CHALMERS

Environmental Potential of Increased Human Consumption of Grain Legumes

An LCA of food products

Master of Science Thesis in the Master Degree Programme,
Automation & Mechatronics

ANDERS ABELMANN

Department of Energy and Environment
Division of Environmental Systems Analysis
CHALMERS UNIVERSITY OF TECHNOLOGY
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Preface

This report is a master thesis carried out within the Masters Degree Programme of Automation & Mechatronics at Chalmers University of Technology in Gothenburg, at the Division of Environmental Systems Analysis, Department of Energy and Environment, under supervision of the examiner, associate Professor Björn Sandén.

The work has been carried out at the Swedish Institute of Food and Biotechnology (SIK AB), where Dr. Jennifer Davis, researcher, and Dr. Ulf Sonesson, senior researcher, have been main and assistant supervisors, respectively.

I would like to thank my advisors and my examiner; the people at Swedish Meats; and my co-workers at SIK for help and encouragement during my work with this report. I would also like to thank my family for their never ending support.

Göteborg, November 2005

Anders Abelmann

Abstract

The environmental potential of an increased human consumption of grain legumes has been assessed using life cycle assessment (LCA). The product type that has been studied is a sausage, and three variants with different protein mix were included in the study: an animal product, an animal product with some vegetable protein, and a fully vegetarian product. The animal product is based on the "Hot Dog", manufactured by Swedish Meats in Örebro, Sweden. Site-specific data for the sausage factory have been obtained from that facility. The other recipes have been created using recipe software. The functional unit in the study is "one kg sausage prepared and eaten in a household". The protein content is equal for all three products. Two scenarios were set up; one where 10% of the animal protein was substituted for a vegetable alternative; and one where a fraction of the sausages consumed was substituted for a vegetable product.

Two kinds of vegetable proteins have been studied, soy and pea. The reason for including soy is that no commercial pea product was found. Raw material and energy use, emissions, and waste data were collected for involved materials and processes. Chosen impact categories were: global warming potential (GWP), acidification, and eutrofication. The net energy input to each product was also calculated, as well as land use, expressed in m^2.

The environmental impact of vegetable protein production is less than 10% of the impact of animal protein production in all categories. The impact of pea protein is lower than the impact of soy protein. However, the substitution of 10% pea protein for animal protein in the hot dog only resulted in a decreased impact of about 5% due to a simultaneous change of recipe. To maintain certain characteristics of the Hot Dog the proportion of beef meat was increased in relation to pork. For the 100% vegetable soy sausage the impact decreased by between 55 and 87% compared to the Hot Dog, for the three impact categories eutrofication, acidification and GWP.

A hot spot analysis reveals that the meat production accounts for the absolute largest share of the environmental impact, with home transports as runner-up. Looking at the sausage factory processes only, it can be seen that the peeling process (where a casing is removed from the sausage) accounts for a large impact, due to the steam production.

The soy recipe is hypothetical in that it is constructed using a recipe software, due to that no manufacturer was willing to participate with a vegetable recipe. Thus, the calculations of the environmental impact from the soy product are uncertain, apart from the impact of the soy protein. Also, the sensory properties are unknown.

It is more environmentally efficient to use vegetables as a primary protein source, not to feed animals but to produce it for human consumption. The future potential of vegetable protein relies much on the marketing and acceptance of new products like the partially vegetable sausage that is presented in scenario 1.

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1 Introduction

1.1 Background

The field pea, or simply "pea", belongs to grain legumes, a group which also contains beans, peanuts and other podded plants. They are used both as fresh immature seeds (green peas), and as dry seeds (yellow peas). Historically they have been an important protein source, but the consumption has declined steadily since World War II, partly because of the image of peas being "food for the poor", and partly because of undesirable gastrointestinal effects associated with the consumption (Sandberg, 2000). These effects are caused by the high oligosaccharides content, fibres which humans neither can decompose nor digest; instead they are fermented by intestinal bacteria, causing gases to form (Andersson, 2003).

Today, as the demand for healthy and natural food increases; the pea as a traditional, natural foodstuff could play an important role in the development of new food products (Sandberg, 2000). A prospective study by the Swedish Environmental Protection Agency suggests a ten-fold increase in grain legume consumption in Sweden from today's 5 g/day, to make up for a recommended decrease in animal protein consumption, which in turn would be a way to implement and establish more sustainable food habits (SEPA, 1997).

Grain legumes can also assist in improving the sustainability of farming in Europe. Grain legumes naturally fix atmospheric nitrogen, which provides a vital nutrient for their growth and maintains soil fertility for subsequent crops in rotations. This ability of grain legumes to utilise nitrogen moderates the need for artificial fertilisers. An indirect benefit of growing grain legumes is also the change they introduce in crop rotations, currently dominated by cereals. By acting as break-crops grain legumes slow the build-up of cereal pests, diseases and weeds thus reducing the need for pesticides in subsequent cereal crops (GLIP, 2005).

Peas hold a protein content of about 23-25%, compared to 34% in soy beans, and studies have shown the feasibility of using pea protein instead of soy protein in many applications (Bertilsson et al, 2003; Braudo et al, 2001; Fredrikson, 2001; Nichols, 2005; Strid Eriksson, 2004; Vose, 1980). One study showed that since pea protein can be combined with e.g cereals to obtain a complete set of essential amino acids for human needs (Andersson, 2003). The use of pea protein in food products as animal protein substitutes or additives has in Sweden dramatically decreased; this is due to allergic concerns and/or consumers' demand for more "clean" products (Osmark, 2005). The "clean" approach pushes manufacturers to decrease both amounts and number of additives, e.g making meat the only protein content in sausages (Scan, 2004). However, compared to other legume protein sources, such as soy or peanuts, pea allergy seems to be less frequent (Cosucra, 2000). Being excluded from "regular" food products, pea protein is today mainly used in nutrition and vegetarian products.

In 2004, the European Commission initiated a project called Grain Legumes, striving to develop strategies to enhance the use of grain legumes crops in food for human consumption and animal fodder in Europe and beyond (GLIP, 2005). As a part of this project, SIK AB is responsible for assessing the impact on the environment of cropping systems and animal production systems with grain legumes, as well as of different sorts of meals for humans. In addition, SIK AB will also look at a regional scenario for both human consumption and animal fodder, aiming to investigate the potential of an increased consumption and production of legumes in Western Sweden (VGR), and to analyse the resulting environmental impact. This latter project is funded by Västra Götalandsregionens miljönämnd (the environmental office of the regional government of Western Sweden). The focus of this report is on the environmental impact of increased human consumption on the regional scenario.

1.2 Outline

For this study, it was decided that a life cycle assessment (LCA) of one or more food products was to be carried out. The goal was to use as current data as possible; primarily from manufacturers, secondly from literature and to make assumptions where data were not available. All data were first interpreted, when needed converted, and documented in Microsoft Excel. Calculations were then made using LCA software, PRé Consultants SimaPro 6.0 (PRé Consultants, 2004). The results from these calculations are presented in this report.

The report will begin with a brief introduction to LCA followed by definitions, statements and decisions connected to the method. What follows next is the documentation of the data from the inventory analysis, in terms of tables and explanations to all numbers, as well as descriptions of all processes involved. After that, a brief introduction to considered environmental impact categories is followed by the results. To finish up, the results are discussed, conclusions are drawn, and recommendations are made.

2 LCA methodology

Most of the information in this chapter on the methods of life cycle assessment (LCA) has been collated from Baumann & Tillman (2004). LCA is a method in which the energy and raw material consumption, different types of emissions and other important factors related to a specific product are measured, analysed and summoned over the products' entire life span.

The method is standardised in ISO 14040-43 (ISO, 2005), and consists of four phases:

Goal and scope definition
Inventory analysis
Impact assessment
Interpretation

An LCA is an iterative process, meaning that some phases may be repeated until the goal is achieved, as shown in Figure 1.

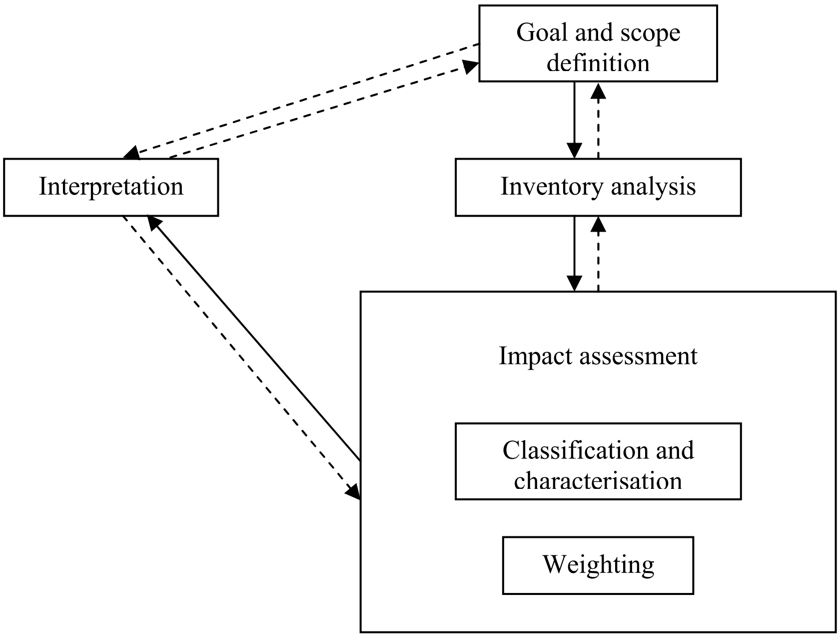

Figure 1 A simple description of an LCA process

In the goal and scope definition, the product to be studied and the purpose of the study are decided upon. It also includes "stating the intended application of the study, the reason for carrying it out, and to whom the results are intended to be communicated". Further more, the functional unit is chosen and system boundaries defined. The functional unit is the expression of the system in quantitative terms. Already at this stage it is helpful to create a general flowchart of the system to be studied.

The next phase is usually the most time-consuming. Basically the inventory analysis starts with the construction of a more detailed flowchart, based on system boundaries decided upon in the goal and scope definition. This flowchart is developed as more knowledge and information is obtained. As the system gets more complicated, new complexities in the flows may appear, e.g. in the case when several products share the same process. To take this into account, the ISO standard states that system expansion is preferred. System expansion is where the extended system is added to the assessment, and its flows are assessed as thoroughly as the rest of the system. When system expansion is not feasible, economic allocation should be used. That is, the respective product's share of a process is based on the included products' relative prices or gross sales value. The data collection for all activities is accompanied by continuous documentation of collected data. The last step in this phase is to calculate the environmental loads of the system, in relation to the functional unit.

Upon having gathered enough information, the impact assessment takes on. The aim of this phase is to describe the environmental consequences of the environmental loads quantified in the inventory analysis. First it must be decided which impact categories to consider. This selection is based partly on the goal and scope definition, and partly on the outcome of the inventory analysis. One list of common impact categories can be found in Lindfors et al (1995). The successive classification means that the result parameters are sorted into chosen impact categories (some examples are shown in Figure 2 below), and characterisation that the size of each environmental impact is calculated.

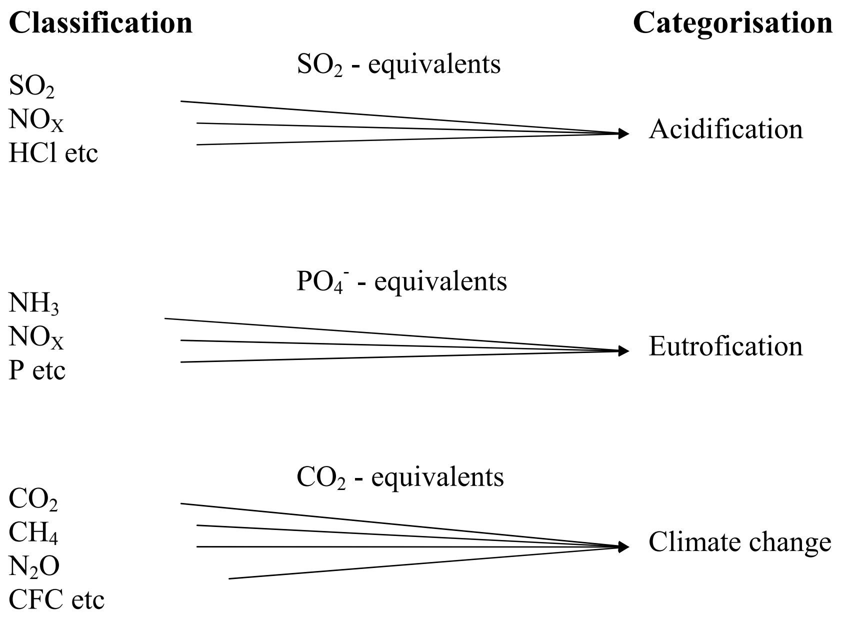

Figure 2 Examples of categorisation processes

Characterisation is carried out using one or more methods; and the aim is that these methods be based on scientific methods. However, due to the complexity of environmental systems, the different methods differ from each other depending on which categories or impacts that the method developers have found most important. Some topics are subject to more controversy than others, e.g. how to assess resource depletion and land use.

Both characterisation and the succeeding weighting are ways to present the results in different forms depending on the target audience. For example, chemists may be most interested in the specific amounts of substances, while a climate researcher might prefer results presented in terms of CO_2 equivalents. Weighting is the aggregation of characterization results across impact categories to present one single "environmental value". This is not supported in the ISO guidelines for LCA (Vroonhof et al, 2002), and as this is of minor importance in this study, it will not be included.

The interpretation is a systematic way to identify, approve, check, and review information obtained in the inventory analysis and the results from the impact assessment. It is important to address issues related to robustness; in other words to check and assess completeness, consistency, uncertainty, sensitivity, variation, and data quality.

