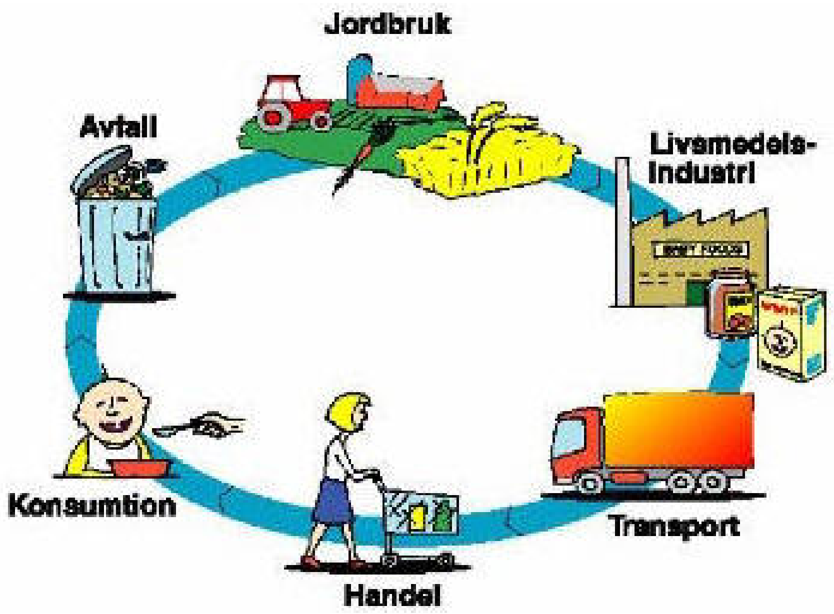

LCA of Spanish meals with different protein sources

Increased share of grain legumes in food

Master of Science Thesis in the International Master Degree Programme, Industrial Ecology

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Göteborg, Sweden 2007
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Preface

This report is a master thesis carried out within the Master Degree Programme of Industrial Ecology at Chalmers University of Technology in Gothenburg, at the division of Environmental Systems Analysis, Department of Energy and Environment, under the supervision of the examiner, Professor Anne-Marie Tillman.

The work has been carried out at the Swedish Institute of Food and Biotechnology (SIK AB), where Dr Ulf Sonesson, senior researcher has been my supervisor.

I would like to thank my coordinator of Master, my co-workers at SIK for help and encouragement during my work with this project. I would like also to thank my family for their never ending support.

Gothenburg, December 2006

Paul-Louis Lafargue

Summary

Life Cycle Assessment (LCA), which is a method for analysis of the environmental impact caused by products systems, and its application to food chain, has been studied. For food products, the complete product system includes: production of inputs to agriculture, agriculture production, industrial processing, storage and distribution, the household phase and waste management. The overall objectives were to learn more about environmental impact of product system in Spain and to evaluate the potential environmental improvement of increasing the share of grain legumes in the human food chain. Various products have been chosen to compose the meal. The pork production is of course in the centre of the focus as well as the peas, but other food products appear as well in the study as tomatoes, potatoes, white bread or mineral water.

For these various products, an LCA from cradle to gate were carried out. Energy used and emissions were quantified and the potential contribution to global warming, acidification, eutrophication, photo-oxidant formation and ozone depletion were assessed. The great scarcity of environmental data was one of the major problems encountered when applying the LCA methodology to food products in Spain. Therefore the data collection was very time consuming and uncertainties of the results were quite large. For pork production, data from Germany had to be used and a dominance and sensitivity analyses were assessed to evaluate the potential results for Spain.

The results of this LCA show that, for all the environmental impact categories studied, an increased share of grain legume in the human alimentation is a sustainable solution. Thus, global warming, acidification, ozone depletion and photochemical smog have the same trends for the 4 scenario studied. One can observe a net reduction of the environmental loads when the amount of meat is lower; hence the meat production appears to be the main contributor for the various emissions. The pork production at the farm and the slaughterhouse are very energy demanding processes with high contributions to the environmental impacts.

1 Introduction

1.1 Background

The demand for high quality protein for animal feed and human consumption in Europe doesn't stop increasing. Bovine spongiform encephalopathy (BSE or mad cow disease) led to the ban on using animal-derived protein in livestock feed which in return raised the demand for vegetable protein sources. The cultivation of grain legumes such as peas, beans and lupines that are rich in protein, starch, fibre and essential nutrients would be a suitable alternative to meet this need. In addition grain legumes possess important agricultural advantages. In symbiosis with bacteria, they can fix atmospheric nitrogen providing them with this important nutrient and adding it for subsequent crops. These crops need less nitrogen fertiliser, and this has beneficial environmental effects as a result of reduced nitrogen losses from fertiliser manufacturing and application as well as a substantial reduction of energy demand (Charles & Nemecek, 2002). Furthermore grain legumes have an indirect effect on crop rotations because they act as break crops slowing the build-up of cereal pests, diseases and weeds and resulting in a reduced need for pesticides (Nemecek et al., 2004a). Despite these advantages, only 5% of Europe's arable land is currently cultivated with grain legumes. As a result, 70% of Europe's plant-derived protein demand is imported, mostly as soybean meal from North or South America, and this has adverse environmental impacts, including long transport distances (GLIP, 2004).

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, 2004). As a part of this project, the Swedish Institute for Food and Biotechnology (SIK AB) is responsible for assessing the impact on the environment of meals for humans.

The analyses are done for two regions, Spain and Sweden. These regions represent two rather different systems both in terms of household, cooking and surrounding systems as energy and waste management system. Hence the results from these regions will facilitate a discussion about the importance of different factors that would not be possible if only one region was studied. In this report, the Spanish part is reported; the Swedish part will be published.

For that, one will study all the various phases of the conception of a meal as well as its consumption in a household. This leads to the question how household consumption affects the environment? Every stage of the food production chain (from growing crops to transportation or storage, manufacturing, distribution, purchasing, or dealing with waste) has environmental impacts. When Swedish researchers compared the greenhouse gas emissions given off over the life cycle of four different meals with the same energy and protein content, they found that they ranged from 190g carbon dioxide-equivalent for a vegetarian meal with local ingredients to 1,800g for a meal containing meat, with most ingredients imported (EEA SOER report 2005).

1.2 State of the art

Before a meal can be eaten, the raw materials are produced by agriculture, processed by an industry, it is purchased from retailer and then the food has to be prepared. Different modes of transportation have moved the food from one location to another. These activities affect the environment by the use of resources and by emissions to air, water and soil. For example, the energy used in the life cycle of the food chain, agriculture to consumption, was estimated to be approximately 17% of the total energy use in Sweden (Uhlin, 1997). Of this total, agriculture accounted for 15-18%, industry 17-20%, distribution 20-29% and consumption 38-45%. To the greenhouse gases, the food system contributes around 28% (calculation based on SEPA 2004 and Uhlin, 1997). Through these figures we understand better the importance of the environmental impact of the food chain and why such a large number of life cycle assessment (LCA) studies on agricultural products have been carried out.

First of all, it is important to understand the full mechanism and the potential of LCA. A thorough description is presented by Bauman and Tillman (2004), where the concepts are defined and the methodology is detailed. For all life cycle steps it is important to understand the place of each step in the full process. One of the first LCA studies involving food industry was the study on Life Cycle Assessment (LCA) of Food Product and Production Systems (Andersson, 1998). This study focused on ketchup and bread. The overall objectives were to learn more about the feasibility and limitations of LCAs of food systems and to generate information on the environmental impact of such systems. For foods, the complete product system includes: production of inputs to agriculture, agriculture production, industrial refining, storage and distribution, packaging, the household phase and waste management.

Then, once the LCA methodology fully understood and the importance of the environmental impact of food product estimated, it is interesting to learn about the different studies done around the food industry, in order to place our work in its context.

The following overview will focus mainly on product LCAs of the products milk, pork, egg and chicken and linked production systems, e.g. the production of concentrated feed.

The production of pork has been the subject of several LCA studies. Basset-Mens & van der Werf (2005) have studied the environmental impacts of three contrasting pig production systems in France using LCA methodology. The scenarios they compared were good agricultural practise according to French production rules, a French quality label scenario called Red Label and a French organic scenario. They found that, when expressed per kg pig produced, the good agricultural practise had the lowest environmental impacts for the impact categories energy use, land use, climate change and terrestrial toxicity. However, the Red Label production system had the lowest impacts on eutrophication and acidification. Per kg of pig produced the French organic scenario had comparatively the lowest environmental impacts only in the category of pesticide use (Basset-Mens & van der Werf, 2005). In a Swedish study by Eriksson et al. (2005) the impact of the feed choice for pig production was examined. The chosen scenarios were feed formulations for pigs where a) the present trend of soybean use was extrapolated, b) a formulation consisting of domestic feed (no soybean) with low crude protein level and added synthetic amino acids and c) the pig feed used was from organic production. The results show that of all feed ingredients soybean meal had the highest impact for all impact categories. For soybean meal over 50% of the energy use and 75% of the acidification were due to long distance transportation. For the different impact categories the results of the three scenarios for one kg of pig growth were as follows: The scenario with soybean meal had the lowest environmental impacts for land use, whereas for energy use and global warming potential the scenario with organic pig feed had the smallest impacts. Regarding acidification and eutrophication, the scenario using domestic feed enriched with synthetic amino acids was the most favourable concerning environmental impacts (Eriksson et al., 2005). A similar study has been performed by van der Werf et al. (2005) on the environmental impacts of the production of concentrate feed for pigs in Brittany. The authors defined six diets for pigs adapted to their development stage. The feed components were either from local, national or overseas sources. Most diets were cereal based in combination with soya, rape or sunflower meal or peas as protein sources. For the local crops pig slurry was assumed to be the main source of fertiliser. The results based on one ton of pig feed show that for the impact categories energy use, climate change and acidification the contribution of transport processes was substantial. Compared with a feed consisting mainly of non-processed crop-based ingredients a feed containing mainly co-products had higher environmental impacts in the category energy use and lower impacts in the category terrestrial ecotoxicity. Comparing wheat-, maize- or co-product-based feeds per ton of compound feed produced, and the wheat-based formulation is the most favourable for the impact categories land use, energy use and climate change. The co-product-based feed has the lowest impacts for acidification and terrestrial ecotoxicity. Generally the wheat-based feed was more favourable than the maize-based one, the exception being the category of eutrophication (van der Werf et al., 2005).

There are several LCA studies internationally published on single food products, from farm to consumption, among them milk (Hospido et al., 2003; Eide, 2002) and bread (Andersson & Ohlsson, 1999). For pork and potatoes there are LCAs from Sweden published (Anonymous, 2002). Studies describing whole meals or similar are limited. Kramer (2000) presented a study on the food consumption in the Netherlands and identified options for decreased emissions of greenhouse gases and energy use, using a methodology based on national statistics on energy use and emissions from sectors. Sonesson et al (2005) and Sonesson & Davis (2005) reported LCAs for different ways of preparing two meals, one based on meatballs and the other based on chicken.

Our study on environmental impact of the food chain is also a product LCA, but on a whole meal, including various food products. In these meals European grain legumes are included in various proportions, either as feed for the pigs or consumed directly as replacement for pork. Data from the agricultural study will be used for the food study.

1.3 Outline of the study

In this study, a life cycle assessment (LCA) of different food products was performed. For the data collection it was decided to use current data as much as possible, primarily from manufacturers, secondly from literature and previous studies and then to make assumptions where data were not available. All the calculations were made using the software Simapro 7.0 and the results of these calculations are presented.

The report will begin with a brief introduction to LCA followed by definitions, statements and decisions connected to the method. Thereafter he documentation of the data from the inventory analysis is presented in tables, followed by 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. Finally, the results are discussed, conclusions are drawn, and recommendations are made.

2 LCA methodology

Life Cycle Assessment (LCA), which is a method for analysis and assessment of the environmental impact caused by products systems, and its application to food products have been studied.
LCA is sometimes called cradle to grave analysis: a complete life cycle includes raw material extraction, processing, transportation, packaging, storage, use and waste management system (fig 1).

