Sveriges lantbruksuniversitet
Swedish University of Agricultural Sciences

Faculty of Natural Resources and Agricultural sciences
Department of Food Science

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- A study on carrots and turnips

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ABSTRACT

Environmental impact originating from food production is of great concern since it is related to every single customer in the world. Food is cultivated, transported, stored and processed in different ways, and every step in the life cycle has an impact on the environment whereas the nutritional value of food is altered in many of the steps. Waste of food is also an important aspect. A majority of the food waste in households and large-scale catering establishments is related to vegetables and it may be assumed that fresh vegetables have a higher waste than frozen at consumer stage. Further on, whether fresh or frozen vegetables provide consumers with most nutrients for every g of CO_2-equivalent (eq) generated during production of the vegetables may be a concern.

This study aimed to answer whether there is any difference in nutritional value of fresh and frozen coarse vegetables and if the production of these has different global warming potential. The vegetables investigated were carrots and turnips. Nutritional content was measured by nutrient index score, NRF9.3 (Nutrient Rich Food). Global warming potential was investigated by Life Cycle Assessment. Cultivation, storage, processing, packaging and transportation were investigated; from harvest to processing plant, wholesaler and restaurants and large-scale catering establishments, including storage losses and preparation waste.

The results show that frozen root products has a lower nutritional content than fresh before cooking but after cooking the difference in nutritional content between fresh and frozen is decreased due to increased solubility and extractability of nutrients, and disrupted cell membranes. Fresh carrots provide consumers with the highest nutritional value for every g CO_2-equivalent generated during production of these products, followed by (in descending order) frozen carrots, fresh turnips and frozen turnips, independent of cooked or uncooked state. Thus, from an environmental and nutritional perspective (bioavailability disregarded)) fresh carrots are the best choice of the products examined in current study. Complementary research on vegetables that are more easily spoiled during time of storage is needed in order to investigate whether fresh or frozen vegetables in general are the best choice from an environmental and nutritional perspective.

ABBREVATIONS

DW- Dry Weight
Eq- Equivalent
FU- Functional Unit
GWP- Global Warming Potential
GHG- Greenhouse Gas
HCl- Hydrogen Chloride
LCA- Life Cycle Assessment
LDPE- Low Density PolyEthylene
NI- Nutrition index
RAE- Retinol Activity Equivalents
WW- Wet Weight

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1. INTRODUCTION

The greatest environmental impact of products within the European Union originates from consumption of food and drink (alcohol included), private transport and housing. Together these three areas are responsible for 70- 80% of the environmental impact of consumption. Concerning private consumption, food and drink is responsible for 20- 30% of the environmental impact when primary production and distribution are included. Meat, meat products and dairy products, in descending order, are most important within this consumption area. (European Commission Technical Report, 2006)

Thus, food production is highly important in the discussion of limiting our environmental impact. Primary production generally constitutes the major part of the environmental impact originating from food production, primarily regarding animal products (Gustavsson *et al*. 2011a). The subsequent processing, transportation, packaging, cooking and waste also contribute in varying extents depending on type of product (Sonesson *et al*. 2010). For vegetables these post-farm activities are often important contributors to the global warming potential (GWP)[1] and therefore these activities may be of greater importance than cultivation of these products (Sonesson *et al*. 2010). Further, storage is one of these post-farm stages that contribute to environmental impact to varying extent depending on the storage method used (European Commission Technical Report, 2006). Different processing and storage methods, e.g. freezing/chilling and fresh storage may have different environmental impact.

Since a third of all food produced is estimated to be wasted (Jensen *et al.* 2011) and whereof some is avoidable, it is important to decrease the environmental impact from the food sector by reduction of waste during processing as well as in households and during storage. One study showed that freezing can reduce the waste of food with more than 30%, given that the consumer goes from only purchasing fresh vegetables to only frozen (Manchester Food Research Centre, 2010). From an environmental perspective possible differences between storage methods (e.g. freezing/cooling/room temperature) can be evaluated from a life cycle perspective that considers both energy and waste in the whole chain. A Swedish study on households and large-scale catering establishments shows that a majority of the food waste is fruits and vegetables (Modin, 2011), which is why it is interesting to examine and evaluate these types of food.

Nutritional value of food products is dependent on many factors varying from processing methods and storing to time of harvest and cultivar. When evaluating the preferable storage method from an environmental point of view, possible differences in nutritional value between frozen and fresh products need to be considered. Bioavailability of nutrients may be of greater importance than nutrient content, thus should also be considered.

1.1. Aim

The aim of this study was to investigate if and how nutritional value and GWP differ for roots that are either consumed after freezing or as fresh coarse vegetables, without prior cooking. The investigated vegetables were carrots (*Daucus carota* L.) and turnips (*Brassica napus*, group *Napobrassica*). This in order to evaluate whether it can be motivated to produce and consume frozen carrots and turnips instead of fresh when considering possible differences in nutritional value and GWP. Nutritional value and bioavailability of cooked carrots and turnips

[1] GWP: A relative measure of how much heat a greenhouse gas traps in the atmosphere. Related to one of Sweden's 16 national environmental objectives.

was also investigated, but the life cycle assessment (LCA) did not include GWP originating from the cooking process.

1.2. Research questions

This study aims at answering the questions:

- Is there any difference in nutritional value between frozen root vegetables and fresh root vegetables, both in uncooked and cooked state?
- Does the production of (uncooked) frozen and fresh root vegetables have different GWP?
- What is the GWP of production of (uncooked) frozen and fresh root vegetables in relation to their nutritional value?

The questions were answered on basis of data concerning fresh and frozen carrots and turnips.

1.3. Limitations

This study was limited according to the system boundaries presented in goal and scope (section 3.1). The environmental impact was limited to GWP. In order to compare environmental impact of fresh and frozen carrots and turnips in relation to their nutritional value, a nutrition index was used. This index did not include all nutrients in the products.

This study did not examine sensory quality of frozen and fresh vegetables. The microbiological aspect of blanching and freezing was only briefly investigated in the literature analysis. Nutritional value after cooking is relevant from a consumer perspective but due to large variation in cooking methods; amount of water, time, type of stove and energy consumption (the two latter aspects related to the LCA) etc. comparison on that basis is uncertain which is why nutritional value of cooked products in relation to GWP was only briefly investigated.

2. BACKGROUND

2.1. Production of root vegetables

2.1.1. The process

An example of how production of fresh and frozen roots may be executed is shown in Figure 1. The figure is based on information from the three companies interviewed in this study.

Fresh root vegetables

During harvest the roots are sorted. Haulms are sorted away mechanically and ploughed down[2]. After harvest the roots are stored at farm or at factory in cold storing and sorted continuously according to the sales (Widegrens Gård, 2013), or sorted fairly directly and stored at factory or wholesaler (Nyskördade morötter, 2012b). It is also possible to keep not yet harvested carrots under a layer of straw during the winter and harvest continuously during the winter, which is called ‘freshly harvested carrots’ (Nyskördade morötter, 2012b).

Handling, processing and transportation of fresh roots after harvest vary between the companies, type of vegetable and season. Some companies wash their roots in connection with sorting while other companies do not (VRIC, 2012), depending on type of product; e.g.

[2] Company A, 2013. Company A wished to be anonymous in current study; hence both the interviewed person and the company are anonymous.

in Sweden potatoes may be sold washed or unwashed while carrots commonly are sold washed. Carrots and turnips are commonly washed at the processing plant (VRIC, 2012). The roots may be packaged in plastic bags or are sold in bulk and are therefore packaged in big sacks or equivalent big packages (Nyskördade morötter, 2012b).

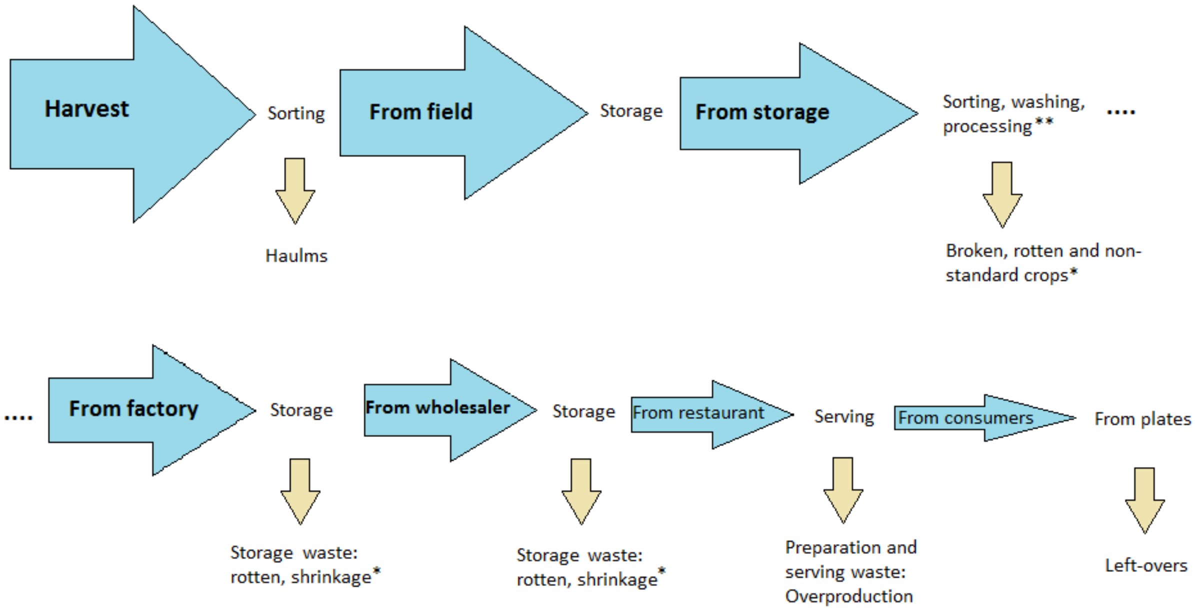

Figure 1. *Example on how fresh and frozen roots are produced with focus on type of waste created in each step. *Of fresh roots: Non-standard crops are primarily sorted away in production. Shrinkage only concern fresh roots. **Processing of frozen roots*
Note: the difference in size of the arrows is exaggerated. The size of the arrows cannot be translated to the actual reduction created by the waste in each step.

It is common to peel roots before consumption and preparation waste caused by removal of some parts of the root (VRIC, 2012), e.g. stem or root part and blemishes is common (Company A, 2013). The waste during processing, storage and consumer steps is further described in section 2.3. The quality demands on fresh and frozen carrots and turnips depend on demands from the customers, especially regarding size (VRIC, 2012) and type of product being produced, i.e. branched carrots is used in production of frozen carrots[3] but not of fresh[4]. The production of and quality demands on turnips is similar to the production of carrots (Lagerberg Fogelberg, 2008). Fresh carrots are sold to households, the food industry, restaurants, wholesalers and large-scale catering establishments.

Frozen root vegetables
The production of frozen roots is similar to the production of fresh with the addition of blanching and processing roots into frozen. The quality demands at processing plant are commonly lower since non-standard vegetables (e.g. branched) and many sizes may be used[5]. The most important steps in processing of roots is blanching and freezing. Washing, peeling and cubing/slicing are also applied in this process (Company A, 2013).

In order to reduce contaminating micro-organisms not inactivated by freezing the roots are blanched prior to freezing. Blanching is based on application of heat through boiling the product in water or steam treatment. Loss of nutrient and sensory quality is highly dependent on time and temperature in combination, and the combination of blanching and cooling

[3] Company A, pers. com. 2013
[4] Nilsson, pers. com. 2013
[5] Company A, pers. com. 2013

method (see section 2.5.2.). Short time and high temperature cause smaller nutrient losses than long time and low temperature (Fellows, 2000).

Blanching also inactivates natural enzymes e.g. lipoxygenase, polygalacturonase, polyphenoloxidase and chlorophyllase which is necessary because enzymes are not inactivated by freezing. Enzymes need to be inactivated before freezing and frozen storage since the enzymes otherwise will have access to concentrated solutes caused by ice crystals that disrupt cell membranes and decrease the water activity. Sufficient blanching is crucial; under-blanching should be carefully avoided because it increase deterioration of products by rupturing protecting cell membranes, thereby making the content available to insufficiently inactivated enzymes. (Fellows, 2000)

The freezing process is based on removal of heat which reduces biochemical activities in food. Chemical reactions, microbial activities and water activity are reduced, resulting in a very small reduction of nutritional value and sensory quality during storage and therefore freezing increase the shelf life tangibly. Some micro-organisms are resistant or insensitive to low temperature, e.g. *Staphylococcus aureus* and *Enterococci* and some mold spores. Spores of e.g. *Bacillus* and *Clostridium* are close to unaffected by freezing and during frozen storage. Ice crystal formed during the freezing process may damage the more rigid cell structure in vegetables. (Fellows, 2000)

Frozen carrots and turnips (not in mixes) are semi-finished products that are sold to food industry, restaurants, wholesalers and large-scale catering establishments[6]. Frozen carrots that private consumers in Sweden may purchase are commonly sold in vegetable mixes e.g. with peas or cauliflower (Findus, 2010a). Frozen turnips are available for Swedish private consumers in mixes containing e.g. carrots, parsnip, celeriac, leek and onion (Findus, 2010b).

2.1.2. Storage

Fresh root vegetables
Appropriate storage temperature depends on type of root. The optimum storage temperature of fresh carrots is 0-1°C (Gross *et al.* 2004a) but somewhat higher temperatures may be suitable as well (Wills *et al*. 2007). The respiration rate of carrots is low and the typical storage life of fresh carrots in appropriate conditions is 5-20 weeks (Fellows, 2000), but fresh carrots may be stored up to 9 months (Gross *et al.* 2004a). Since carrots are prone to drying a relative air humidity of 98-100% should be applied. Bundled carrots are more sensitive than top-trimmed, thus have shorter storage capabilities (Gross *et al.* 2004a). The optimum storage condition of turnips is 90-95% relative air humidity. Since turnips not are sensitive to low temperatures they may be stored at 0°C. They can be stored 4-5 months at optimum conditions (Gross *et al.* 2004b). Fruit and vegetables at retailers are stored in so called ‘air conditioning’ rooms where chillers supply with cold air (Nilsson & Lindberg, 2011). Root vegetables may be stored for a longer time than salad vegetables (Swedish National Food Agency, 2011) and they have a higher storage capabilities and lower environmental impact compared to salad vegetables (Modin, 2009).

During storage the produce may shrink due to several factors, the most important being uneven and/or too high temperatures in the storage area, low relative humidity caused by insufficient cooling or insulation and excessive air circulation. Improved cooling and insulation in combination with effective vapor barriers reduces weight-loss and the quality of the produce after storage is better than the case would be otherwise. (Wills *et al*. 2007)

[6] Company A, 2013

At restaurants and large-scale catering establishments fresh roots are stored in cooling-rooms or refrigerator at refrigeration temperature. In private households refrigerators are used, but some consumers store some roots in butlery or possibly even in earth cellars.

Frozen root vegetables
At factory, wholesalers, restaurants and large-scale catering establishments frozen products are stored in cold chambers or freezers at appropriate temperature (-18°C). At retailers frozen products are stored in freezing counters which usually are horizontal or vertical. In households freezers are used with a temperature of -18°C. (Nilsson & Lindberg, 2011)

In households, frozen foods causes a lower waste than fresh food which is why freezing can be used as a way to reduce waste in households (Manchester Food Research Centre, 2010). It should also be noted that frozen vegetables are likely to be stored a longer time than fresh, both before purchase of customer but also in households (Favell, 1998).

2.2. GWP of vegetable production

2.2.1. Primary production

Post-farm activities are often important contributors to the GWP of the total production of vegetables, unlike animal production, and therefore these activities may be of greater importance than the cultivation but this is highly dependent on how the vegetables are produced (Sonesson *et al*. 2010). Cultivation in greenhouses, especially fossil fueled, have considerably higher GWP than cultivation on open land (Modin *et al*. 2011). Cultivation of roots and tubers has a high yield per hectare and the GWP/kg product from production is therefore low and post farm steps are of greater importance. However, whether the product is cultivated in peat or mineral soil is also important. A study by Sonesson *et al*. (2010) shows that carrots cultivated in peat soil has a tangibly higher GWP than cultivation in mineral soil. Thus, GWP originating from cultivation may still be relevant. GWP of fresh vegetables varies depending on production method, origin and type of vegetable; e.g. root vegetables (roots, onions, cabbage) have lower GWP/kg product than salad vegetables, based on primary production, processing, packaging and transportation (Röös, 2012). The variance in kg CO_2-eq/kg product is lower regarding root vegetables (Röös, 2012).

Salad vegetables (e.g. cucumbers and tomatoes) have a higher GWP than coarse vegetables like root vegetables, onion and cabbage, cauliflower and broccoli. The former is to a considerably higher extent cultivated in greenhouses which require more energy than cultivation on open land. Fossil fuel heated greenhouses have higher greenhouse gas emission than fossil-free fueled greenhouses (Modin *et al.* 2011). Cultivation on open land is common for coarse vegetables and they may be stored for a longer time than salad vegetables (Swedish National Food Agency, 2011).

2.2.2. Fresh and frozen vegetables

GWP from production of vegetables originates from cultivation, processing, packaging, transportation, distribution and retail, and consumption. Regarding fresh vegetables transportation is the most contributing life cycle stage, while all transportation, distribution and retail, and consumption are the most important life cycle stages for frozen vegetables (Lightart *et al*. 2005). Vegetables with lower storage capability, i.e. salad vegetables and higher environmental impact, seem to become waste to a higher extent than coarse vegetables (Modin, 2009).

The process of freezing food products, such as vegetables, demand energy in terms of sorting, washing, peeling, blanching, and in many cases also cutting, slicing or cubing in smaller pieces. Energy consumption causes greenhouse gas (GHG) emissions (Weisser, 2007) which need to be considered. Since frozen vegetables are prepared for consumption it is possible that the waste in in the late stages of consumption, i.e. at customers, meaning that the amount of product being unnecessary transported is reduced in comparison to fresh vegetables.