It is important to have in mind that an LCA does not provide exact answers; the results should rather be seen as guidelines. Assumptions and neglects made to simplify complex systems contribute to this. However, following existing LCA guidelines and standards enables the LCA commissioner to carry out and present a rigid assessment.

3 Goal and scope definition

3.1 Goal

As a part of SIK AB's part of the Grain Legumes project, the overall aim of the study is to assess the potential environmental impacts of substituting animal protein for regionally grown vegetable protein in food products. The first objective is to analyse three food products of the same type, and the purpose is to compare the environmental impact of the products and also to identify the most important contributors to the total environmental impact of each product. The products are described as follows.

A product in which all protein is animal protein

A product in which 10% of the animal protein is replaced with vegetable protein[1]

A product in which all protein is vegetable protein

Furthermore, the objective is to provide useful information on the products that can be used in other environmental systems analysis, e.g. in meal studies.

The second objective is to explore two scenarios by using the information gained on the three sausages:

Looking at the total consumption of sausages in Western Sweden, what would the difference in environmental impact be if all meat sausages where exchanged with sausages in which 10% of the protein is vegetable protein?

Providing there are environmental savings in the first scenario, what proportion of the consumption of meat sausages would need to be exchanged with sausages with 100% vegetable protein to achieve the same amount of savings?

3.2 Scope

The food product chosen was a sausage type, commonly known as “grillkorv”, which means barbeque sausage, although the most common way to prepare it is to fry it in a pan. The reasons for selecting this particular product were that sausage is a common food product, and the feasibility of substituting animal protein in sausages has previously been shown (Tömösközi et al, 2001). There are also vegetable alternatives commercially available, but unfortunately no suitable commercial product containing both vegetable and animal protein was found, and therefore a hypothetical sausage was

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[1] The specific 10% fraction stems from Sandberg (2000), in which 10% pea protein was found to be a feasible substitution to make, without affecting sensory or taste properties of the product.

created. Consequently this study assumes that pointing out the nutritional benefits of the lower animal protein content could increase the demand for such a product. A comparing life cycle assessment has been performed of three sausage products:

Hot Dog, a product manufactured by Swedish Meats.

A hypothetical sausage, where some of the animal protein content has been substituted for pea protein; in this study called "Pea Dog".

An approximation of a commercial soy sausage; in this study called "Soy Dog".

For the last alternative, a pea protein product would have been preferred, but no commercial product was found. Communication with business and research representatives indicated that issues related to texture and consistency are the major reasons for this (Fondelius, 2005; Braudo, 2005). All three sausages are assumed to have been manufactured by Swedish Meats' factory in Örebro, Sweden, they have all comparable protein content. Simple flow charts for the different production processes are shown in Figure 3 and Figure 4 below.

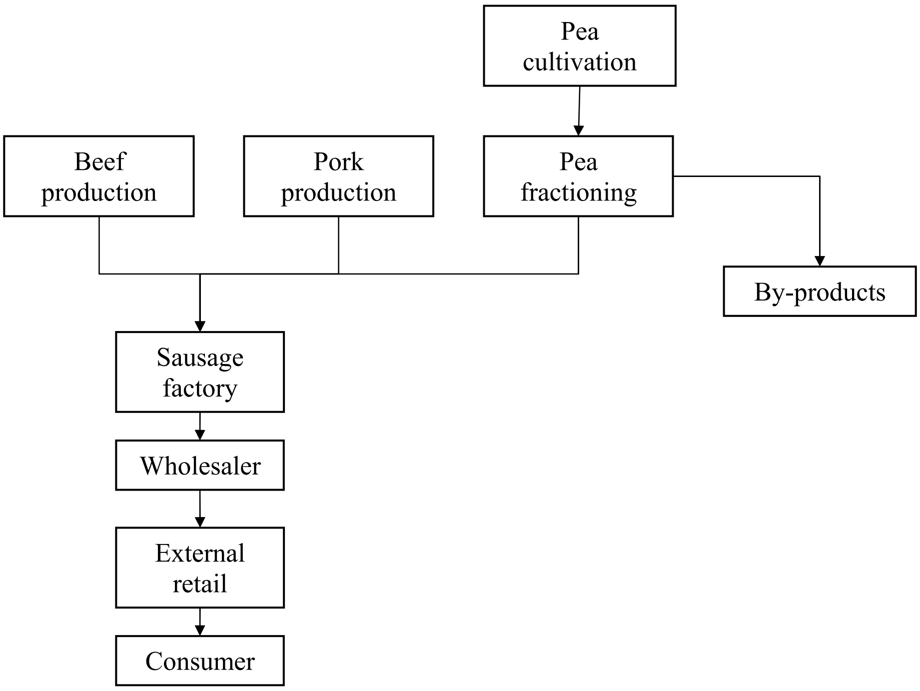

Figure 3 Simple flow chart for the animal and pea sausage system

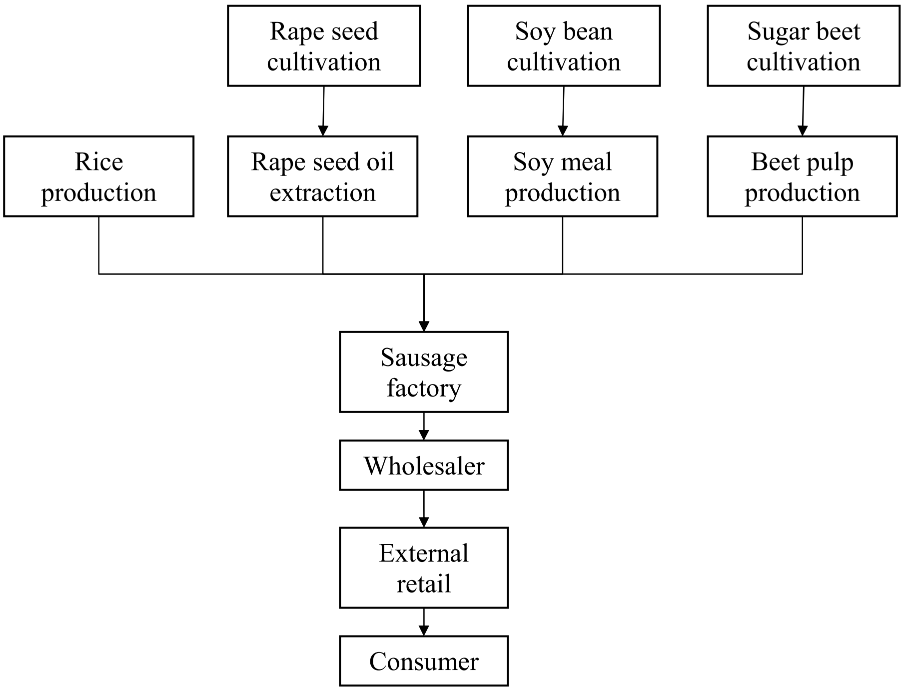

Figure 4 Simple flow chart for the soy sausage production system

3.3 Functional unit

The functional unit (F.U.) was set to one (1) kg of sausage, with a protein content of 8.5-8.6%, and prepared and eaten in a household.

3.4 System boundaries

3.4.1 Geographical boundaries

Most ingredients in the two animal-based products originate from Sweden; exceptions are among others pea protein (however the peas are harvested in Sweden) and plastic film from Finland for the packages. The soy alternative contains soy meal from Brazil and rice from the U.S. among other ingredients. However, the products are solely intended for the Swedish market. The functional unit is assumed to be sold at a large external retail: Coop Forum in Hisings-Backa, Sweden.

3.4.2 Time horizon

The goal has been to use as present data as possible. Most data on the Örebro facility is based on actual numbers from 2004.

3.4.3 Technical boundaries

The life cycle starts with the production of raw materials for the product and ends with the preparation in the household. Studies have shown that post-consumption activities such as sewage treatment play an important role in a food products life cycle in terms of environmental impact (Sonesson et al, 2004). However, since the nutritional value of the three products is assumed to be equal, activities of this kind (i.e. treatment of urine and faeces) are not included. However, the wastage in households has been included, following recommendations from Sonesson et al (2005:2), a study concerning home transports and wastage. Data on ingredients and other inputs include use of materials and energy, as well as waste and emissions to air and water. System expansion was used when possible, and when allocation had to be used, an economic allocation approach was used.

Site specific data have been used where available. For other processes, especially transports and electricity, average data have been used. Changes in the process chain, e.g. decreased resource use, could impact the results. This does not fit within the time frames of this study, but this kind of sensitivity analysis would be of great interest, and is recommended for future work. Two other reasons for not including this in the report are firstly the fact that previous studies has shown that the processes usually contribute insignificantly to the overall impacts; and secondly that the different products use most processes in similar ways.

Transports within the system have been defined as accurately as possible, in terms of mode and distance. Not included are any aspects regarding personnel. An expansion of the system was made to manage the use of by-products from the pea fractioning in ethanol production, and also the extra yield of wheat due to the introduction of peas in the crop rotation.

Pesticides, fungicides and herbicides are used widely within agriculture, thus also in meat production. Due to the toxicity of these substances, manufacturers have for many years undertaken risk assessment studies because of legal requirements. However, it is not until just recently that LCA tools have been started to be developed (Hellweg & Geisler, 2003). Hence, no general method is available for practical use today. In this study the use of pesticides are not known for all processes, and data on specific substances are missing. For these reasons, pesticides, fungicides and herbicides are only taken into account quantitatively in the inventory section in this study (when data have been available), but are not analysed further in the results section.

3.4.4 Data requirements

Within the time frame of this study, data have been collected and required from actual facilities and processes, where available. For remaining data, general numbers or literature information has been used. As for choice of database from SimaPro’s collection, BUWAL 250 (1996) has been used where available and applicable, e.g. for electricity production and transports.

3.4.5 Cut-off rules

No general rule has been applied; the goal has been to be as accurate as possible. However, some ingredients in the food processes have been judged to contribute very little to the overall process, and have therefore been excluded. Some cut-offs can also be found in the previous sections in this chapter.

4 Inventory analysis

Using the simple flowcharts presented in section 3.2, the system was systematically assessed. More detailed flowcharts was developed, both being presented below. Figure 5 shows the flowchart for the Hot Dog and the Pea Dog process (the difference is only whether the pea cultivation and fractioning) is included or not) and Figure 6 shows the Soy Dog. Production of inputs to the various processes, e.g. fertilisers, fuel and electricity, is included in the study, but not portrayed in the flowcharts.

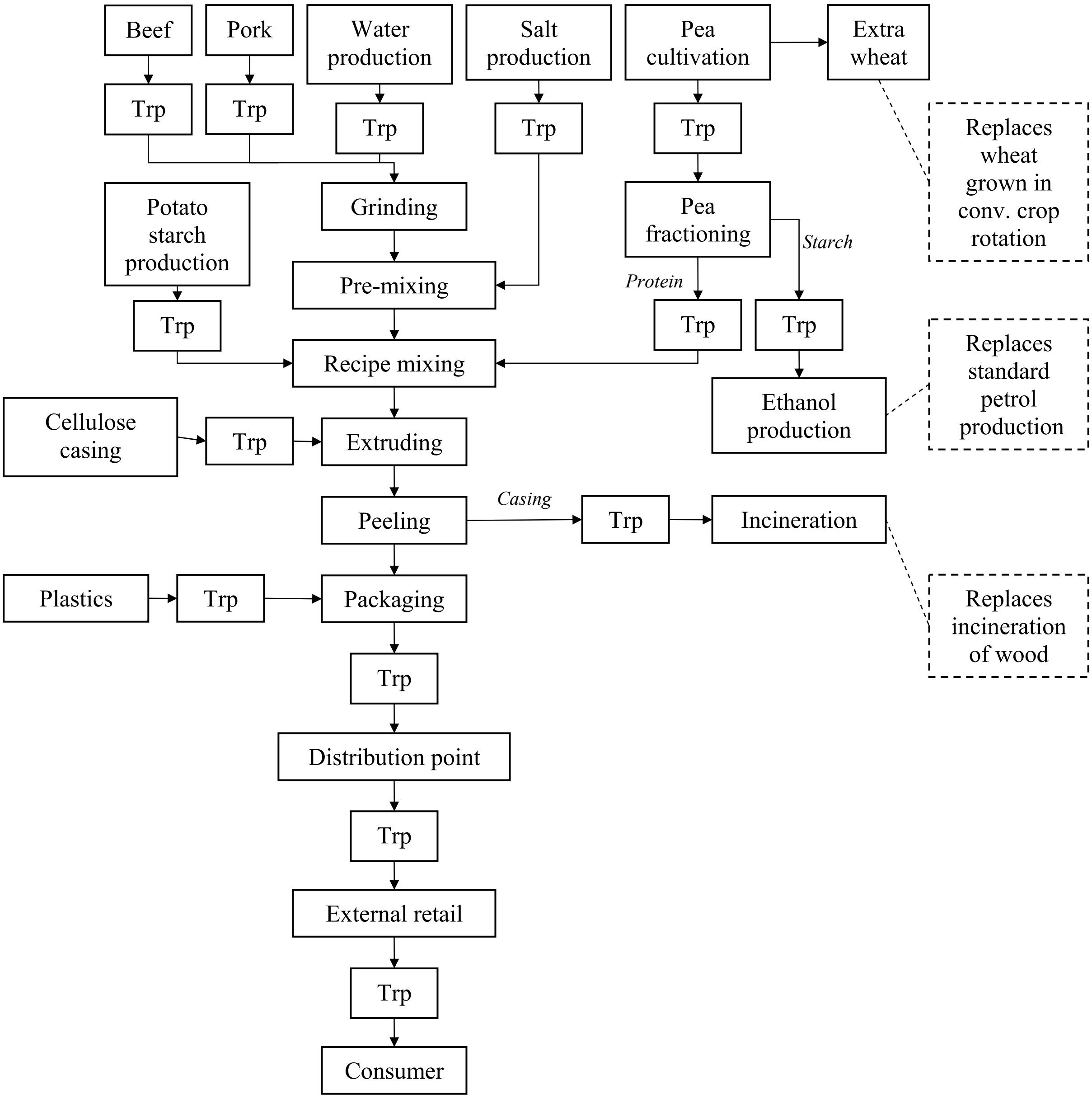

Figure 5 Detailed flowchart of the Hot Dog/Pea Dog production

The ethanol production from pea starch replaces standard petrol production. The replaced amount is calculated from the energy content of ethanol and petrol (further details in sections 4.3.3.3 and 4.10).