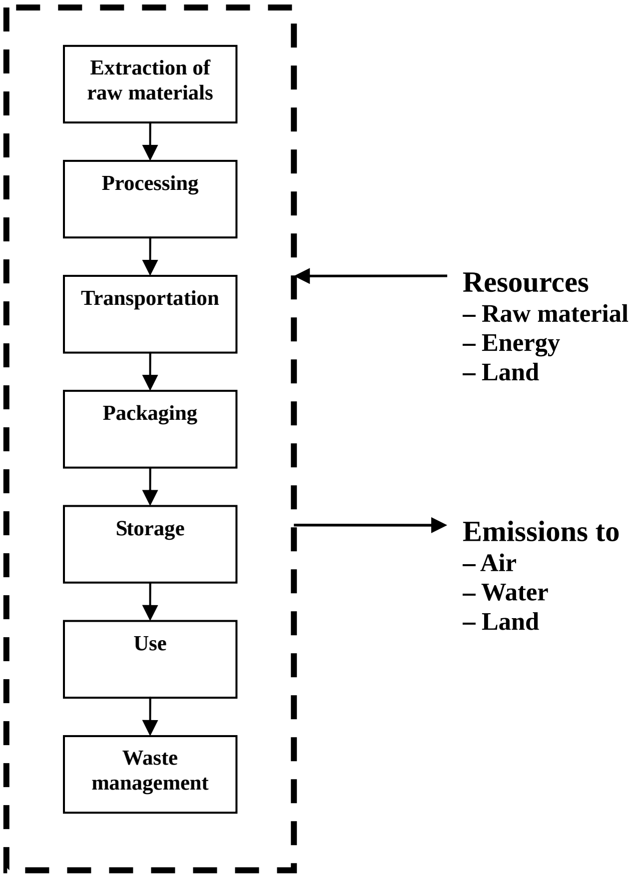


Figure 1 ***Overall scheme of a product's life cycle.***

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 fig 2. The results from later phases often make it necessary to go back and make changes in earlier phases.

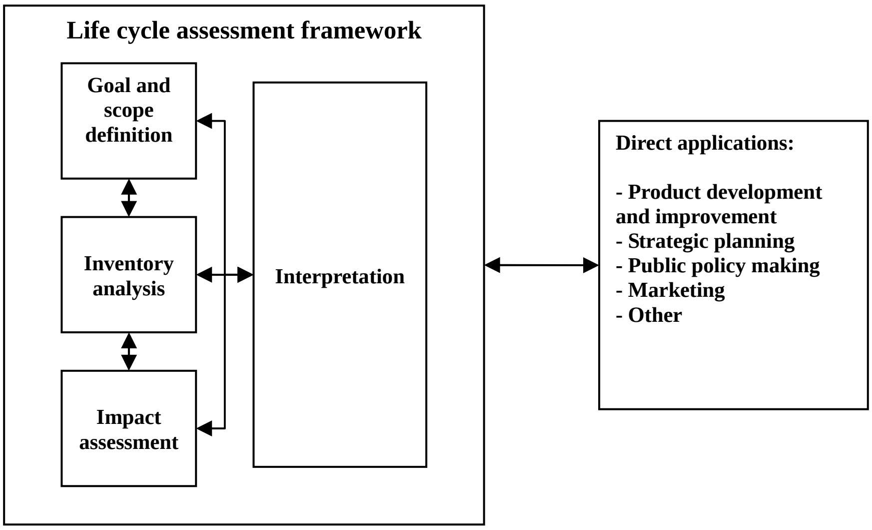


Figure 2 ***Phases of an LCA (CEN, 1997)***

In the *goal and scope definition*, the aim of the study and its intended application and limitations are defined. The product to be studied and the purpose of the study are decided; it also includes the reason for carrying it out, and to whom the results are intended to be communicated. Moreover the functional unit is chosen, and the 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 *inventory analysis* is usually the most time consuming phase. It 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. The data collection for all activities is accompanied by continuous documentation of collected data. The last step is to calculate the environmental loads of the system, in relation to the functional unit. The inputs to the system in terms of resources (such as raw material and energy) and the outputs from the system in terms of emissions to air, water and soil are identified and quantified.

The aim of the *impact assessment* is to analyse and assess the environmental impacts of the inputs and outputs identified in the inventory analysis. The impact assessment can be divided into three steps.

1. *Classification*, the inputs and outputs of the system are grouped into impacts categories.
2. *Characterisation* is the assessment of the relative contributions of each input and output to its assigned impact categories and the aggregation of the contributions within the impact categories.
3. *Valuation* means the weighting of either inputs and outputs or environmental effects. Methods from the social sciences are used, since the valuation is concerned with values held by humans in the social system.

The *interpretation phase* means drawing conclusions from both the inventory and the impact assessment. It can include a data quality review or a sensitivity analysis. It 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, it means to check and assess completeness, consistency, uncertainty, sensitivity, variation and data quality.

3 Goal and scope definition

3.1 Goal

The ultimate goal for grain legume production is to feed people either directly or indirectly via meat. The purpose of this LCA is to identify the potential environmental improvement resulting from European production of protein for the consumer, and hence a meal is the most appropriate function as basis for the analysis, which will place the results in a practical context.

The main question to answer is so:
"How to assess the environmental impact of grain legumes use in human food in order to identify the environmental constraints to the increase of grain legumes in Europe and to suggest new strategies to overcome them."

The main objective is to analyse four different products. The purpose is to compare the environmental impact of each product and also to identify the most important contributors to the total environmental impact of each product. They are described as follow:

- 2 products in which all protein is animal protein (slices of pork, on feed with soja and the other with grain legumes).
- 1 product in which 10 % of the animal protein is replaced within vegetable protein.
- 1 product in which all protein is vegetal protein.

In order to make it possible it was decided to include these products in meals which composition will be explained and detailed later on (3.6 Composition of the meals).

The target groups of this report are the scientific community, extension services, the food industry, retailers, and consumers' organisation, authorities and policy makers. Farmers are not primarily part of the target group for this report. They will be addressed mainly through extension services.

3.2 Scope

The food products chosen were slices of pork fried in a frying pan, an alternative sausage and a vegetarian burger made of pea both fried as well. The reason to choose these products to base the meal on was that pork is a commonly used meat in Spain and the sausage is a popular food product, and the feasibility of substituting animal protein in sausages has been shown before (Tömösközi et al, 2001). The information concerning the pork production in Spain has been collected from an institute in Switzerland (Agroscope FAL Reckenholz, Zurich) and data from Germany have been used. In order to include this data in the project and to stay in the focus of the study, dominance and sensitivity analyses have been carried out. Thus it has been possible to approximate the results with Spanish data.
The data concerning the meat at the gate of the pork farm, information of the slaughterhouse process in Spain and retailing have been added. The two last meal alternatives have previously been studied in a Swedish case study (Abelmann, 2005) and data from that study have been used for the inventory. Simple flow chart for the preparation of one meal is presented bellow.

The reason for choosing a meal (instead of Kg protein) was that 1 Kg of protein from peas supply other functions (as energy) that 1 Kg of protein from meat; hence other ingredients in the meal must change to supply the same functions.

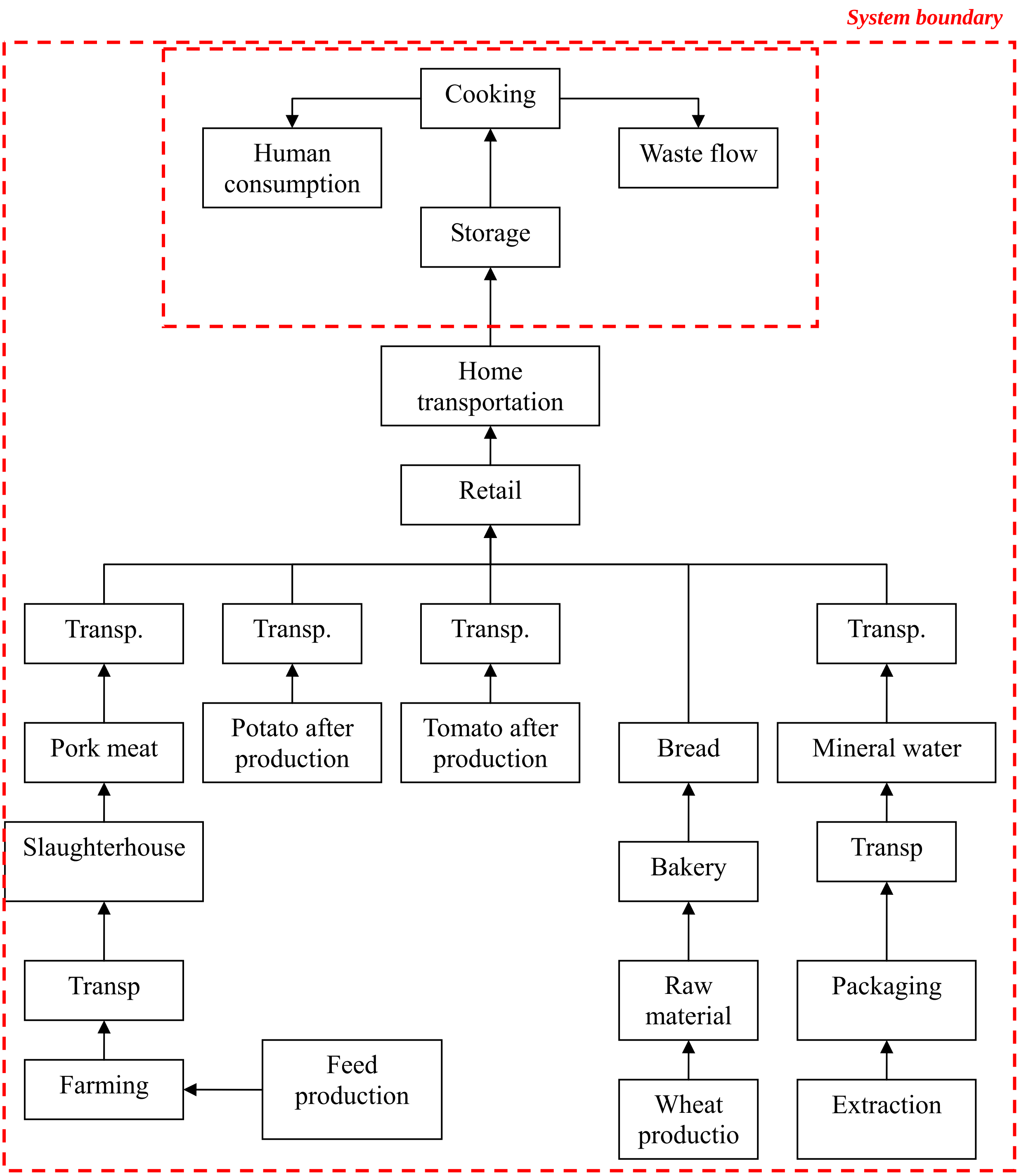


Figure 3 ***Simple flow chart of the composition of 1 meal***

3.3 Functional unit

Food has many functions for humans, the principal one being to supply nutrients (energy protein and vitamins). However, pleasure, cultural and social identity are also important functions of food. We have chosen the function of basic nutrient supply. The functional unit for the study is one meal served at the table in the household for 2 people. The meals deliver the same amount of energy whereas the protein and fat content must be within the limits set by Swedish Food Administration. The proportions between proteins, fat and carbohydrates are within the recommendations on nutrient intake from official bodies as the Swedish Food Administration.

3.4 System boundaries

The boundary between the technical system and the natural environment is not clear when agriculture is considered, as the production takes place in the natural environment. In the study all the different phases are taken into account, from the agricultural phase including fertiliser production, to the consumption phase in the household with the waste management system.

3.4.1 Technological boundaries

The life cycle starts with the production of raw materials for the product and ends with the waste management system after the household. Studies have shown (Sonesson et al. 2004) that the sewage treatment plays an important role in food product life cycle in term of environmental impact. That is why it has been included it the flow chart. The data use on ingredients and other inputs include use of materials and energy as well as waste and emissions to air and water.

Site-specific data have been used where available as for the slaughterhouse; for other processes, especially transports and household, average data have been used.

Pesticides, fungicides and herbicides are used widely in agriculture, thus also in growing of feed used in meat production. Due to the toxicity of these substances, manufacturers have for many years undertaken risk assessment studies because of legal requirements. In this study, the use of pesticides is 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 but are not analysed further in the results section.
In the parallel work within the GLIP performed by ART in Switzerland, the impact of pesticide use will be included.

3.4.2 Time horizon

The goal has been to use as present data as possible and the results will be described in the present situation.