GWP from the freezing process is dependent on type and amount of energy used which in turn is dependent on property and any possible packaging of the product, energy needed for starting equipment, and capacity of the freezer. GWP of Swedish electricity mix, import excluded, is 40 g CO_2-eq/kWh. This electricity mix results in a GWP from the freezing process between 4.5-9 g CO_2-eq/kg product. Type of equipment used during the refrigeration (freezing) process may have different GWP and be used for different products. Example on this is cod refrigerated in a spiral freezer which has a GWP of 17 g CO_2-eq/kg product and refrigeration of peas by fluidization process for individual quick freezing (IQF) that has a GWP of 14 g CO_2-eq/kg product (waste excluded in this study). (Nilsson & Lindberg, 2011)

The energy efficiency of the storage generally decreases further down the grocery chain; the closer to the consumer the more energy/kg product for storage is needed (further presented in section 4.1.5.). This is related to space of storage, number of doors/openings and turn-over of goods. GWP of chilled warehouse is lower compared to frozen warehouse due to higher efficiency of refrigeration compressors for chilled storage than for frozen storage. How the products are stored at retailers also affect total GWP. Doors and covers reduce the energy consumption by maintaining the cold inside the storage device. Increased exposing and area of exposure of products increase the infiltration, meaning that cold air escape from the storage device. (Nilsson & Lindberg, 2011)

2.2.3. Fresh and frozen carrots and turnips

A study based on data from the Netherlands showed that the environmental impact from frozen carrots packed in cartons or plastic bags was higher than from fresh carrots in bundles or peeled. Frozen carrots showed a relatively high environmental impact in relation to fresh carrots. For fresh carrots, transportation and cultivation were the stages that showed the highest environmental impact and whereof transportation contributed most to the GWP. Different electricity consumption of fridges and freezers at homes were shown to have a minor effect on the total life cycle, thus the results were robust in this aspect. In the case of food waste the results were more sensitive, especially in relation to fresh carrots. This study also showed that the most contributing life cycle stages on GWP of frozen carrots packaged in plastic bag or carton were (Ligthart *et al*. 2005):

- Distribution and retail, including storage
- Consumption (only plastic bag), including storage and preparation

One study on Swedish carrots showed that storage, cultivation and transportation, in descending order, gave that highest greenhouse gas emissions regarding carrots delivered to retailer (GWP). Leakage of refrigerant accounted for one third of the total emissions. This study also showed that Swedish carrots had tangibly lower total GWP compared to carrots from Denmark, the Netherlands, Germany and Great Britain. The study also assumed that energy efficiency increased with storage time and that leakage of refrigerants per kg product decreased with increased storage time. Thus, increased storage time per kg product would inevitably decrease emissions per kg product. (Carlsson-Kanyama, 1998)

Another study on fresh carrots from Sweden showed slightly different results. GWP of fresh carrots was dominated by sorting, washing and packaging, while it for frozen carrots was highly dominated by the energy use during processing and storage (Table 1). Due to expected high turnover time and short storage time at wholesaler, potential environmental impact of storage of frozen carrots at wholesaler and catering unit, is not likely to greatly affect the results. Transportation and cultivation of fresh carrots showed comparable GWP. The values were specific for each stage, i.e. GWP of farming of fresh carrots was specific for one company and the GWP of farming of frozen carrots specific for another company. (Lagerberg Fogelberg & Carlsson-Kanyama, 2006)

Table 1. GWP and energy use for consumption of fresh and frozen carrots in Sweden

	GWP (kg CO_2-eq.), 100 years			
	Farm[1]	**Farm[2]**	**Packaging[1,3]**	**Transportation to wholesaler[1]**
Fresh carrots	0.018	0.08	0.032	0.019
Frozen carrots	0.023	N/A	0.195	0.049

[1]*Adapted from Lagerberg Fogelberg & Carlsson-Kanyama (2006). Storage included. Handling of waste excluded, except for inputs on farm and processing plant related to waste handling. Per kg carrots at wholesaler*
[2]*Davis* et al. *(2011). At farm gate for one kg carrot*
[3] *Packing of fresh carrots. Processing and packing of frozen carrots* *N/A: Not available*

Yet another study on fresh carrots cultivated on 95% mineral and 5% peat soil showed tangibly higher values of GWP (Table 1). No studies regarding cultivation of turnips were found. Lagerberg Fogelberg (2008) however estimated that turnips are expected to have potential environmental impact comparable to that of carrots, since the production and yield is similar.

2.3. Food waste

About one third of the food produced globally is wasted (Jensen *et al.* 2011). In Sweden primary households contribute to the major part of food waste at customer stage, about 67% (Jensen *et* al. 2011), unlike the common perception that retailers are responsible for the majority of the food waste at this stage (Konsumentföreningen Stockholm, 2009). The food industry is responsible for 17% of food waste in the food chain, restaurants 10% and retailers 4% (Jensen *et al*. 2011).

In this study, the term 'food waste' was used, but it should be emphasized that a difference between food waste and food wastage can be observed, especially when comparing developing and developed countries. Developing countries have problems with food waste that generally occur early in the food chain, e.g. at farmers and producers due to poor storage, inefficient harvesting, transportation and infrastructure, while developed countries have more problems with food wastage that primarily is a problem at retailers and in households due to '*consumer behavior'* and '*lack of coordination between different actors in the supply chain*' (Gustavsson *et al*. 2011a). This food wastage could have been easily avoided (Modin, 2011).

Food waste and wastage have to be reduced because it not only concerns waste and wastage of food but also of resources; land, water and energy hence the emissions created when producing the food was created in vain. With a growing population and predicted increased consumption of animal products, which requires greater areas of land and resources compared to grain-based diets, managing of food waste and wastage will help when addressing sustainability issues. Elimination of losses and reduction of waste can theoretically provide 60- 100% more food along with liberating resources for other uses, and give opportunities to meet predicted increased demands for food. Further, this would reduce environmental risk and be beneficial from a sustainability view. Reduction of food waste and wastage should therefore be prioritized (Institution of Mechanical Engineers, 2012).

2.3.1. Waste at farm

At the farm the proportion of waste of some vegetables is estimated to less than one percentage but due to the great quantity of vegetables harvested the quantity is high. These vegetables can be used for other purposes than 'regular' human consumption, e.g. as animal feed or as ingredient in a process (e.g. potato as potato flour) (Jensen *et al*. 2011). Gustavsson *et* al. 2011a) calculated the waste of fruit and vegetables, roots and tubers, caused by agriculture to around 20% which differ quite a lot form the estimations made by Jensen *et al.* (2011).

2.3.2. Food waste in retail

The recorded data of waste at retailers of fresh fruit and vegetables is estimated to have the highest uncertainty of all food subgroups (Eriksson *et al*. 2012). Waste of fruits and vegetables is partially related to supermarkets rejecting fruits and vegetables not meeting the company's physical standards demands; size, appearance, color, marks and damages (Gustavsson *et al*. 2011b). In Europe waste of fruit and vegetables is around 45% and slightly more than 50% for roots and tubers, when production, postharvest, processing, distribution and consumption are included (Gustavsson *et al*. 2011a). Only processing of fruits and vegetables in Europe causes around 9% waste and consumption 12%. Only processing and consumption of roots and tubers causes around 12 and 9% of waste (Gustavsson *et al*. 2011a).

In Sweden the waste of vegetables at retailers is 4.3%, whereof 3% is considered 'pre-store waste' i.e. fresh fruit and vegetables rejected at delivery to the store and sent back to supplier (Eriksson *et al*. 2012). A survey made by *Konsumentföreningen Stockholm* (2009) showed that consumer waste of fresh vegetables was 36% in Sweden, but due to underestimations among consumer this number is likely to be higher (Modin, 2011). The avoidable food waste caused by Swedish consumption is responsible for 2% of the total greenhouse gas emission in Sweden (Modin, 2011).

2.3.3. Food waste at the consumer

The consumed and waste food constitutes 25% of the GWP of consumption for a general Swedish consumer (Swedish Environmental Protection Agency, 2010). Some of the waste is unavoidable; e.g. coffee grounds and peel of banana or potato. The unavoidable waste constitutes 65% of the total waste in households. (Jensen *et al*. 2011). Some examples of unavoidable food waste are peel of root vegetables, vegetables and fruits, coffee grounds, meat bones and egg shell (Jensen *et al.* 2011; Modin, 2011).

Avoidable food waste is: '*Food that is disposed but could have been consumed if the food had been handled differently*' (Jensen *et al*. 2011). Examples of avoidable food waste are related to inaccurate or long storage, expired best before date, leftovers not consumed, or misinterpreted rules in large-scale catering establishment (Modin, 2011).

This means that with better planning of menu and purchase, better storing, transportation and knowledge, and more careful handling this food waste could have been avoided quite easily.

Food waste at consumers; restaurants, large-scale catering establishments and households have several causes and origins. It can be divided into several categories according to Engstrom & Carlsson-Kanyama (2004):

- Waste during storage caused by inaccurate or to long storage
- Waste due to preparation, peeling and trimming, dependent on type of product, whether it is raw material, processed raw material, semi-finished products or finished products

- Serving waste; left-overs in boilers, canteens and serving dishes that has been moved from the kitchen to the dining room but not consumed, thus has to be thrown away
- Plate waste; left-overs washed or thrown away
- So called 'security- waste'; overproduction of food just to be sure it will be enough
- Other waste

A Swedish study on households and large-scale catering establishments shows that a majority of the food waste is fruits and vegetables (Modin, 2011). Waste of vegetables is likely to be related to sensitive crops with a short lifespan, like lettuce, while waste from grains, canola oil and sugar beets are close to zero (Jensen *et al.* 2011). Waste is also related to limited storage time of fresh fruit and vegetables and sensitivity to handling (Sonesson *et al*. 2010), but also due to poor temperature management during display (Gustavsson *et al*. 2011b). In Sweden, 'low-quality' vegetables and fruits are commonly sold as feed, for a lower price or exported (Jensen *et al*. 2011).

2.3.4. Handling of food waste

During management of waste, food waste can be mixed with or separated from other waste. In the latter food waste is processed separately in biological treatments (Jensen *et al*. 2011) e.g. production of biogas, meaning that the food waste can be used and not only wasted. It is estimated that the total food waste in Sweden is 10%, but usage of this waste in bio-gas production does not compensate for the loss of energy during the production (Goldstein, 2006). It is estimated that the energy from biogas production is equal to 10% of the energy used during production of the food product (Loxbo, 2011). Hence reduction of food waste saves more energy than usage of waste in bio-gas production, especially regarding animal products. Also, reduction of food waste reduces the GWP more than recycling of the same waste (Goldstein, 2006).

Freezing can reduce the waste of food with more than 30%, given that the consumer goes from only purchasing fresh vegetables to only frozen (Manchester Food Research Centre, 2010). The general consumer who already purchases fresh and frozen vegetables is likely to have a smaller reduction in waste by increasing the consumption of frozen vegetables, but the reduction may still be significant. This reduction may also be related to a reduced shrinkage during storage (Wills *et al*. 2007), which occur in fresh vegetables.

2.4. Description of Life Cycle Assessment

Life cycle assessment (LCA) is a method used to quantify and evaluate the environmental impact of products, services or systems, from cradle to grave. The total environmental impact is analyzed, from primary production and processing to retailers, consumers and waste, depending on goal and scope of the study. Transportation and energy use is also included in a LCA. (Roy *et al*. 2009)

A LCA consist of four phases (Roy *et al*. 2009):

- *Definition of goal and scope*
  What is the aim and purpose of the study? What are the system boundaries; what is included and excluded? Is the LCA accounting (attributional) or consequential (change-oriented)? Functional unit is defined. If more than one product is delivered by a process economical or physical (mass or energy) allocation may be needed. System expansion is an alternative when allocation is not suitable.
- *Life Cycle Inventory Analysis (LCI)*
  A flow chart is constructed and data on the insources and outsources of emission are

collected, in relation to the functional unit. The data may be achieved from databases, a company, previous LCA studies, measurements etc.

- *Life Cycle Impact Assessment (LCIA)*
  Classification and categorization is executed. Values from the LCI are aggregated and translated into categories to make the inventory analysis more comprehensible and easier to communicate. Normalization and weighing may also be executed.
- *Interpretation*
  Results are interpreted in relation to goal and scope. Recommendations may be formulated. Insecurities in data, calculations, system boundaries etc. should be stated and discussed. Insecurities can be measured by a sensitivity analysis or uncertainty analysis (Goedkoop & Oele, 2004; Björklund, 2002).

A sensitivity analysis measures the influence and magnitude of the effect of the most important assumptions in a LCA and is carried out by changing the assumptions and recalculating the LCA (Goedkoop & Oele, 2004). There are several methods to perform a sensitivity analysis. One of them is tornado diagram where the input parameters are changed equally (e.g. ± a certain percentage), one parameter at the time and the other parameters kept constant, and thereafter the change in output value is noted (Björklund, 2002). This result in lying graphs where the sensitivity of each parameter is illustrated (Björklund, 2002).

LCA is an iterative process; if the uncertainties are too high better data needs to be collected, and the analysis may need to be refined if a sensitivity analysis show that some decision are crucial. LCA is standardized according to ISO 14040- 14044. (Curran, 2013)

2.5. Nutritional aspects

2.5.1. Nutrition index

Nutrition index is tool for ranking and/or classifying nutrient composition of food (Fulgoni *et al*. 2009) and may be used to compare environmental impact of meals or food products (Kägi *et al*. 2012), marketing and health claims (Drewnowski & Fulgoni, 2008). Ranking of foods on the basis of nutrient content is also called nutrient profiling (Drewnowski & Fulgoni, 2008). It is important to define the functional unit in relation to goal and circumstances, and what is to be compared; amount of food, nutritional health or nutritional value of food (Kägi *et al*. 2012).

Current models focus on one of three alternatives: *"Qualifying nutrients known to be beneficial to health, mostly vitamins and minerals; disqualifying nutrients, mostly fats, sugars and minerals; some combination of both"* (Drewnowski & Fulgoni, 2008). The most accurate feature of the nutritional value of foods is provided by a combination of both qualifying and disqualifying (nutrients to limit) nutrients. However, combination of both qualifying and disqualifying nutrients limit the ability to use the nutrient index in combination with environmental assessment. This may result in negative values to some foods, values that are not possible to apply directly in LCA. Another limitation with nutrient indexes is that they are meant to be applied on unfortified foods. It is suggested that nutrients to limit should be included differently than in current indexes before further usage of nutrient indexes in LCA. Nutrients to include should be highly considered and evaluated (Saarinen, 2012). One major drawback with nutrient index available today is that they (of the nutrient index found) do not account for bioavailability of nutrients. Hence nutrient index need to be improved by including nutrients to limit differently and by evaluation of the nutrient index against nutritional requirements of consumers and nutritional science (Saarinen, 2012) and therefore comparison between nutritional value of fresh and frozen carrots and turnips, should be carefully executed. However, nutrient index score can be functional to use in the current study as a basis for comparing frozen and fresh carrots and turnips since no further comparison with other products or between carrots and turnips is performed.

Examples of nutrient indexes are Nutrient Rich Food (NRF*n*.x; where n= number of qualifying nutrients, and x= number of nutrients to limit), Naturally Nutrient Rich (NNR) and Nutrient Adequacy Ratio (NAR15; where 15= number of qualifying nutrients). The two latter indexes do not involve nutrients to limit. (Saarinen, 2012)

In this study nutrient density indexes which relate proportions of nutrients towards energy content of food were not used since these indexes are more suitable regarding limiting the energy intake. Nutrient density indexes result in a lower environmental impact for food with high energy content than food with a low energy content which would reverse the interpretation of the LCA (Saarinen, 2012). Hence nutrient density indexes are not suitable for nutritional calculations related to environmental impact. However, currently NRF9.3 is a stable nutrient index when applied on fruits and vegetables, especially when the reference base is per RACC[7] or 100 kcal and is close related to healthy eating index (HEI)[8] (Fulgoni *et al*. 2009).

NRF*n*.x, like many other nutrient indexes, combines macronutrients, vitamins and minerals in an index. The number of qualifying nutrients varies from 6 to 15 and nutrients to limit are three; saturated fat, added sugar and sodium. The scores from NRF can be calculated per 100 g, 100 kcal or RACC (Drewnowski & Fulgoni, 2008). The system based on 100 g does not make allowance for different consumption amounts of foods and drinks; i.e. energy-dense foods such as nuts and dried fruits that are consumed in small amounts are punished, while other foods such as sugared beverages are not. The consumption amount (portion size) of raw carrots and turnips is 70 g (Swedish National Food Administration, 2013). However, nutrient density is not aimed to be investigated in this study. Thus, 100 g was used as a reference amount in the calculations in this study (Drewnowski, 2009). The qualifying nutrients (NE) in NRF9.3 are protein, fiber, vitamin A, vitamin C, vitamin E, calcium, iron, magnesium, potassium, and the nutrients to limit (LIM) are saturated fat, added sugars and sodium (Kägi *et al*. 2012; Fulgoni *et al*. 2009).

2.5.2. Nutritional value

It is crucial to remember that the nutritional content of vegetables varies. Pre- and postharvest factors affect the final nutritional value of foods, hence also nutrient content, which in turn affects nutrient index score in current study. The mechanisms behind postharvest losses are thermal destruction, enzymatic oxidation and leaching (Selman, 1994). The final nutrient content in vegetables is affected by:

- Cultivar, variety (Selman, 1994; Rickman *et al*. 2007a), vegetable type and genetic variations (Klein & Perry, 1982). Different cultivars have different nutritional quality and are used for different types of products (Rickman *et al*. 2007a).
- Maturity of the plant/vegetable at harvest (Selman, 1994; Howard *et al.* 1999)
- Processing (Howard *et al*. 1999), e.g. blanching which is dependent on temperature, time of blanching, post-blanch water cooling and pH of blanch water (Selman, 1994; Albrecht *et al.* 1991)
- Storage time and conditions (Albrecht *et al*. 1991; Klein & Perry, 1982)

[7] RACC- Reference Amount Customarily Consumed. Reference base used in the US (Fulgoni *et al*. 2009).
[8] HEI- '*Healthy Eating Index is a measure of diet quality that assesses conformance to federal dietary guidance*' (Center for Nutrition Policy and Promotion USDA, 2013). HEI can be used to validate nutrition indexes

- Botanical structure of the vegetable (Selman, 1994; Howard *et al*. 1999)
- Piece sizes; pieces with small surface area/volume has higher nutritional value than pieces with big surface area/volume (Selman, 1994; Klein & Perry, 1982)
- Quantity of light during cultivation (Selman, 1994)
- Concentration and location of vitamin in the vegetable (Selman, 1994)
- Cooking; amount of water, time, temperature/power. Cooking in a large volume of water causes a greater loss of water soluble vitamins compared to a small volume of water, because of leaching. Increased cooking time also increase loss of water soluble vitamins (López-Berenguer *et al*. 2007)

Fresh vegetables have a continuous biochemical and microbiological activity, which along with respiration (Howard *et al*. 1999) slowly reduces the nutritional value during storage. Durability of fresh green vegetables (spinach, peas, green beans and okra) is short and in order to handle seasonality and perishability frozen storage can be applied (Giannakourou & Taoukis, 2003). However, root vegetables have higher durability than salad vegetables (Swedish National Food Agency, 2011), which reduce the benefits with freezing of the former in comparison with the latter.