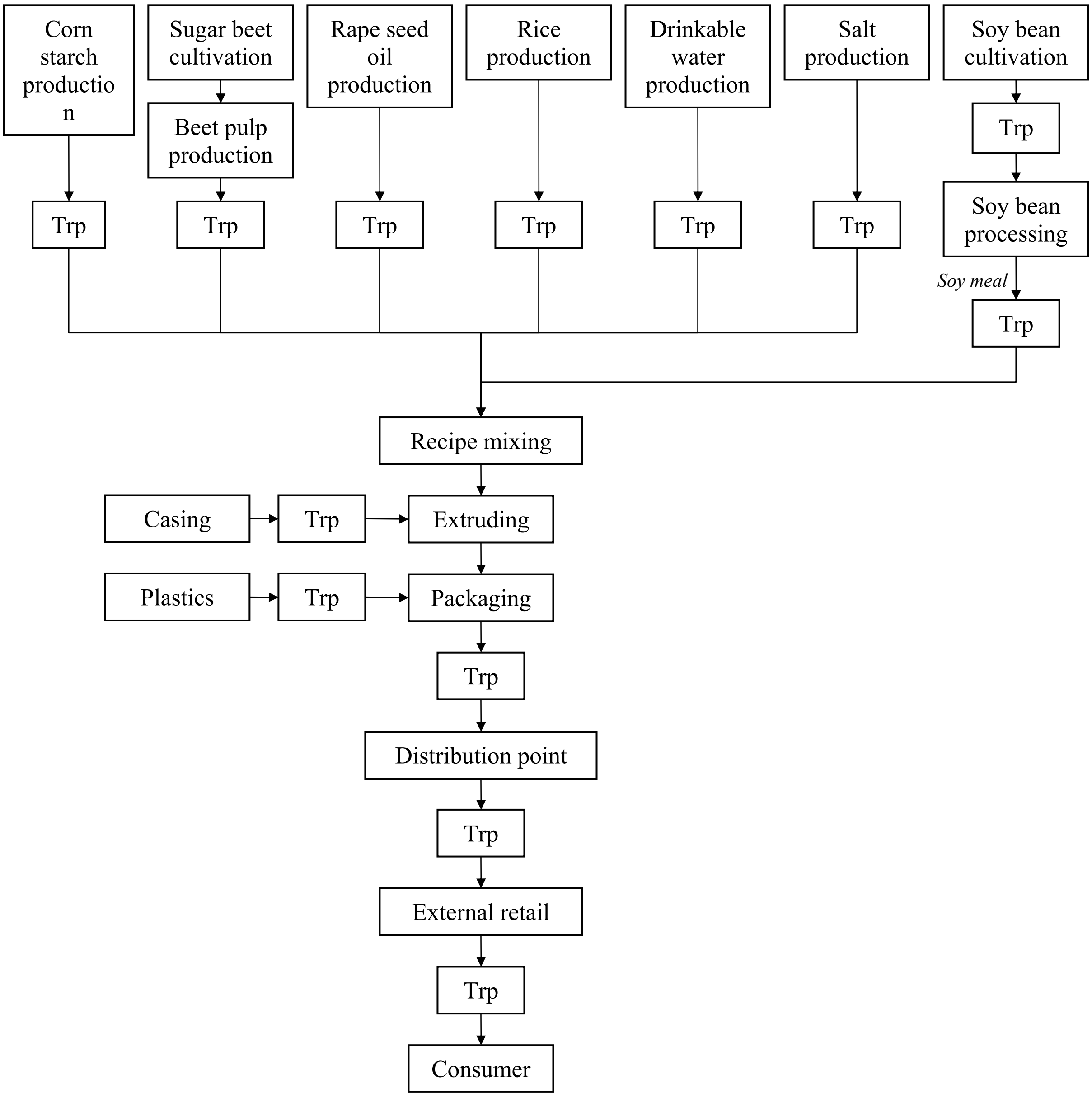

Figure 6 Flowchart of the Soy Dog production

Emissions are not shown in the flowcharts, neither are waste flows except the casing to incineration. The consumer process includes storage and cooking.

4.1 Meat production

The Swedish meat consumption is quite constant, about 25 kg beef and 36 kg pork per capita each year. Domestic production accounts for 58% (139 million kg) and 79% (295 million kg) of the beef and pork production respectively (Meatinfo, 2005). The company participating in the study, Swedish Meats, is one of the biggest food companies in Sweden, producing 58% of the slaughtered meat consumed. The company offers slaughtering and refining of beef, lamb and pork (Swedish Meats, 2005).

4.1.1 Description

The production of meat affects the environment in many ways. As for eutrofication and acidification, the largest contributor is the handling of manure; either in storage or as fertiliser in agriculture. Here ammonia in the form of emissions from manure and nitrogen leakage from crop cultivation are the most important substances, for acidification and eutrofication respectively. The cultivation of crop for use as fodder in the animal production affects the environment in other ways also, as an example the production of 1 kg of pork requires 11 m^2 of land, out of which 9 m^2 in Europe and 1.5 m^2 in South America, the latter mainly for soy cultivation. A cow emits about 120-130 kg methane annually (Ahlmén, 2002), which corresponds to the global warming potential of the carbon dioxide emissions from an average car driven 12 600 km (KO, 2005). This methane is formed by micro organisms in the cow's stomach when fodder is broken down and most of this is released through the cow's mouth.

4.1.2 Data

Data on meat production was obtained from a life cycle assessment of seven Swedish food products, including beef and pork (Ahlmén, 2002). The report presents emissions and energy use; used numbers are shown below. The tables include production of inputs to the farm, e.g. fertilisers. The energy use is included in the emissions.

Table 1 Energy use for meat production [MJ/kg]

Energy source	Pork	Beef
Fossil	19.3	35.65
Electricity	8	7.8
Renewable	0.28	0.22
District heating[2]	-0.88	-1.2

Table 2 Greenhouse gas emissions from meat production [g/kg meat]

Substance	Pork	Beef
Carbon dioxide (CO_2)	1 559	2 860
Methane (CH_4)	40	295
Dinitrogen oxide (N_2O)	6.3	15

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[2] Avoided production of district heating from use of waste.

Table 3 Acidifying emissions [g/kg meat]

Substance	Pork	Beef
Ammonia (NH_3)	26	138
Nitrogen oxides (NO_X)	8.6	17
Sulphur oxides (SO_X)	4.2	7.4

Table 4 Eutrofying emissions [g /kg meat]

Substance	Pork	Beef
NH_3	26	138
NO_X	8.6	17
Nitrogen (water)	55	87
Phosphorus (water)	1.3	0.5
Other	-	12

4.2 Pea cultivation

4.2.1 Description

Peas require a relatively cool and humid climate, preferably in the temperature range of 7-30°C. They are cultivated in most parts of the world, being one of the most important legumes among soybean, groundnut, and beans. It is considered to be a suitable rotational crop, as it is self-providing with nitrogen and thus does not require additional fertilisers, except when nodulation is poor of fails completely (Muehlbauer & Tullu, 1997). Crop rotation helps creating diversity in the agricultural system, and to use resources in an efficient way. Examples of benefits are according to EFA (2005):

Nutritional support; different crops use nutrition from different soil layers

Crop protection; the risks of diseases and parasites are reduced

Weed prevention; specific species are less likely to be favoured

It has been shown that using peas as a precursor crop to winter wheat can increase the yield of winter wheat substantially, from about 6 000 kg/ha to 7 000 kg/ha (Jordbruksverket, 2004; Cederberg & Flysjö, 2004:1). However, it is not recommended that peas are cultivated more often than every seventh or eighth year, in order not to ruin the benefits achieved from crop rotation (EFA, 2005). In this study we assume that the extra wheat generated replaces cultivation of winter wheat in a cereal crop rotation. Apart from increasing the yield, peas can also reduce the need for pesticides in the subsequent crop. This is not taken into account in this study but is explored further within the Grain Legumes project.

Harvested peas usually have a water content of about 20%, hence the crop has to be dried in order to reach the desired value for storage and processing of about 14-15%, this in order to maximise durability (LivsmedelsSverige, 2002).

4.2.3 Data

Data on pea and wheat cultivation was taken from Cederberg & Flysjö (2004:1), based on a pea yield of 3 400 kg/ha.

Table 5 Data on pea cultivation

Process	**Per kg peas**		**Comment**
Energy			
Diesel[3]	0.88	MJ	
Heat oil	0.2	MJ	For drying
Electricity	0.36	MJ	-"-
Heat oil	0.03	MJ	For milling
Electricity	1.51	MJ	-"-
Input			
Water	0.09	l	
Pesticides			
Herbicides	0.056	g	
Insecticides	0.044	g	
Emissions			
Nitrate (NO_3)	0.0071	g	
N_2O	0.00047	g	

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[3] Based on an energy content of 9.8 kWh/l.

Table 6 Data on wheat cultivation

Process	**Per kg wheat**	
Energy[4]		
Oil	3.5	MJ
Electricity	2.5	MJ
Emissions		
CO_2	560	g
CH_4	0.6	g
NH_3	1.5	g
NO_X	0.1	g
N_2O	1.2	g
Nitrogen (water)	3.1	g
Phosphorus (water)	6.4	g

4.3 Pea fractioning

Peas can be fractioned into its three main constituents of protein, starch and fibres. The protein content is about 23-25% per DM (dry matter) (Fredrikson, 2001; Nichols et al, 2005), starch about 46% DM, and fibres about 20% DM (Fredrikson, 2001).

There are two main techniques used for pea fractioning; dry and wet processing. The dry process uses dry milling and air classification. After drying, whole peas are first cracked and dehulled. An aspiration process is then undertaken to remove hull, before pin milling the pea fraction to desired size. The starch and protein fractions are thereafter separated using air classification. The results are fine fractions with high protein content and coarser fractions with high starch content (Wu & Nichols, 2005). The theoretical protein yield from this process can be 75% (Sandberg, 2000). Improvements of this technique, including establishing cut points for the different fractions, have been suggested by Nichols et al (2005). The end product is usually a protein isolate, with a protein content of 92% DM.

4.3.1 Description of wet processing

An alternative, wet process was presented by Fredrikson et al (2001) and is shown in Figure 7 below.

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[4] Emissions from energy use are included under “Emissions”.

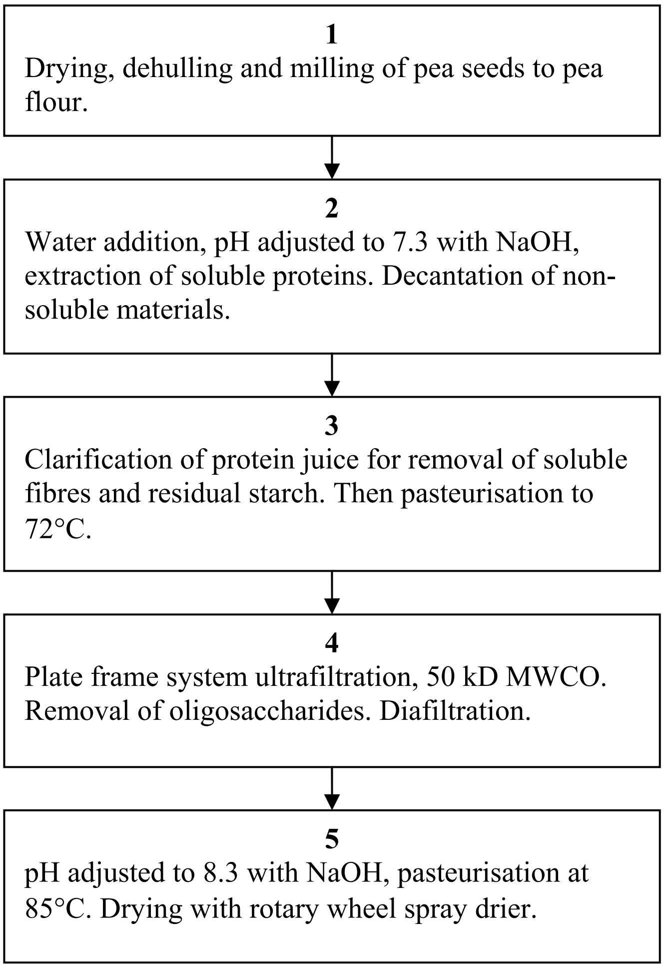

Figure 7 Flowchart of industrial standard process for production of pea-protein isolates

Some key processes are identified below; please refer to the reference for a more extensive description of the complete process.

The wet isolate can be dried in different ways: drum-drying, freeze-drying, or spray-drying; the last one is used in this study (Sumner et al, 1980). The basic spray-drying process consists of three processing steps. First the atomization process, where the slurry in question is divided into droplets. These droplets are then sprayed into a warm gas medium, usually air or steam, where the individual droplets are dried into solid particles. The substance is then collected by recovering both the precipitated particles and from separation of the spent drying air (Christiansen, 2002). The protein yield depends on several factors such as particle size of the flour and the kind of solving agent, but some techniques may yield protein recoveries of 90-94% (Sandberg, 2000), however the standard industrial process yield is only about 65% (Fredrikson, 2001).

Further details about pea protein are given in section 1.1.