3.4.3 Data requirement

The goal is to use real world data, but for some parts of the system data bases and literature data will be used. When no data are available, estimates or data from similar processes have been used. As a choice of database from Simapro's collection, Ecoinvent has been used where available and applicable, e.g. for electricity production.

3.5 The scenarios

In Spain, pork is widely consumed meat. The pork are assumed to be fried in slices in a frying pan, the potatoes are oven baked, the tomatoes are eaten raw, the bread is made of wheat and baked in a large scale bakery and the water is mineral water.

Four scenarios are considered in this study, one reference and the other three with different degree of grain legumes in the production.

1. Meal with conventional pork (soybean fed), oven baked potatoes, raw tomatoes, wheat bread and mineral water.
2. Meal with pork from pea based protein feed (GL- pork), the same as "conventional pork", but the meat is produced with a pea-based protein feed, and oven baked potatoes, raw tomatoes, wheat bread and mineral water.
3. Meal with partial replacement of pork (partial GL-pork replacement by peas, other ingredients adjusted to maintain energy and protein content), oven baked potatoes, raw tomatoes, wheat bread and mineral water.
4. Meal with full replacement of pork (by peas and other ingredients to maintain energy and protein content), oven baked potatoes, raw tomatoes, wheat bread and mineral water.

3.6 Composition of the meals

Based on the recommendations from Livsmedelsverket (Swedish national food administration), the energy level for a woman and a man on a daily basis (3meals plus 2 snacks) is respectively 9.1 MJ and 11.5 MJ. We decided so to take an average of 10.3 MJ.

The recommended meal pattern is:

- 20-25% for the breakfast
- 25-35% for the lunch
- 25-35% for the dinner
- 2 or 3 snacks can be added

The meal we choose represent about 1/3 of the daily energy required so about 3.1 to 3.8 MJ
Energy from fat should not overcome a maximum of 30 % of the total energy: 1.05 MJ
Energy from protein should not overcome a maximum of 10 to 17 % of the total energy: 0.525 MJ
Energy from carbohydrates should not overcome a maximum of 50 to 60 % of the total energy: 1.925 MJ

In the tables 1 to 4 the four meals that compose the different scenarios are presented. One can see the composition in grams of all the ingredients with the amount of energy relative to each ingredient and the share in grams of protein, fat and carbohydrate.

Table 1 ***Composition and energy content of scenario 1***

	Total		Protein		Fat		Carbohydrates	
	Grams	**MJ**	**MJ**	**Grams**	**MJ**	**Grams**	**MJ**	**Grams**
Meat	120	0,92	0,396	23,28	0,533	14,40	0,000	0,00
Potatoes	270	0,84	0,083	4,86	0,010	0,27	0,741	43,58
Tomatoes	90	0,09	0,014	0,81	0,003	0,09	0,072	4,23
Bread	120	1,27	0,169	9,96	0,107	2,88	0,996	58,56
Total	**600**	**3,12**	**0,66**	**38,91**	**0,65**	**17,64**	**1,81**	**106,37**

Table 2 ***Composition and energy content of scenario 2***

	Total		Protein		Fat		Carbohydrates	
	Grams	**MJ**	**MJ**	**Grams**	**MJ**	**Grams**	**MJ**	**Grams**
Meat	120	0,92	0,396	23,28	0,533	14,40	0,000	0,00
Potatoes	270	0,84	0,083	4,86	0,010	0,27	0,741	43,58
Tomatoes	90	0,09	0,014	0,81	0,003	0,09	0,072	4,23
Bread	120	1,27	0,169	9,96	0,107	2,88	0,996	58,56
Total	**600**	**3,12**	**0,66**	**38,91**	**0,65**	**17,64**	**1,81**	**106,37**

Table 3 *Composition and energy content of scenario 3*

	Total		Protein		Fat		Carbohydrates	
	Grams	MJ	MJ	Grams	MJ	Grams	MJ	Grams
GL sausage	100	0,83	0,145	8,50	0,518	14,00	0,151	8,90
Potatoes	270	0,84	0,083	4,86	0,010	0,27	0,741	43,58
Tomatoes	90	0,09	0,014	0,81	0,003	0,09	0,072	4,23
Bread	120	1,27	0,169	9,96	0,107	2,88	0,996	58,56
Total	**580**	**3,03**	**0,41**	**24,13**	**0,64**	**17,24**	**1,96**	**115,27**

Table 4 *Composition and energy content of scenario 4*

	Total		Protein		Fat		Carbohydrates	
	Grams	MJ	MJ	Grams	MJ	Grams	MJ	Grams
Pea burger	100	0,58	0,118	6,94	0,146	3,94	0,512	30,11
Potatoes	270	0,84	0,083	4,86	0,010	0,27	0,741	43,58
Tomatoes	90	0,09	0,014	0,81	0,003	0,09	0,072	4,23
Bread	120	1,27	0,169	9,96	0,107	2,88	0,996	58,56
Total	**580**	**2,90**	**0,38**	**22,57**	**0,27**	**10,51**	**2,32**	**136,48**

All the meals are quite similar. It has to be taken into account that these figures don't include any fat for cooking. This explains why meals 3 and 4 have lower energy content than the recommendations. It is because the sausage and the vegetarian burger are fried in a large amount of fat (olive oil have been chosen in the inventory analysis).

Moreover, it can seem that the last meal is not very well balanced. It was quite problematic to find the good equilibrium between a nice meal and balanced energy content. The fat content is quite low but the oil for frying is not included, then the carbohydrate content is quite high (about 20% higher) but it allows compensating with the low protein content of this vegetarian meal.

4 Inventory analysis

4.1 Pork production

4.1.1 Farming phase

4.1.1.1 Description

For the data collection of pork production, information for pork production in North Rhine-Westphalia in Germany has been used (table 5, bellow).
Due to some changes in the overall project plan, data for Spanish pork production couldn't be included in this report. In order to keep the focus of the project, an alternative solution was to use data from Germany and from these results evaluate the potential differences with the Spanish case study.
In order to evaluate the differential various analyses have been carried out: first a dominance analysis and then a sensitivity analysis. With this, it becomes possible to forecast with certain approximation the impact on the results if Spanish data should have been used.
The dominance analysis is a tool to determine which factors and processes most influence the different environmental impact categories. Then the sensitivity analysis answers the question how the result changes if a parameter is changed.

4.1.1.2 Data

Table 5 ***Environmental impact of German pork production (Baumgartner and Nemecek, 2007. Report in preparation, ART, Zürich Switzerland)***

Impact categories	SOY	GLEU	Units
Non-renewable energy resources, fossil & nuclear	28,656	27,062	[MJ-eq]
GWP 100 years	3,467	3,316	[kg CO2-eq]
Photochemical ozone formation, high NOx POCP	0,001	0,001	[kg ethylene-Eq]
Stratospheric ozone depletion, ODP 100 years	$1{,}625E^{-7}$	$1{,}516E^{-7}$	[kg CFC-11-Eq]
Nutrient enrichment, combined potential	0,044	0,042	[kg N]
EDIP, acidification	0,053	0,052	[kg SO2-Eq]
Resource P	0,012	0,014	[kg P]
Resource K	0,042	0,039	[kg K2O]
Land occupation	4,990	5,124	[m2a]

In the table above, two different types of pork have been compared. The first one (SOY) represents a pork production feed by soya bean meal mainly coming from South America and cereals. In the second case (GLEU for European grain Legume), the pork is feed with peas, rape seed, soya bean meal and cereals.
The impact categories have been considered according to Goal&Scope Report 2005 (Baumgartner et al., 2005) but have not all been used in this study. Land occupation and P&K resources have not been considered.

4.1.2 The slaughterhouse process

4.1.2.1 Overview of the company

The data have been collected by interview at a slaughterhouse called Carnicas Yeles, situated close to Toledo (60 km South of Madrid). The interview was later complemented by email and telephone.
The contact person there was the veterinary of the slaughterhouse, Mr Alfonso Fuentes and the visit was lead by the coordinator of the operations Mr Apolinar Diez.

The first useful information concerns the use of the pork. For each animal there is about 23% of waste and the rest of the pork (the hot carcass) is divided in the different categories as shown in the graph below.

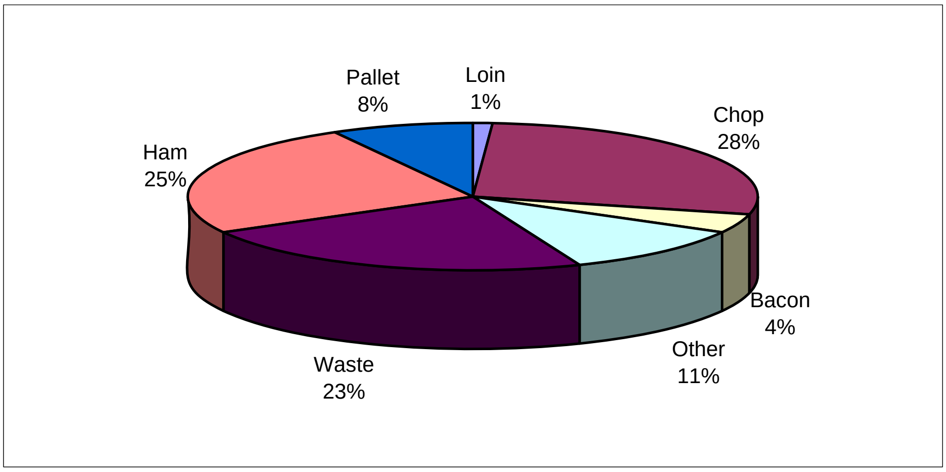


Figure 4 ***The use of pork***

Regarding the 23% waste of the animal, not everything is going to the sewage treatment. The waste are devided in:

- By products
    - Boiled blood
    - Hair
    - Large intestin
- Remains
    - Not human consuming
        - Spleen
        - Stomach
        - Liver
        - Lung
    - Human consuming
        - Heart
        - Tongue
        - Kidney
        - Gizzard...

Some of the remains are also used to make medicine, like the pancreas in the production of insulin and windpipe to treat arthritis.

4.1.2.2 Process in the slaughterhouse

First, as shown in the flow chart below (figure 5) the trucks arrive from the pig farms. Everyday the slaughterhouse receives about 1600 pigs. The first step is to receive the truck and to weight it. Then a veterinarian performs a sanitary control of each animal and the dead ones are directly sent to another plant. The truck is then emptied and cleaned with fresh water and then has to pass through a gate to be disinfected before leaving.

From the truck, the pigs are taken to small rooms where they are first divided in lots and cleaned. Each lot is independent and processed separately in order to avoid any contamination if some blood test is negative.

Then, the process starts. The pigs are electrocuted one by one with a 600 volts electrocution and then hung up by the feet to an electrical chain. All the pigs follow each other and go through a circuit to achieve all the steps of the process. First the pig is emptied of blood. This blood is pumped and put into big tanks to be filtered. If the pig seems to be ill or with some external sign of bad health the operator cut the ear of the pork and the blood is directly thrown away.

The filtered blood is conserved in containers and sent to another plant whereas the blood residue is cooked onsite in 90 º C water for 50 min, then cooled in cold water and finally cut in bricks to be sold as food ingredient to another company for human consumption.
After that the pork goes into a bath of hot water (between 63º C and 67º C depending on the skin of the animals). During this 2 minutes bath, two electric turbines make the pork turn in order to remove most of the hair. The hair is conducted outside and is stored in big tanks with other wastes.

Then the pork go through two turning brushes to dry and pass through a block of 20 welding torches to finish drying and eliminating the last hair. Then the pork is manually opened and all the valid animals (without any ear cut) are eviscerated. The viscera are directly divided in two parts: the white and the red viscera. They are process in different areas, and for the ear cut pigs, all the inside of the animal is separately managed. During all these steps, the operators use knifes which are sterilized at 82º C and changed after each lot.

Thus, when the hot carcass is empty and before being weighted to decide its category, an operator removes some meat of the animal for sanitary control. If the test indicates some problems, all the lot is checked one by one. Otherwise after the weighting, the pork carcasses continue their way to go to a last water shower and the carcasses are stored in cold rooms.

