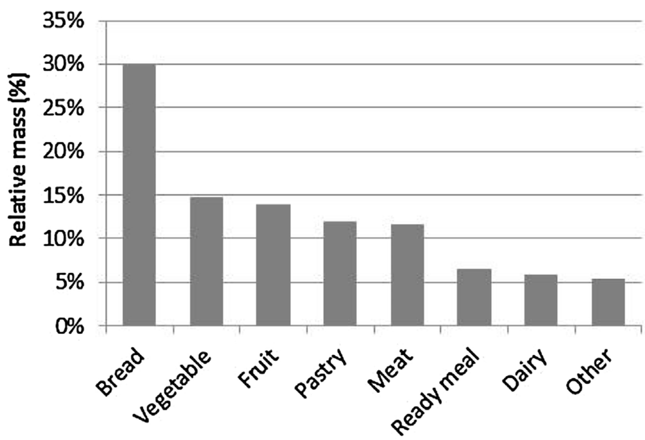

Fig. 3. Contribution of each fraction to the total food waste at the supermarket.

are comprised of waste from fresh products sold in the supermarket. Pastries are mainly produced at the supermarket chain's bakery and include products such as pies and rolls. Ready meals are frozen or chilled meals that usually come as a single portion and require little preparation. The dairy fraction includes several wastes, such as milk, creams, cheese, skim milk and yoghurt. Food waste products that were not included in the previous categories, such as snacks, egg and beverage wastes were grouped in the 'other' category. Non-food products, such as medicines and cleaning products, were not considered in this study.

Fig. 3 shows that bread waste is the largest waste fraction by mass, with an annual quantity of 6.7 t. Most of the bread waste is from fresh bread baked at the supermarket chainís bakery. Fruits and vegetables together have a share of 29% by mass, which corresponds to 6.4 t. Since bread waste is less dense than other waste fractions (e.g., meat and dairy), the volume of bread waste far exceeds the volume of other waste fractions. The total waste in the meat fraction was 2.6 t, which is 12% of the total waste by mass. The quantities of the different waste fractions are presented in table 1of the Supplementary material.

3.2. LCA of the supermarket food waste

The mass of all of the waste fractions included in the LCA (beef, pork, chicken, bread, strawberries, bananas, tomatoes, lettuce, potatoes, carrots, cabbage and apples) was 11 t, which is 49% by mass of the entire food waste at the supermarket during the year of study. The relative contribution of each waste fraction to the total mass of all products included in the LCA is given in the first column in Fig. 4. Similar data is given for the economic costs and selected impacts categories in the remaining columns in the figure, and in Section 2 of the Supplementary Material. In Fig. 4 all of the fruits and vegetable waste is grouped into one fraction for the sake of clarity. The environmental impacts per kilogram of each waste fraction and the impact from different parts of the supply chain are also discussed in Section 2.2 of the Supplementary material.

Fig. 4 reveals that bread, beef and pork waste typically have the highest environmental impacts among the food waste fractions that were included in the LCA. Beef waste has the largest environmental impact in six of the nine environmental impact categories, while bread waste has the largest contribution in the remaining three environmental impact categories. Bread waste also has the largest contribution to the total mass of the waste and the economic costs suffered by the supermarket.

In spite of its fairly low mass fraction, beef waste has the majority share of the emissions in the climate change impact category (third column in Fig. 4). This fraction is responsible for 22.4 t of CO_2eq. emissions per year, mainly due to the enteric fermentation of cattle and the use of fertilizer when growing animal feed. Beef waste has the largest contribution to particulate matter, photochemical ozone formation, acidification as well as terrestrial and freshwater eutrophication. Pork waste has an intermediate impact in most of the categories, and has the second largest contribution to economic costs. Chicken has lower impacts in all categories compared to beef and pork.

Bread waste has the largest contribution in mass, economic costs incurred by the supermarket, ozone depletion, freshwater ecotoxicity and resource depletion. In the climate change category, bread waste was responsible for the emission of 5.5 t of CO_2eq. year^{-1}.