4.3.2 Data

As no manufacturer was willing to participate in this study and data on the pea fractioning process had to be approximated. To estimate the energy use for the fractioning process, the above flowchart was used together with Fredrikson (2001), Salome et al (2004) and product data from Alfa Laval (2005).

Marcotte (2003) presented data on energy use for spray-drying and the steam production is assumed to be fuelled with fossil gas.

The energy use of the centrifuge process was found to be about 0.059 MJ/kg pea protein. Due to uncertainties about the energy use for the rest of the process, a factor of 4 was added to this. The output from this process is a protein isolate with a protein content of 85.5%, and the protein yield is 65%, as presented in section 4.3.1.

Table 7 Data on the pea fractioning process

Process	Energy use		Comment
Energy			
Centrifugation, Decantation, Filtration	0.24	MJ/kg pea protein	Electricity
Spray-drying[5]	2.2	MJ/kg water removed	Steam from fossil gas[6]
Material use			
Pea meal	6.7	kg/kg pea meal	
Water	36.4	kg/kg pea meal	

4.3.3 By-products

Peas consist of three main fractions; protein, starch and fibres. In this study the main interest lies with the protein, hence the other fractions are seen as by-products, as described below.

4.3.3.1 Starch

The best solution would be if the pea starch could be used together with the pea protein in the food products where starch is required, as in the sausages in this study. However, some differences exist between different starches. The information in the first paragraph of this section was gathered from personal communication with Ståhl (2005).

The amylose content of pea starch is about 40 %, causing it to retrograde substantially more than potato starch which has a content of around 20 %, while the gelatinisation temperature is only slightly higher (64°C compared with 61-63°C). The swelling of the granule is slower than for potato starch. The granules are smaller, 10-35 µm with an average of 25 µm compared with 5-100 µm in potato starch with an average of 40-45 µm. The pea starch is harder to cook than potato starch, mainly due to the higher amylose content and more residual fat in the starch. The strong gel that is created after the pea starch has been fully cooked comes from the retrogradation of amylose and is prone to synereses during storage of the gel. A fully cooked solution of pea starch gives a short paste where the potato starch is long in texture. The firmness of the foodstuff will therefore not be the same, and the water binding capacity will be different. Some genetic varieties like high amylose varieties as well as high amylopectin varieties have been isolated. These ones will change the properties of the pea starch and might be of commercial interest. Up to date these ones have not been commercialyl exploited.

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[5] Based on a water content of the protein solution of 75% and a final water content of 4%.

[6] The energy efficiency is assumed to be 90%.

All these things affect the behaviour and possible use of pea starch as a substitute for potato starch. Similar to pea protein, pea starch might leave a taste in the product; a big disadvantage to potato starch (Sandberg, 2000). There are however some food manufacturers that use pea starch as an ingredient, e.g. in canned foods or vermicelli noodles (Norben, 2005; Penglai, 2005), but this has not been assessed further in this report.

One study suggests that the starch content obtained from the pea fractioning process be used as feedstock for ethanol fermentation, where its functionality is comparable to corn starch, measured in ethanol yield (Nichols et al, 2005). According to the same study, pea starch can also be mixed with corn starch without any negative effects on the process. Bioethanol production in Sweden is currently based mainly on wheat (Agroetanol, 2005). However, the wheat quantities available are at such levels that manufacturers are eager to find other sources, especially facing a possibly increased future demand (Örn, 2005). Today whole wheat is used in the process, with a mix of fibres and protein as a by-product. The latter mix is sold to fodder manufacturers. According to Gundberg (2005), pea starch could be used as substitute for whole wheat.

4.3.3.2 Fibres

One possible application for the fibres is to use them as ingredient in breads, cakes, cookies, tortillas, pasta, soups or fibre drinks (ID Food, 2005; BCP, 2005). However, in this study all fibres are assumed to be contained in the hull, which is removed in the pea milling process. Due to lack of information on what happens with this fraction, it will not be traced back.

4.3.3.3 Data

It has been assumed that the by-products from pea fractioning will be transported from Belgium for use in bioethanol production in Sweden. Data on bioethanol production from wheat fermentation was presented by Gartmeister (2000). It takes 3.14 kg wheat to produce 1 kg ethanol and the starch content in wheat is approximately 70% (Gundberg, 2005). Assuming wheat starch can be substituted with pea starch on a 1:1 ratio, the by-products from fractioning 1 kg of peas, holding a starch content of 46%, will be enough to produce 0.21 kg ethanol.

The ethanol produced is assumed to replace a corresponding amount of the average fuel of the transport sector, which is petrol. There are several arguments for this choice:

The environmental impact from ethanol depends heavily on the type of process (Jonasson & Sandén, 2004). Today, Sweden's ethanol demand is much higher than the Swedish production capacity, 80% of the ethanol is imported from Brazil. It is hard to decide what type of ethanol that would be replaced, and therefore hard to acquire suitable data.

The ethanol demand increases steadily. By 2009, almost 6% of the EU fuel consumption must be renewable sources, and ethanol is proposed as one alternative (Jonasson & Sandén, 2004).

The transport sector is big enough to swallow any, relatively small contribution, here in the form of ethanol from pea starch fermentation.

The corresponding amount of replaced petrol is calculated by comparing the energy content of ethanol (22.3 MJ/kg) and petrol (33.1 MJ/kg). The resulting amount of petrol replaced is 0.13 kg for each kg of peas.

4.4 Animal sausage production

Sausages are common food in many countries, with a history that dates far back. In the beginning it was a way to preserve meat for a long time, and also to use the parts of the animal that could not be used as whole meat. There is a wide selection of different sausage types available, usually each country has its own variants and recipes.

Within the category in which the studied sausage falls, today's market offers a variety of products, however the industry has changed slightly in recent years. Customer demands on food contents and health concerns regarding e.g. allergenic properties of vegetable protein have forced the manufacturers to simplify their recipes (Osmark, 2005; Scan, 2005). There are also vegetable alternatives available, such as soy sausages.

In co-operation with Swedish Meats, a production facility in Örebro, Sweden, was studied. The reason for choosing the particular facility was that it mainly produces one product, named "Hot Dogs". In order to get a better overview and understanding, a company visit was conducted.

4.4.1 Description

The main production process consists of eight processes, of which some may be divided into two or more steps. The production line is known as the "barbecue sausage line" and a process description is found in Table 8 (Persson, 2005:1).

Table 8 Process description

Process	Description
Grinding	Frozen products are thawed before use. The meat ingredients are ground, and an automatic device is used to supervise the fat content.
Pre-mixing	The meat mixture is mixed with water, ice, and salt.
Ripening in silo[7]	Storage of meat mixture, usually for 1-5 days. Six silos, each with a capacity of 12 tonnes.
Recipe mixing	Mixing of meat mixture with other ingredients, such as potato starch and spices. A highly automated process, where the operator just defines the amounts, after which the mixture is prepared by the machine.
Extruding	Four extruding machines, which are loaded with cellulose tubes. The sausage batter is extruded through the tubes at high speed, whereupon casing-covered sausages are formed. The cellulose casing is manufactured by Viscofan SA in Pamplona, Spain. Long strings of sausages are then cooked, smoked[8], and cooled down.
Peeling of sausage strings	Four parallel machines use steam to peel the casing off the sausages.
Packaging	Six packaging lines with various capacity, each including several steps: Positioning Vacuum packaging. Big rolls of plastic wrapping are heat-moulded into shape, sausages are inserted, and the packages are sealed. Scale/metal detector, defective products are removed. Picker, a fast robot loads the packages into plastic trays. Robot loading trays on pallet.
Loading area[7]	Facility office; stock input to logistics software, and back-reporting of customer orders.

4.4.2 Recipe

The Hot Dog is a casing-free sausage with mild seasoning. There are two package sizes, 500g and 1500g, which are wrapped and vacuum-sealed in plastic (Persson, 2005:1).

The aim of this study has been to model real and present conditions. However, the manufacturers were not able to share their recipes and therefore the following recipes were used in this study:

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[7] Specific data is not known; hence the process is included in the process called “General emissions”, which is explained in section 4.4.3.

[8] The “smoking” process consists of a smoke flavour being sprayed onto the product. Data on this product has not been found, and is therefore not included in this study.

Hot Dog, based on an estimate of the real recipe.

Pea Dog, a hypothetical product based on the Hot Dog recipe, but with 10% of the animal protein substituted for pea protein.

Soy Dog, a hypothetical recipe based on the contents and nutritional value of Dafgård's soy sausage (Dafgård, 2005), with a protein content of about 7% (Nilsson, 2005).

Berg & Hjalmarsson (2005) constructed the recipes; using Receptassistenten 3.0; recipe software available from SIK AB (SIK AB, 2005). In order to simplify the recipe, different pork products have been aggregated into "pork", and beef products have in the same way been aggregated into "beef". In a real product, also ingredients such as ascorbic acid, lactate and acetate have to be added because of their function as preservatives and such; but as they usually make up very small shares of the product, they have been omitted from the recipe. The soy alternative is presented in section 4.5. The protein content of the products are equal, and the other nutritional properties are assumed to be similar.

Table 9 shows the composition of the two recipes which contain animal protein. The average protein content of the meat ingredients is 17.5%.

Table 9 Hot Dog and Pea Dog recipes [kg/100 kg product]

Raw material	Hot Dog	Pea Dog
Pork	49.5	45.5
Beef	3.9	4.1
Water I[9]	30.5	32.2
Water II	3.8	4.0
Potato starch	10.0	10.5
Nitrite salt[10]	1.8	1.9
Spices[11]	-	-
Sugars[11]	-	-
Pea protein	N/A	1.0

4.4.3 Process inputs

The energy used in the manufacturing process derives from electricity, heat oil, district heating, and biogas. The peeling process uses steam which is produced using biogas and fuel oil. Data on biogas was presented by Nilsson (2001). Water is used for cooling, both machines and the actual products. It is also an important component in all products.

Data on energy and material use for specific processes is partly known, as is the total use for the entire facility. The data from specific processes was gathered at the facility, and was presented by Persson

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[9] The notation on the water fractions refers to the fact that water is added twice during the production process. Four kg of water are lost during the production process.

[10] Nitrite salt is sodium chloride with a nitrite content of 0.5 % (GastroCorner, 2005) and is included to impedes on the growth of the bacteria Clostridium Botulinum. About a third is left in the product after processing. (Scan, 2004).

[11] The fractions are small and have not been taken into account.

(2005:2), and shown in Table 10. The total use has together with known, but non-traceable emissions and resource use been allocated to a process called "General emissions and energy use of the plant". All data in Table 11 originate from the mandatory environmental report that Swedish companies present each year, and they are the cumulative numbers for one year for the whole facility.

Table 10 Energy use for the sausage production processes at the Örebro facility [Per kg product][12]

Process	**Electricity [MJ]**	**Biogas [MJ]**	**Heat oil [MJ]**	**District heating [MJ]**
Grinding	0.05			
Pre-mixing	0.05			
Recipe mixing	0.20			
Extruding	0.12			
Conveyor	0.12			
Peeling	0.086	2.79	0.128	
Packaging	0.13			
General energy use of the plant	1.22			0.43

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[12] Note that this is per kg processed part product, and not per end product.

Table 11 Environmental data on the production facility in Örebro (Eklöf, 2005).

Process/material	**In/Out**		
Energy use			
Electricity	I	10 200	GJ
Oil	I	3 630	GJ
District heating	I	3 530	GJ
Biogas	I	22 080	GJ
Sum	I	39 450	GJ
Emissions to water			
BOD 7	O	456	mg/l
COD	O	961	mg/l
Phosphorus	O	6.00	mg/l
Fat	O	56	mg/l
Nitrogen	O	21	mg/l
pH	O	6.4	pH
Water use			
Water	I	128 368	m^3
Water to treatment plant	O	64 370	m^3
Water for cooling	O	15 591	m^3
Chemicals consumption			
	I	27 226	tonnes
Waste			
Waste to deposit	O	45.93	tonnes
Compost	O	74.24	tonnes
Recycled hard plastics	O	0.45	tonnes
Recycled soft plastics	O	2.40	tonnes
Recycled cardboard	O	31.88	tonnes
Waste to energy production	O	179.92	tonnes
Sludge from water treatment	O	685.10	m^3
Recycled paper	O	37.32	tonnes
Electronics scrap	O	1.81	tonnes
Wood	O	1.00	tonnes
Metals	O	3.39	tonnes

The packaging film used is manufactured by a Finnish company, located about 100 km outside Helsinki. The film is a mix of PE, PA and PP (Persson, 2005:2), the proportions of each type shown below. Data on the different plastics was found in SimaPro.

Table 12 Fractions of different plastics in sausage packaging film [%]

Type	In upper film	In lower film	Total
PA	19.35	25	22.2
PE	80.65	50	65.3
PP	0	25	12.5

4.4.4 Production waste

The primary waste products are process water and sausage cassations, and from the animal products also cellulose casing. The process water is, after a rough removal of fat, transported to the city's waste water treatment system. To avoid the cost of treating the cassations, for instance through incineration (since it is no longer legal to deposit nor to compost animal waste in Sweden), Swedish Meats sells them to Skyberga Lantbruksprodukter AB in Örebro, who uses it as raw material for mink fodder (Eklöf, 2005). No further information on this was available, such as if the cassations are used for substituting any other protein fodder. Hence, the effects of this are not taken into account in this study.

The cellulose casing waste is sold to Linköpings Energi, an energy provider in Linköping which recovers the energy through incineration to produce district heating. As information about the cellulose casing's energy content is missing, it has been assumed that it is approximately equivalent to that of average wood, 20 MJ/kg (Mörtstedt & Hellsten, 1987). Following this discussion, the energy recovered from the incineration would substitute 0.179 MJ from the base load margin per kg peeled sausages, where the base load is assumed to be heat oil.