In contrast to fresh vegetables vitamin loss in frozen vegetable is related to the blanching process. Heat-sensitive and water-soluble vitamins (e.g. thiamin, folate and vitamin C) tend to be reduced during blanching and the vitamin content in root vegetables may be reduced with 25-50% during blanching (Selman, 1994). However, vitamin losses caused by blanching are dependent on blanching method and product. Nutrient and/or product losses are also dependent on the combination of blanching and cooling method. Steam-blanching followed by cooling by cold-air or cold-water sprays retains the nutrient retention better than cooling with running water and the latter may cause increased yield by absorption of water (Fellows, 2000). Increased absorption of water is highly relevant when measuring nutritional content on wet weight (WW) basis since it may give misleading results (Rickman *et al.* 2007a) by not compensating for moisture content. Dry weight (DW) basis is more accurate. Steam blanching gives a small volume waste, smaller loss of water-soluble components and soluble heat sensitive components, hence a smaller nutrient loss, compared to hot-water blanching (Fellows, 2000). Blanching causes loss of water soluble vitamins, flavors and sugars due to leaching, thermal destruction and oxidation, but the following freezing retains remaining vitamins well (Fellows, 2000). Further, steam blanching can result in over 100% retention of carotene due to protein binding carotenes being denaturated, which increase solubility and thereby extractability of carotene (Howard *et al*. 1999). Slow oxidation of lipids occurs under freezing temperatures, and low water activity, loss of water soluble vitamins due to drip losses during thawing and leaching during cooking of frozen products should be considered (Fellows, 2000). Subsequent storage and leakage during thawing is also important. The mineral content is unaffected by rinsing and blanching (Rickman *et al*. 2007a).

Frozen vegetables may be stored for a long time before consumption and the temperature in domestic freezers often fluctuates and deviates from optimal conditions. Ascorbic acid is oxidized and further hydrolyzed into 2,3-diketogulinoc acid during processing, distribution and storage of frozen vegetables. This acid possesses no vitamin C activity. Activity of ascorbate oxidase, which is pH dependent, is probably enhancing the loss of ascorbic acid. (Giannakourou & Taoukis, 2003)

Favell (1998) showed that reduction in content of ascorbic acid (DW) in 5 different vegetables (peas, broccoli, whole green beans, carrots and spinach) was smaller for 12 months frozen storage compared to storage at 4°C during seven days. Storage of fresh vegetables at

20 °C showed even higher decreases. Favell (1998) also noted that the cooking time of frozen vegetables normally is shorter than for fresh vegetables. Another study by Howard *et al.* (1999) showed that the content of β-carotene (WW) in fresh carrots varied a lot the first 20 days after harvest, as the first 40 days of frozen, and the content was stabilized after 200 days of the frozen but not of fresh stored 84 days. The content of β-carotene was higher in fresh carrots. Howard *et al.* (1999) also showed that the content of ascorbic acid in frozen carrots may vary with year of harvest but that there is no significant difference between fresh and frozen carrots before and after cooking (in microwave). Content of ascorbic acid was shown to vary a lot during the first time of storage, both regarding fresh and frozen carrots. Shredded fresh carrots have been shown to have a slight decrease in carotenoid content during 13 days of chilled storage (Alasalvar *et al*. 2005).

In the beginning of the food chain the content of a nutrient may be high and the bioavailability low, and during the food chain the former decrease and the latter is improved due to storage, processing, preparation, mastication and digestion (Prada & Aguilera, 2007). Bioavailability of nutrients is an important aspect since a high nutrient content may have a low value for consumers if the bioavailability is low. Bioavailability is improved when extractability increase (Parada & Aguilera, 2007) and may be affected by processing such as heat treatment and mechanical homogenization (van het Hof *et al*. 2000, Parada & Aguilera, 2007). Mild heating and grinding are two types of food processing where bioavailability may be improved, either by cell walls being disrupted, nutrient-matrix complexes dissociated or by transformation of molecular structures into more active structures (Parada & Aguilera, 2007). Hence, the food matrix in the plant tissue is an important factor regarding bioavailability of several nutrients (Parada & Aguilera, 2007). Further, digestion and mastication disrupt cell walls making nutrients available for absorption while interactions between nutrients and macromolecules in the gut may reduce or improve bioavailability of said nutrients by forming colloidal structures and chemical complexes (Parada & Aguilera, 2007). Cooking has been shown to increase carotenoid content in vegetables which probably is due to increased extractability from vegetable matrix (Dietz *et al.* 1988; Khachik *et al*. 1992 as in van het Hof *et al*. 2000; Parada & Aguilera, 2007) which also can be associated with increased bioavailability of carotenoids (van het Hof *et al*. 2000). Cooking also increase extractability and bioavailability of β-carotene (Parada & Aguilera, 2007). The content of minerals may seem not to be affected by food processing when measuring ash values (Watzke, 1998), but may actually be lost during preparation, e.g. peeling of vegetables, and leaching into water during blanching and cooking (Bergström, 1994). Especially potassium is prone to be lost in cooking water (Bergström, 1994). If boiled in hard water, calcium and magnesium may be added to food (Bergström, 1994). Minerals may also be combined with co-nutrients or non-food components during processing, rendering them unavailable for digestion, while bioavailability may be improved by destruction of binding ligands such as phytates (Watzke, 1998). Yadav & Sehgal (1995) stated that HCl- extractability of calcium and zinc increase by cooking and blanching and that soluble calcium may leach out in blanching water during blanching.

3. MATERIAL & METHODS

3.1. Goal and scope of the LCA study

3.1.1. Goal

The aim of present study was to use LCA as a tool in order to compare frozen and fresh carrots and turnips. This in order to evaluate whether it can be motivated to produce and consume frozen carrots and turnips instead of fresh when considering possible differences in nutritional value and GWP. As a Master's thesis this study's intended audience was the scientific community.

3.1.2. Scope

This LCA was accounting and describes two different scenarios:

- Production of frozen carrots and turnips
- Production of fresh carrots and turnips

Functional unit

The functional unit (FU) was 1 kg product at customers; restaurant and large-scale catering establishments, according to the main function of the production system.

In the chapters following the term 'customers' refers to restaurants and large-scale catering establishments.

System boundaries and flowchart

The major differences were expected to occur after farm gate. The GWP from cultivation was therefore entirely based on values from earlier LCA. GWP of packaging was also included, along with transportation and storage from farm gate to processing plant, wholesaler and customers, energy input during this process and waste. The system boundaries ended before waste management (Figure 2).

Focus was on the part of food chain were private consumers are not immediately included, i.e. where they do not purchase, transport and cook the product since frozen carrots and turnips (not in mixes) are most commonly sold to restaurants, food industry and large-scale catering establishments. Hence focus in current study was on restaurants, wholesalers and large-scale catering establishments. Retailers were not included in present study. Only waste during storage and preparation was considered and left-overs from plates, canteens etc. while so called 'security- waste' were excluded. Waste beyond storage and preparation waste was not included due to difficulties in estimating waste from left-overs and security-waste of only carrots and turnips at customers. The food chain examined was based on that wholesalers take care of the transportation to other customers. Further on, GWP of the production of production capital (machinery, vehicles, buildings etc.) was excluded.

Geographical and time limitations

The data collected were based on Swedish conditions, except corrugated cardboard that was assumed to be produced on European electricity mix.

Allocation procedures

The haulms of carrots and turnips are ploughed down during harvest, thus the climate burdens were allocated to the carrots used for human consumption, as for company A[9] and *Haverlands Gård* that gave the waste away for free. *Nyskördade morötter*, producing fresh cut carrots sell the waste (originating from post-farm stage) as animal feed making it possible to economically allocate the climate impact between the carrots used for human consumption and carrots used as animal feed. This was based on the average waste during processing (sorting).

[9] Company A, pers. comm. 2013

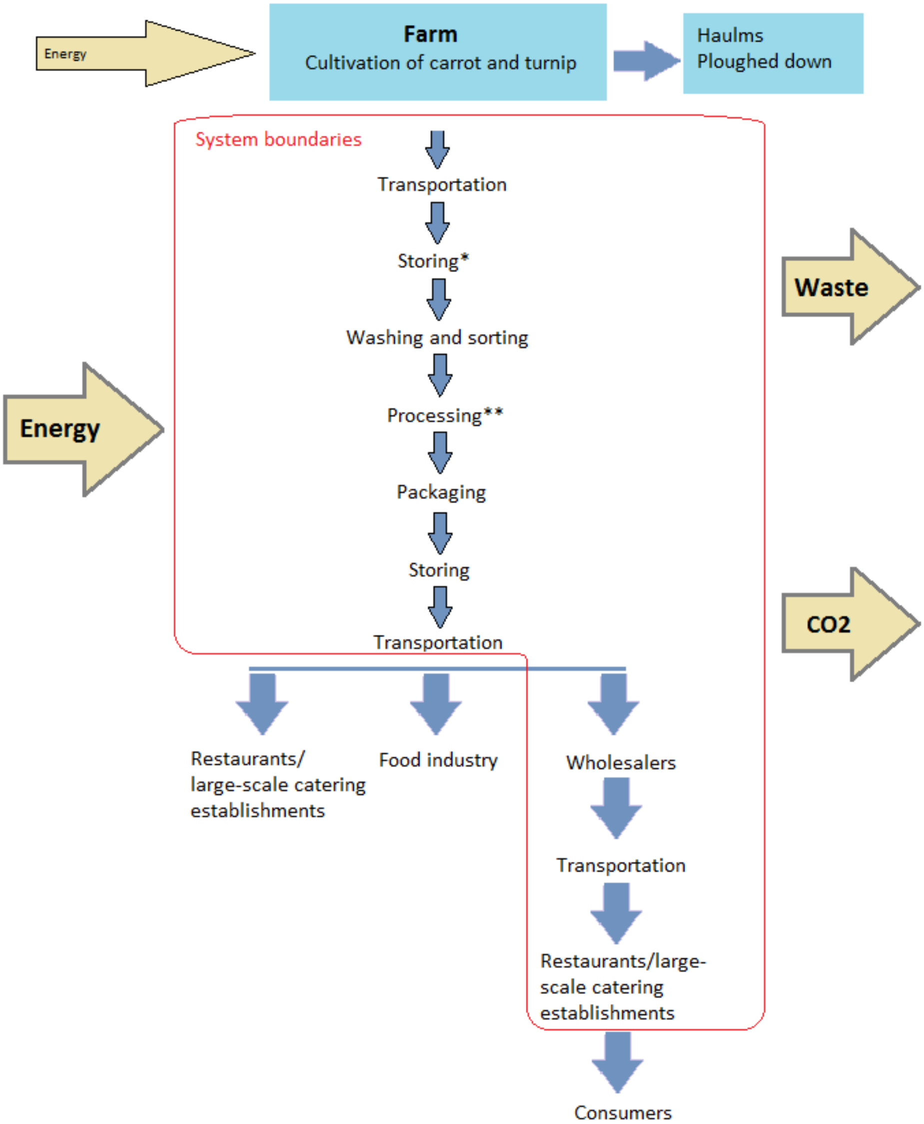

Figure 2. *Flow chart of processing, transportation and storage of fresh and frozen carrots and turnips. System boundaries are shown in the red, continuous line. *Only fresh carrots and only in some companies or some parts of the total production. **Only frozen carrots and turnips are processed. Fresh are commonly not processed.*

Impact categories

The impact category being considered was GWP (CO_2-eq) calculated from a 100-year perspective.

3.2. Nutritional value

3.2.1. Data collection

The nutrients presented and discussed were based on the nutrient index presented in this study (section 2.5.1); hence not all nutrients within the products were considered. Since the index Nutrient Rich Food (NRF9.3) was used, only protein, fiber, calcium, iron, magnesium, potassium, vitamin A, vitamin C, vitamin E, saturated fat and sodium were discussed. The data was compiled and calculated in Excel and based on average values (DW). Since average values were used, no statistical analysis was possible to accomplish.

NRF9.3 was calculated according to Drewnowski (2009). The equation was modified according to Saarinen (2012) to suit the reference amount 100 g:

NRF9.3 = ($\sum_{1-n}$((Nutrient/DV) x 100)/n) – ($\sum_{1-z}$((Nutrient/MRV)*100)/z)

DV= Daily Value, Recommended Daily Intake
MRV= Maximum Recommended Value
n= number of qualifying nutrient
z= number of nutrients to limit

The achieved index score is a way to *"quantify an average share (%) of selected nutrients in 100 g of a product with reference to the daily nutrient recommendation"* (Saarinen, 2012).

The Recommended Daily Intake (i.e. Recommended Daily Value) of the nutrients investigated in this study is shown in Table 2. The values are based on Nordic Nutrient Recommendations (NNR) for an 18-60 year old male.

Table 2. Recommended daily intake (RDI) of qualifying nutrients and population target of nutrients to limit[1]

Nutrient	Recommended daily intake (g/100g)
Protein	55
Fiber	30
Vitamin A (RAE)	0.0009
Vitamin C	0.075
Vitamin E	0.01
Calcium	0.8
Iron	0.009
Potassium	3.5
Magnesium	0.35
Sodium[2]	2.8
Saturated fatty acids[2]	90

[1]According to NNR (2004) *[2]Nutrients to limit*
RAE: Retinol Activity Equivalents.

The data presented in Table 2, 4 and 5 was used as basis for the calculations. GWP of cooking was not measured in current study and in order to avoid incorrect conclusions GWP in relation to nutrient index of cooked products is only shortly discussed in the discussion and further presented in Appendix 1.

USDA National Nutrient Database for Standard Reference is based on data compiled from published and unpublished sources from scientific literature, food industry, government agencies and '*research conducted under contracts initiated by USDA's Agricultural Research Service*' (USDA, 2012) and is therefore considered as a reliable and good source. Due to the many sources in this database it was not possible to examine or estimate the nutritional value in relation to time of storage but was however discussed in relation to the information given in section 2.5.2. Studies regarding nutritional value of frozen and fresh carrots have been published but they differ in method, choice of cultivar, examined nutrients etc. and therefore these studies were not considered in the following section. Studies regarding nutritional value of turnips were also limited which is why only the data from the USDA National Nutrient Database for Standard Reference was considered. The data regarding cooked carrots and turnips were based on the vegetables being cooked and drained without salt, meaning that water used for cooking was not included.

3.3. Representative productions

3.3.1. Data collection

The LCA and a tornado diagram sensitivity analysis were carried out according the description in section 2.4, but no normalization and weighing were executed. The sensitivity analysis was based on ± 20% change in each parameter and the result was presented in change in percentage of total GWP. The data was based on average values compiled and calculated in Excel. The data regarding GWP from transportation (extra fuel needed for the freezing/chilling in the truck excluded) was compiled from NTM Calc and from the road carrier company that company A consult.

The data was collected from interviews with Swedish companies, earlier LCA based on Swedish conditions and literature research on production and processing of Swedish root vegetables. The data was supplemented with information and data from earlier LCA. The data obtained from the interviews performed during current study was considered as sufficient and representative for the specific companies while the data from earlier LCA was considered as sufficient for this study.

This LCA was based on specific data of production and processing of carrots and turnips. The data regarding frozen transportation from factory to wholesalers and additional fuel consumption of cooling/freezing aggregate was specific (given by the road carrier company) while data on transportation from wholesalers to customers was average (given by NTM Calc). GWP of cultivation was based on an earlier LCA, which was based on plant-specific data from producers and included parameters such as fuel use, greenhouse gas emissions and transportation. Calculations of GWP from different electricity mix were based on data from Nilsson & Lindberg (2011) (Appendix 2, Table 10).

3.3.2. Fresh carrots

Nyskördade morötter is one of the leading companies on the Swedish (fresh) carrot market (Nyskördade morötter, 2013e). Carrots being harvested when mature and stored in refrigeration bearing houses was examined in this study even though this production only constitute 20% of *Nyskördade morötter*s total production. This because today 'freshly harvested carrots' is only executed by this company in Sweden (in large-scale), while carrots being harvested during the autumn and stored in bearing houses during the winter is a more common procedure among the other companies on the Swedish carrot market.

Nyskördade morötter (Appendix 4) sort the carrots according to the diameter of their top[10]. Non-standard carrots (Table 3) are sorted away and sold as animal feed (Nyskördade morötter, 2012a). So called 'cut carrots' are used raw in salads and due to microbiological aspect, the quality demands are higher for this product. The waste from this production is higher compared to consumer products (i.e. products sold at retailers to consumers).[10]

This company transports the harvested carrots by means of tractor and trailer to packaging where the carrots are sorted, washed and packaged. The company produces carrots that are harvested when mature (in November at latest and stored until May/all the carrots are sold), and stored in refrigerated (0.5-1°C) bearing houses (Nyskördade morötter, 2012b). Cut carrots are packaged 10 kg bags of low density polyethylene (LDPE) (Nyskördade morötter, 2012d). These bags are packed 20 in each pallet and surrounded by corrugated cardboard (Table 3).[10]

3.3.3. Fresh turnips

The company *Haverlands Gård* produces fresh turnips. During harvest, haulms of turnips are crushed and ploughed down (Appendix 4). The turnips are transported by means of tractor and trailer to the processing plant where they are cooled down and stored in bearing houses.

[10] Nilsson, pers. comm. 2013

Table 3. Summary of the representative productions regarding product, size of packaging, how the product are sorted, long-time storage, transportation distance and further comments

Company	Product	Size of packaging	Packaging	Sorting[1]	Maximum long time storage	Transportation distance[2]	Comment
Nyskördade morötter	Fresh cut carrots	10 kg x 20	LDPE+ corrugated cardboard	Non-standard: branched, broken, blemishes, containing stones[11]	Nov-May/everything sold	150 km	Microbiological concerns
Haverlands Gård	Fresh turnips	12 kg x 1	SRS crates	Bad quality, e.g. rotten	Oct-May	2 km	-
Company A	Frozen carrots	2.5 kg x 4	LDPE+ corrugated cardboard	Broken with stones in it, rotten	Autumn-Mar	150 km	No sorting according to size
Company A	Frozen turnips	2.5 kg x 4	LDPE+ corrugated cardboard	Broken with stones in it, rotten	Autumn-Mar	150 km	No sorting according to size

[1] Carrots/turnips being sorted away, becoming waste
[2] From farm to factor y

During the autumn the storage may be only one day while the turnips harvested in October may be stored until May (Table 3).[12] After storage the turnips are sorted and washed in water. Turnips sorted away are transported to the neighboring farm and crushed to animal feed. The farmer achieves the turnips for free in return for taking care of the waste. The turnips are packaged in plastic crates. These plastic crates (SRS[13] crates) are acquired for a deposit, are returnable and many food companies, retailers etc. use them. The SRS crates are reused frequently during its service time and *Svenska Retursystem* (2013) estimate the service life to 10 years. The turnips are transported to customers the same day as the packaging.