The eight fractions of fruit and vegetable waste selected for this study have relatively low contributions to all categories. The total waste in these eight fractions is responsible for 0.94 t of CO_2eq. year^{-1}. The types of waste, within the fruit and vegetable waste

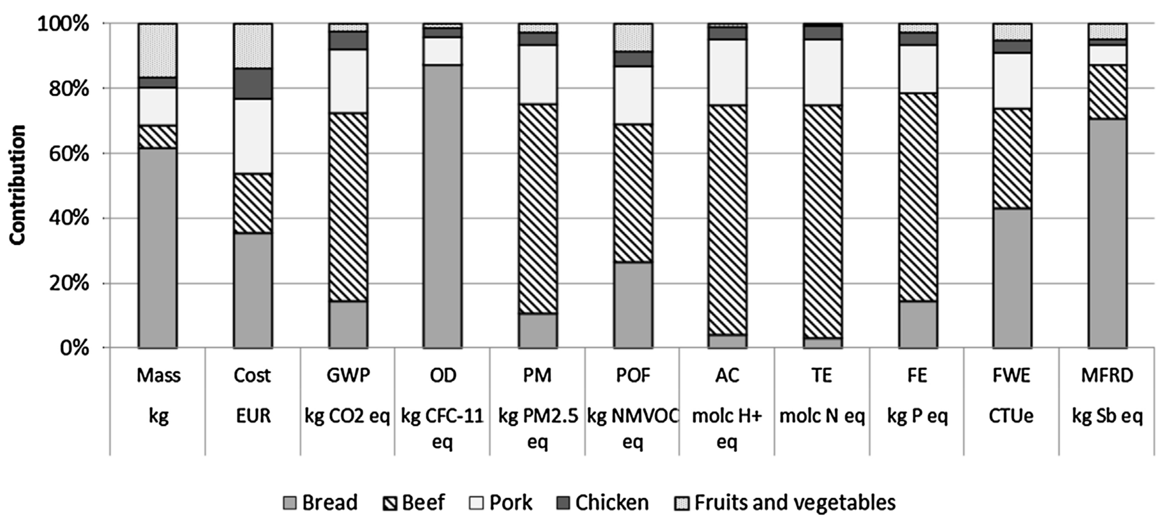

Fig. 4. Relative contribution of each waste fraction to the total mass, economic cost, climate change (GWP), ozone depletion (OD), particulate matter (PM), photochemical ozone formation (POF), acidification (AC), terrestrial eutrophication (TE), freshwater eutrophication (FE), freshwater ecotoxicity (FWE), and resource depletion (MFRD).The data is for waste fractions that were selected for the LCA and that, together, contribute to 49% of the total annual food waste at the supermarket.

fraction, which contribute the most to climate change are banana, strawberry and tomato. Together they are responsible for 70% of the emissions from the fruit and vegetable waste fraction.

3.3. LCA of alternative waste management scenarios

One of the objectives of this study is to provide information for supermarket top management to support development of strategies and actions that can reduce the environmental footprint of the supermarket. Therefore, the two alternative waste treatment scenarios discussed above with reference to Fig. 2 (Sc. II and Sc. IV) were compared with the current one practiced by the supermarket (Sc. I and Sc. III).

Both of the alternative waste treatment scenarios resulted in lower emissions of greenhouse gases compared to the waste treatment that is currently used.

The comparison of Scenarios I and II shows that the emissions from Sc. II are 1027 kg CO_2eq·year^{-1} lower than from Sc. I. Fig. 5 shows that most of the savings in Sc. II came from the higher efficiency of the system, with more food waste going to anaerobic digestion instead of incineration. Therefore, it led to an increase in the energy and fertilizer production, which substituted electricity, heat and mineral fertilizer production. Sc. II also avoided the production of virgin material due to increased recycling rates of the packaging materials. The positive part of the graph represents the emissions from the anaerobic digestion, transportation and the recycling processes.

The waste treatment in Sc. IV reduces emissions of CO_2eq. by 1549 kg year^{-1} compared to

Sc. III. The reduction on the emissions in Sc. IV is primarily due to the avoided production of wheat used as animal feed (Fig. 5). The process emissions for Sc. IV represent the emission from the bread transportation to be use as feed. For the reference scenario (Sc. III), the emissions are from the anaerobic digestion process and the savings are from energy and fertilizer production, similar to Sc. I.