4.4.5 Other ingredients

Data on potato starch production was found in SimaPro's database, and life cycle data on drinking water was presented by Wallén (1999). Sodium chloride (salt) has replaced nitrite salt in the assessment, as nitrite only makes up for 0.5% of the salt. Salt data was presented by Bousted (1994).

From the combination of the fact that the amount of cellulose casing is small, only 8.96 g/kg sausage (Persson, 2005:2), and the judgement that the raw materials in the casing probably have minor environmental impact (Dean, 2005); this study does not take into account the casing production process, only the transport from the manufacturer to the facility in Örebro. Neither has data on the production of spices been taken into account, because of the small share and assumed minor contribution to the overall environmental impacts.

4.5 Soy alternative

A lot of information is available about soy and its functionality and fields of use. However, in this report it will only be used as reference, and therefore no thorough explanation or information will be given.

4.5.1 Description

Soy protein is the only plant protein which is “complete”, in the sense that it provides all the essential amino acids needed for human health. It is low in saturated fat and cholesterol-free (NSRL, 2005). It is extracted from the soy bean, which is cultivated in temperate climates. Most of the Swedish and European soy is imported from Brazil in the form of soy meal and the lion’s share of it is used in animal fodder.

The most common vegetable sausage alternative is the soy sausage, which in Sweden is marketed by several manufacturers. The soy content usually consists of textured soy protein (Dafgård, 2005), which in turn consists of 70% protein and 23% dietary fibres (Soy Foods, 2005). The concentrate is hydrolysed in order to obtain desirable properties. A presentation of the protein content in some soy products is shown below. Using the same yield as in the case of pea protein (65%) an amount of 3.6 kg of soy beans is needed to produce 1 kg of textured soy protein. As data on the protein extraction process is missing, the “soy protein” input in the analysis is assumed to be equivalent to, and replaced by soy meal. The amount is based on protein level.

Table 13 Protein content in selected soy products

Soy form	**Protein content [%]**
Soy bean	43
Soy meal	34
Textured soy protein	70

4.5.2 Recipe

The recipe for this sausage, called Soy Dog, was constructed using Receptassistenten 3.0 (SIK AB, 2005), with the input of ingredients based on contents and nutrient content of a commercial soy sausage, obtained from the manufacturers’ website (Dafgård, 2005). Note that the recipe may not be feasible to produce, as no sensory or texture assessments have been undertaken. The original recipe also included egg white powder, but since data on egg production was missing, and in order to present a fully-vegetable recipe, this has not been included.

Table 14 Soy Dog recipe

Raw material	**[kg/100 kg sausage]**	**Data source**
Water	57.1	Wallén, 1999
Rape seed oil	13.2	See text
Soy protein	12.3	See text
Rice meal	7.9	-“-
Corn starch	7.9	BUWAL 250, 1996
Sugar beet pulp	3.1	See text
Nitrite salt	1.8	Bousted, 1994
Spices[13]	-	-

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[13] The fractions are small and have not been taken into account.

4.5.3 Production process

The soy product is assumed to be produced in the same manner as the other two products, with two exceptions:

> There is no meat to grind, so the grinding process is not included.
>
> Due to uncertainties of the feasibility of the recipe to actually hold together, the cellulose casing is not removed through the peeling process. (The casing is edible; many sausage products are sold and eaten in casing.)

4.5.4 Data

Cederberg & Flysjö (2004:2) presented data on Brazilian soy production.

Table 15 Data on soy bean cultivation

Process	**Per ha**		**Comment**
Energy			
Electricity	142.2	MJ	Drying
Heat oil	1 042.8	MJ	-"-
Diesel	2 293.2	MJ	Field operations
Fertilisers			
N	8	kg	
P	31	kg	
K	57	kg	
Pesticides			
	1.5	kg	

Table 16 Data on soy bean processing (Cederberg & Flysjö 2004:2)

Process	Per tonne soy bean		Comment
Energy			
Wood	973	MJ	
Electricity	165.6	MJ	
Material use			
Water	3.28	l	
Hexane	0.4	kg	Data for naphtha
Emissions			
N-N_2O	1,7	kg	
N-NO_3	36	kg	
P	3	kg	
Hexane	8.0E-5	kg	

The processing of soy beans yields soy meal and soy bean oil. Economic allocation was used for the different soy products (Table 17). In this study, it is then assumed that 100% of the economic value of the soy meal can be allocated to the protein.

Table 17 Price relations used for allocation of soy products (Cederberg & Flysjö, 2004:2)

Product	Price ratio [%]
Soy bean oil	32
Soy meal	68

4.5.4.1 Other ingredients

Data on the other ingredients in the soy sausage.

Table 18 Data on rape seed cultivation, assuming a yield of 3 200 kg/ha (Cederberg, 2000)

Process	Per ha		Comment
Energy			
Heat oil	84.7	MJ	For drying
Fertilisers			
N	160	kg	
P	14	kg	
Potassium (K)	28	kg	
Pesticides			
Metazaklor	500	g	
Esfenvalerat	10	g	
Field operations			
Diesel	3 528	MJ	
Emissions			
N to water	42	kg	
P to water	0.3	kg	

Table 19 Data on rape seed oil extraction (Cederberg, 2000)

	Per tonne rape seed		Comment
Energy			
(Total)	918	MJ	
Electricity	459	MJ	Allocated of 50% the total energy
Gas	459	MJ	-“-
Emissions and waste			
CO_2	51	kg	
NO_X	33	g	
SO_2	6	g	
COD	63	g	
N	2	g	
Hexane	0.4	kg	
Solid waste	0.2	kg	
Water consumption			
Drinkable water	0.4	m^3	

Table 20 Price relations used for allocation of rape seed products (Cederberg, 2000)

Product	**Price ratio [%]**
Rape seed oil	67
Rape meal	33

Table 21 Data on sugar beet cultivation (Cederberg & Flysjö, 2004:2)

Process	**Per ha**	
Fertilisers		
N	106	kg
P	43	kg
K	44	kg
Pesticides		
	2.74	kg
Emissions		
NO_3-N	22.5	kg
NH_3-N	2.4	kg
P	0.3	kg
N_2O-N	1.5	kg

Table 22 Data on beet pulp extraction (Cederberg & Flysjö, 2004:2)

Process	**Per kg**	
Energy for drying		
Natural gas	5.2	MJ
Heat oil	0.86	MJ

Table 23 Price relations used for allocation (Cederberg & Flysjö, 2004:2)

Product	**Price ratio [%]**
Sugar	83
Beet pulp	11
Molasses	6

One of the ingredients is denoted “rice”. In the recipe software, it has been assumed to be rice meal. Data on drying was adapted from a corn drying process in SimaPro (BUWAL 250, 1996). Milling data was taken from a study by Andersson (1998), which presented data on wheat; the energy use for

40 000 milling one kg of wheat flour was set to 0.42 MJ from electricity and 0.028 MJ from heat oil. In addition, 0.09 litres of water were also used.

Table 24 Data on rice cultivation with a yield of 7 362 kg/ha (Carlsson-Kanyama & Faist, 2000)

Process	Per ha	
Energy		
Electricity	20	MJ
Natural gas	1 800	MJ
Field operations		
Diesel	13 000	MJ
Gasoline	2 200	MJ
Fertilisers		
N	164	kg
P	26	kg
K	21	kg

4.6 Transports

All road transport distances were calculated using an online route planner (MapQuest, 2005). Data on transports were based on Truck 40t B250 (BUWAL 250, 1996; Persson, 2005:1), except the last transport to household, which was based on Passenger car B250 and the boat transport on Sea ship B250 (BUWAL 250, 1996). Approximations of sea transport distances were calculated using Indo.com (2005).

4.6.1 Transport of raw materials

The average meat transport distance was calculated using the weight fractions from different origins respectively (Persson, 2005:1). The origin of peas was set to Skara, located in the agricultural region of interest for this study.

Table 25 Transport distances for sausage ingredients

Substance	Origin	Destination	Category	Distance [km]
Meat	Various	Örebro, Sweden	40 t Truck	220
Beet pulp	Falkenberg, Sweden	-“-	40 t Truck	380
Pea starch	Warcoing, Belgium	Norrköping, Sweden	40 t Truck	1 470
Cellulose casing	Pamplona, Spain	Örebro, Sweden	40 t Truck	2 650
Corn starch	Texas, USA	-“-	Sea ship[14]	8 000
Pea protein	Warcoing, Belgium	-“-	40 t Truck	1 520
Peas	Skara, Sweden	Warcoing, Belgium	40 t Truck	1 420
Plastic film	Finland	Örebro, Sweden	40 t Truck	300

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[14] Even if the distance is partly covered by truck transports, the Sea ship fraction is assumed to be superior.

			Sea ship	520
Potato starch	Kristianstad, Sweden	-“-	40 t Truck	450
Rape seed oil	Karlshamn, Sweden	-“-	40 t Truck	430
Rice	Texas, USA	-“-	Sea ship[14]	8 000

4.6.2 Soy transports

Data on transports were originally presented by Cederberg & Flysjö (2004:2). As shown, different fractions originate from different locations within Brazil.

Table 26 Transport data on soy (Cederberg & Flysjö, 2004)

Transport	Category	Distance [km]	Share of product [%]
Farm - crusher	40 t Truck	25	100
Crusher - Santos	Train, diesel[15]	1 800	60
Crusher - Santos	40 t Truck	1 800	15
Crusher - Paranagua	Train, diesel	500	20
Crusher - Paranagua	40 t Truck	500	5
Santos-Rotterdam	Sea ship	10 080	100
Rotterdam-Gothenburg	Sea ship	750	100
Gothenburg-Örebro	40 t Truck	280	100

4.6.3 Distribution and home transport

For transports of the ready-made sausage product, the following distances have been applied to the system:

> The distance from the production facility in Örebro to the distribution point in Gothenburg is about 285 km (MapQuest, 2005).
>
> The distance from the distribution point to the external retail Coop Forum in Hisings-Backa is approximately 10 km.

4.6.3.1 Home transport

To calculate the energy use from transports from external retail to household, a model presented by Sonesson et al (2005:2) was adjusted in order to fit a sausage meal. It was decided that the allocation of the sausage’s part of this transport be based on energy content and nutritional recommendations. The energy content of the Hot Dog is 9 MJ/kg (Swedish Meats, 2005), and it is assumed that 125 g sausage is consumed each meal, which implies a 1.125 MJ energy contribution from the sausage each meal. This corresponds to 11.25% of the recommended daily energy intake (SLV, 2002). (However the recommended energy intake depends on age, gender, and amount of physical activity; an average value of 10 MJ/day has been assumed.) The serving size of 125 g implies one kg to be enough for about 8 dinners. The energy content of the three sausages is assumed to be equal. This leads to an allocation factor (Table 27).

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[15] No data on diesel train was found, average data for European diesel and electric trains was used.

Sonesson et al (2005:2) assessed shopping habits to four stores of different size and type, for a household consisting of 2.2 persons. Mode of transport, distance and shopping frequency was determined. This, combined with the previously calculated allocation factor and the average fuel consumption, can be used to calculate the energy use for one kg of sausages.

Table 27 Numbers and factors used for home transport calculations

			Data source
Fuel consumption	8.64	litres/100 km	KO, 2005
Distance per household, driven by car	28	km	Sonesson et al, 2005:2
Persons per household	2.2		
Allocation factor (0.1125*8/365)	2.47E-3		-
Energy use[16]	5.0	MJ/kg sausage	-

4.6.4 Other transports

The transports of waste can be found below.

Table 28 Mode and distance for transports of waste

Substance	**Origin**	**Destination**	**Category**	**Distance [km]**
Casing waste	Örebro, Sweden	Linköping, Sweden	40 t Truck	140
Cassations	Örebro, Sweden	Örebro, Sweden	40 t Truck	20

4.7 Storing and cooking

Data on storing in stores was presented by Carlson & Sonesson (2000). The reference reflects the energy use for storing 1 litre of milk, and in this study it has been assumed that this data is approximately equivalent to storing 1 kg of sausage.

For storing in households, a model proposed in Sonesson et al (2003) was used:

Equation 1 Model for calculating energy use for cold storage in refrigerator

$E_{product} = 371.59 * V_{cabinet}^{-0,8982} * V_{cabinet} * (D_{stored}/365) * (V_{product}/V_{used})$ Energy needed for storing the product in a refrigerator (MJ)

$V_{cabinet}$ – Average volume of the cabinet	272	l
$V_{product}$ – Estimated volume of product	1	l
$V_{used} = V_{cabinet}/3$ – Estimated used volume in the cabinet	91	l
D_{stored} – Estimated time the food is in storage	3	days

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[16] Corresponding to a fuel use of 0.32 l./kg sausage.

$E_{product}$	**0.060**	**MJ/kg sausage**

Another model proposed by Sonesson et al (2003) has been used to calculate the energy use for cooking (a cast iron pan is assumed to be used at medium temperature). One functional unit corresponds to 20 sausages, and it is assumed that six to seven sausages are fried at a time.

Equation 2 Model for calculating energy use for frying sausages in a pan

$E_{HU} = m_{fp} * \rho + e_{hu} * A_{fp}$ - Energy for heating the pan and stove to frying temperature (MJ).

ρ – Heat capacity of iron	4.5E-7	MJ/(g*°C)
m_{fp} – Mass of frying pan	2 382	g
A_{fp} – Area of frying pan	95	cm^2
e_{hu} – Constant dependent on type of hotplate and frying temperature	5.3E-3	MJ/(cm^2)

$E_{MT} = t_f * e_{mt} * A_{fp}$ - Energy needed to maintain the temperature during frying (MJ).

t_f – Time for frying	5	minutes
e_{mt} – Same as e_{hu}	4.8E-4	MJ/(minute*cm^2)
$E = E_{HU} + E_{MT}$	0.73	MJ
Number of pans needed	3	
E_{total} = 3*E	**2.18**	**MJ/kg sausage**

4.8 Wastage in household

The production waste has already been mentioned in section 4.4.4. Sonesson et al (2005:2) presented data on food wastage generated after meals and storage in an average Swedish household. For this study, it has been assumed that the waste of sausages can be approximated to that of “other meat products”, about 10%. Hence, to provide 1 kg of ingested sausages, 1.1 kg has to be produced.