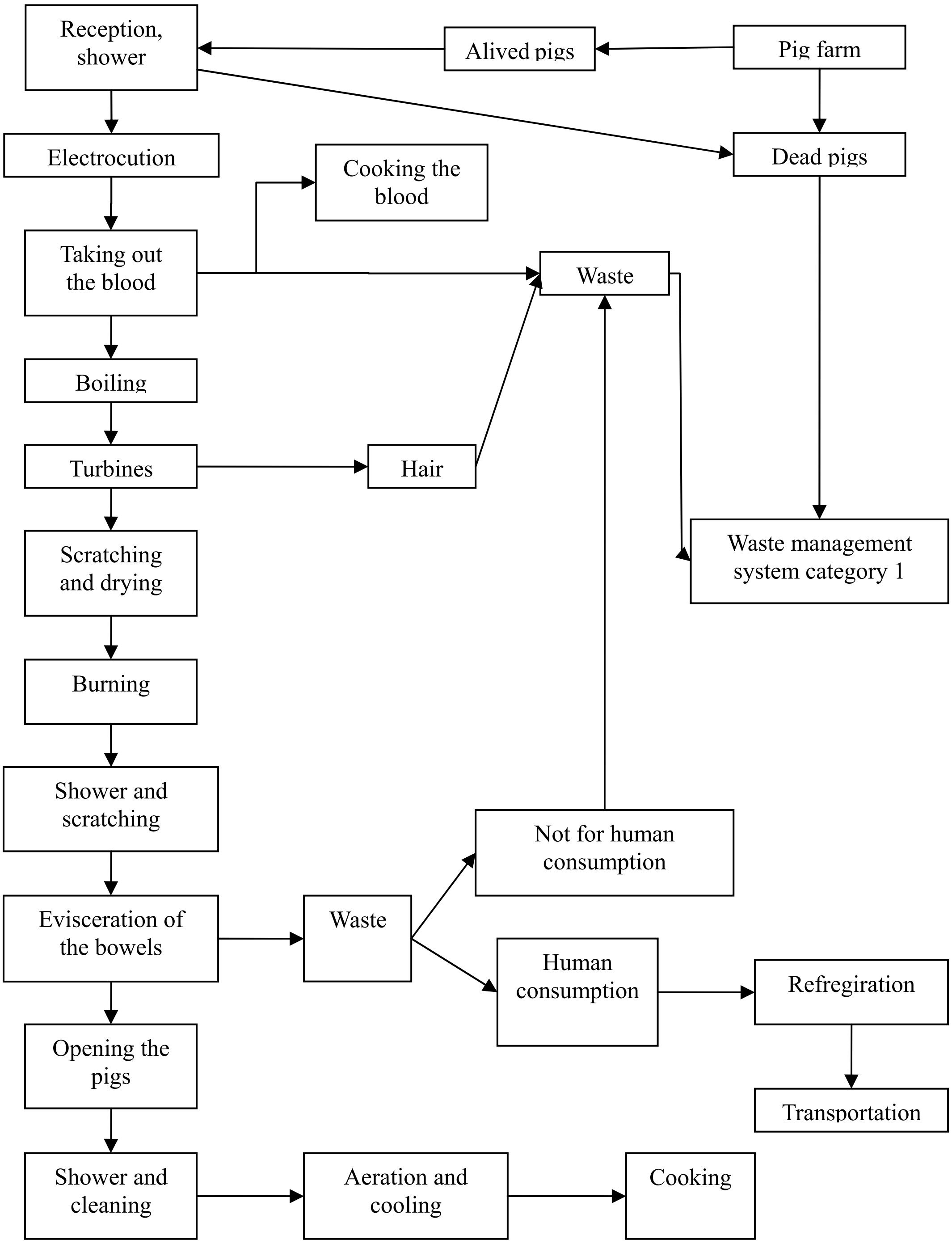


Figure 5 ***Flow chart of the slaughterhouse***

4.1.2.4 Energy use

Energy consumption depends on the age and scale of the plant. The actual numbers are going to change because of the various innovations in the process of the slaughterhouse. For example a new line is going to be taken into operation soon where the pigs are not electrocuted but are killed with carbon dioxide, which is considered less stressful for the pigs.

Processes involving heating, such as cooking or boiling are very energy intensive whereas some other like filleting requires less energy. Thermal energy in the form of steam and hot water is used for cleaning, heating the water and sterilizing. Electricity is used for the operation of machinery and for refrigeration, ventilation and lighting.

The rough estimations of the energy and water consumption in the slaughterhouse (data from the interview) are:

- **Electricity 26,500 MWh/year**
- **Thermal energy 58,000 MWh/year**
- **Water 760,000 m^3/year**

Like water consumption, the use of energy for refrigeration and sterilization is important to ensure good quality products in order not to break the cold chain. Storage temperature is often controlled by regulation. As well as use of fossil fuel resources, the consumption of energy causes air pollution and greenhouse gas emissions, which are linked to global warming. **The energy use is 900 kW per ton of hot standard carcass weight.**

4.1.2.5 Wastewater generation

Fresh water consumption has a major impact on the volume of pollutant load of the resulting wastewater. The wastewater has a high concentration of organic substances and a high oil and grease load. In the slaughterhouse, the water is mainly used for washing the carcasses during the various steps of the process and for cleaning at the end of each shift (about every 50 pork). About 80 to 95% of the water used is discharged as effluent.

The wastewater from the slaughterhouse contains blood, manure, hair, fat, and bones and may have a high temperature. Untreated effluent may be as high as 8,000 mg/L BOD with suspended solids at 800 mg/L or higher.

The wastewater as well may contain pathogens, including mainly Salmonella. Pesticide residues may be present from treatment of animals of their feed. Chloride levels may be very high, up to 77,000 mg/L; cooking activities also increase the fat and grease concentration in the effluent. That is why all the wastewater (85% of the total water) is treated on a waste management plant of category 1.
Category 1 is the highest risk category and includes carcases and materials known to be or suspected of being infected by a Transmissible Spongiform Encephalophathie such as scrapie or BSE. This category also includes experimental animals (as defined by Article 2 of Council Directive 86/609/EEC and pet, zoo and circus animals. [Article 4 of Chapter II of the Regulations specifies that experimental animals are always Category 1 Animal By-product material, EAUC]

The cleaning of trucks also result in water use, and hence waste water generation.

4.2 Pea sausage alternative

The sausage is a common food in many countries, there is a wide selection of different sausages and usually each country has its own variants and recipes. For this study, the description of the production process and the recipe has been taken from the work of Anders Abelmann (2005) on his study on the environmental potential of increased human consumption of grain legumes for Swedish circumstances.

4.2.1 Description

The chosen alternative is a hypothetical product based on the hot dog recipe, but with 10% of the animal protein substituted by pea protein.
The table 6 below shows the composition of the two recipes which contain animal protein. The average protein content of the meat ingredients is 17.5%.
Nearly 50% of the mass content is meat, but in protein content this represents only about 10% of the product; hence we have 10% of the protein content coming from pea.

Table 6 Comparison between the classic Hot dog and the Pea alternative recipes [kg/100kg product]

Raw material	Hot Dog	Pea alternative
Pork	49.5	**45.5**
Beef	3.9	**4.1**
Water	34.3	36.2
Potato starch	10.0	10.5
Nitrite salt	1.8	1.9
Spices	-	-
Sugars	-	-
Pea protein	N/A	**1.0**

One can notice from the table above, that the pork content has decreased, due to the addition of pea protein, but the beef content has increased (from 3.9 to 4.1%). This increase could seem to be very small but can have a large impact on the result.
The reasons for such a recipe are that changing the recipe by introducing grain legume in a sausage must not change the taste, and texture of the product in order to fulfil all the requirements of the consumer.
The production of sausages consists of eight processes that have been included in the life cycle inventory. The process description is found in table 7.

Table 7 ***Process description***

Process	Description
Grinding	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	Storage for 1 to 5 days.
Recipe mixing	Mixing of the meat mixture with other ingredients such as starch potatoes and spices.
Extruding	Four extruding machines loaded with cellulose tubes. Viscofan SA in Pampelona (Spain) manufactures the cellulose casing.
Peeling of sausage strings	Four parallel machines use steam to peel the casing off the sausages.
Packaging	-
Loading area	Facility office, stock input to logistics software, and back reporting of customer orders.

4.2.2 Data

For the pea protein, data have been collected from the GL-pro report (Thomas Nemecek and Daniel Baumgartner, 2006): Environmental Impacts of introducing grain legumes into European crop rotations and pig feed formulas September 2006.
The crop rotation studied was composed of pea, wheat, and barleys in the region of Castilla y Leon. It has been shown that using peas as precursor crop to winter wheat can increase the wheat yield, from about 6000 kg/ha to 7000 kg/ha (Jordbruksverkert, 2004; Cederberg & Flysjö, 2004:1). 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 different soil layer for nutrient supply
- *Crop protection*, the risks of diseases and parasites are reduced
- *Weed prevention*, specific species are less likely to be favoured

The production conditions in Castilla y Leon are quite different from the other regions of Spain. Firstly the production intensity is relatively low and the yields are at a modest level (the pea yield is 2.5 t/ha). The quantity of inputs (fertilisers and pesticides) is relatively low. It was further assumed that fertiliser management is not changed in consequence of grain legumes, which corresponds to the current practice of the farmers in the region. This means that the same quantity of N fertiliser is applied after peas as after non-legume. According to consistent experimental results (summarised in von Richthofen et al. 2006), it should be possible to reduce the N fertiliser rates after a grain legume. This shows that an improvement potential exists in the cropping system in Castilla y Leon.

The results of von Richthofens study are summarised in the table 6 bellow and have been used as input for the pea cultivation in the present study.

Tabel 8 Environmental impact of pea production in Spain

Impacts	Value per ha per year	Unit
Energy demand	1.07E+1	GJ-eq
Global warming potential	2.17E+0	tCO_2-eq
Ozone formation	3.54E-1	Kg ethylene-eq
Eutropication separate N	6.62E+1	Kg N
Eutrophication separate P	9.01E-1	Kg P
Acidification	9.77E+0	Kg SO_2-eq

The low production intensity leads to a relatively low energy demand of about 10 GJ/ha per year, which is 2-3 times less than in other regions.

4.3 Pea burger production

4.3.1 Description

For the vegetarian alternative, I have chosen to study a vegetarian burger made of pea. The assumption has been to take the same recipe and production process as for the Swedish study (Davis et al. 2006).

4.3.2 Recipe

Table 9 ***Recipe of the pea burger***

Recipe	Weight (g)	MJ/100g	Protein (g)/100g	Fat (g)/100g	Carbohydrates (g)/100g
Boiled peas, 3.5 dl	120	1,24	21,5	1	49,3
Corn starch	30	1,47	1,8	0,1	16,14
1 onion	95	0,13	0	0	87
1 egg	60	0,61	12,6	10,1	1,4
1 tablespoon butter	15	2,98	0,60	80,00	0,40
Total content	320	2,87	33,99	19,29	147,55
Total per 100g fried burger		**0,58**	**6,94**	**3,94**	**30,11**

4.3.3 Production process

The pea burgers are assumed to be produced industrially. The raw materials and the packaging material are transported on average 300 km to the industry. Data and information on a reasonable composition of the product as well as on the production process are based on discussions with a producer of vegetable products based on chickpeas.

The energy use for manufacturing, frying, freezing and storing of the product is 2,95 MJ electricity/kg and 1.25 m^3 liquid nitrogen/kg (Gratchev, pers. comm.., 2006, cited as in Davis et al. 2006). We assume also that 30 g cardboard is used for packaging of one kg. All these figures are directly included in the results for the pea burger production in the inventory analysis.

4.4 Tomato and water production

4.4.1 Description

Tomato and mineral water are both part of the different meals and needed to be study for the Spanish case study. For the tomato production, the data are based on a study in Turkey. For the mineral water, a case study has been done based on the mineral water Agua de Solares.

4.4.2 Tomato production

Due to the lack of information concerning tomato production in Spain, data from a Turkish study on greenhouse tomato production have been used and shown in the table 10 below (Hatirli et al., 2005).