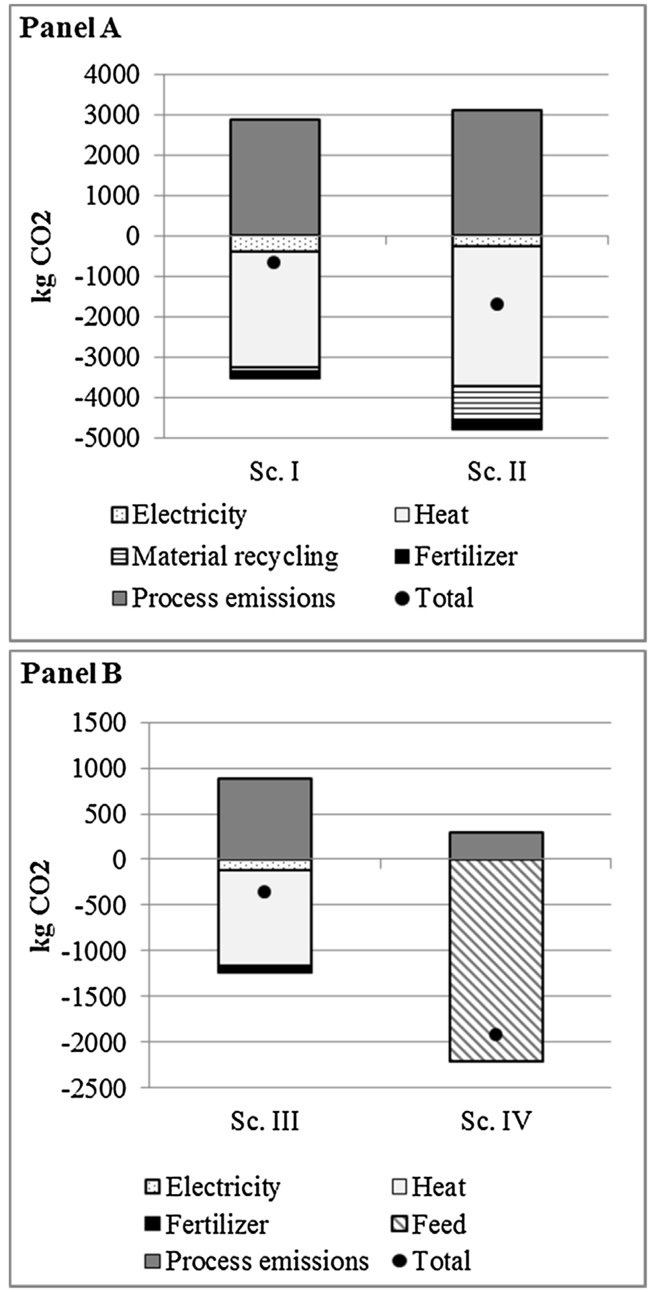

Fig. 5. Climate impact for the waste treatment Scenarios I and II (Panel A) and III and IV (Panel B). The scenarios are discussed in the text with reference to Fig. 2.

4. Discussion

Many studies (Scholz et al., 2015; Stenmarck et al., 2011) of supermarket food and food waste focus on a single measurement, such as mass of the food or food waste, or assess only a few environmental impact categories. The present study focuses on various fractions of supermarket food waste and their contribution to the total mass of food waste, the economic costs for the supermarket and the environmental impact for all waste included in the LCA. The different relative contribution of each waste fraction to the total mass, economic costs and the environmental impacts highlights the importance of analysing the effects of food waste in terms of several indicators. Fig. 4 shows that beef and bread waste contribute the most to supermarketís environmental impact and economic losses, but have different relative contributions in different categories.

Comparing the present results with previous studies is hindered by the fact that different methods and measurement techniques have been used in the studies. Many studies of food waste present the results as a percentage of the total sales, and the present study did not have access to this data. Also, some studies include pre-supermarket waste in the analysis.