4.9 Land use

Quantitative data on land use was gathered. No possible differences in types of land have been taken into account.

Table 29 Land use for different products [m^2/kg]

Product	Land use	Data source
Beef	32.6	Ahlmén, 2001
Corn	1.5	EC, 2004
Peas	2.9	SCB, 2005:2
Pork	10.8	Ahlmén, 2001

Potatoes	0.4	EC, 2004
Rape seed	3.1	Cederberg & Flysjö, 2004:2
Rice	1.4	Kanyama-Carlsson & Faist, 2000
Soy beans	4	Cederberg & Flysjö, 2004:2
Wheat	1.4	Jordbruksverket, 2004; Cederberg & Flysjö, 2004:1

4.10 Constants

To interpret and to translate some of the data to be used as input to the software, some constants were used. A list of constants used in calculations is shown below, in which the emission factors were used to calculate the emissions from the meat production, as those were given in terms of equivalents in the reference paper.

Table 30 Constants used in calculations

Type	Factor		Comment	Data source
Emission factors				
NH_3	0.059	mol H^+/g	Worst case	Lindfors et al (1995)
NO_X	0.022	mol H^+/g	-“-	-“-
SO_X	0.031	mol H^+/g	-“-	-“-
N^{aq}	20	g O_2/g	-“-	-“-
P^{aq}	140	g O_2/g	-“-	-“-
CH_4	21	g CO_2/g	-	Ahlmén (2002)
N_2O	310	g CO_2/g	-	-“-
Density				
Diesel	817	kg/m^3	At 15°C	Shell (2005)
Ethanol	790	kg/m^3		
Petrol	740	kg/m^3		
Water	1 000	kg/m^3	-	
Energy content				
Diesel	35.28	MJ/l	-	Shell (2005)
Ethanol	22.32	MJ/l	-	SEPA (2005:2)
Petrol	33.12	MJ/l	-	Shell (2005)
Fossil gas	35.0	MJ/m^3	-	SEA (2005)
Energy conversion				
	3.6	MJ/kWh	-	-

5 Environmental impact assessment

5.1 Environmental impacts considered

Impact categories considered in this study are energy use, land use, global warming potential (GWP), eutrofication and acidification. The data format varied between data sources, and this is most likely reflected in the results; e.g. the data source of the energy consumption for meat production presented data in terms of emission output and not primary energy requirement; imposing a lack of inventory of used resources such as crude oil for the energy production. Hence, a mixture of the level of data quality, availability and importance are all parts of the reason for choosing the categories in question. Still, the main reason for the choice of categories is that other LCA studies of food products have shown these categories to be of interest (e.g. Sonesson et al, 2005:1). Pesticides are very important, but not included as stated in the goal and scope definition. Results in other categories, such as Photochemical Ozone Creation Potential (POCP), have been excluded from this report. However, results in POCP show similar relationship between the studied products, as the chosen categories. Brief descriptions of considered impacts are given below.

5.1.1 Energy

Energy and material are resources, thus they are more or less limited. Different characterisation methods treat resources in different ways; they can be divided into either renewable and non-renewable, or biotic and abiotic resources (Baumann & Tillman, 2004). When comparing production systems with different geographical locations, one has to take into account possible differences in energy sources, e.g. the difference between the European and Swedish electricity mixes. All different fossil energy carriers have in this study been denoted as simply “fossil energy”.

5.1.2 Global warming potential (GWP)

GWP is defined by United Nations Framework Convention on Climate Change (UNFCCC, 2005) as “an index representing the combined effect of the differing times greenhouse gases remain in the atmosphere and their relative effectiveness in absorbing outgoing infrared radiation”. In turn, greenhouse gases are substances which enable the for human life essential ability of the atmosphere to trap heat. However, the incineration of fossil fuels has increased the concentration of these gases, thus more heat has been trapped. As a result the temperature in the atmosphere has risen significantly since the beginning of the industrial age. Global warming is in LCA terms an ecological consequence (Lindfors et al, 1995), and is usually considered in an LCA. The most important emissions that contribute to this impact are: CO_2, N_2O and CH_4, the emission factors used for these emissions are presented in Table 31 below. The most commonly used unit is CO_2-equivalents, which denotes the relative global warming potential that a substance has in comparison to carbon dioxide.

Table 31 Emission factors for the most important contributors to global warming potential (GWP) [kg CO_2 equivalents/kg]

Substance	Emission factor
CO_2	1
N_2O	310
CH_4	21

The time horizon for the method used in this report, CML 2 baseline 2000, is 100 years; other methods may use for instance 10 or 1 000 years.

5.1.3 Acidification

This is the denotation of decreased pH in water or soil, caused by sulphur and nitrogen in precipitation, which in turn is entailed by the combustion of oil, coal and other fossil fuels. The main effect is the decline in number of species (both animals and plants) that occur at only small changes in pH. Acid precipitation is now diminishing due to the concrete actions that have been undertaken the last decades towards more "clean" emissions, but many lakes are still acidified and have to be limed regularly in order for sensitive species to be able to survive there (SEPA, 2005:1). The most important emissions that contribute to acidification are SO_2, NO_X and NH_3. Various emission factors exist, however SimaPro uses SO_2-equivalents.

Table 32 Emission factors for the most important contributors to acidification [kg SO_2 equivalents/kg]

Substance	Emission factor
SO_2	1
NO_X	0.5
NH_3	1.6

5.1.4 Eutrofication

Another considered category is eutrofication, maybe the most important impact from food systems. Previous studies have shown that the food system accounts for the absolutely largest share of total eutrofication in society (Sonesson et al, 2005:2). The largest contributors are sewage outfalls and fertilised farmland, which leak nitrogen and phosphorus compounds to lakes, watercourses and coastal waters. However, sewage outfalls and similar point sources are easier to control than the diffuse emissions from arable land. In Sweden, the phosphorus fertilisation level has been brought down to the 1920's level, but the amount of phosphorus stored in arable land remains undiminished. Therefore the leaking of nutrients to nearby marine environments (both coastal and inland) continues (SEPA, 2005:1). Emissions that contribute to eutrofication include NO_X, NH_3, NO_3 (to water), PO_4 (to water) and organic matter (measured as Biological Oxygen Demand (BOD) or Chemical Oxygen Demand (COD)).

Table 33 Emission factors for the most important contributors to acidification [kg PO_4^- equivalents/kg]

Substance	Emission factor
NO_X	0.13
NH_3	0.35
NO_3	0.1
PO_4	1.34
COD	0.022

5.1.5 Land use

The impact category “land use” describes in LCA methodology the environmental impacts of occupying, reshaping and managing land for human purposes. It can either be about the long-term use of land as in farming, or changing the type of land, e.g. from rainforest to arable land. In this study, land use has only been taken into account in a quantitative manner, and most land is cultivated land. Although this is not that detailed, it still provides a number on an aspect of resource use of food systems that is becoming more and more important.

As the world’s population continues to grow, the land has to supply more and more food, an increased demand which must be handled by either increased yields or by increased acreage of cultivated land. Most of the land suitable for agriculture is already in use, and the remainder is covered by valuable natural ecosystems such as rainforests. Also, in a time when alternatives to fossil fuels are sought, food crops may have to compete with other crops such as energy forest. All this makes land use an important parameter which will play a leading role in the construction of sustainable food systems.

6 Results

The results from this study are valid for the specified systems only. The numbers and figures presented below have been calculated using LCA software SimaPro (PRé Consultants, 2004) and the charts have been constructed in Microsoft Excel. The method used is the CML 2 baseline 2000 (CML, 2001), as it is relatively recent and includes the impact categories chosen in this study.

6.1 Comparison of the three products

Figure 8 shows the environmental impact from the three products, in terms of global warming potential. The post-factory process category includes distribution, home transports, storing, and cooking; and is of course equal for all three products.

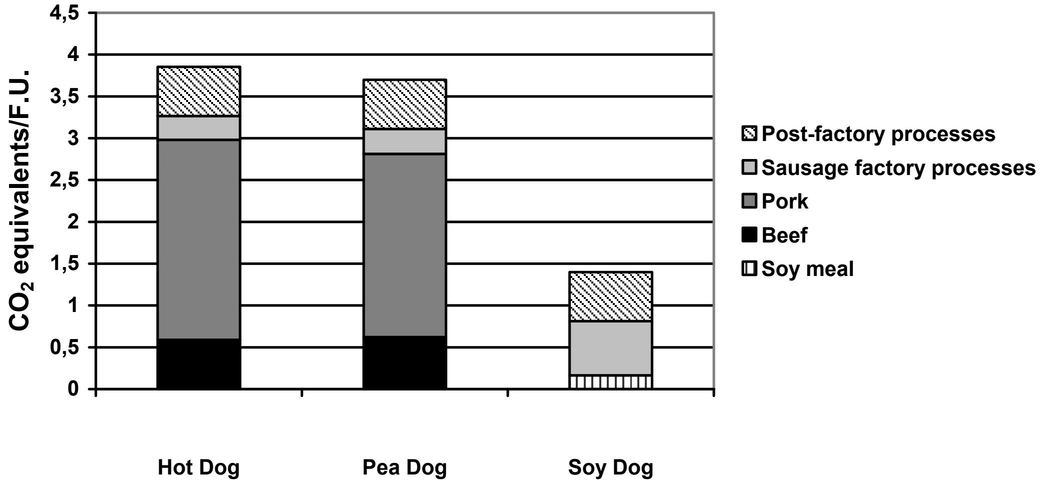

Figure 8 Environmental impact in terms of GWP from the different products

The meat production is superior to all other processes and its impact is more thoroughly described in section 4.1.1. There is a slight difference in the proportions of beef and pork in the two animal recipes due to sensory properties of meat and pea protein. The Pea Dog contains a larger fraction of beef than the Hot Dog and beef has a relatively larger impact potential than pork (section 4.1). Because of this the difference between the Hot Dog and the Pea Dog are smaller than they would have been if the two meat types been decreased proportionally. It is however possible that another mixture of pork and meat would yield satisfying sensory results, and would of course have great impact on the results.

The largest contributor in the post-factory category is the transports, or more precisely transport from the external retail to the household (assessed in section 6.5.3). The sausage factory processes are disaggregated in more detail in section 6.5. The contribution from the pea protein is too small to be visible in the figure, and is included in the sausage factory process, as is the contribution from the avoided wheat and ethanol; whose contribution is in fact negative. The resulting numbers for the three main categories are listed in Table 34 below.

Table 34 Environmental impacts

Product	Acidification [mg SO_2 equivalents/F.U.]	Eutrofication [mg PO_4^- equivalents/F.U.]	GWP [g CO_2 equivalents/F.U.]
Hot Dog			
Pork	28.1	19.2	2.4
Beef	10.5	4.0	0.6
Sausage factory processes	2.2	1.0	0.3
Post factory process	1.9	0.1	0.6
Total	**42.7**	**24.3**	**3.9**
Pea Dog			
Pork	25.8	17.6	2.2
Beef	11.0	4.2	0.6
Sausage factory processes	2.2	1.0	0.3
Post factory process	1.9	0.1	0.6
Total	**40.9**	**22.9**	**3.7**
Soy Dog			
Soy meal	0.7	2.2	0.2
Sausage factory processes	3.1	0.9	0.6
Post factory process	1.9		0.6
Total	**5.7**	**3.2**	**1.4**

The proportions between the different products are rather similar in all three categories. However, the post-factory process mainly contributes to the global warming potential, as it is almost solely originates from transports. When the post-factory process is excluded from the figures, the proportions are quite similar in all three categories.

Table 35 Difference in environmental impact, same units as before, per F.U.

Product	GWP [g CO_2 equivalents/F.U.]	Acidification [mg SO_2 equivalents/F.U.]	Eutrofication [mg PO_4^- equivalents/F.U.]
Pea Dog	-0.149	-1.3	-1.8
Soy Dog	-2.47	-21	-37

A fourth product was also assessed briefly, a product similar to the Pea Dog, but with soy protein instead of pea protein as substitute for 10% of the animal protein. The product is denoted Soy Dog II and the results from this product were very similar to those from the Pea Dog; hence it is not included in any figures or tables.