Table 10 ***Energy input, output in greenhouse tomato production.***

Inputs (unit)	Quantity used per unit area (ha)	Total energy equivalent (MJ/ha)	%
Diesel (Litre)	651,0	36 657,8	34,35
Fertiliser (Kg)	940,9	29 443,9	27,59
Electricity (kWh)	4746,8	17 088,6	16,01
Chemicals (Kg)	107,4	10 872,5	10,19
Human power (h)	4009,8	9 222,6	8,64
Machinery (h)	46,9	3 041,1	2,85
Water (m^3)	618,5	389,7	0,37
Seeds (Kg)	0,1	0,1	0,01
Total energy input (MJ/ha)		106 716,2	100,00

From this table, Ecoinvent database has been used to calculate all the emissions.
Energy use in agriculture has become more intensive as the Green Revolution led to increasing use of high yielding varieties, fertilizers and chemicals as well as diesel and electricity. Energy consumption per unit area in agriculture is directly related to the development of technology in farming and the level of production. In that case, as a

greenhouse production, it is generally carried out in a small family farm in the research area. The average greenhouse size is 0.25 ha (Hatirli et al., 2005).

4.4.3 Mineral water

In order to obtain data for mineral water, a Spanish mineral water (Agua de Solares) was inventoried. The zone of extraction is in Solares, Cantabria. It is a source situated in the North of Spain, 430 Km North of Madrid. It is a widely consumed water in all Spain. The chosen format is the 1.5 L bottle.

The process is quite simple; the water is extracted, bottled and transported to the retailer in Madrid. The focus on the study was on the bottle since the plastic production represents the major environmental impact for this process.
Information about plastic bottles and process production (figure 6) has been taken from a comparative LCA on plastic packaging (1N1800, Lehmann et al. 2005).

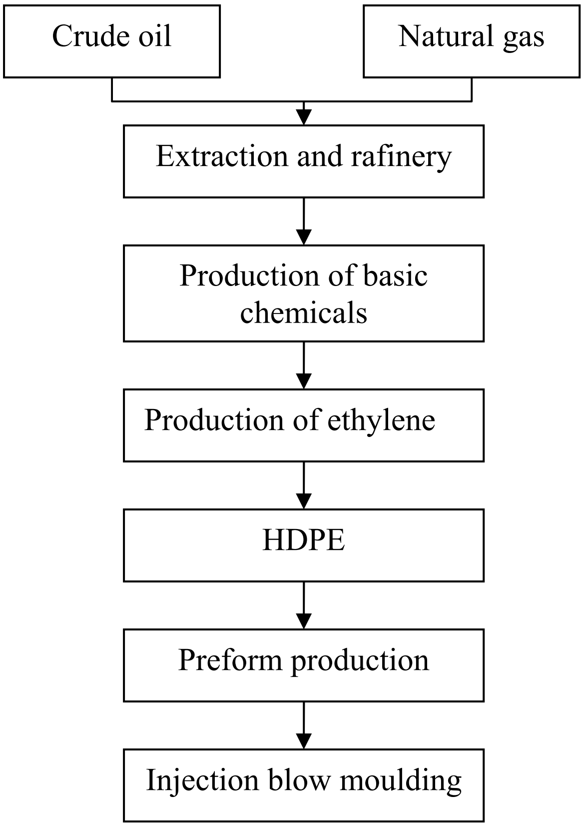


Figure 6 ***Simple flow chart of the plastic bottle production***

The average weight of the HDPE bottle is 32-54g, so for the 1.5L bottle we considered a 50g of HDPE (High Density Polyethylene) plastic per bottle of water (Lehmann et al. 2005).

Plastics are made from oil and natural gas, both of which are non-renewable resources. We have chosen the HDPE plastic because polyethylene is the most common polymer in daily life; it offers a wide range of packaging application with low cost and good barrier properties. More than 1.5 million tons of plastic are used to bottle water (Facts and figure: Bottled Water: International Year of Freshwater 2003). HDPE (the substance that water bottles are made of) requires less energy to recycle than glass or aluminium, and releases less emission into the atmosphere. The processes used to make plastics can however cause serious pollution affecting both the environment and human health if left unregulated.

4.5 Transportation

Data on transport were based on Truck 28t B250 (BUWAL 250, 1996; Persson, 2005:1), except the last transport to the household, which was based on Transport Passenger car RER/ S (Ecoinvent system processes).

4.5.1 Transportation of products

Table 11 ***Tranport distance for the different products***

Substance	Origin	Destination	Category	Distance [km]
Tomato	Sierra y Leon	Madrid	Truck 28 t B250	343 km
Potato	Sierra y Leon	Madrid	Truck 28 t B250	343 km
Pea	Sierra y Leon	Madrid	Truck 28 t B250	343 km
Mineral water	Solares	Madrid	Truck 28 t B250	430 km
Wheat	Sierra y Leon	Madrid	Truck 28 t B250	343 km
Pork meat	-	Toledo	Truck 28 t B250	-

The distance between the farm and the slaughterhouse is not known. German data have been used for the pork production and assumed to be produce in the same region that the slaughterhouse.

4.5.2 Distribution and home transport

For the home transportation some allocations have been done in order to calculate the energy use for transport from the retail to the house.
It was assumed that the distance between the retail and the house is 5 km both ways. Assuming as well that only one person of the household goes shopping twice a week, with a 75% allocation for the food.
A meal represents the third of the food of a day, so we have a total distance per meal of:

$$d=5*(2/7)*0,75*(1/3)=0,35714 \text{ km.}$$

4.6 Description of the surroundings systems

The surroundings systems are the inputs and outputs of the studied system that are situated outside of the system boundaries but which have a direct impact on the studied system.
First of all there is the energy mix for electricity production in Spain. For all the processes, the electricity input have been done with Simapro; with an input date from the Buwal 250 database. The electricity mix in Spain is composed of (BUWAL 250):

Table 12 ***Electricity mix for electricity production in Spain***

Uranium	35,4%
Coal	30,5%
Hydropower	13,3%
Lignite	9,9%
Oil	9,2%
Gas	1,7%

The amount of waste generated per household in Spain has increased by 17% between 1998 and 2003 to reach about 1.52 tons per household and per year (Perfil Ambiental de Espana 2005). Around 80% of Spain's annual 15 million tonnes of municipal waste are landfilled; there are only 124 controlled landfills.

Table 13 ***Evolution of the waste management system of the urban wastes***

	1999 (%)	2002 (%)
Controlled landfill	12,82	55,51
Not controlled landfill	18,01	3,51
Compost	58,77	27,39
Selective sorting	4,75	7,59
Incineration with energy recuperation	5,31	5,93
Incineration without energy recuperation	0,34	0,07
Total	100	100

Concerning the generation of biodegradable waste in the household, 66.9% is going to recycling, 2.4% to incineration and 30.6% to landfill (INE Instituto Nacional de Estadística).

4.7 Household

Between 1991 and 2001, the number of households in Spain has increased with 19.7%, with some important modifications in their compositions. On the one hand, one of the main changes concern the 1 person household (from 1,6 to 2,9 millions), on the other hand, one has to notice the diminution of the 4 and more children families (Cifras INE).

Table 14 ***Number of household in Spain, 2001***

Number of people per household	Number of household	%
1	2.875.422	20,3
2	3.581.496	25,2
3	3.003.941	21,2
4	3.047.852	21,5
5	1.099.738	7,7
6 and more	575.577	4,1
Total	**14.184.026**	**100**

For our study, we have chosen a 2-person household. This choice has been made for different reasons, first because they represent the biggest share of the population. Moreover, we want to reconstitute a practical case and the case study being based in Madrid, a 2 people household was the most reasonable case. Another alternative would have been to take the average of a 2.8 people household, but this solution doesn't fit in our practical case.

4.7.1 Cooking and storing

Data on cooking was presented by Sonesson et al (2003). Different models have been used to calculate the energy use for cooking. For the meat a first model has been used, the functional unit corresponds to 2 batches of meat and it is assumed that they are fried at the same time.

Table 15 ***Model for calculating energy use for frying in a pan.***

Input data			
t_f	Time for frying	10	min
M_{fp}	Mass of the frying pan	800	g
A_{fp}	Area of the frying pan	254,3	cm²
$\mathbf{E_{total}}$		**1,07**	**MJ**

For the potatoes, they are oven baked and the following model has been used. Depending on the type of oven used, with a batch of 2 potatoes (540g) cooked during 30 min in a 200ºC oven, we have an energy used of 4.370 MJ.

Table 16 ***Model for calculating energy use in oven.***

Input data		
Volume oven	59	Litres
Temperature	200	ºC
Preparation time	30	Minute
Frozen product	0	Grams
Not frozen product	540	Grams
Temperature ≠ between start & ready product	180	ºC
Water loss	15	%
Results		
Warming up	2,360	MJ/ batch
Maintaining	1,487	MJ/ batch
Evaporation	0,183	MJ/ batch
Melting	0,000	MJ/ batch
Heating up	0,340	MJ/ batch
Total	**4,370**	**MJ/ batch**

Another model has been used for the storage in the refrigerator. For example, storing a product of half a litre during 2 days in a refrigerator of 150 litres, filled to 75%, demands energy of 0,023 MJ.

Table 17 ***Model for calculating energy use in refregirator.***

Input data		
Volume refrigerator	150	Litre
Time stored	2	Days
Volume product	0,5	Litre
Volume used in refrigerator	75	%
Total	**0,022607**	**MJ/batch**

4.7.2 Wastes

Table 18 below shows the different percentages of waste for the various components of the meals. They are based on average. (Sonesson et al., 2005:2) and represent the share of waste product generated before cooking, for example peeling of vegetables or waste during food storage.

Table 18 ***Food wastage generated after meal and storage.***

	After storing	After meal
Vegetables/roots	44,1%	8,3%
Meat	6,9%	3,7%
Potatoes	2,9%	4,8%
Bread	0,8%	0,5%

These figures have been used for the mass outflow, in order to evaluate the quantity of products needed for the composition of the meal and the quantity of products thrown away in the waste management system.

5 Environmental impact assessment

The method chosen for this study is EDIP. This method (Environmental Design of Industrial Products, in Danish UMIP) was developed in 1996. For this study, the V2 version, adapted for Simapro 7.0 was used.

Impact categories in this study are energy demand, global warming potential (GWP), photooxidant formation, stratospheric ozone depletion, eutrophication, acidification and ecotoxicity (table 19).

Table 19 ***Impact categories for the EDIP method.***

Impact category	Normalization	Weighting
Global Warming Potential	1,15E-7	1,3
Ozone depletion	4,95E-3	23
Acidification	8,06E-6	1,3
Eutrophication	3,36E-6	1,2
Photochemical smog	5,00E-5	1,2
Ecotoxicity water chronic	2,13E-6	2,3
Ecotoxicity water acute	2,08E-5	2,3
Ecotoxicity soil chronic	3,33E-5	2,3
Resource	0	0

5.1 Environmental impacts

5.1.1 Climate change for a time horizon of 100 years

Global warming is a warming of the atmosphere, which causes climate changes. Some of the largest human contributors to global warming are the combustion of fossil fuels like oil, coal and natural gas. Global warming potential are in this study presented in g CO2-equivalents.

5.1.2 Photooxidant formation

Photochemical smog formation occurs when Volatile Organic Compounds (VOC's) are released in the atmosphere and oxidized in the presence of nitrogen oxides (NOx). The most significant VOC's emissions originate from unburnt petrol and diesel and the use of organic solvents, like paints. Photochemical smog attacks organic compounds in plants, animals and materials exposed to air, causing problems in the respiratory tract in humans. For agriculture it causes a reduction in yield. Photochemical smog formation potentials are in this study presented in g ethene equivalents.

5.1.3 Stratospheric ozone depletion

Stratospheric ozone is broken down as a consequence of man-made emissions of halocarbons (CFC's, HCFC's, haloes, chlorine, bromine etc.). The ozone content of the stratosphere is therefore decreasing causing thinning of ozone layer, often referred to as the ozone hole. The consequences are increased frequency of skin cancer in humans and damage to the plants.

5.1.4 Eutrophication

Another considered category is eutrophication, maybe the most important impact from food systems. Previous studies have shown that the food system accounts for the absolutely largest share of total eutrophication 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. Emissions that contribute to eutrophication 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)).

5.1.5 Acidification

Acidification is the process whereby air pollution – mainly ammonia, sulphur dioxide and nitrogen oxides – is converted into acid substances. It is caused by acids and compounds which can be converted into acids that contribute to death of fish and forests, damage on buildings etc. The most significant man made sources of acidification are combustion processes in electricity and heating production, and transport. Acidification potentials are in this study presented in g SO_2- equivalents.