It should also be noted that the present study is for a single supermarket. Although this has the strength that recent and relevant data for this supermarket is used, it has the weakness that the results may not be directly generalizable to other supermarkets. Also, the LCA reported here excluded dairy waste. Although this waste has a low mass compared to other fractions (see Fig. 3), dairy products have high environmental impacts per kg. The dairy waste may therefore have a significant environmental impact. However, a study by Scholz et al. (2015) estimates that supermarket dairy products contribute to approximately 5% of the supermarket's carbon footprint.

A study by the Swedish Environmental Research Institute indicates that fresh bakery products are the most wasted product in retail (Stenmarck et al., 2011). This is in agreement with the results of the present study. Interviews with the retail management revealed that use of bread waste as animal feed is not practiced by the supermarket chain studied in that work and, according to the Swedish Waste Management Association, anaerobic digestion is the most common method to treat food waste in Sweden (Avfall Sverige, 2014). This indicates that the results obtained here (both amounts and effects of bread waste as well as the proposed alternative waste treatment scenarios) are relevant for many supermarkets in Sweden.

Previous studies on the environmental impacts of supermarket waste did not include bread in the scope of products studied (Scholz et al., 2015). The results obtained in the present study show that bread waste is key when developing strategies to reduce the environmental impact of supermarkets.

As discussed by Scherhaufer and Schneider (2011), the high amount of bread waste may be connected to the demands and behaviour of the consumers. The demands for freshness and for a wide range of types of bread necessitate frequent production in sufficiently large quantities so that fresh bread is available throughout the day (Scherhaufer and Schneider, 2011). Interviews performed by Stenmarck et al. (2011) indicate that supermarkets often produce 7% more than the expected sales in order to meet the consumer demands. Reducing overproduction may be challenging, since predicting consumer demands is difficult. Factors such as weather, which are in themselves hard to predict, can cause significant variations in the demand (Stenmarck et al., 2011). Thus, the use of bread waste as animal feed has an advantage, since it decreases the environmental impact at the same time as being a revenue stream for the supermarket.

A study by the Waste and Resource Action Program (WRAP, 2013) showed that bakery products are the fourth largest fraction in household food waste, accounting for 800,000 million tonnes per year in the United Kingdom. A questionnaire used in the study revealed that consumers believe that they produce only small amounts of bread waste and that its environmental impact is low. Therefore, communication of the results from the present life cycle assessment to consumers has the potential to increase awareness of the impacts of bread waste, perhaps reducing the waste not only at supermarkets, but also by households.

The alternative treatment routes (Sc. II and IV) led to a decrease in greenhouse gas emission. However, these routes may demand more investment in staff training than the current waste treatment scenarios (Sc. I and III), since source separation at the supermarket is required. The increase in energy demand and in cost was not assessed in this study. Moreover, the environmental assessment of alternative waste treatment routes is limited by the impact assessment of the carbon footprint, since some data that is needed for modelling other impact categories is not available. The energy used for separating the waste at the supermarket was not assessed, but it is expected that it will be done by the staff of the supermarket, and is therefore expected to be small.

5. Conclusion

Food waste leads to loss of valuable resources, such as energy, water, land and labour and to unnecessary emissions of pollutants. The research described here investigated supermarket food waste by categorising and quantifying the waste at a supermarket, assessing the environmental impacts of the waste and suggesting alternative ways to treat the waste in order to reduce its environmental footprint.

The life cycle assessment results reported here reveal that the annual wastage of bread and beef products have the largest contribution to the environmental footprint of the supermarket. Compared to the other waste fractions included in the LCA, the annual bread waste has the largest contribution to the total mass of the food waste, the economic costs incurred by the supermarket and the environmental impacts in ozone depletion, freshwater ecotoxicity and resource depletion categories. Beef waste has the largest contribution to particulate matter, photochemical ozone formation, acidification as well as terrestrial and freshwater eutrophication categories.

Alternative waste treatment scenarios, that require separation of the food waste from its packaging at the supermarket and that allows for material recycling of the packaging and the use of bread waste as animal feed, have the potential to reduce the emissions of CO_2eq. by as much as 1027 and 1549 kg per year respectively, in comparison with the current waste treatment practiced by the supermarket.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.resconrec.2016.11.024.

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