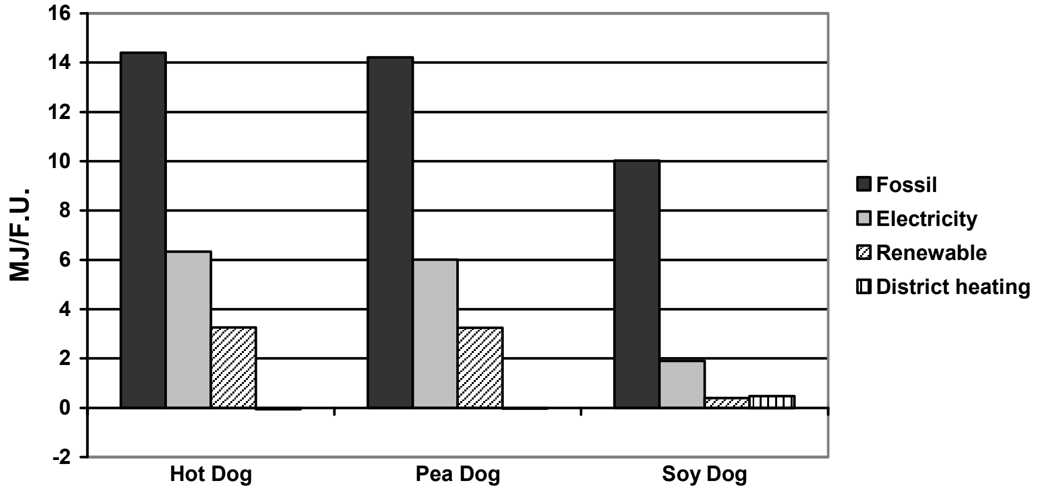

Figure 9 Net energy input to the different products

Figure 9 shows the net energy input for the production system. Note that Figure 9 differs from Figure 8 in the sense that the post-factory processes are not included, since they are equal for all products (as can be seen in Figure 8). The full result for net energy use is given in Appendix A. The renewable energy use is the biogas used for peeling. For the Soy Dog, most energy is used in the production of raw materials such as soy meal, corn starch and rape seed oil, and originates mostly from either transports or field operations. There is a small negative contribution from district heating to the Hot Dog and the Pea Dog, however too small to see in the chart. The negative number originates from the energy retrieval from waste in the meat production process which is used for district heating. The reason that the difference between the Soy Dog and the other products is smaller here than for instance GWP, is the large emissions of N_2O and CH_4 from pork and beef production.

Land use was also calculated for all three products. The results of these calculations are shown in Table 36; the numbers have similar proportions as in net energy input. Though the sausages contain more than just protein, it is worth noticing that one functional unit of Hot Dog only accounts for 35% less land use than for an equal amount of pork.

Table 36 Total land use of the different products

Product	**Land use [m^2/F.U.]**
Hot Dog	7.6
Pea Dog	7.4
Soy Dog	2.8

6.2 Comparison of protein source

One of the main interests in this report is to compare the environmental impact from the different protein sources. Figure 10 shows these relations, normalised to meat. The input to the assessment is the amount of each substance that is needed in order to make up the same protein amount. Only data on protein production is included; for the vegetable substances, cultivation and processing, and for the animal protein, primary production of meat. The "meat" is a mix of beef and pork, based on the proportions used in the Hot Dog recipe (section 4.4.2).

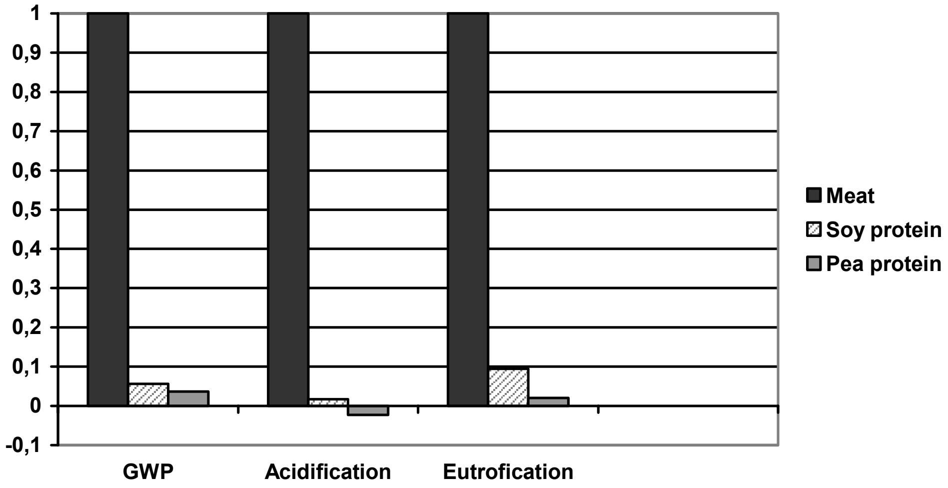

Figure 10 Environmental impacts normalised to the results from the assessment of the Hot Dog

The negative result from the pea protein production in the acidification category is a result that the combination of the extra wheat yield and the avoided ethanol production (section 4.3.3.1, respective 4.2.1) is superior to the impact from pea cultivation and fractioning.

It is also interesting to assess the different protein sources in terms of land use, a drastic difference can be noted between the different alternatives. For peas and soy, the similarity is a combination of higher yield of peas than soy beans, but higher protein content in soy beans than in peas.

Table 37 Total land use of the different protein sources

Product	Land use [m^2/kg protein]
Meat	72.9
Pea	16.9
Soy	16.3

This comparison is based on solely the protein content; in reality meat contributes with more than just protein. Meat also provides selenium, iron, fat, and other essential substances. To make an accurate comparison, one would have to make a system expansion in order to capture the differences in nutrition. Suggestions for how this could be carried out include an expansion to either include the production of tablets, or to assess complete meals. This is not included in this report.

6.3 Scenario 1

As stated in the goal and scope definition, different scenarios for the future potential of using vegetable protein in food products were assessed. The accumulated Swedish production of food products within this category (similar types of sausages) amounted in 1998 to 54 443 tonnes (Eidstedt, 2001), while the population at the time was 8 854 322 (SCB, 2005); which implies an average consumption of about 6 kg per capita. The population in Western Sweden (Västra Götaland, VG) was 1998 1 486 918 (SCB, 2005:3). Today, 4 140 ha of the arable land in VG is used for pea production. The available land area for a potentially increased consumption is somewhat hard to define; one reason being that EU legislation demands 5% of the arable land area to lie fallow, in order to decrease the grain surplus within the union.

In the first scenario, the amount of sausages corresponding to the annual demand in Western Sweden is modified by substituting 10% of the animal proteins by vegetable proteins. This would require 220 tonnes of pea protein or soy protein. The generated demand in terms of peas and arable land is shown in Table 38. Soy Dog II denotes a Hot Dog where instead of using pea protein, 10% of the animal protein has been substituted for soy protein.

Table 38 Vegetable demand in scenario 1

Product	**Protein [tonnes]**	**Cultivation [tonnes]** [17]	**Arable land [ha]**[18]
Pea Dog	220	1 470	430
Soy Dog II	220	790	320

To fully undertake the comparison between the different products, one would calculate the amount of soy protein needed to produce enough sausages to cover the annual demand. However, this is not part of this study, neither is it a realistic scenario.

6.4 Scenario 2

A common soy sausage contains approximately 7% textured soy protein (Nilsson, 2005), but in order to make the comparison more valid, the soy sausage in this study contains 8.5% soy protein, which corresponds to the other products. In scenario 2, it was investigated what quantities of soy sausage that would be needed to substitute animal products in order to gain the same effect on the environment as in scenario 1. This depends slightly on which impact categories that the calculations are based on, however the difference is negligible. The results from these calculations can be found in Table 39.

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[17] Assuming a protein content of 23% (Nichols, 2005), and a protein yield of 65% from pea fractioning using wet processing (Fredrikson, 2001:2). For soy, corresponding figures are 43% and 65%, respectively.

[18] The pea yield in Western Sweden is 3 400 kg/ha for conventional farming (SCB, 2005:2) and the average soy bean yield is 2 500 kg/ha (Cederberg & Flysjö, 2004:1).

Table 39 The two fractions denote the percentage of the sausage consumption that is needed of each product in order to achieve the same environmental savings as in scenario 1

Criteria	Hot Dog fraction[19]	Soy Dog fraction	Soy protein [tonnes]	Soy bean [tonnes]	Arable land [ha][20]
GWP	94%	6%	42	151	60
Acidification	95.1%	4.9%	34	122	49
Eutrofication	93.8%	6.2%	43	155	62

This means that in order to achieve the same environmental savings in scenario 2 as in scenario 1 with the Pea Dog, roughly 6% of the sausage consumption in VG needs to be Soy Dogs.

6.5 Hot spots

The dominating processes are the beef and pork production, the latter contributing more simply because of its larger fraction; the relation between them in the recipes is about 9 to 1. The agriculture is in turn the dominating process within the meat production, in which the fodder makes up the lion's share.

6.5.1 Hot Dog production

Figure 11 presents a view of the different processes' respective share of the overall energy use and environmental impact from the sausage factory. The peeling process' relatively large share is related to the use of biogas and heat oil for steam production, while the recipe mixing's contribution originates mainly from the production processes of the different raw materials, such as potato starch.

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[19] Each fraction denotes the respective share of the annual sausage consumption that is allocated to the different products.

[20] The average soy bean yield is 2 500 kg/ha (Cederberg & Flysjö, 2004:1).

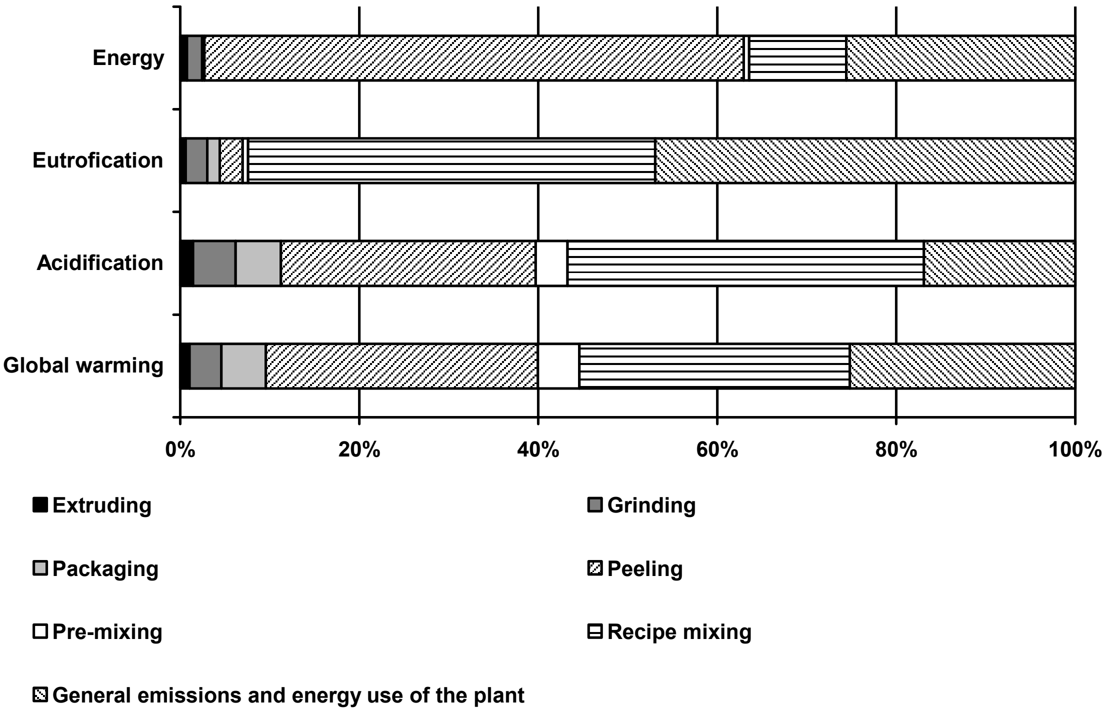

Figure 11 Sausage factory processes' respective shares of the overall environmental impact and energy use

Actual numbers on the energy use and the environmental impact from the sausage factory processes can be found in appendix A. It should be noted that the sausage factory's share of the product's overall impact is small, only about 7% of the total environmental impact. The energy share is larger, about 20%, but as it is mostly electricity the environmental load is limited. The latter is due to the fact that the calculations are based on the Swedish energy mix, where hydropower and nuclear energy is dominating.

A corresponding figure for the Pea Dog would render quite similar results, as the proportions in the recipe only differ slightly. Also results belonging to the production of the Soy Dog would look similar, but without the peeling and the pre-mixing processes. The actual numbers can be found in Appendix A.

6.5.2 Whole production chain

All three products generate the same environmental impact after the sausage factory; all transports and the preparation are equal. However, since the magnitude of the overall environmental impact of the animal and the vegetable alternative are different; these "fixed" impacts' share of the overall impact of the different products is unequal in size. An example of this is shown below, where Figure 12 shows the share of home transports, storing and cooking of the total GWP of the different products. "Total" includes all processes, even distribution which is equal for all products. Figures for the other impact categories show similar proportions.

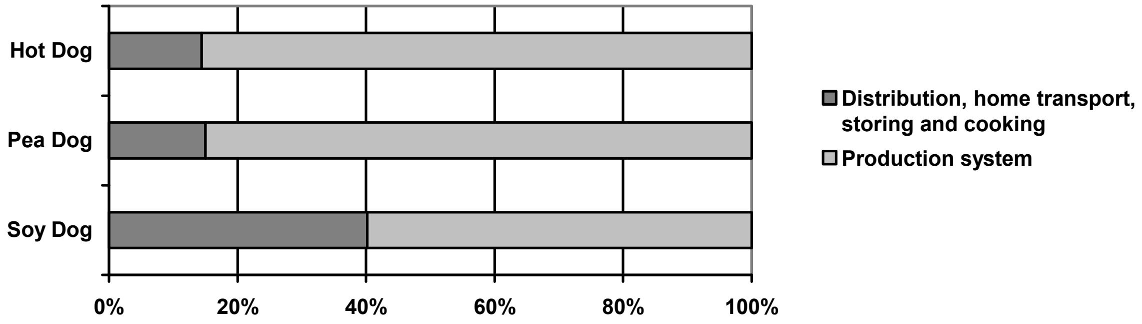

Figure 12 Comparison between the "fixed" impacts' share to the overall GWP for the three products

Table 40 shows the different parts of the post-factory's net energy input. The home transport is the dominant process, in which the environmental impact originates solely from the use of a car.

Table 40 Net energy input to the post-factory processes [MJ/F.U.]

Process	Fossil	Electricity
Distribution	0.29	-
Home transport	5.88	-
Storing and cooking	-	2.4
Total	**6.17**	**2.4**

6.5.3 The soy alternative

In the soy sausage, the non-protein ingredients play a larger role than in the animal products. The soy only accounts for 11% of the acidification impact, while the "recipe mixing" process accounts for 42%. All ingredients except for the soy are included in the latter process. Hence, the uncertainties in the soy recipe in terms of ingredients and individual proportions make this assessment less reliable, e.g. it is clear that alterations in the recipe may have substantial impact on the results of the assessment.