6 Results

The numbers and figures presented below have been calculated using LCA software SimaPro 7.0.2 and the charts have been built with Mircrosoft Excel. In a first part, results will be presented for each impact category to have an overview of the difference between each scenario. In a second part, we will focus on the process contributions, analysing each impact category makes it possible to focus more on which specific process contributes most to the result.

6.1 Overview, comparison of the scenarios

This overview is a comparison between the different meals studied, for each impact category. We may recall that the main difference between the different scenarios is in the source of protein. The 2 first meals are based on slices of pork, in the first meal the pork is feed with soya from South America and in the second one with grain legumes from Europe. The third meal is based on a grain legume sausage composed mainly of pork, beef and grain legume (respectively 40%, 4% and 10%) and the last meal is based on a fried pea burger.
The scenario 1 has been studied before and represents the actual situation; that is why it has been established as the reference for the comparison.

6.1.1 Global Warming Potential

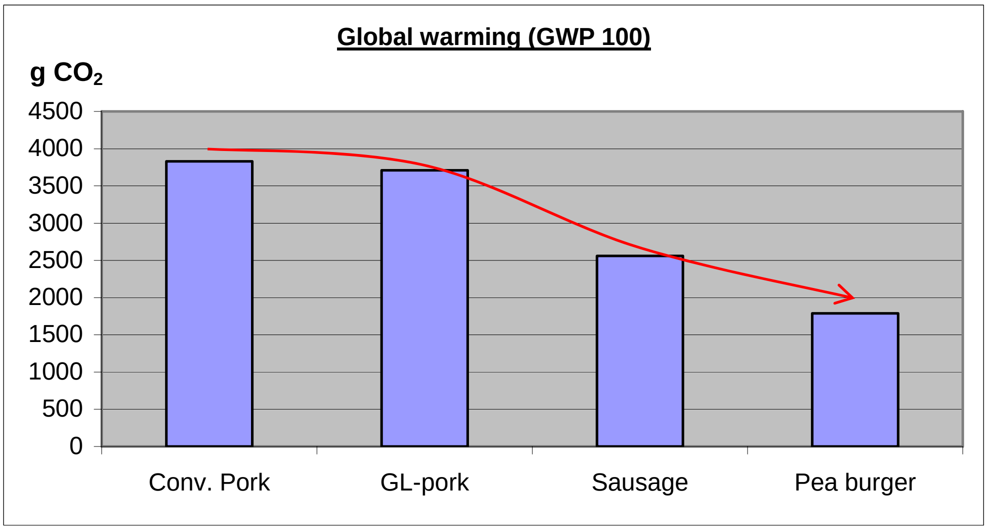


Figure 6 ***Impact assessment global warming***

The 2 first scenarios have a similar impact on global warming (only - 3% for scenario 2), but one can notice a decrease of the amount of carbon dioxide emissions, 33% less for the scenario 3 and 53% less for the scenario 4 compare to the reference (scenario 1).

6.1.2 Photochemical smog

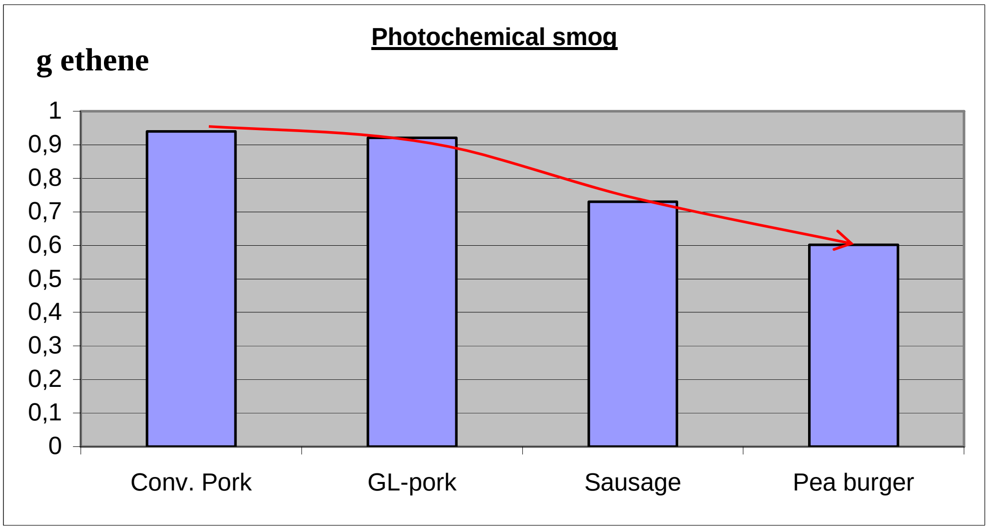


Figure 7 ***Impact assessment photochemical smog***

We can observe the same trends with this impact category. The 2 first scenarios are quite similar (Δ=2% between the 2 values); and then the 2 last scenarios have a smaller impact:-22% and -36% for respectively scenario 3 and 4.

6.1.3 Ozone depletion

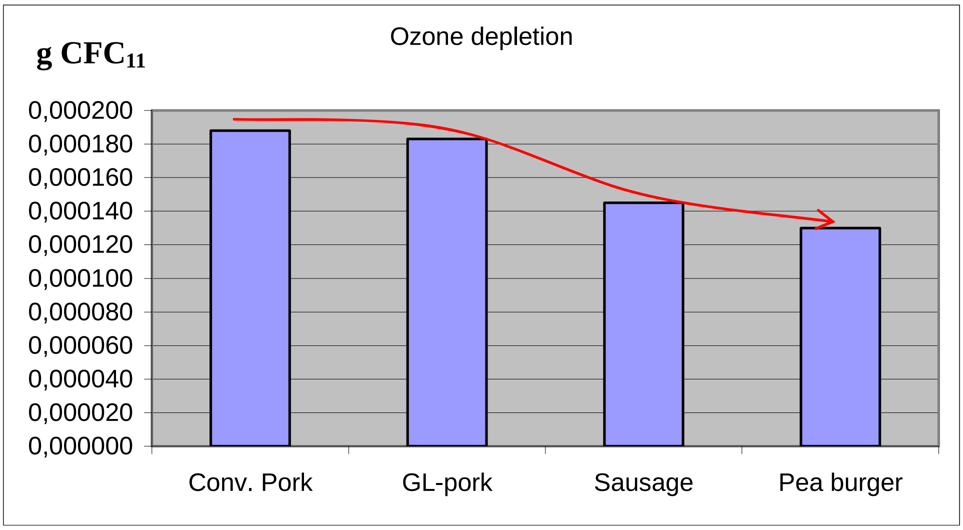


Figure 8 ***Impact assessment ozone depletion***

On this graph there is a net decrease of the amount of CFC´s emitted. The 2 first scenarios are still very similar (Δ~ 2,7 %); then the decrease represents 22,8 % and about 30 % for scenario 3 and 4. One should notice that the scale of the graph is very small. This is of importance to highlight the fact that even if the difference between the 4 scenarios seems important, that doesn't represent a big differential of value (Δ= 5,8 E^{-5} g CFC_{11} between the scenario 1 and 4).

6.1.4 Eutrophication

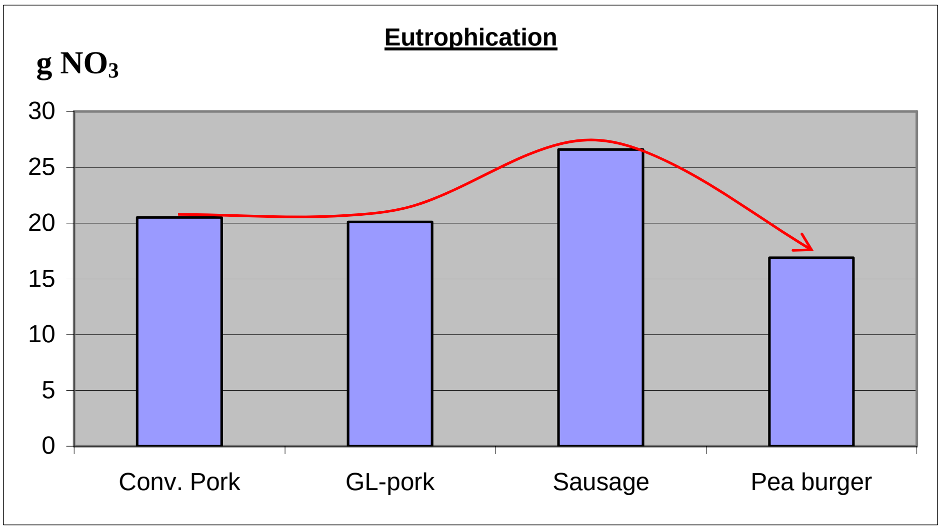


Figure 9 ***Impact assessment eutrophication***

The main contribution for eutrophication comes from meal 3. It represents about 35% more than the scenario1.

6.1.5 Acidification

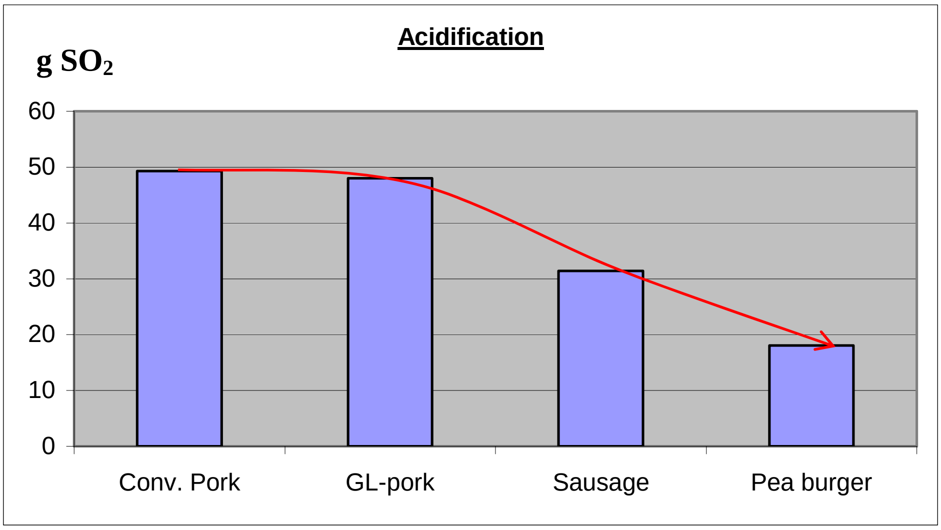


Figure 10 ***Impact assessment acidification***

For the acidification, there is an important decrease in the scenario 3 and 4, respectively -36,3% and -63,3%. It is the impact category that shows the biggest differential between the various scenarios.

After a global view of all the impact categories, one can notice that the 2 first scenarios have nearly similar results, with little less impacts for the scenario including pork fed with grain legumes. The reason is that these 2 scenarios are very similar; the only difference is in the pork production (see figures in table 5).

Concerning the scenarios 3 and 4, they have less impact and in a first time this seems to be logic according to the thoughts.

Some more information must be added for eutrophication, since the scenario 3 has a much larger impact than the 3 other scenarios. The analysis of the processes contribution will help us to understand better where these differences come from.