3.3.4. Frozen carrots and turnips

The company A (Appendix 4) produces and packages seven frozen products (potatoes, turnips, celery, parsnips, beetroot, Jerusalem artichoke and "polka beet", a type of beetroot) at the factory in Sweden and imports the other frozen products on their journal of sales. All of the products are sold on the Swedish market. This study based the inventory analysis on the 80% vegetables that the company processed immediately after harvest and on transportation to customers by means of the road carrier Company A consult. The specific product further investigated in the LCIA was 2.5 kg bags packed four and four in corrugated cardboard (Table 3).

[11] Nilsson, pers. comm. 2013
[12] Fritiof, pers. comm. 2013
[13] SRS: *Svenska Retursystem.* Plastic crates used for storage at transportation of food products within Sweden

During the production of frozen vegetables (semi-finished products) the raw material is, in the following order (Company A, 2013):

1. Transported to the factory after harvest, by tractor and open trailer
2. Weighed and controlled
3. Washed
4. Root vegetables are peeled
5. Manually controlled
6. Cubed in a cubing machine
7. Mechanically scanned
8. Blanched; hot water blanching[14]
9. Cooled with running water in a cooling water loop
10. Flow freezer; fluidization process for individual quick freezing (IQF)[14]
11. Sorted
12. Screened in a metal detector
13. Packed in bags at a bag station
14. Packed in pallets, bags/unpacked (bulk) products marked
15. Stored in bearing houses at freezing temperature
16. Loaded to customers who transport the products by themselves or loaded by a road carrier company and transported to customers

The harvest of carrots takes place during the autumn and 80% is produced directly while the remaining 20% are stored in cold storage at company A until Jan-Mar when they are processed. All carrots and turnips are sorted at company A. There is no sorting according to size and broken carrots are used, since all sizes and broken carrots are used for different cuttings. The carrots being sorted away are rotten or broken with stones in it. Processing and sorting of turnips is executed the same way as for carrots.[14]

At the processing plant the crop is washed with water without additives. During washing remaining sand, soil, stones, rotten crop, broken crop containing stones are removed, giving a waste. During the processing there is also a waste, mainly due to peeling. The waste is given away for free as animal feed to farmers.[14]

IQF allow quick continuous freezing of small produce like peas and diced vegetables without causing so called ‘cluster freezing’ where the product is frozen together in big clumps (Nilsson & Lindberg, 2011; George, 1993). The frozen products are packaged in 2.5 kg LDPE bags. The majority of the 2.5 kg bags are packed four and four in corrugated cardboard. The food industry, wholesale and restaurants are the company’s main customers. They also have a market of private consumers.

When the products are frozen and packaged they are transported with trucks of different sizes with freezing capabilities (-18°C). The products are transported to industrial customers, wholesalers or to retailers. Half of the production is transported of customers using their own trucks/cars/transportation.[15] The other 50% is transported by a road carrier company[15], which aims to be the most environmentally friendly alternative in the business. Their policy is to drive environmentally friendly with maximum load, shortest distances possible to reach the destination and with the latest technology. The majority of the trucks in this company are fueled by diesel and a few by vehicles-gas or rapeseed oil (RME). About 15% of the trucks returning to the company are empty.

[14] Company A, pers. comm. 2013

[15] The road carrier company wished to be anonymous in current study.

4. INVENTORY ANALYSIS

4.1. Nutritional value

4.1.1. Carrots

Fresh carrots contain slightly more protein (0.18 g/100 g) than uncooked frozen carrots and cooked fresh carrots (Table 4). The protein content is reduced during cooking; more in frozen carrots than in fresh. Cooking has a small impact on fiber content. Carrots are a very good source of β-carotene, the only form of vitamin A available in vegetables (Nilsson *et al*. 2006). Frozen uncooked carrots have a considerably lower content of β-carotene than the other carrots, which have comparable content of vitamin A. After cooking the content is comparable between fresh and frozen carrots. Cooking decreases the vitamin C content in both fresh and frozen carrots. The content of vitamin E is increased by cooking in both fresh and frozen carrots, as is the content of iron. The content of potassium is decreased during cooking, especially regarding fresh carrots. The content of calcium is reduced by cooking in fresh carrots and increased in frozen.

Table 4. Content of nutrients (DW) and moisture content (WW) in fresh and frozen carrots[1]. The cooked carrots are drained and cooked without salt

Nutrient	Fresh carrots	Frozen carrots	Cooked, fresh carrots	Cooked, frozen carrots
Water (g/100 g)	88.3	90.0	90.2	90.3
Protein (g/100 g)	1.050	0.866	0.843	0.642
Fiber (g/100 g)	3.17	3.67	3.33	3.65
Vitamin A (RAE, µg/100 g)	946	789	945	937
Vitamin C (mg/100 g)	6.68	2.77	3.99	2.55
Vitamin E (mg/100 g)[a]	0.748	0.633	1.14	1.11
Calcium (mg/100 g)	37.3	35.5	33.3	38.8
Iron (mg/100g)	0.34	0.49	0.377	0.587
Potassium (mg/100 g)	362	260	260	212
Magnesium (mg/100 g)	13.6	13.3	11.1	12.2
Sodium (mg/100 g)	78.1	75.5	64.3	65.3
Saturated fatty acids (g/100 g)	0.042	0.052	0.0333	0.133

[1] *According to USDA National Nutrient Database for Standard Reference (2011). Values recalculated into DW since the values provided by USDA were based on WW.*
[a] *α-tocopherol*

Concerning nutrients to limit, carrots contain negligible amounts of saturated fatty acids and the content of sodium in uncooked, fresh carrots is equal to uncooked frozen. The content of sodium is reduced by cooking in both cases. No sugar is added in this product and was therefore not considered. Hence, uncooked fresh carrots have higher contents of protein, vitamin A, vitamin C, vitamin E and potassium, less iron and dietary fiber and equal or comparable contents of the remaining nutrients, when compared to uncooked frozen carrots. Cooking results in comparable contents of vitamin E and sodium in fresh and frozen carrots. (USDA, 2011)

4.1.2. Turnips

Uncooked frozen turnips have a slightly higher content of protein than uncooked fresh turnips; 0.98 g/100 g and 1.09 g/100 g (Table 5). The difference is increased by cooking. β –carotene is (close to) absent in turnips, but present in uncooked frozen turnips. Concerning the content of vitamin C, fresh turnips contain 5 times the amount in frozen in uncooked state and 3 times in cooked state. Hence, cooking reduce the vitamin C content in fresh turnips more than in frozen.

Table 5. Content of nutrients (DW) and moisture content (WW) in fresh and frozen turnips[1]. The cooked turnips are drained and cooked without salt

Nutrient	Fresh turnips	Frozen turnips	Cooked, fresh turnips	Cooked, frozen turnips
Water (g/100g)	91.9	95.7	93.6	93.6
Protein (g/100 g)	0.980	1.087	0.759	1.63
Fiber (g/100 g)	1.96	1.88	2.14	2.14
Vitamin A (RAE, µg/100 g)	0.0	1.05	0.0	0.0
Vitamin C (mg/100 g)	22.7	4.6	12.4	4.17
Vitamin E (mg/100 g)[a]	0.0229	N/A	0.020	0.0214
Calcium (mg/100 g)	33.0	24	35.3	34.1
Iron (mg/100 g)	0.330	0.73	0.190	0.105
Potassium (mg/100 g)	208	143	189	194
Magnesium (mg/100 g)	12.0	10.5	9.62	15.0
Sodium (mg/100 g)	72.9	26.1	17.1	38.5
Saturated fatty acids (g/100 g)	0.0120	0.0178	0.00855	0.0267

[1] According to USDA National Nutrient Database for Standard Reference (2011). Values recalculated into DW since the values provided by USDA were based on WW.
[a] α-tocopherol
N/A: Not available

The vitamin E content in uncooked frozen turnips is not presented in the database, but after cooking the fresh and frozen turnips has equal contents of vitamin E. The content of calcium in uncooked fresh turnips is higher than in frozen but cooking increase the calcium content in both fresh and frozen, and more in the latter. Fresh turnips contain tangibly more potassium than frozen in uncooked form and comparable when cooked. The content of iron decreased more by cooking in frozen turnips than in fresh turnips. Content of sodium in fresh turnips is decreased by cooking while it for frozen turnips is increased by cooking. No sugar is added in this product and was therefore not considered.

Thus, fresh turnips contain more vitamin C, calcium, potassium, sodium and saturated fatty acids than frozen turnips. Frozen turnips contain more vitamin A and iron than fresh turnips. Cooking decrease the differences between fresh and frozen turnips, except for protein and dietary fiber where the difference in content is increased.

4.2. Cultivation

A study by Davis *et al.* (2011) showed that GWP from cultivation was 0,08 kg CO_2/kg carrots at farm gate. This value was more accurate to use in current study than the study by Lagerberg Fogelberg & Carlsson-Kanyama (2006). The latter was site-specific and concerned cultivation of fresh and frozen carrots with a kg carrot at wholesaler as functional unit. The number of studies on turnips is limited, but Lagerberg Fogelberg (2008) estimated the environmental impact from production of turnips to similar to the production of carrots. Hence the same values regarding turnips were used.

4.3. Processing

The energy consumption of processing of fresh carrots (energy consumption from storage, heating of building and offices etc. excluded) at processing plant is 0.080 kWh/kg fresh carrots (Nyskördade morötter, 2012c). Regarding production of fresh turnips, the total energy consumption at processing plant is 150,000 kWh/year and the total production of turnips is 11,000 ton/year,[16] thus 0.0136 kWh/kg fresh turnips and year.

[16] Fritiof, pers. comm. 2013

Table 6. Energy consumption at company A, production of frozen carrots and turnips

	Carrots	Turnips
Share of production (%)	21	11
Electricity (kWh/year)	632,000	316,000
Electricity consumption (kWh/kg product and year)	0.179	0.140
GWP electricity (kg CO_2-eq/FU)	0.0137	0.00910
GWP fuel consumption (m^3/year)	275	275
GWP fuel (kg CO_2-eq/FU)	0.0138	0.0107

Calculations shown in Appendix 5 (section 5.2.)

Company As total electricity consumption is 3,000,000 kWh/year. The total production of vegetables is 4,500- 5,000 ton and the company keep 12,000 ton in the frozen warehouse.[17] Further values are shown in Table 6. The energy consumption originates from electricity and fuel oil. The electricity consumption originates from sorting, washing, packaging and storage of the total production along with storage of the imported products. Processing of the products (blanching, peeling etc.) is based on fuel oil instead of electricity. The electricity consumption of carrot production is 0.179 and of turnips production is 0.140 kWh/kg product and year (Appendix 5, section 5.3.). Electricity consumption from storage was subtracted from the total electricity consumption according to values of bulk frozen warehouse given in Table 8, in order to avoid duplication of GWP from storage at processing plant.

For the processing of the products company A use fuel oil, 250-300 m^3/year. The emission factor of fuel oil is 10.2 kg CO_2/gallon (U.S Energy Information Administration, 2013). This was recalculated to a GWP of 0.014 kg CO_2-eq/kg carrots at customers and 0.011 kg CO_2-eq/kg turnips at customers.

4.4. Waste

As shown in Figure 1 the total waste increases through the food chain. The waste during storage at processing plant before processing was considered to be included in the waste at sorting and washing since carrots/turnips becoming rotten or of low quality during the storage time are sorted away during this step. The waste of the fresh cut carrots (with higher quality demands of microbiological concern) is 15% units higher than the waste from the company's other production of fresh carrots which has 20% waste. The waste of the latter varies a lot during the year; from 10% during the summer to 30-35%, or even as high as 50% during the winter. The waste of cut carrots is quite stable around 35% during the year[18]. Since fresh cut carrots are supposed to be used without further preparation in salads or grated the waste at customer stages was estimated to close to zero (Table 7). However, if peeling was required the waste would have been 15% based on that peeled carrots cause (Appendix 3, Table 11) 13% waste while grated carrots cause 15-18% waste (Karlsson & Carlsson-Kanyama, 2004). However, the total waste during the life cycle is similar. The average waste during storage was estimated to 2.7% per month, based on estimation made by Karlsson (2011) that the total loss during storage (from harvest in September to April) is 19%.

The waste of frozen carrots and turnips at customer stages was estimated to be very close to zero due to the long shelf-life and storage capabilities. This since the carrots are 'ready-to-use', already peeled and cut in appropriate sizes. The waste of carrots and turnips at processing plant is in average 10% during sorting/washing and further 12.5% during

[17] company A, pers. comm. 2013
[18] Nilsson, pers. comm. 2013

processing. The waste may vary between 10 and 40%. If the waste is 40% company A reject the product from the farmer.[19]

Table 7. Waste of fresh and frozen carrots and turnips during washing and sorting at processing plant, storage at wholesaler and preparation. The values were obtained from interviews with concerned companies

Product	Sorting/ washing (%)	Processing (%)	Storage at wholesaler (% per month)	Preparation waste (%)	Variation of waste[2] (%)
Fresh carrots	35	N/A	2.7	0[1]	35
Frozen carrots	10	12.5	0	0	10-40
Fresh turnips	15	N/A	2.7	15	10-20
Frozen turnips	10	12.5	0	0	10-40

N/A: Not applicable
[1]The product does not require peeling at customers; hence the preparation waste was estimated to zero.
[2] Variation of waste during the year, originating from sorting, washing and processing at processing plant

The average waste of fresh turnips during sorting and washing is 15%. During the autumn the waste is lower (10%) while the waste during the end of the spring is over 20%. The neighboring farmer achieves the turnips for free in return for taking care of and handling the waste. The maximum storage time of fresh turnips at processing plant is about 7 months (October to May).[20] Only one study on waste of preparation of turnips was found; Cumming *et* al. (1977) show that peeling and trimming of turnips gives 15% waste. When taking preparation waste of carrots into account (15%) (estimation according to Appendix 3, Table 11 and values given by company A) and waste during processing of fresh turnips at processing plant (12.5%), it was estimated that a reasonable preparation waste of turnips was 15%.

The waste of fresh turnips[21], frozen carrots and frozen turnips[22] is given away for free to farmers as animal feed. Waste from the production of fresh carrots is sold as animal feed for 25 SEK/20 kg sacks or 175 SEK/m^3 (one m^3 = 500 kg) (Nyskördade morötter, 2012b). The cut fresh carrots sold in 10 kg plastic bags are sold to for 8.60 SEK/kg.[23] This means that 87% of the income from the cut fresh carrots could be economically allocated to the carrots sold for human consumption and 13% to the carrots being sold as animal feed.

4.5. Packaging

Fresh carrots are likely to be packaged in low density polyethene (LDPE). GWP of LDPE is 2 kg CO_2-eq/kg material, based on European electricity mix. GWP of corrugated cardboard is 0.44 CO_2-eq/kg material, based on European electricity mix which has high proportion of fossil fuels and thereby higher GWP than Swedish and Nordic electricity mix. (Wallman & Nilsson, 2011)

A 10 kg plastic bag of cut fresh carrots requires about 61 g LDPE (calculated according to data given by company A). These bags are packed 20 in each pallet, surrounded by corrugated cardboard.[24] It was assumed that one pallet requires 2 kg corrugated cardboard, but this value was only compared to the values given by company A (below). A pallet was assumed to

[19] Company A, pers. comm. 2013
[20] Fritiof, pers. comm. 2013
[21] Fritiof, pers. comm. 2013
[22] Company A, pers. comm. 2013
[23] Nilsson, pers. comm. 2013
[24] Nilsson, pers. comm. 2013

require less corrugated cardboard/kg product than boxes containing four 2.5 kg packages (Appendix 5, section 5.1.).

The frozen carrots are packaged in plastic bags, in 450 kg bulk or in plastic bags (LDPE) and cardboard before transportation to customers. The plastic bags contain 2.5 kg product and the plastic material in each bag weighs 13 g respectively. The bags are packaged in corrugated cardboard, four bags in each box. The material in each box weighs 310 g. 2.5 kg packages (packaged four and four) are likely to be used in restaurants and large-scale catering establishments. Frozen turnips were assumed to be packaged in the same types and sizes of bags as frozen carrots.

The fresh turnips are packaged in SRS crates which have a long service life (Svenska Retursystem, 2013) and therefore were estimated to have a very low environmental impact/kg product. Washing of each unit (at washing facility) is however required, demanding 0.154 kWh/unit (Svenska Retursystem, 2013).

4.6. Storage

The average values concerning time of storage were used in the calculations of GWP/NI score, e.g. if the maximum storage time at processing plant is 6 months, an average value of 3 months was used (Figure 5 and 6).

The fresh carrots were estimated to be stored at maximum 6 months (long-time storage), from November until June at processing plant, before processing (Nyskördade morötter, 2012b). At wholesalers the storage time was set to 5 days (short-time storage) based on the assumption that the wholesaler has a high turn-over of products, both of fresh and frozen. It is likely that fresh products at restaurants and large-scale catering establishments are used within a few days (short-time storage) from delivery and therefore the storage time at these customers was set to 5 days. Frozen products were assumed to be stored 1 month (short-time storage) at customers and a maximum of 6 months (long-time storage) at processing plant, after processing.

GWP of different warehouses in large scale is shown in Table 8 and is based on Swedish electricity mix including import. Carrots and turnips were assumed to have approximately the same density (liter/kg) as potato. The difference between distribution cold/frozen warehouses and industrial/bulk warehouses is the turn-over of products. The former has a high turn-over of products and greater losses of energy due to more openings than in industrial warehouses (Nilsson & Lindberg, 2011).

Energy consumption in restaurants and large-scale catering establishments' was calculated according to Appendix 5 (section 5.2.). It was assumed that the fresh carrots and turnips were stored in a 7.28 m^3 cold chamber, and the frozen carrots and turnips in a 6.29 m^3 cooling room. The cold chamber use 1.46 kW (Bureca: Butik, Restaurang och caféutrustning, 2010a) and the cooling room 0.71kW (Bureca: Butik, Restaurang och caféutrustning, 2010b). The total energy consumption in the cooling room was estimated to 0.012 kWh/kg product and day based on 30% filling degree and 0.011 kWh/kg product and day in the cold chamber based on 55% filling degree. The GWP of storage in cooling room was calculated to 1.07 g CO_2-eq/kg product and day, and 1.04 g CO_2-eq/kg product and day for products stored in cold chambers. These values are fairly reasonable in relation to the values given by Nilsson & Lindberg (2011), which show that the GWP of a household refrigerator varies between 0.13 and 5.46 g CO_2-eq/kg product and day. How ambient temperature and filling degree effect energy consumption was not considered. The same electricity mix as for the warehouses was used.