7 Discussion

This part discusses and assesses the parts of the results that need to be explained or that are of particular interest. Furthermore, some aspects on potential future changes in consumption habits are discussed.

7.1 Production and processing

The results show that agriculture makes up for a superior part of the environmental impacts of the food products in question, no matter which environmental impact category that is considered. This is mainly due to the large amount of fodder needed for the meat production, in which beef production is “worse” than pork production.

In the study, the peas are assumed to be produced in Sweden, but processed in Belgium; thus the peas are transported back and forth between Sweden and Belgium. Should large-scale use and consumption of peas become interesting in future, environmental consequences of processing elsewhere would be important to assess. Unfortunately no vegetable protein manufacturer (neither pea, nor soy) was interested in participating in the study; hence data on the production systems are approximated from literature and assumptions. Though this part might be somewhat inaccurate, these processes most likely do not contribute significantly to the overall impact.

7.1.1 Energy and transports

The energy use is presented in net energy input. This provides little information about the impact, and should be considered as an overview only. The energy use in the processes in this study emanates mostly from fossil fuels, and the impact of the electricity is quite small. This is due to the Swedish energy mix which consists primarily of hydropower and nuclear energy.

The home transports makes up a big part of the fossil energy use. Depending on product, the home transports have different weight in the overall impact. This leads to a distinction between where in the system enhancements seem most urgent and where they would induce the largest yield. Agriculture is the bad guy in the case of animal products, while the situation seems a bit more diffuse when looking at vegetable products.

7.1.2 The recipes

The recipes are more or less realistic, as stated in the inventory analysis (sections 4.4.2 and 4.5.2). The two animal products are most likely feasible to manufacture, while the soy sausage is a hypothetical recipe and the feasibility of manufacturing the product is unknown. The nutritional content is more or less identical for the animal products, but only the protein content is equivalent in the soy product also. Since the animal ingredients are superior to all other ingredients in terms of environmental impact, small uncertainties in the composition are of minor importance, but as the fractions of the different raw materials of the soy sausage are rather similar, the outcome of that assessment is more uncertain. What is very important is the change in meat proportion between pork and beef; this has great influence on the outcome of the study. Had both the Hot Dog and the Pea Dog had the same proportions, the difference in environmental impact would be close to 10%, thus close to a doubling in effect.

7.1.3 Protein comparison

As mentioned in the results section, the straightforward comparison of protein does not provide altogether precise results, as meat contains more than just protein. Protein may be the main nutrient of meat, but the other substances are also important, especially when looking at meat as a foodstuff, and not only as a source for essential nutrition. More aspects of vegetable protein as alternatives to meat are discussed in section 7.3 below. The environmental impact from the vegetable proteins would be higher if production of the missing nutrients was taken into account.

7.1.4 Preparation

The preparation method used is frying, but the way of preparing the food in question varies; sausages need not to be fried, they can also be heated in hot water or grilled. Especially in the summertime, barbecuing is popular not only in Sweden, but in most countries. The environmental impact then depends on which type of grill is used: propane, charcoal, wood, etc; all of them being a worse alternative than an electric stove. From this, it is apparent that the electric stove alternative (frying or heating in hot water) is really not valid for all produced sausages and may in fact be a “best-case scenario”.

7.1.5 Wastage

A study by Berlin (2005) pointed out the importance of the environmental impact from the production waste. The waste within the sausage factory is almost 1%. Also, it can be derived from Figure 8 in section 6.1 that the environmental impact from the 10% household wastage is almost as big as the impact from the sausage factory. Together, these two waste processes make up a big share of the product’s environmental impact, in that about 1.11 kg must be produced and distributed for each functional unit. Looking at the entire system, decreasing the waste in the households might be the easiest and most efficient way to decrease the environmental impact,

7.2 The scenarios

The required acreage for cultivating the amount of peas needed in scenario 1 is less than 10% of current acreage used for pea cultivation in Western Sweden; hence enough arable land for this increase in production should be possible to acquire.

Figures for the annual Swedish soy import for food applications are not known, but the demand in scenario 2 is most likely just a fraction of the total soy import (for both fodder and food applications), since the import for fodder applications makes up an amount of more than 200 000 tonnes in itself (SJV, 2005). However, what lies beyond the scope of this report is to assess the decrease in soy import for fodder production that would be the consequence of a potential decrease in animal production.

The two scenarios presented in this study represent two different approaches to establish more sustainable food habits. Is it a better solution to “hide” some vegetable protein in all products for everyone to eat, than to spend all that protein in fully vegetable products, for the minority of vegetarians to eat (or perhaps to try to increase the number of vegetarians)? Even though the actual number of vegetarians in Sweden is not known, it is most likely lower than the required fraction (6%) in scenario 2. It is also hard to define “vegetarian”; many people have vegetarian food once in a while.

7.3 Future potential

Not too many years ago, most manufacturers of cured meats changed their recipes to contain as few additives as possible. This was done in order to meet the increased consumer demand of products low in allergenic substances, as well as of products with a short list of contents. This put an end to old traditions of vegetables being used to enhance properties and to lower the price of such products.

How much value does a health label have to customers? In the U.S., the authorities have approved a health claim label for use on soy-based food products, after having reviewed studies pointing out soy protein’s value in lowering cholesterol levels. Though no such authority-backed labels have yet been introduced in Sweden, recent debates on e.g. high sugar content in many food products have made manufacturers not only eager to point out more “healthy” products within their line of products, but have also forced them to develop new products. Many vegetarians claim their diet to be healthier than an animal one, but whether a vegetarian diet is preferred to a balanced, partly animal diet is not clear. Perhaps at least a diverse diet, rich on all kinds of foodstuff is healthier than the average diet in Western society.

Although the aim of the Grain Legumes project is to assess the potential of decreasing the dependence on soy, e.g. through substitution by other protein sources, it is obvious that also a transition from animal consumption to soy consumption would induce substantial environmental savings, as the overall protein demand would be significantly lower. An investigation of possible market potential has not been included in this study, but is obviously a crucial component in a more extensive evaluation of the future for vegetable protein products.

Yet another parameter when one discusses possible changes and development of future food systems is the issue of land use. Again, the question of how vegetable proteins should be used arises; should they be used as fodder to protein-producing animals, or should they be used for human consumption? Evaluating the results from the assessment of the land use for different protein sources highlights the low efficiency of the first alternative.

7.4 The software

A student version of the LCA software was used for the calculations, offering a more narrow range of libraries and processes. Even if this made the selection of processes and materials easier, the use of the full version of the software might have offered more appropriate data. Some raw materials in the student version are represented by materials that are not traced back, thus leaving out some important factors such as emissions from extraction.

Other than that, the program fits this type of study well. Most process and material data have European origin; hence most data on transports and energy are available for the "actual" conditions. Some disturbing phenomenons do occur in the program. It does not seem likely that a contribution of 10^{-17} g of a substance has anything to do with a result that is measured in kilograms, and still results like these are presented by the software. Some kind of filter would be desirable.

8 Conclusions and recommendations

The goal with this study was to assess and compare food products with similar properties, but different composition. That goal should be considered to have been reached, in terms of the quality of the data that were gathered. The difference in environmental impact between the Hot Dog and the Pea Dog is not substantial, but this has a lot to do with different proportions of meat types (beef and pork) in the recipes. A proportional decrease of the meat would render a clearer view of the importance of the vegetable protein.

It is maybe even without research obvious that it is more effective to ingest proteins from a primary source, instead of a secondary as in the case of meat. In the meat production, the animals are fed vegetable protein in order to produce protein products. Hence, a shift in the human protein consumption towards a larger fraction of vegetable protein is desirable from an environmental point of view.

As far as the different scenarios goes, within the frames and scope of this study a satisfying level of results have been achieved. A substitution of 10% of the animal protein in the Hot Dog by pea vegetable protein does yield positive environmental effects, however they are not very big. The difference would be larger (about twice as big) if the proportions of beef and pork were equal in the products. The meat in sausages has traditionally been completed by other raw materials, such as vegetables. It is only recently that customer demand for short lists of contents, and concerns about allergenic properties, have made the manufacturers change their recipes.

Instead of the 10% protein substitution, about 6% of the total consumption could be exchanged for a vegetable alternative to obtain the same environmental effects. However, this would require a change in consumption for many people, since the 6%-fraction most likely exceeds the number of vegetarians. Further, if it is taken into account that the Pea Dog recipe possibly could be altered to contain less beef and thus have a smaller environmental impact, scenario 1 illustrates an interesting opportunity to reduce impact while remaining product properties. (It is analogous to low percentage blends of ethanol in petrol.)

Scenario 1 seems most realistic. It is important to assess the consumer acceptance and possible demand for such products. If positive health benefits could be connected to a shift from animal to vegetable proteins, the acceptance would probably grow. Pointing out environmental benefits may also help to create interest and demand for alternatives to animal protein.

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Appendix A – Data output from LCA software

Table 41 Environmental impact from the three products

Process	***GWP [CO_2 equivalents/F.U.]***			***Acidification [SO_2 equivalents/F.U.]***			***Eutrofication [PO_4^- equivalents/F.U.]***		
	Hot Dog	Pea Dog	Soy Dog	Hot Dog	Pea Dog	Soy Dog	Hot Dog	Pea Dog	Soy Dog
Soy meal	0	0	0.164	0	0	0.000654	0	0	0.00215
Wheat	0	-0.0168	0	0	-0.00011	0	0	-2.6E-05	0
Ethanol	0	-0.0182	0	0	-0.00013	0	0	-2.2E-05	0
Beef	0.59	0.622	0	0.0105	0.011	0	0.00399	0.00421	0
Pork	2.39	2.19	0	0.0281	0.0258	0	0.0192	0.0176	0
Peas	0	0.0391	0	0	0.000132	0	0	7.73E-05	0
Conveyor	0.000223	0.000223	0.000223	2.64E-06	2.64E-06	2.64E-06	6.97E-08	6.97E-08	6.97E-08
Extruding	0.00276	0.00276	0.00276	2.92E-05	2.92E-05	2.92E-05	5.81E-06	5.81E-06	5.81E-06
Grinding	0.0102	0.00972	0	0.000107	0.000102	0	2.32E-05	0.000022	0
Packaging	0.0143	0.0143	0.0143	0.000114	0.000114	0.000114	1.36E-05	1.36E-05	1.36E-05
Peeling	0.0872	0.0872	0	0.00064	0.00064	0	2.47E-05	2.47E-05	0
Pre-mixing	0.0132	0.0135	0	7.95E-05	0.000081	0	5.72E-06	5.83E-06	0
Recipe mixing	0.0867	0.0953	0.559	0.000895	0.000983	0.00264	0.000439	0.000472	0.000474
General emissions and energy use of the plant	0.0723	0.0723	0.0723	0.00038	0.00038	0.00038	0.000453	0.000453	0.000453
Storing and cooking	0.00782	0.00782	0.00782	8.34E-05	8.34E-05	8.34E-05	3.72E-06	3.72E-06	3.72E-06
Distribution	0.031	0.031	0.031	0.000324	0.000324	0.000324	7.06E-05	7.06E-05	7.06E-05
Home transport	0.503	0.503	0.503	0.000964	0.000964	0.000964	1.23E-05	1.23E-05	1.23E-05
Total	3.852883	3.704003	1.380583	0.042741	0.040941	0.005694	0.024255	0.022953	0.003192

Table 42 Net energy use in each process, divided into energy carriers [MJ/F.U.]

Product	**Hot Dog**				**Pea Dog**				**Soy Dog**			
Energy carrier	*Fossil*	*Electricity*	*District heating*	*Renewable*	*Fossil*	*Electricity*	*District heating*	*Renewable*	*Fossil*	*Electricity*	*District heating*	*Renewable*
Soy meal	0	0	0	0	0	0	0	0	0.804	0.141	0	0.394
Beef	1.560	0.340	-0.052	0.010	1.640	0.359	-0.055	0.010	0	0	0	0
Pork	10.600	4.400	-0.484	0.154	9.750	4.040	-0.444	0.141	0	0	0	0
Sausage production	2.252	1.594	0.475	3.100	2.826	1.616	0.475	3.100	9.220	1.765	0.475	0
Total. pre-factory	14.412	6.334	-0.061	3.264	14.216	6.015	-0.024	3.251	10.024	1.906	0.475	0.394
Post-factory processes	5.88	2.685	0	0	5.88	2.685	0	0	5.88	2.685	0	0
Total	20.292	9.019	-0.061	3.264	20.096	8.700	-0.024	3.251	15.904	4.591	0.475	0.394

Table 43 Environmental impact from the sausage factory processes [per F.U.]

Process	**Unit**	**Conveyor**	**Extruding**	**Grinding**	**Packaging**	**Peeling**	**Hot Dog Pre-mixing**	**Recipe mixing**	**General emissions and energy use of the plant**	**Total**	**Sausage factory's percentage of total impact**
GWP	g CO_2 equiv.	0.000223	0.00276	0.0102	0.0143	0.0872	0.0132	0.0867	0.0723	0.286883	7,4%
Acidification	g SO_2 equiv.	2.64E-06	2.92E-05	0.000107	0.000114	0.00064	7.95E-05	0.000895	0.00038	0.002247	5,5%
Eutrofication	g PO_4^- equiv.	6.97E-08	5.81E-06	0.0000232	1.36E-05	2.47E-05	5.72E-06	0.000439	0.000453	0.000965	4,0%
Energy	MJ	0.010988	0.040084	0.11518589	0.015873	4.065406	0.04057	0.7327145	2.021555	7.042377	22,0%