6.2 The process contributions

6.2.1 Global warming

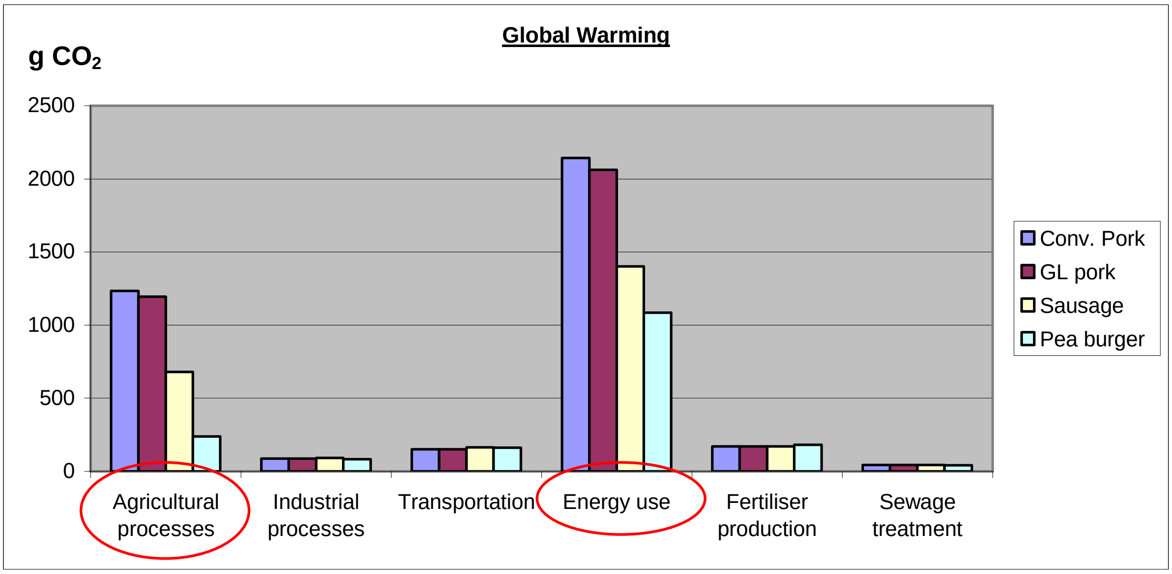


Figure 11 ***Process contribution global warming***

The agricultural phase and the energy use are the categories influencing the results most. For the agricultural phase, the CO_2 emissions mainly comes from the pork production, with respectively 1090g and 1050g of CO_2 emitted, in other words the pork production represents in both case about 85% of the CO_2 emissions of the agricultural processes.
For the energy use, it is again the pork production that is the main cause of the CO_2 emissions. The slaughterhouse is a very energy demanding process that contributes for a large part.

6.2.2 Photo-oxidant formation

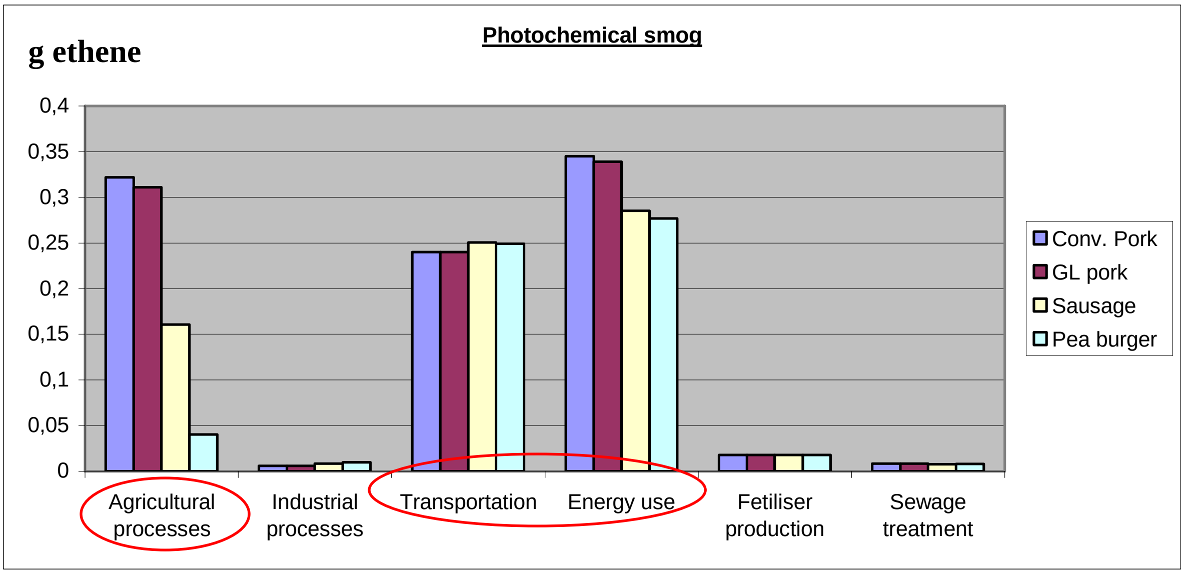


Figure 12 ***Process contribution photochemical smog***

For this environmental impact category, we still have the agricultural processes and the energy use that represent a big share, but this time transportation are also playing an important part. Focusing more on the transportation, one can see that 73% of the emissions due to transportation come from the home transportation.

6.2.3 Stratospheric ozone depletion

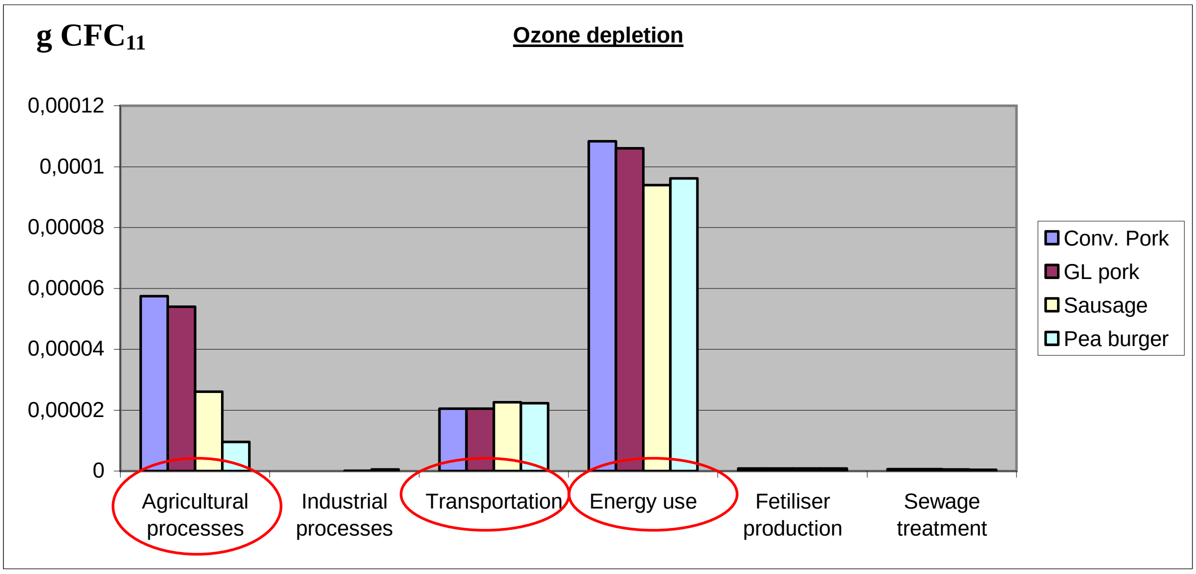


Figure 13 ***Process contribution ozone depletion***

The energy use is the main contributor for Ozone depletion. Here again, it comes from the electricity use in the slaughterhouse process, for cooling down the pork meat. An interesting point to notice is that the scenario 4 as a larger CFC_{11} emission than scenario 3. This difference is not so important but results from the fact that the pea burger is frozen industrially, while the other meals are chilled which is less energy demanding.
Concerning the agricultural processes, the pork production is again the largest contributor for the CFC_{11} emissions.
The transportation is not negligible for this impact category; the home transportation represents nearly 39% of the global emissions of the transportation.

6.2.4 Eutrophication

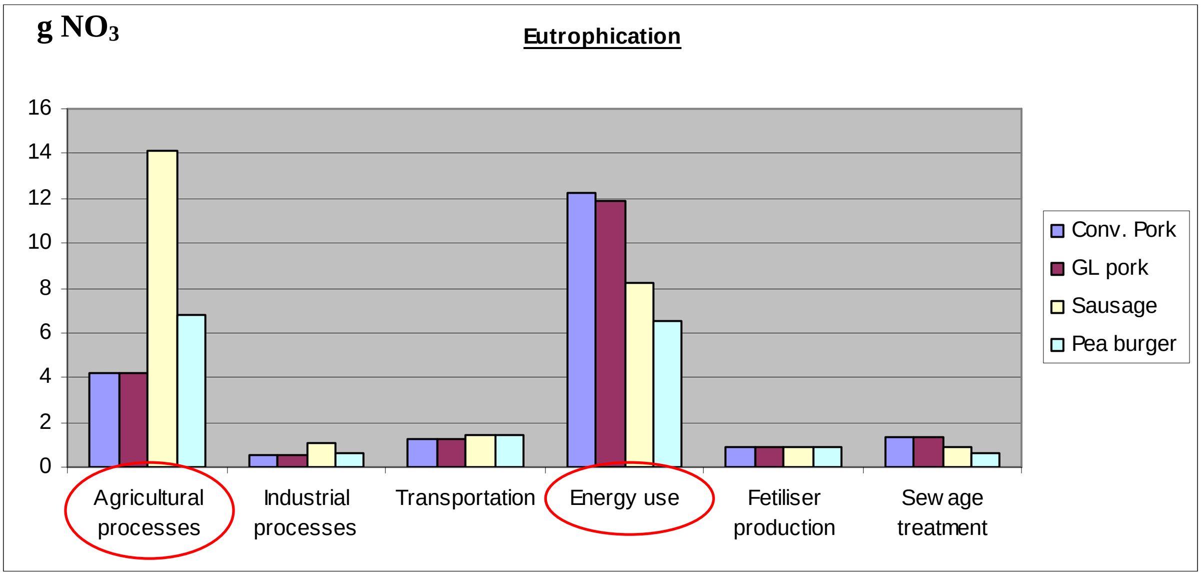


Figure 14 ***Process contribution eutrophication***

Also for eutrophication (figure 14), the agricultural processes and the energy use have the biggest impact on eutrophication.
For the agricultural processes, scenarios 3 and 4 have higher nitrogen emissions, and this could appear strange. The explanation is that the scenario 3 includes beef and pea production.

6.2.5 Acidification

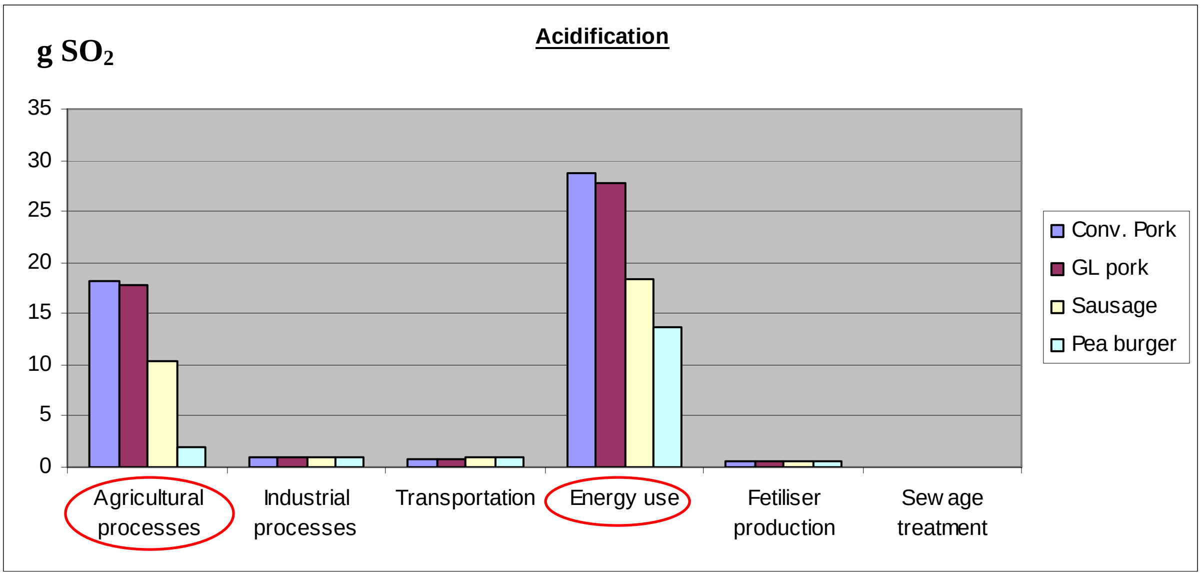


Figure 15 ***Process contribution acidification***

With 92% of the agricultural processes emissions, the pork production is again the main reason of acidification. The energy use is also equilibrating the same and the slaughterhouse process is the main contributor for this impact.

6.3 Dominance & Sensitivity analysis

The main goal of these analyses is to evaluate with the maximum precision, an estimation of the results in a virtual Spanish case study. In other words, because of the results have been done with a pork production from Germany, it is of importance to try to forecast what would have been the results if Spanish data would have been used.

First of all we have to know what are the main differences between the German and the Spanish pork production (production including all the phases till the farm gate).
A study on the environmental impacts of introducing grain legumes into European crop rotations and pig formulas (Nemecek and Baumgartner, 2006) gave us the following results summarised for Germany and Spain in the table bellow.