Table 8. GWP of different types of storing of carrots or turnips

Type of storage area	GWP (g/liter product and day)	GWP (g CO_2-eq/kg product and day)[2]
Industrial refrigerated warehouse[4]	0.030[1]	0.039[2]
Distribution cold warehouse[5]	0.060[1]	0.078[2]
Bulk frozen warehouse[6]	0.060[1]	0.078[2]
Distribution frozen warehouse[5]	0.10[1]	0.13[2]
Cold chamber[7]	N/A	1.04[3]
Cooling room[7]	N/A	1.10[3]
Refrigerator, household	0.10-4.20[1]	0.13-5.46
Freezer, household	0.20-0.50[1]	0.26-0.65

[1] Nilsson & Lindberg (2011). Size of storage area: 50,000- 100,000 m.[3] *N/A: Not applicable*
[2] Calculated according to Muñoz (2007) *[5]At wholesaler*
[3]Calculated according to Appendix 5 *[6]At processing plant, after processing*
[4]At processing plant, before processing *[7]At customers*

4.7. Transportation

Transportation to company A; from farm to processing plant is executed by tractor and in this study a semitrailer was used as an example of trailer. The maximum distance between farm and factory in the case of frozen vegetables is 150 km, as for the transportation of fresh carrots. Transportation of fresh carrots is done by means of open trucks and semitrailers. The maximum distance regarding fresh turnips is 2 km.

Transportation of fresh carrots from processing plant to wholesalers was set to 120 km, the distance from *Nyskördade morötter* to the central warehouse of one of their biggest customers located in Helsingborg. The carrots were assumed to be transported by trucks with trailers with cooling capabilities and with average load capacity of 26 ton to customers and 24 ton to wholesaler. The average transportation to the former was set to a distance of 400 km in order to reach many customers in Sweden (distance Helsingborg- Stockholm is 550 km). Transportation of fresh turnips was set to the same distances and vehicles as fresh carrots. All of the vehicles transporting fresh products were assumed to be fueled by diesel with 100% load.

The frozen carrots are transported to customers by freezer trucks (car + trailer) with a diesel consumption of 4.33 liter/10 km when fuel for frozen storage (aggregate) is excluded. The aggregate for the truck and the trailer has a fuel consumption of 3 and 4 liter/hour each that was added to the total fuel consumption (in relation to the transportation distance). This fuel consumption is the same for frozen and chilled transportation, but varies plus/minus 0.5 liter/hour during the year (less during the winter). Leakage of refrigerants during transportation has been estimated to correspond to an extra 0.3 l diesel/hour concerning greenhouse gas emissions (Winther *et al*. 2009). The truck can take 18 pallets and the trailer 30 pallets, thus a total of 48 pallets. The load of frozen carrots and turnips on each pallet is 400 kg and 500 kg respectively. Around 15% of the transports back to the company are empty, giving an average of 85% load in the cargo area during transportation back. The emission factor of combustion of diesel is 2.67 kg CO_2-eq/liter (100% mineral diesel) (AEA, 2011). The distance between company A and their customers vary. In the calculations in this study an average distance of 120 km from processing plant to wholesaler and 400 km from wholesaler to customers was applied, thereby covering the customers in *Götaland* and parts of *Svealand*.

5. RESULTS

5.1. Nutrition index

The difference in nutrition index score of uncooked fresh and frozen products were greater before cooking than after. After cooking there was no difference in nutrition index score for carrots (Figure 3) while the difference for turnips was only slightly changed (Figure 4). The nutritional value of frozen carrots was positively affected by cooking while the fresh carrots were unaffected. Fresh turnips seemed to have a small reduction in nutritional value due to cooking while frozen turnips had a small increase. Whether the differences are significant or not is unknown, since no statistical analysis was possible to accomplish on basis of the data used. Due to lack of data, α-tocopherol was excluded from nutrient index of uncooked turnips, but if the value from fresh uncooked turnips is applied on uncooked frozen turnips the NI score increased with 0.03 on both fresh and frozen turnips.

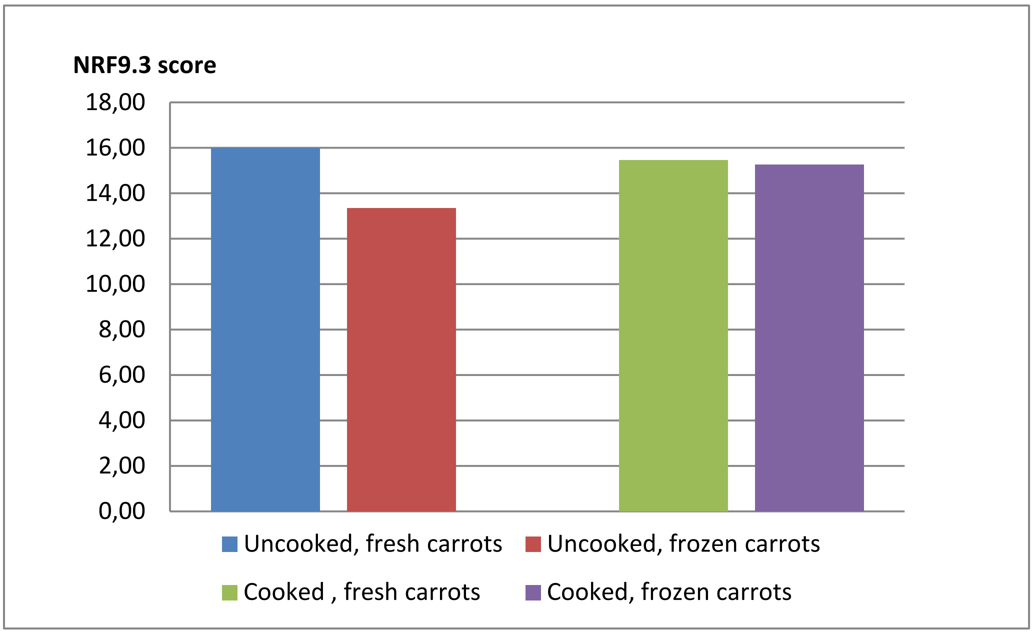

Figure 3. *Calculated nutrient score according to NRF9.3 (DW) for fresh and frozen carrots in uncooked and cooked state.*

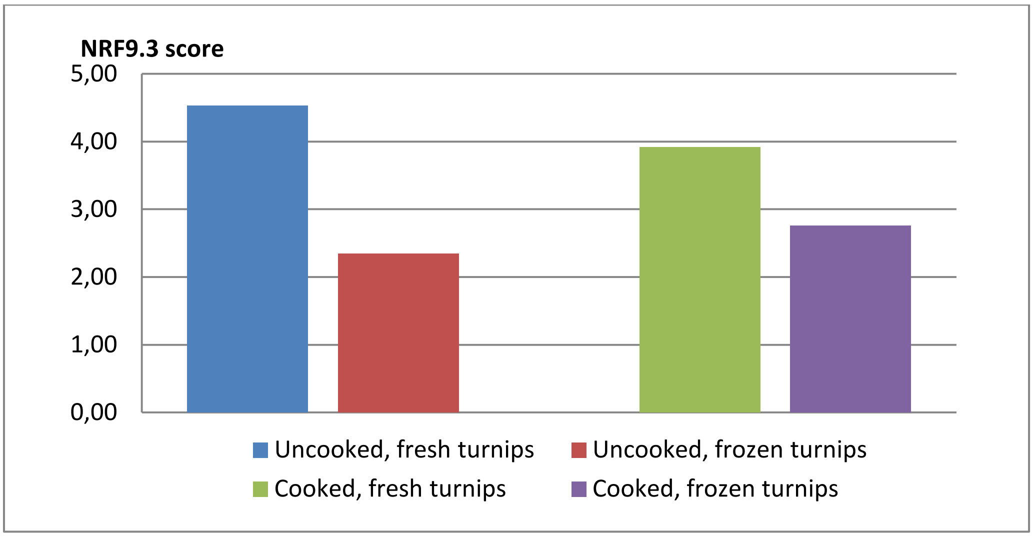

Figure 4. *Calculated nutrient score according to NRF9.3 (DW) for fresh and frozen turnips in uncooked and cooked state. Due to lack of data vitamin E (α-tocopherol) was excluded from calculation of NRF9.3 score of uncooked fresh and uncooked frozen turnips.*

5.2. Comparison fresh and frozen root vegetables

Comparison of fresh and frozen (uncooked) carrots and turnips, respectively based on GWP (kg CO2-eq/kg product at customer) and nutrient index score (NI) (DW basis) is shown in Figure 5 and 6. The figures were based on mean values regarding time of storage. Detailed figures are available in Appendix 1. GWP/NI regarding cooked products is only presented in in Figure 14 and 15 in Appendix 1 and is only shortly discussed since GWP of cooking was not included in the system boundaries.

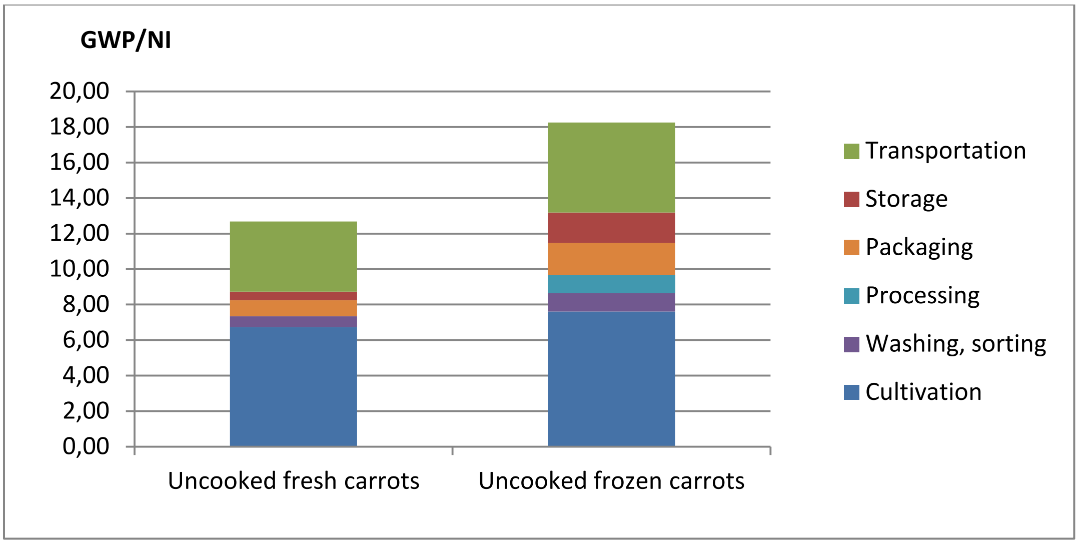

Figure 5. *GWP (g CO_2-eq/kg product at customer)/NI of fresh and frozen carrots in uncooked form.*

Comparison of fresh and frozen carrots and turnips show that fresh provided more nutritional value for every g CO_2-equivalent generated during production of each product compared to frozen; 12.7 of fresh carrots, 18.3 regarding frozen carrots, while corresponding values for turnips were 40 and 100 g CO_2-equivalent/kg product at customer/NI. The dominating life cycle stage of GWP/NI (kg CO2-eq/kg product a customer/nutrition index) of production of fresh and frozen carrots was cultivation followed by transport with transportation to customers as the most contributing transportation (Appendix 1 for details). Besides transport the dominating life cycle stage regarding frozen carrots in relation to NI was cultivation, followed by packaging and storage.

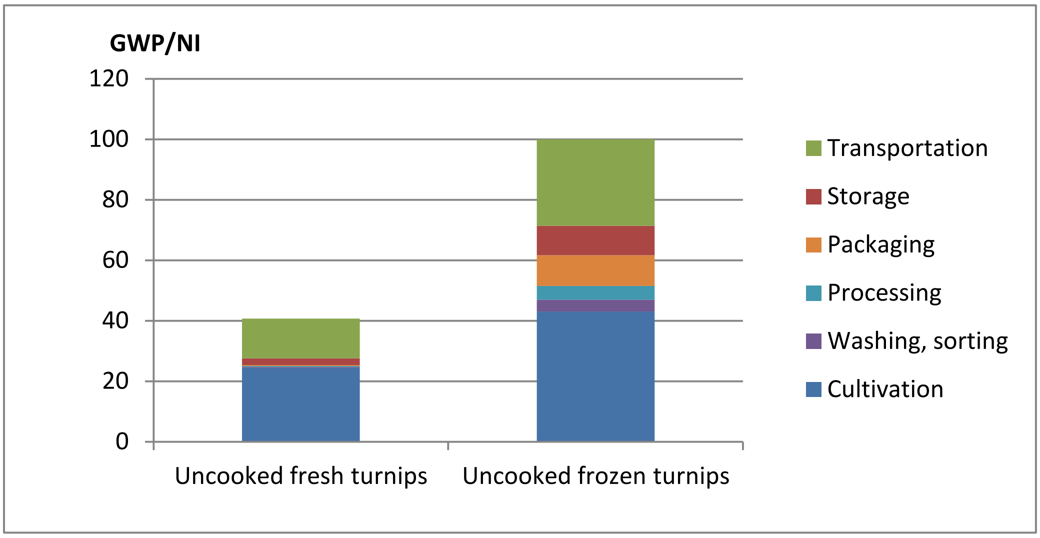

Figure 6. *GWP (g CO_2-eq/kg product at customer)/NI of fresh and frozen turnips in uncooked form.*

As for carrots, regarding fresh turnips the most dominating life cycle stage of GWP/NI is cultivation followed by transport, especially transportation to customers. Packaging and storage are also important life cycle stages.

5.3. Effect of storage time

GWP/kg product at customer was very similar between frozen carrots and turnips, and fresh carrots and turnips (Figure 7). Transportation was excluded from the figure in order to focus on the effect of storage, waste and cultivation. One of the reasons for the very noticeable difference between fresh and frozen products is because washing, sorting and packaging of fresh carrots and turnips takes place after long-time storage at processing plant, while processing and packaging of frozen carrots and turnips takes place before long-time storage. Therefore GWP of frozen products was tangibly higher than that of fresh products during the first six months.

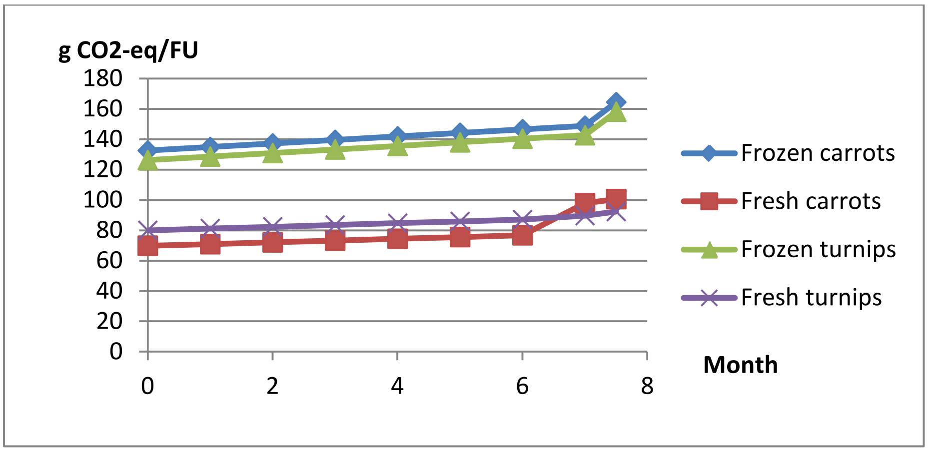

Figure 7. *GWP (g CO_2-eq)/kg product at wholesaler and storage time. The frozen products are cultivated, processed and packaged before storage from month 1 to 6, which is followed by storage at wholesaler and further on customers. The fresh products are cultivated and after that stored from month 1-6, which then is followed by processing, packing and storage at wholesaler and customers. Transportation is excluded.*

As shown in Figure 8 storage of frozen products had higher GWP/kg product at customer. The time of storage, including 2.7% waste/month of fresh carrots and turnips and no waste of frozen, had a minor impact on the total GWP. One month of freezing increased GWP with 2.34 g CO_2-eq/kg product at customer. One month of chilling (including 2.7% waste during this storage) increased GWP with 1.17 g CO_2-eq/kg product at customer.

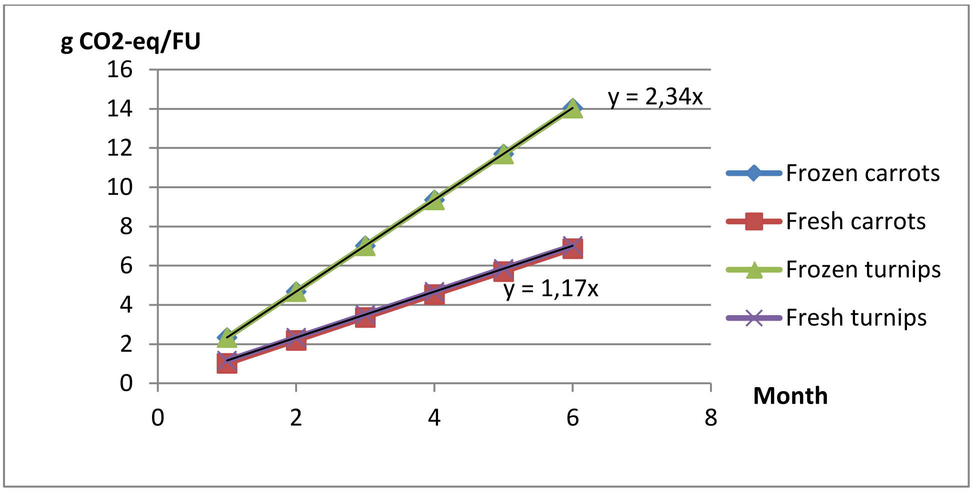

Figure 8. *g CO_2-eq/kg product at customer and storage time. Frozen carrots and turnips have higher GWP/kg product at customer compared to fresh.*

5.4. Sensitivity analysis

A sensitivity analysis (Table 9) was executed in order to examine whether there were any assumed or estimated parameters that were crucial for the results of the LCA and affect the total GWP. Sensitivity analysis of long-time storage (more than 1 month) was executed but not of short-time storage (1 month or less) since the latter has a low GWP/kg product and day. Sensitivity analysis of electricity mix (Table 10) and extreme values of waste (Table 11) was also executed. Further, altering the NI score with ± 20% changed GWP/NI with -20% to +22% on carrots and -17% to +25% on turnips.

Table 9. Sensitivity analysis of assumed and estimated parameters, consisting of ± 20% of each input parameter and the impact of each respective change (output value) in total GWP is shown in the table. The output values are truncated to closest 1 %

Input parameter	Fresh carrots		Frozen carrots		Fresh turnips		Frozen turnips	
	-20%	+20%	-20%	+20%	-20%	+20%	-20%	+20%
Vegetable/volume (kg/m^3)	0	0	+ 2	- 1	0	0	+ 2	- 1
Filling degree (%) of storage space at customer	0	0	+ 2	- 1	0	0	+ 2	- 1
GWP originating from cultivation	- 11	+ 11	- 8	+ 8	- 12	+ 12	- 9	+ 9
Electricity consumption (kWh/kg product and year)	- 1	+ 1	- 3	+ 3	0	+ 1	- 3	+ 3
Fuel consumption (m^3/year)	N/A	N/A	- 1	+ 1	N/A	N/A	- 1	+ 1
Waste at processing plant (%)	- 6	+ 8	- 3	+ 3	- 2	+ 2	- 3	+ 3
Long-time storage (days)[1]	0	0	- 1	+ 1	- 1	+ 1	- 1	+ 1
Distance factory- customer (km)	- 1	+ 1	- 1	+ 1	- 1	+ 1	- 1	+ 1
Corrugated cardboard/product (kg/kg)	- 1	+ 1	a	a	N/A	N/A	a	a
Waste at customer (%)	N/A	N/A	N/A	N/A	- 3	+ 4	N/A	N/A
Fuel consumption refrigeration aggregate (liter/hour)	- 2	+ 1	- 2	+ 1	- 2	+ 1	- 2	+ 1

a: Amount corrugated cardboard/kg product was not estimated or assumed.
N/A: Not applicable. The frozen products were assumed to have no waste at customers, while fresh cut carrots are used without further preparation, i.e. peeling
[1]*Industrial refrigerator (fresh products), bulk frozen warehouse (frozen products)*

Table 10. Sensitivity analysis of electricity mix. Output values (total GWP) are truncated to closest 1 %

	Fresh carrots	Frozen carrots	Fresh turnips	Frozen turnips
Swedish electricity mix	- 6	- 11	- 2	- 10
Nordic electricity mix	+ 12	+ 21	+ 4	+ 19

Table 11. Sensitivity analysis of extreme values of waste of each product. Output values (total GWP) are truncated to closest 1 %

	Fresh carrots	Frozen carrots	Fresh turnips	Frozen turnips
10 %	- 18[1]	- 7	- 4	- 7
20 %	-	-	+ 4	-
30 %	-	-	-	-
40 %	-	+ 18	-	+ 17
50 %	+ 20[1]	-	-	-

[1] *Concern 'regular' fresh carrots, not fresh cut carrots where the waste is stable at 35% during the year*
- Not applicable

6. DISCUSSION

6.1. Global warming potential

The production of fresh and frozen carrots and turnips differ in GWP, fresh carrots having the lowest GWP/NI followed by frozen carrots and fresh turnips. The frozen vegetables had a comparably high GWP and since turnips had low NI, frozen turnips had high GWP/NI. Thus carrots, and especially fresh carrots, are the best choice from an environmental and nutritional (bioavailability disregarded) content perspective, despite the fact that fresh carrots have a waste during time of storage. Consumers achieve more nutrients from carrots than from turnips for the same quantity of GWP. However, NI varies depending on pre- and postharvest factors (Selman, 1994; Howard *et al*. 1999; Albrecht *et al*. 1991; Klein & Perry, 1982). Thus the values presented in current study should only be considered as guidance regarding magnitude of GWP/NI and not as absolute values, especially since the sensitivity analysis showed that altering NI score ±20% substantially changed GWP/NI with -19% to +25%. NI and nutritional value of the specific products used in the processing plant would improve the quality of the study. Nevertheless since this study was based on average values (originating from a large database) regarding nutritional value, GWP/NI may be considered as quite stable. GWP/NI of frozen carrots and turnips is lower after cooking than before while fresh have comparable GWP/NI before and after cooking (Figure 14 and 15), but this could be have been affected by that GWP from cooking was not included whereas the nutritional value was increased or maintained during cooking. Further research on this is required.

The sensitivity analysis showed that (in descending order) electricity mix, GWP from cultivation and waste at processing plant are crucial parameters. Extreme values regarding waste at processing plant of frozen products varies a lot and was also shown greatly affect the result even though the quality demands of fresh carrots and turnips are higher. This may be related to large variation in waste of the products, except for fresh turnips where the variation was comparably low, as shown in Table 7 and 11. Lower quality demands on frozen vegetables might result in a larger variation in waste whereas the sorting of fresh cut carrots is more stringent with a high waste (35%) and ‘regular’ fresh carrots have a larger variation in waste compared to the frozen products.

The frozen products and fresh carrots were assumed not to become waste at customers and therefore the sensitivity analysis show that this parameter is not important for these products while it for fresh turnips was shown to be an important parameter. As shown in the results GWP of packaging is smaller for fresh turnips, which is due to the company using SRS crates which has a lower GWP compared to LDPE and corrugated cardboard.

Long-time storage increased GWP per month with about 2.3 g CO_2-eq/kg product at customers in bulk frozen warehouse and 1.2 g CO_2-eq/kg product at customers regarding industrial refrigerated warehouse. The difference is likely to be related to type of storage area during the long-time storage; closer to the consumer the energy efficiency is lower due to space of storage, turn-over of goods and number of doors/openings (Nilsson & Lindberg, 2011). It should also be noted that waste at processing plant differ a lot during the year (except for fresh cut carrots). It should also be noted that the energy consumption from production of fresh carrots only regards the processing, thus is likely to be too low, whereas the energy consumption of the other three products in this study was based on the total energy consumption.

This study shows that cultivation and transportation are important factor which is in line with Ligthart *et al*. (2005) of fresh carrots Lagerberg Fogelberg & Carlsson-Kanyama (2006). The comparably high GWP from transportation in current study can possibly be explained by that fuel consumption of refrigerator aggregate was included, since this was an important contribute in current study. Whether Lagerberg Fogelberg & Carlsson-Kanyama (2006) included impact of refrigerator aggregate during transport is unclear. Current study have results that are comparable with Lagerberg Fogelberg & Carlsson-Kanyama (2006) regarding the total GWP of frozen carrots; 0.267 kg CO_2-eq/kg frozen carrots at wholesaler compared to 0.244 kg CO_2-eq/kg frozen carrots at customers in current study. The values regarding fresh carrots were shown to be considerably higher in current study; 0.203 kg CO_2-eq/kg carrots at customers compared to 0.069 kg CO_2-eq/kg carrots at wholesaler. Thus, current study showed a smaller difference between fresh and frozen carrots, but when considering time of storage there is a greater difference which is in line with Lagerberg Fogelberg & Carlsson-Kanyama (2006).

This study was performed on carrots and turnips which are root vegetables that have a lower waste higher durability than salad vegetables during the same period of time (Modin, 2009; Swedish National Food Agency, 2011). This reduced the benefits with freezing of the former in comparison with the latter. Further research on vegetables that are more easily spoiled during time of storage is needed in order to investigate whether fresh or frozen vegetables are the best choice from an environmental and nutritional perspective.

6.2. Nutrition

In this study, a statistical analysis and nutritional content in relation to time of storage would have been beneficial, but since the USDA Nutrient Database for Standard Reference is compiled of many sources and only average values are presented in the database, it was not possible to accomplish. Published reports regarding nutritional value of fresh and frozen carrots and turnips in relation to time of storage could not be used as basis for calculations of NI since they were very limited. Further, since no statistical analysis could be accomplished it is unclear whether the differences in nutrient content and NI are significant, which is important to remember when reading the following discussion.

Since the USDA database is compiled from (most likely) a large quantity of data, variations and variability in analytical methods are not likely to have had a great impact on the values in the database. The data regarding turnips is likely to be more limited thus variations in analytical methods might have had an impact on the average value, in comparison with carrots. Variations in pre- and postharvest conditions such as cultivar (Selman, 1994), year of harvest (Howard *et al*. 1999) and storage time (Albrecht *et al*. 1991; Klein & Perry, 1982) is therefore also not likely to have had great impact. In relation to a single report/published research however, there might be a difference.

The portion size of turnips and carrots is equal (Swedish National Food Administration's food database, 2013), but is questionable whether the portion sizes are the same when the vegetables are cooked and how common it is to consume raw turnips in Sweden. Nutritional content of raw turnips may therefore be of less relevance for the consumer. Carrots on the other hand are consumed raw as well as cooked. It should also be noted that frozen vegetables are most likely to be consumed cooked, which is why the cooked vegetables are more relevant to investigate in future research. Frozen vegetables are typically stored several months and have smaller reduction in nutrient content (Favell, 1998), but (fresh) root vegetables such as carrots and turnips have a great storage capabilities (Modin, 2009) as shown in Table 3.

The difference in NI between fresh and frozen carrots and turnips in uncooked state is evident, but after cooking the difference is decreased in a beneficial way regarding the frozen products while fresh decrease or remain in NI. This could be explained by that i) heat treatment increase extractability of nutrients from vegetable matrix (Dietz *et al.* 1988; Khachik *et al*. 1992 as in van het Hof *et al*. 2000; Parada & Aguilera, 2007) which concern both blanching and cooking, ii) decrease cooking time of frozen in comparison with fresh vegetables (Favell, 1998) which decrease loss of water soluble vitamins (López-Berenguer *et al*. 2007), and iii) cell membranes being disrupted by ice crystal during the freezing process (Fellows, 2000) which increase extractability and solubility of nutrients hence also water soluble vitamins in cooking water being discarded. As shown in Table 4 and 5, this can also be related to remained/increased content of fat soluble vitamins during cooking, which can be related to β-carotene binding proteins being denaturated during heat treatment (van het Hof *et al*. 2000) such as steam blanching, resulting in facilitated extraction of β-carotene (Howard *et al*. 1999). Blanching was also shown to decrease content of water soluble nutrients in current study, in line with Fellows (2000). Company A is likely to have greater losses of vitamins, since they use hot water blanching and cool with running water, compared to a company using steam-blanching followed by cold-air or cold-water sprays.

The content of ascorbic acid in this study is probably not in line with Howard *et al*. (1999) which showed no significant difference between fresh and frozen carrots when cooked and uncooked, but this might be related to differences in cooking method. The tangibly lower content of vitamin C in frozen carrots and turnips might be related to ascorbic acid being hydrolyzed into 2,3-diketgulonic acid that has no vitamin C activity (Giannakourou & Taoukis, 2003), besides leakage into blanching water. Regarding frozen uncooked turnips it is unlikely that β-carotene is created under the processing into frozen turnips, considering that fresh turnips it was not possible to quantify β-carotene, thus might be related to the analytical method.

This study showed that cooking increase mineral content in frozen turnips (except calcium) and frozen carrots (except calcium and iron) while it decreases in fresh turnips and carrots. Calcium was shown to increase by cooking of fresh turnips. This might be related to the analytical method; HCl-extractability of calcium is increased by cooking/blanching (Yadav & Sehgal, 1995) or to the vegetables being cooked in hard water where calcium is added (Bergström, 1994). The decrease of mineral content can also be related to leakage of minerals into the cooking/blanching water, and peeling and cutting of the frozen products before blanching (Bergström, 1994). Increase of some minerals in frozen turnips during cooking could possibly also be related to the preparation method. It is also possible that some of the differences are not significant, which would comport with that minerals are unaffected by blanching and cooking (Watzke, 1998; Rickman *et al*. 2007a).

Increased extractability is relevant for the consumer since it improves bioavailability of vitamins (Parada & Aguilera, 2007). Heat treatment and disruption of the vegetable matrix increase both extractability and bioavailability and therefore the mentioned factors regarding heat treatment and disrupted matrix may be implied on bioavailability. However, interactions between nutrients and macromolecules in the gut may reduce or improve bioavailability of nutrients (Parada & Aguilera, 2007) and should be considered. Also, NI does not account for bioavailability which limits the use of these indexes, since bioavailability may be of greater importance than nutrient content for the general consumer.

This study show that regarding content of nutrients, the choice between fresh and frozen turnips before cooking is of greater importance than after cooking. With increased time of storage the nutritional quality of fresh carrots and turnips is reduced, possibly more than of frozen carrots and turnips. However, due to the blanching process frozen products have a lower nutritional content to begin with, making fresh carrots a better choice in this aspect.

6.3. Further research

During compilation of this thesis it became apparent that further research is required. Nutrition index with improved inclusion of limiting and qualifying nutrients and with accounting of bioavailability of nutrients is needed. Nutritional value in relation to time of storage, regarding both fresh and frozen product is also useful. Further research on GWP of storage and production in large-scale catering establishments and restaurants is needed since many of the published studies available today only concern wholesalers and retail. Lastly this study could be improved/complemented with research on vegetables that are easily spoiled and have lower storage capabilities compared to coarse vegetables, but that are sold both in unprocessed and semi-processed form, e.g. spinach and bell pepper.

7. CONCLUSION

Frozen carrots and turnips were shown to have lower nutritional content than fresh before cooking. After cooking the difference is decreased. GWP of frozen carrots and turnips was shown to be higher than for fresh carrots and turnips and the difference increase with time of storage. Fresh, uncooked carrots provide customers with the highest nutritional value for every g CO_2-equivalent generated during production of each product, followed by (in descending order) uncooked frozen carrots, uncooked fresh turnips and uncooked frozen turnips independent of cooked or uncooked state. From an environmental and nutritional perspective (with no consideration of bioavailability) fresh carrots are the best choice of the products examined in current study. However, uncooked fresh turnips are seldom consumed in Sweden while carrots are both consumed raw and cooked. Further research on vegetables that are more easily spoiled during time of storage is needed in order to investigate whether fresh or frozen vegetables are the best choice from an environmental and nutritional perspective. Further consideration of bioavailability of nutrients is also needed.

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Reference list

AEA. (2011). *2011 Guidelines to Defra / DECC's GHG Conversion Factors for Company Reporting*. Produced for the Department of Energy and Climate Change (DECC) and the Department for Environment, Food and Rural Affairs (Defra), version 1.0.

Alasalvar, C., Al-Farsi, M., Quantick, P.C., Shahidi, F., Wiktorowics, R. (2005). Effect of chill storage and modified atmosphere packaging (MAP) on antioxidant activity, anthocyanins, carotenoids, phenolics and sensory quality of ready-to-eat shredded orange and purple carrots. *Food Chemistry*, vol. 89, pp. 69-76.

Albrecht, J. A., Schafer, H. W., Zottola, E. A. (1991). Relationship of total sulfur to initial and retained ascorbic acid in selected cruciferous and noncruciferous vegetables. *Journal of Food Science*, (55) pp. 181-183.

Berström, L. (1994). *Nutrient Losses and Gains in the Preparation of Foods*. Swedish National Food Agency, Sweden: SLV. (SLV Report 1994: 32),

Björklund, Anna. E. (2002). Survey of Approaches to Improve Reliability in LCA. *International Journal of LCA Methodology*, vol. 7 (2), pp. 66-67.

Carlsson-Kanyama, A. (1998). Food consumption patterns and their influence on climate change: green house gas emission in the life-cycle of tomatoes and carrots consumed in Sweden. *Ambio*. Vol. 27, No 7, pp. 528-534.

Cumming, D.B., Stark, R., Chipman, E.W. (1977). A feasibility study on the production and processing of small, whole (prepeeled) rutabaga. *Canadian Journal of Plant Science*, vol. 58, pp. 175-178.

Davis, J., Wallman, M., SUnd, V., Emanuelsson, A., Cederberg, C., Sonesson, U. (2011). *Emissions of Greenhouse Gases from Production of Horticultural Products. Analysis of 17 products cultivated in Sweden*. SIK, Sweden: SIK. (SIK Report 828, pp. 37-38.

Dietz, J. M., Kantha, S., Erdman, J. W. (1988). Reversed phase HPLC analysis of α- and β-carotene from selected raw and cooked vegetables. *Plant Foods Human Nutrition*, vol. 38, pp. 333-341.

Drewnowski, A., Fulgoni III, V. (2008). Nutrient profiling of foods: creating a nutrient-rich food index. *Nutrient reviews*, vol. 66 (1) pp. 23-29.

Drewnowski, A. (2009). Defining nutrient density: Development and validation of the nutrient rich food index. *Journal of the American College of Nutrition*, vol. 28 (4) pp. 421-426.

Eriksson, M., Stridh, I., Hansson, P-E. (2012). Food losses in six Swedish retail stores: Wastage of fruit and vegetables in relation to quantities delivered. *Resources, Conservation and Recycling*, vol. 68, pp. 14-20.

European Commission Technical Report. (2006). Environmental impact of products (EIPRO): *Analysis of the life cycle environmental impacts related to the final consumption of the EU-25*. EUR 22284 EN, May 2006, pp. 17.

Favell, D.J. (1998). A comparison of the vitamin C content of fresh and frozen vegetables. *Food Chemistry*, vol. 62, No 1, pp. 59-64.

Fellows, P.J. (2000). *Food processing technology: principles and practice.* 2nd edition. Woodhead Publishing Limited, pp. 233-240, 418-440.

Fuentes, C., Carlsson-Kanyama, A., Biel, A., Bergström, K., Grankvist, G., Lagerberg Fogelberg, C., Shanahan, H., Solér, C. (2006). *Environmental information in the food supply chain*. Stockholm: FOI- Swedish Defence Research Agency (FOI report 2006: FOI-R-1903-SE), pp. 57-62.

Fulgoni, III, V. L., Keast, D. R., Drewnowksi, A. (2009). Development and validation of the Nutrient-Rich Foods Index: a tool to measure nutritional quality of foods. *The Journal of Nutrition*, vol. 139, pp. 1549-1554.

Giannakourou, M.C., Taoukis, P.S. (2003). Kinetic modelling of vitamin C loss in frozen green vegetables under variable storage conditions. *Food Chemistry*, vol. 83 (1), pp. 33-41.

George, R.M. (1993). Freezing processes used in the food industry. *Trends in Food Science & Technology*, vol 4, pp. 134-138.

Goedkoop, M., Oele, M. (2004). *SimaPro 6- Introduction to LCA with SimaPro*. Version 3.0.1. Pré Consultants, pp. 32.

Goldstein, B. (2006). *Miljövinster med att minska totala avfallsmängder: översiktlig analys*. For: Swedish Environmental Protection Agency. 26, 27, 39. (In Swedish)

Gustavsson, J., Cederberg, C., Sonesson, U., van Otterdijk, R., Meybeck, A. (2011a). *Global food losses and food waste: extent, causes and prevention*. Rome: Food and agriculture organization of the United Nations.

Gustavsson, J., Cederberg, C., Sonesson, U. (2011b). *Global food losses and food waste*. SIK, FAO. Presentation May 16.

Harden, C. (2010). Nutrition. In: Young, B., Evans, J., Martindale, W., Harden, C. *The British Frozen Food Federation- A Food Vision.* pp. 22-26.

Howard, L. A., Wong, A. D., Klein, B. P. (1999). β-carotene and ascorbic acid retention in fresh and processed vegetables. *Journal of Food Science*, vol. 64 (5) pp. 929-936.

Institution of Mechanical Engineers. (2012). *Global food: waste not, want not*, pp. 2-5.

Jensen, C., Stenmarck, A., Sorme, L., Dunso, O. (2011). *Matavfall 2010 från jord till bord*. Norrkoping: SMED (SMED Report 2011:99). (In Swedish)

Khachik, F., Goli, M B., Beecher, G. R., Holden, J., Lusby, W. R., Tenorio, M. D., Barrera, M. R. (1992). Effect of food preparation on qualitative and quantitative distribution of major carotenoid constituents of tomatoes and several green vegetables. *Journal of Agricultural Food Chemistry*, vol. 40, pp. 390-398.

Klein, B. P., Perry, A. K. (1982). Ascorbic acid and vitamin A activity in selected vegetables from different geographical areas of the United States. *Journal of food science*, vol. 47, pp. 941-948.

Konsumentföreningen Stockholm. (2009). *Rapport från en slaskhink*. (In Swedish)

Karlsson, R. & Carlsson-Kanyama, A. (2004). Food losses in food service institutions. Examples from Sweden. *Food Policy,* vol. 29 (3), pp. 203-213.

Karlsson, H. (2011). *Seasonal Vegetables: An Environmental Assessment of Seasonal Food*. Norwegian University of Life Sciences. Department of plant and environmental sciences (Master Thesis), pp. 20.

Kägi, T., Zschokke, M., Dinkel, F. (2012). *Nutrient based functional units for meals*. 8th conference on LCA in the agri-food sector, 1-4 October 2012, pp. 378-382.

Lagerberg Fogelberg, C. (2008). *På väg mot miljöanpassade kostråd: Vetenskapligt underlag inför miljökonsekvensanalysen av Livsmedelsverkets kostråd*. Swedish National Food Agency, Sweden: SLV. (SLV Report 2008: 99), pp. 40. (In Swedish)

Lagerberg Fogelberg, C. & Carlsson-Kanyama, A. (2006*). Environmental assessment of foods- an LCA inspired approach*. In: Fuentes, C., Carlsson-Kanyama, A., Biel, A., Bergström, K., Grankvist, G., Lagerberg Fogelberg, C., Shanahan, H., Solér, C., *Environmental information in the food supply chain*. Stockholm: FOI- Swedish Defence Research Agency (FOI report 2006: FOI-R-1903-SE), pp. 57-62.

Ligthart, T.N., Ansems, A.M.M., Jetten, J. (2005). *Eco-efficiency and nutritional aspects of different product-packaging systems; an integrated approach towards sustainability*. Netherlands: TNO (TNO Report 2005:232)

López-Berenguer, C., Carvajal, M., Moreno, D. A., García- Viguera, C. (2007). Effect of microwave cooking conditions on bioactive compounds present in broccoli inflorescences, *Journal of Agricultural Food Chemistry*, (55) pp. 10001-10005.

Loxbo, H. (2011). *Hållbar konsumtion av jordbruksvaror: Matsvinn- ett slöseri med resurser?* Sweden: Jordbruksverket (Jordbruksverket Report 2011:20), pp. 21. (In Swedish)

Manchester Food Research Centre. (2010). *Cost, waste and taste comparison of frozen food versus fresh food in a consumer market: Project carried out by the Manchester Food Research Centre on behalf of British Frozen Food Federation.*

Modin, R. (2011). *Livsmedelssvinn i hushåll och skolor- en kunskapssammanställning*. Swedish National Food Agency, Sweden: SLV. (SLV Report 2011: 4). (In Swedish)

Muñoz, I. (2007). *Life Cycle Inventory (LCI): Modelling for retail to plate operations.* In: Milá i Canals, L. *LCA Methodology and Modelling Considerations for Vegetable production and Consumption*. United Kingdom: CES-Centre for Environmental Strategy, (CES Working Paper 2007:02), pp. 23.

Nilsson, K., Lindberg, U. (2011). *Klimatpåverkan i kylkedjan- från livsmedelsindustrin till konsument*. Swedish National Food Agency, Sweden: SLV. (SLV Report 2011: 19). (In Swedish)

Parada, J., Aguilera, J.M. (2007). Food Microstructure Affects the Bioavailability of Several Nutrients. *Journal of Food Science*, vol. 72 (2), pp. 21-32.

Rickman, J.C., Bruhn, C.M., Barrett, D.M. (2007a). Review: Nutritional comparison of fresh, frozen and canned fruits and vegetables II. Vitamin A and carotenoids, vitamin E, minerals and fiber. *Journal of the Science of Food and Agriculture*., vol. 87, pp. 1185-1196.

Rickman, J. C., Barrett, D. M., Bruhn, C. M. (2007b). Review: Nutritional comparison of fresh, frozen and canned fruits and vegetables. Part 1. Vitamins C and B and phenolic compounds. *Journal of the Science of Food and Agriculture*, vol. 87, pp. 930-944.

Roy, P., Nei, D., Orikasa, T., Xu, Q., Okadome, H., Nakamura, N., Shiina, T. (2009). A review of life cycle assessment (LCA) on some food products. *Journal of Food Engineering*, vol. 90 (1), pp. 1-10.

Röös, E. (2012). *Mat- klimat-listan: version 1.0*. Uppsala: Swedish University of Agricultural Sciences (SLU Report 2012:040) (In Swedish)

Saarinen, M. (2012). *Nutrient in LCA: Are nutrition indexes worth using?* 8th conference on LCA in the agri-food sector, 1-4 October 2012, pp. 378-382.

Selman, J.D. (1994). Vitamin retention during blanching of vegetables. *Food chemistry*, vol. 49, pp. 137-147.

Sonesson, U., Davis, J., Ziegler, F. (2010). *Food production and emissions of greenhouse gases: An overview of the climate impact of different product groups*. Gothenburg: SIK (SIK report, 2010: 802).

Svenska Returssystem. (2013). *Hållbarhetsredovisning 2012*. pp. 7. (In Swedish)

Swedish Environmental Protection Agency. (2010). *The climate impact of Swedish consumption*. Stockholm: Swedish Environmental Protection Agency. (Rapport 5992).

USDA- U.S. Department of Agriculture (2012). *USDA National Nutrient Database for Standard Reference*. Release 25. Agricultural Research Service, pp. 1.

van het Hof, K. H., West, C. E., Westrate, J. A., Hautvast, J. G. A. J. (2000). Dietary factors that affect the bioavailability of carotenoids. *The Journal of Nutrition*, vol. 130 (3), pp. 503-506.

Wallman, M., Nilsson, K. (2011). *Klimatpåverkan och energianvändning från livsmedelsförpackningar*. Swedish National Food Agency, Sweden: SLV. (SLV Report 2011: 18). (In Swedish)

Watzke, H.J. (1998). Impact of processing of bioavailability examples of minerals in foods. *Trends in Food Science & Technology*, vol. 9 (8-9), pp. 320-327.

Weisser, D. (2007). A guide to life-cycle greenhouse gas (GHG) emissions from electric supply technologies. *Energy*, vol. 31 (9), pp. 1543-1559.

Wills, R., McGlasson, B., Graham, D., Joyce, D. (2007). *Postharvest*. 5th edition, CABI, pp. 23, 110, 201.

Winther, U., Ziegler, F., Skontorp Hognes, E., Emanuelsson, A., Sund, V., Ellingsen, H. (2009). *Carbon footprint and energy use of Norwegian seafood products*. Norway: SINTEF (SINTEG Report 2009: SFH80 A096068), pp. 39.

Yadav, S.K., Sehgal, S. (1995). Effect of home processing on total and extractable calcium and zinc content of spinach (*Spinach oleracia*) and amaranth (*Amaranthus tricolor*) leaves. *Plant Foods for Human Nutrition, vol. 48, pp. 65-72.*

Internet sources

Bureca: Butik, Restaurang och caféutrustning. (2010a). *Frysrum F 1530 + frysagg. ATB 202.* http://www.bureca.se/sw/details_3604.html [2013-05-15]

Bureca: Butik, Restaurang och caféutrustning. (2010b). *Kylrum K 1522 + kylagg. ATN 050.* http://www.bureca.se/sw/details_3581.html [2013-05-15]

Center for Nutrition Policy and Promotion USDA. (2013-03-22). *Healthy Eating Index.* http://www.cnpp.usda.gov/healthyeatingindex.htm [2013-05-21]

Curran, M.A. (2013). Life Cycle Assessment: a review of the methodology and its application to sustainability. *Current Opinion in Chemical Engineering* (in press). http://dx.doi.org/10.1016/j.coche.2013.02.002

Gross K.C, Wang C.Y, Saltveit M. (2004a*). Agricultural Handbook Number 66 -The Commercial Storage of Fruits, Vegetables, and Florist and Nursery Stocks*. USDA (United States Department of Agriculture): ARS (Agricultural Research Service). http://www.ba.ars.usda.gov/hb66/contents.html. [2013-03-24]

Gross K.C, Wang C.Y, Saltveit M. (2004b*). Agricultural Handbook Number 66 -The Commercial Storage of Fruits, Vegetables, and Florist and Nursery Stocks*. USDA (United States Department of Agriculture): ARS (Agricultural Research Service). http://www.ba.ars.usda.gov/hb66/140turnip.pdf [2013-05-17]

Findus. (2010a). *Sommargrönsaker*. http://www.findus.se/produkter/gronsaker/basgronsaker/sommargronsaker/ [2013-08-04] (In Swedish)

Findus. (2012b). *Rotfrukter perfekta till soppa & gryta*. http://www.findus.se/vara-produkter/rotfrukter-perfekta-till-soppa-och-gryta/ [2013-08-04] (In Swedish)

Magnihill. (2013). *Produktion*. *Flödesschema*. http://magnihill.se/produktion/ [2013-05-01] (In Swedish)

Nyskördade morötter. (2012a). *Fodermorötter*. http://www.nyskordade-morotter.se/info/index.php/fodermorotter [2013-04-11] (In Swedish)

Nyskördade morötter. (2012b). *Morotsåret*. http://www.nyskordade-morotter.se/info/index.php/aktuellt [2013-04-11] (In Swedish)

Nyskördade morötter. (2012c). *Miljö*. http://www.nyskordade-morotter.se/info/index.php/miljo2 [2013-04-11] (In Swedish)

Nyskördade morötter. (2012d). *Produkter*. http://www.nyskordade-morotter.se/info/index.php/produkter [2013-04-11] (In Swedish)

Nyskördade morötter. (2012e). *Företaget*. http://www.nyskordade-morotter.se/info/index.php/foeretaget [2013-08-08] (In Swedish)

Svenska Kraftnät. (2013). *Elstatistik för hela Sverige*. http://www.svk.se/Energimarknaden/El/Statistik/Elstatistik-for-hela-Sverige/ [2013-08-01] (In Swedish)

Svenska Retursystem. (2013). *Our products*. http://www.retursystem.se/en/our-products/ [2013-05-13]

Swedish National Food Administration. (2011-08-08). *Fruits and berries, vegetables and legumes*. http://www.slv.se/en-gb/Group1/Food-and-environment/Eco-smart-food-choices/Fruits-and-berries-vegetables-and-legumes/ [2013-02-11]

Swedish National Food Administration. (2013-08-02). *Swedish National Food Administration's reference database*, [2013-05-30]

U.S. Energy Information Administration. (2013-02-14). *Carbon Dioxide Emissions Coefficients.* http://www.eia.gov/environment/emissions/co2_vol_mass.cfm [2013-05-23]

USDA- U.S. Department of Agriculture, Agricultural Research Service. (2011-12-07). *USDA National Nutrient Database for Standard Reference*, Release 25. Nutrient Data Laboratory Home http://www.ars.usda.gov/ba/bhnrc/ndl [2013-04-07]

VRIC- Vegetable Research & Information Center. (2012- 02-15). *Postharvest Handling Systems: Underground vegetables (roots, tubers and bulbs).* University of California Cooperative Extension. http://vric.ucdavis.edu/postharvest/undergnd.htm [2013-04-27]

Widegrens Gård (2013). *Morotsodling i bilder.* http://www.widegrens.se/bilder.pab [2013-03-16] (In Swedish)

Personal messages

Alameri, A. (2013). CEO. Bureca: Butik, Restaurang och Caféutrustning. 2013-05-15.

Fritiof, Carl-Erik. (2013). CEO. Haverlands Gård. 2013-05-11.

Nilsson, Pål. (2013). CEO. Nyskördade morötter, Lyckås Gård. 2013-04-05, 2013-05-10.

Appendix 1. GWP/NI

Detailed bar diagrams of global warming potential/nutrition index (g CO_2-eq/kg product at customer)/NI (DW basis) are shown in Figure 14 and 15. Note that GWP from cooking was not included in current study hence GWP/NI of cooked root vegetables is likely to be greater.

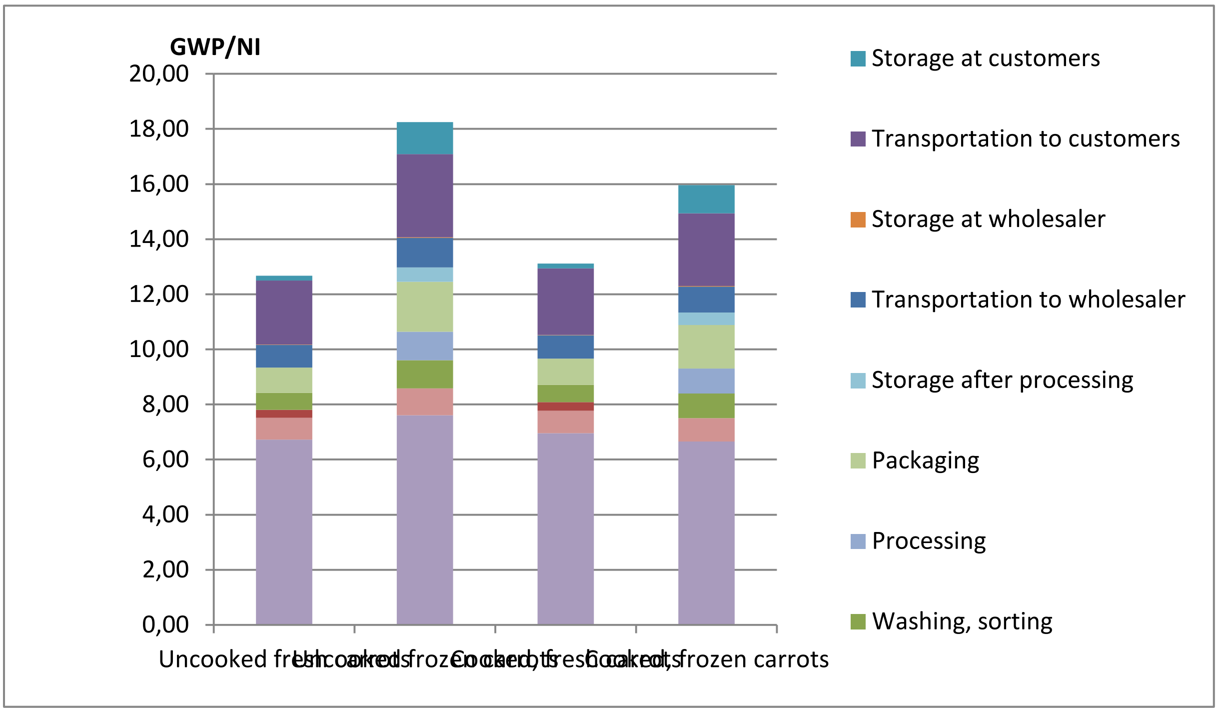

Figure 14. *GWP (g CO2-eq/kg product at customer)/NI of carrot production. Note that GWP of cooking is not included in current study hence GWP/NI is likely to be higher.*

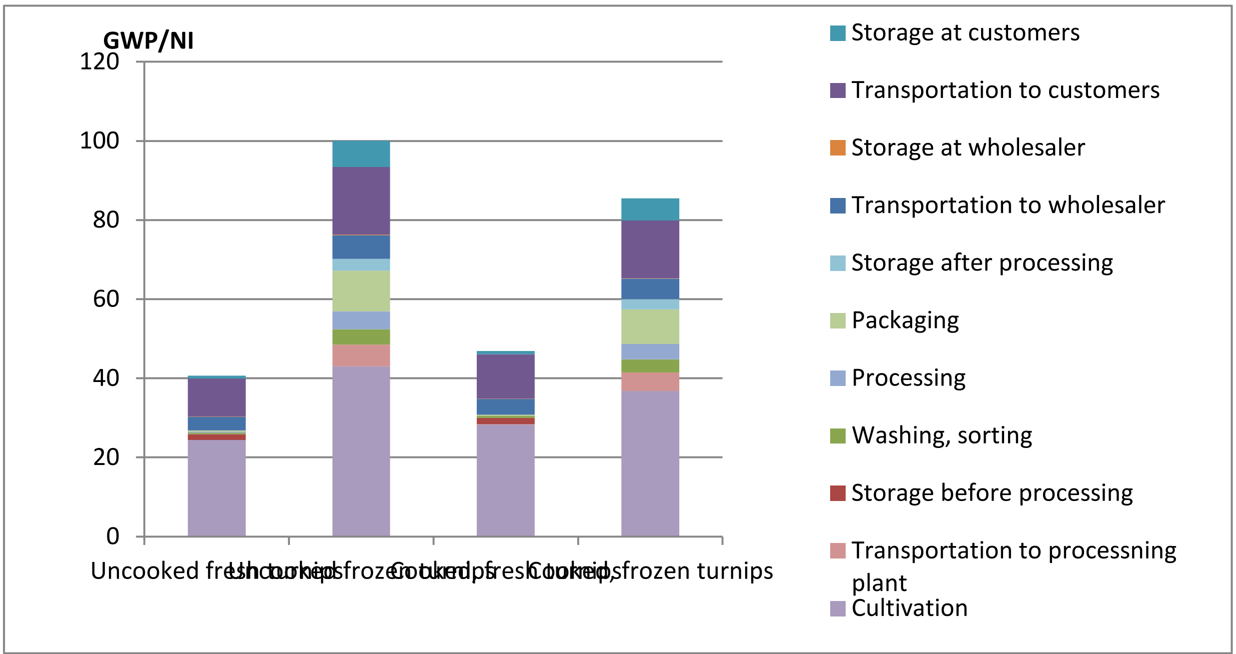

Figure 15. *GWP (g CO2-eq/kg product at customer)/NI of turnip production. Note that GWP of cooking is not included in current study hence GWP/NI is likely to be higher.*

Appendix 2. Energy mix

In the calculations in the LCA in this study Nordic energy mix is applied, but a sensitivity analysis of energy mix was also executed. Swedish energy mix has a GWP of 40 g CO_2-eq/kWh (Table 10). With import the GWP is around 91 g CO_2-eq/kWh. Nordic energy mix (the five Nordic countries) has a GWP of 190 g CO_2-eq/kWh. (Nilsson & Lindberg, 2011)

Table 10. GWP of three energy mixes

Energy mix	GWP (kg CO2/kWh)
Swedish	0.040
Swedish with import[1]	0.091
Nordic countries[2]	0.190

[1] Denmark, Finland, Poland, Norway, Germany (Svenska Kraftnät, 2013)
[2] Sweden, Norway, Denmark, Finland, Island

Appendix 3. Preparation waste

In order to measure how much waste that is created when carrots are peeled, carrots were peeled according to below and waste in percentage calculated on weight basis (Table 11).

Total 5 kg carrots were peeled. The weight of 1 kg carrot packages was measured before and after peeling and the waste calculated. During the peeling, peel and 0.2- 0.5 cm of the end of the carrot (where the haulm has been attached) was removed. Black spots and blemishes were also removed. Average waste due to peeling was calculated to 13.49%.

Table 11. Preparation losses caused by peeling and removal of end of the carrots, based on weight of 1 kg carrot packages before and after peeling

	Weight before peeling (g)	**Weight after peeling (g)**	**Waste (%)**
Sample 1	987.0	850.7	13.81
Sample 2	1011.2	876.8	13.29
Sample 3	1001.0	877.5	12.34
Sample 4	994.6	854.5	14.09
Sample 5	1012.9	872.1	13.90

Appendix 4. Interviews

4.1. Interview person X, company A, 2013-02-27

Is everything produced in Sweden? Where? How large distances does it involve?
The production takes place in Sweden and Denmark. It takes about an hour by truck, equal to about 150 km.

What happens with the haulms after harvest? Is it ploughed down or does it become animal feed?
It is ploughed down.

Do you have any waste in the process of freezing?
No, we have no waste in the freezing process. The vegetables are glazed during the process which is beneficial in this aspect.

All sizes and broken carrots to different cuttings, what does it mean?
The carrots are diced, cut and shredded in different cuttings.

The waste during washing, does it only involve the crop or is soil, sand and rocks included?
Bad carrots are sorted away and become animal feed. We are working on becoming self-sufficient on energy through biogas and are planning on building our own biogas facility where the waste can be used. Hopefully this plan is completed next year.

Concerning transportation, how is the products transported? Do Magnihill transport everything, or does the wholesaler or other customers transport the products themselves?
50% is transported by the customers who use their own trucks/cars/transportation. 50% is transported in our own trucks. The road carrier use gas trucks and cars and drive environmentally friendly.

"Harvest carrots at right taste and nutritional value"? What does it mean? Has it been measured?
We have not taken any samples on the nutritional value. We let the carrots grow until they are mature and then harvest. Harvest before maturity is common with fresh. You can compare it to the production of bananas which are green at harvest, transported and mature closer to destination.

What about data on you energy consumption/produce?
We don't have the energy consumption/produce and we have not measuring instruments on every device so we don't know how much each instrument in the plant consumes in energy. We do have information on daily basis, but not for the products. I can delegate this to my head of production that can have a look at it if necessary.

4.2. Mail conversation company A, 2013-01-29 – 2013-04-29

The flow chart presented by company A is shown in Figure 16.

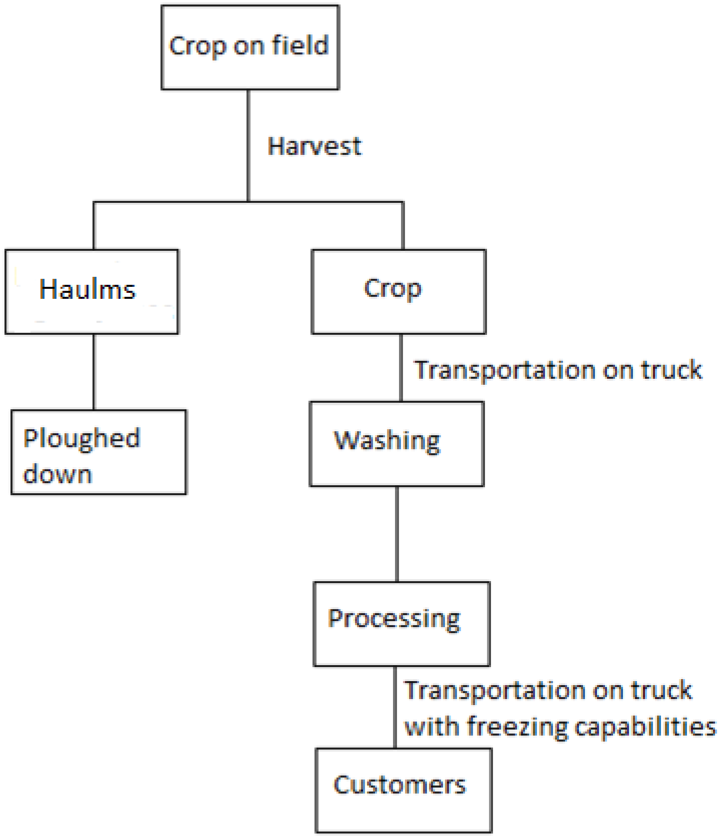

Figure 16. *Flowchart on production of frozen carrots and turnip.*

Transportation of crop is done on open trucks and of different size with freezing capabilities to customers. The crop is washed with water without additives. Customers are the food industry, wholesale and restaurants, and some private consumers. Remaining sand, soil, stones, rotten carrots, broken carrots with stones in it, are removed during washing and sorting causing a waste. During the processing there is also a waste, mainly due to peeling (Table 12). The waste from the processing at the factory is given away for free to farmers. The waste may vary between 10 and 40% under the year.

Table 12. Waste (%) of carrots and turnip during washing and sorting at processing plant

	Waste during washing (%)	Waste during processing (%)
Carrots	5-15	10-15
Turnip	5-15	10-15

Carrots and turnip that will be frozen are harvested at right time, right flavor and nutritional value. All sizes and broken carrots are used for different cuttings. Fresh carrots on the other hand are harvested to keep fresh as long as possible and carrots of wrong size, broken or crooked are not used.

When the products are frozen they are transported with trucks with freezing capabilities (-18°C) and not chilled trucks. The products are transported directly to industrial customers or wholesalers (which further transport to hospitals, schools etc.) or to retailers, but always with transportation with freezing trucks/cars of varying sizes. During the freezing process the company use hot water for blanching and flow freezer (fluidization process for individual quick freezing, IQF).

The electricity consumption is 3 000 000 kWh/year which is used for sorting, washing, packaging and storage of the products. The company also consumes fuel oil (250-300 m^3/year) which is used for the processing of the products.

The company produces frozen potatoes, turnips, celery, parsnips, beetroot, Jerusalem artichoke and so called “polka beet” (type of beetroot). The company also import frozen vegetables to the Swedish market. They handle around 12 000 ton in the freezer and produce 4500- 5000 ton a year whereof 1000 ton is frozen carrots and 500 ton frozen turnip. The share of the stored carrots and turnips is equal to the share of production. All products in the production of their 4500 ton are packaged in plastic bags (LDPE) or in 450 kg bulk. Around 7000 ton is products packaged in plastic bags and cardboard before transportation to customers.

The harvest of carrots takes place during the autumn and 80% is produced directly and the remaining 20% is stored in cold storage at Magnihill until Jan-Mar when they are processed. All carrots and turnip are sorted at Magnihill.

4.3. Interview Pål Nilsson, Nyskördade morötter, Lyckås Gård, 2013-04-05

What are the quality criteria on fresh carrots? What carrots are sorted away?
Carrots are sorted by the diameter of the base (so called ‘*nackdiameter*’), depending on what product it will become. The most common diameter used is 20-45 mm. Nonstandard carrots are sorted away; branched, broken, with spots, fractured and carrots with stones in them.

Approximately how large is the waste during washing and sorting?
About 20% and the size dependent sorting constitute only a small part of this. The largest waste is nonstandard carrots.

Does the waste differ anything during the year?
The waste of the fresh cut carrots 35% while the other carrots (regular consumer packages) have a 20% waste. The waste of the latter varies a lot during the year; from 10% during the summer to 30-35%, or even as high as 50% during the winter. The waste of cut carrots is quite stable around 35% during the year.

Concerning storing of carrots, are they stored washed and sorted or unwashed an unsorted?
They are stored unwashed and unsorted. However, the major part of carrots are stored un-harvested at the field under a large cover of straw and are gradually harvested during the year. This harvest takes place 11 months a year. Storing of unwashed and unsorted carrots is thus not the most common in our company. No waste in this storing.

Do you have any waste in the storing area?
We have three storing areas and since we wash and sort carrots against orders which then is directly transported to our customer, we have no waste in this step.

It might be difficult to answer now over the phone, but do you have any numbers on your energy consumption for washing and sorting?
No, not for washing and sorting. At our homepage, under environment, there are numbers on our total energy consumption. We have a production of 20,000 ton a year.

How much does a 10 kg plastic bag cost to purchase?
The cut fresh carrots sold in 10 kg plastic bags are sold to for 8.60 SEK/kg.

4.4. Interview Carl-Erik Fritiof, Haverlands Gård 2013-08-05

How does the flow chart look like?
The haulms are crushed and ploughed down and are used as nutrient on the field. The turnips are transported by means of tractor and trailer. The turnips are cooled down and stored before processing, but the time of storage depends on when during the year they are harvested. During the autumn the storage might be only one day, and from October and onwards it may be longer. What was stored during October is in yet in storage [May, 2013], so about 5-6 months or even 7. The turnips delivered during the autumn (before October) is only stored one or a few days.

How are the turnips washed?
The turnips are sorted and washed in tap water in a drum.

How far is the distance between harvest and processing plant?
About 5 minutes, meaning 2 km. It differs a bit.

About the waste, how much waste do you have?
The waste during sorting is about 15% a year. Less during the autumn (10%) and more during the spring (above 20%).

What is sorted away?
The turnips that are rotten and/or bad are sorted away.

How are the turnips stored and in what quantities?
They are stored in plastic crates that contain 12 or 6 kg.

How long are the turnips stored after processing, at processing plant?
The turnips are delivered to the customer directly after packaging, the same day.

What happens with the waste of turnips from the processing plant?
The turnips that are sorted away are transported by means of conveyor belt to the neighboring farm, crushed into animal feed and given to cows. The neighbor achieves this for free in return for taking care of and handling the waste.

How much energy do you consume a year?
The energy consumption is 150,000 kWh/year in the production.

Do you produce anything else?
No, we only produce turnips.

Appendix 5. Calculations

5.1. Packaging material

Plastic material (LDPE)
Frozen carrots: 154 g LDPE/25 kg product = 6.16 g LDPE/kg product
Fresh carrots: 6.16 g LDPE x 10 kg product = 61.6 g LDPE/10 kg product

Corrugated cardboard
Frozen carrots: 0.310 kg corrugated cardboard/10 kg product = 0.031 kg corrugated cardboard/kg product
Fresh carrots: 2 kg corrugated cardboard/200 kg product/pallet = 0.01 kg corrugated cardboard/kg product

5.2. Storage

Fresh carrots and turnips were assumed to be stored in cooling rooms (only) at restaurants and large-scale catering establishments. Frozen carrots and turnips were assumed to be stored in cold chamber (only). Calculations regarding energy consumption were based on the parameters shown in Table 13. Carrots and turnips were assumed to have the same density as potato; 1.3 liter/kg and 769.2 kg/m^3 according to Muñoz (2007).

Table 13. Parameters used for calculations of energy consumption of storage at customers

	Cooling room	Cold chamber
Volume (m^3)	6.29	7.28
Energy consumption (kW)	0.71	1.46
Assumed filling degree (%)	30	55
Storage time (days á year)	365	365

Further assumptions regarding the storing are listed below.

- There is place for standing inside the cooling room and cold chamber.
- There is room for two four level shelves in both storage areas for stacking of the products.[25]
- Cold chambers have a greater filling capacity compared to cooling rooms since frozen products may be (and commonly are) packaged tighter together than fresh products.
- No other products are stored in the storage space, which is highly unlikely, but this was very difficult to estimate appropriately since it varies a lot depending on the customer and how much of the product the company store and use on a yearly basis.
- As for the GWP calculated by Nilsson & Lindberg (2011) Swedish electricity mix, including import was used in the calculations.
- The filling degree was assumed to be 30% and 55%, respectively. This is however a very rough estimation.

Filling degree
Cold chamber: 55% x 7.28 m^3 = 4 m^3 769.2 kg/m^3 x 4 m^3 = 3079 kg
Cooling room: 30% x 6.29 m^3 = 1.9 m^3 769.2 kg/m^3 x 1.9 m^3 = 1451 kg

[25] Alameri, pers. comm. 2013

Energy consumption
Cold chamber: 1.46 kW x 365 days x 24 h = 12,800 kWh/year
(12,800 kWh/year / 3079 kg) / storage time = 0.011 kWh/kg product and day

Cooling room: 0.71 kW x 365 days x 24 h = 6,200 kWh/year
(6,200 kWh/year / 1451 kg) / storage time = 0.012 kWh/kg product and day

GWP
Cold chamber: 0.091 kg CO_2/kWh x 0.011 kWh/kg product and day = 1.07 g CO_2/kg product and day
Cooling room: 0.091 kg CO_2/kWh x 0.012 kWh/kg product and day = 1.04 g CO_2/kg product and day

5.3. Total energy consumption company A[26]

The equations used were based on information achieved from company A and designed by the author of current study.

Electricity consumption was calculated according to:

((A/B) x D)/F = G

A: Production of the product (kg)
B: Total production and stored product (kg)
D: Total energy consumption (kWh/year)
F: Total production (storage included) of product per year (kg/year)
G: Electricity consumption (kWh/kg product and year)

Fuel consumption was calculated according to:

(L X 1000 x N x Q x share of production) / total product produced x Z = Y

L: Consumption fuel oil (m^3/year)
N: Coefficient, converting liter to gallons
Q: 10.2 kg CO2/gallon
Y: Climate impact (kg CO2-eq/kg product produced)
Z: Carbon equivalents, coefficient (12/44)

[26] Company A, pers. comm. 2013

Appendix 6. Popular scientific abstract

The aim of this Master's thesis was to investigate if frozen carrots and turnips were a better choice for restaurants and large-scale catering establishments than fresh carrots and turnips. This when considering how environmental impact (limited to global warming potential) of production, processing, transportation and storage, of the root vegetables as well as nutritional content. The results showed that fresh carrots were the best choice, followed by fresh turnips and frozen carrots. Frozen turnips were not a good choice when considering environmental impact and nutritional content. This is due to a low content of nutrients in turnips, especially compared to carrots that have a high content of carotene (converted into vitamin A when ingested). However, turnips and carrots are root vegetables with good storage capabilities, likely low waste during storage and good retained content of nutrients. The results also showed that frozen carrots and turnips had a lower content of nutrients than fresh in uncooked state which is caused by the blanching prior to the freezing process. After cooking the difference between frozen and fresh was decreased. It should also be noted that frozen vegetables are likely to be consumed cooked, which is why the cooked vegetables are more relevant to investigate in future research.

The background of the thesis was that food production contributes to environmental impact in many ways and is of great concern because it is related to every customer in the world. The environmental impact of food production originates from the farm, and when the food is transported between and stored in the different steps of the food chain. Furthermore processing of the food contributes to the environmental impact. There is also waste created in many steps of the food chain, varying from waste during sorting at farm and processing plant, to waste during storage due to reduced quality of the product (e.g. becoming rotten) and waste during preparation and consumption. The resources used for producing the specific food becoming waste are used in vain and could have been saved or used elsewhere. Hence food waste does not only concern the actual food being wasted but also waste of resources (land, water and energy) used for transportation, cultivation, storage and processing of the food being wasted. Further on, a majority of the waste in restaurants and large-scale catering establishments is related to vegetables and fruits. It may be assumed that frozen vegetables have a lower waste than fresh at consumer stages since the frozen vegetables are ready-to-use while the fresh root vegetables commonly require some preparation, such as peeling at consumer stages. The content of nutrients in the food is also altered during the different steps of the food chain both before and after harvest. After harvest the content of nutrients in food is affected by for example processing technique, time of storage and how the products are prepared before consumption. When relating environmental impact and content of nutrients it was interesting to investigate whether fresh or frozen root vegetables provided consumers with highest content of nutrients for every g of CO_2-eq generated during production of the vegetables.

The study was based on a Life Cycle Assessment (LCA) which is a tool that is used to measure environmental impact of a product or process from 'cradle-to-grave'. In this study this means that the environmental impact from cultivation of the carrots and turnips, transportation, storage, processing, packaging and sorting was measured and calculated. The environmental impact was limited to global warming potential (GWP) which also can be called carbon-foot print. GWP is a relative measure of how much heat greenhouse gases (carbon dioxide, methane, nitrous oxide and ozone) traps in the atmosphere. These gases contribute to an increased temperature and thereby affect the climate in a non-beneficial way.

The waste in each step was also accounted for. Fresh and frozen root vegetables had a comparable total waste, but all the waste of the frozen was created at farm and processing plant. The waste of fresh carrots and turnips were created in almost every step, at farm, at processing plant, during storage and prior to consumption.

The content of nutrients was measured by nutrient index that quantifies an average share (%) of how much nutrients 100 g of a product contains in relation to daily nutrient recommendation (how much of the nutrients that should be consumed per day) of the nutrients. The nutrient index did only include nine nutrients so the carrots and turnips contain more nutrients than considered in this study. Another drawback with nutrient index is that it does not account for the bioavailability of nutrients in food, which is more relevant from a consumer perspective than the content of nutrients.

Vegetables with lower storage capabilities with a possibly greater waste and reduction in content of nutrients, such as tomatoes or spinach, might have been more interesting to investigate. Complementary research on these types of vegetables that are more easily spoiled during time of storage is needed in order to investigate whether fresh or frozen vegetables in general are the best choice from an environmental and nutritional perspective.