Table 20, ***Overview of the environmental impact of the crop rotation with grain legume in Germany and Spain.***

Impact category	Per ha per year			Per GJ gross energy yield		
	Germany	Spain	%	Germany	Spain	%
Energy demand [GJ-eq]	2,11E+1	1,07E+1	-49,3	2,10E-1	2,68E-1	**+27,6**
Global Warming Potential [tCO_2-eq]	3,33E+0	2,17E+0	-34,8	3,31E-2	5,41E-2	**+63,4**
Ozone formation [kg ethylene-eq]	7,09E-1	3,54E-1	-50	7,05E-3	8,85E-3	**+25,5**
Eutrophication, combined potential N&P [kg N-eq]	4,74E+1	7,28E+1	**+53,6**	4,71E-1	1,82E+0	**+286,4**
Acidification [kg SO_2-eq]	1,77E+1	9,77E+0	-44,8	1,76E-1	2,44E-1	**+38,6**
Terrestrial ecotoxicity [point]	3,23E+4	4,01E+2	-98,75	3,21E+2	1,00E+1	-96,8
Aquatic ecotoxicity [point]	3,90E+3	2,47E+3	-36,6	3,88E+1	6,17E+1	**+59**

The production of feed for pork production seems to have a larger environmental impact in Spain than in Germany. Even if the figures per ha per year are lower for Spain, Germany has a bigger yield per ha and so the environmental impact per GJ gross energy yield are in favour of Germany.
Hence, we can assume that the results with Spanish data for pork production will have a larger impact on the environment.

One can notice (from the graph in the section 6.2 Processes contribution), that we have similar trends for the following environmental impact categories:

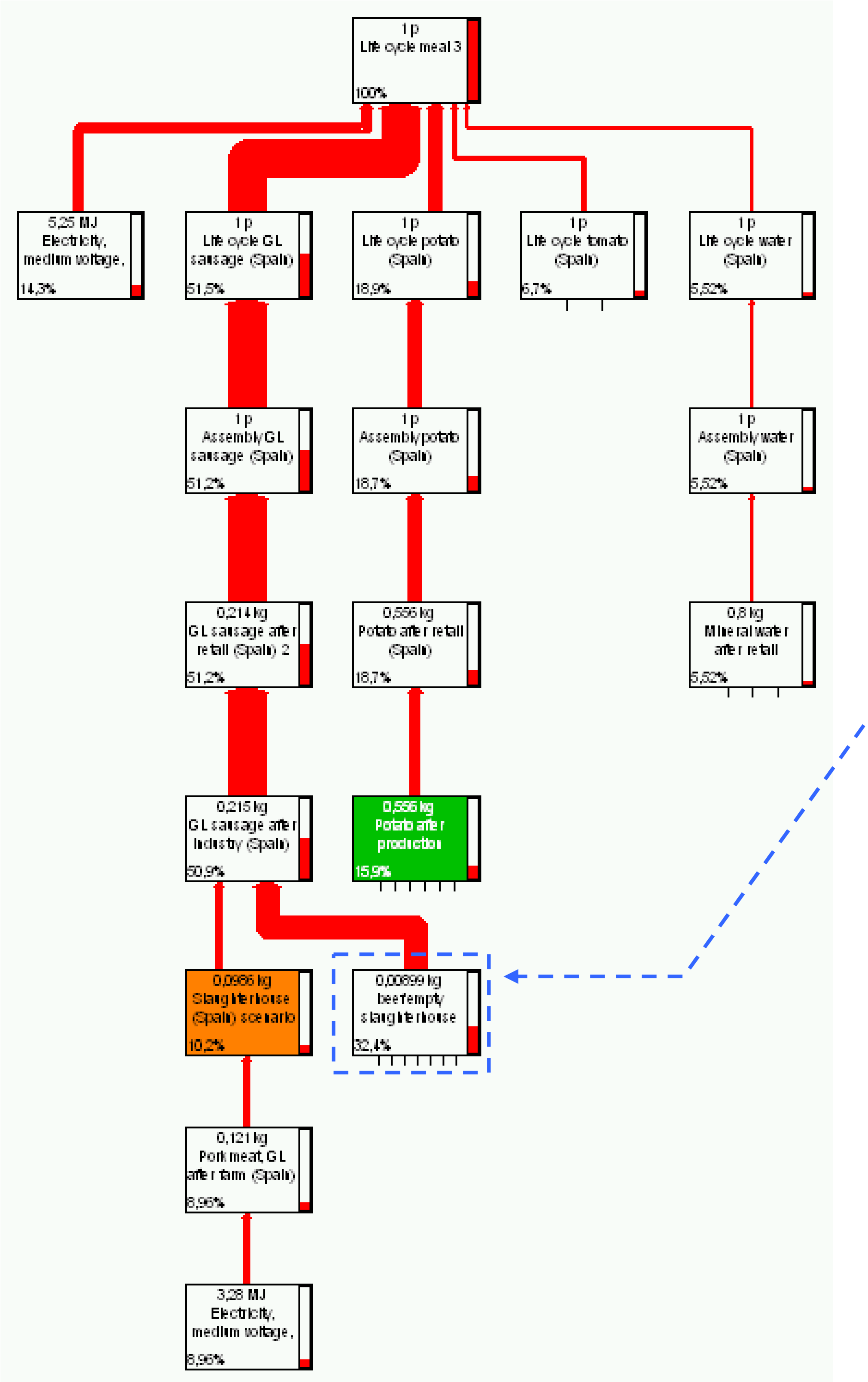
- Global Warming
- Acidification
- Ozone depletion
- Photochemical smog.

The common factors influencing most these impact categories are linked to the meat production. Therefore the production of pork in the farm has a big environmental impact as well as the energy use in the slaughterhouse to process the meat.
Of course speaking about energy use, it is important to notice that the Spanish electricity mix production has a high load for global warming and ozone depletion, since it is mainly based

on burning of fossil fuels (see table 9 p.28). That is why changes on the national electricity mix production or decreasing the energy use will influence the environmental impact significantly.

More attention needs to be put on the ozone depletion and photochemical smog impacts categories. Thus, for these 2 impact categories, transportation is not negligible and the home transportation is the largest contributor. Reducing the home transportation distance or changing the type of transportation will have a large influence on the amount of CFC_{11} and ethene emitted.

Eutrophication is the impact category the most interrogative results; looking at the figure 9; one can see that the scenario 3 presents an important weight for eutrophication. Then focusing more on the various processes, we can notice that this pick of NO_3 emissions comes mainly from the agricultural processes. The main reason is that the meal in the scenario 3 is based with grain legume sausage. This product is composed with share of pork and beef and 10% of grain legume. The beef production (including the farming and the processes in the slaughterhouse) are included in the "Agricultural processes" (see fig. 14). As it is shown in the graph below, the beef represents an important share of the NO_3 emissions.



35.2% of the NO_3 emissions come from the beef production.

Figure 16 ***Tree, process contribution for Eutrophication***

Changing the proportion of beef in the sausage will of course have an important impact on the NO_3 emissions, because in mass flow it represents just 4% of the total mass of the sausage; so even a very small decrease of beef use can lead to a big decrease in NO_3 emissions.

7 Discussion

Concerning the analysis of the results it is important to apply a critical thinking on the results on order to determine the limits of validity of the results. Evaluating the information and the results can be done by rethinking the assumptions that have been done to build the LCA.

7.1 The system boundaries

The first point to mention is the system boundaries of the project. This LCA is part of a large European project and so has to fit in tight boundaries in order to allow comparability between the various parts of the project. The main point is to compare 2 different regions of Europe: Sweden and Spain. Therefore, the system boundaries and the functional unit have been chosen in order to fit in the 2 cases. For example, it could have been interesting to include in this LCA the waste management system after the cooking process, but this was out of the system boundary.

Another important point is the choice of the 4 scenarios. The first scenario composed with the pork feed with soya is presented as the reference, the actual situation. It is important to have it as a basis for any comparison. Then the scenario 2 is composed with pork feed with grain legume to see the impact on the environment of the grain legume on the feed chain. For the scenario 3 and 4 they are based respectively on a sausage with a share of grain legume and a vegetarian burger. On the one hand, the share of meat has been decreases in these two scenarios but still some questions are remaining.
Is it useful to decrease the share of pork in the sausages when there are still some beef used? The environmental impact of beef in the scenario 3 is not negligible and has a large impact on eutrophication for example. Why not first trying to reduce or replace the beef instead of the pork to start with?
Then concerning scenario 4 the meat has been totally replaced by grain legumes, but the industrial processes are much more important. The studied product is a frozen burger; that is why for example the CFC_{11} emissions are still quite high for this scenario.

7.2 The methodology

The characterisation method chosen for analysing the results is the EDIP method. It is a well established method used by a lot of experts; it was developed mainly as a tool for product development in Danish industry. However, the methodology is recognised internationally. This methodology includes several impact categories. Five of them have been chosen for this LCA: Global warming potential, Ozone depletion, Photochemical smog, Eutrophication and Acidification. Of the impact categories not included the probably most interesting are Ecotoxicity, Human toxicity and Land use.

Ecotoxicity potential is an impact calculated for acute and chronic ecotoxicity to water and chronic ecotoxicity for soil. As fate is included, an emission to water may lead not only to chronic and acute ecotoxicity for water, but also to soil. Similarly an emission to air gives ecotoxicity for water and soil. This makes this impact quite complex to study and analyse. Toxicity of food products generally occur mainly in the agricultural phase due to application of pesticides. In the parallel studies on agricultural production performed by ART in Zürich, toxicity impacts are considered. Hence, in the overall analyses planned for the GLIP project, this impact category will be included.

For the data collection, various methods have been chosen. There was an interview, some data were collected from literature, results have been taken from previous studies and some web-cite have served of reference for tables as well. The main problem is to have coherence in the data collection in order to obtain results that make sense. For this study, various problems had to be solved.
The first problem was the lack of information on Spanish food production. Just a few contacts in Spain have been done and so the sources for data collection were quite small. Data for tomato production for example was taken from a Turkish study on greenhouse tomato production (Hatirli et al., 2005). Then, working as part of a European project was as well a problem for the data collection. For example the data concerning the Spanish pork production were missing.
Data collection was a very time consuming part of the LCA, and more accurate date could have been found in order to increase the precision of the results.

7.3 Energy use and transportation

The Spanish electricity mix is apparently at the centre of the problem, since it is composed at more than 40% of coal and oil. A lot of processes were quite energy demanding, especially concerning the meat production.
The slaughterhouse is also a very energy demanding process. The studied slaughterhouse was about to be renovate and so one can estimate that the energy use will be lower. For instance the process to kill the pork was about to be change replacing electrocution by gas asphyxia, which is less energy demanding. Moreover, in order to obtain a 30% reduction of the actual figures some improvements could be achieved in some areas:

- Improvements of the waste recovery systems

- Systematic reduction of energy needs in most processes, like cleaning and decontaminating processes of the plant and the used tools…
- Optimisation of the heating and cooling canalisation and systems with temperatures systems and advanced operation modes.

Regarding transportation, the first opinion is to say that it doesn't have a large impact on the environment compared to the other processes. But looking in more details to the graph (figure 12 & 13); one can see that the home transportation is a process that could be improved in order to decrease its impact on photo-oxidant formation and ozone depletion. Of course the distance for home transportation is negligible compared to the distance for the various products to Madrid; but the result is much greater because the impact is calculated per functional unit, so per kg of product used to the preparation of the meal. Thus some improvements can be done in this area, for example searching for less energy consuming vehicles or other types of transportation. Home delivery systems might be an improvement.

7.3 The waste management system

Building the waste management system with the software Simapro was very complicated. It is very important to have a well balanced mass inflow and outflow; parts of the ingredients are used for the composition of the meal and then go to "human consumption", and then a specific share of the ingredients (see table 18) go to the waste management system.

After a brief overview of the process contribution graphs, one can easily see that the various sewage treatments processes don't make up an important part in the different impact categories. The main reason is that the wastes that have been taken into account are the compost wastes from the ingredients that compose the meals. Their quantities are quite small compared to the one used, and their impact when entering in the waste management system is low. However from figure 14, one can see that eutrophication is the only impact where sewage treatments can be noticed. The main reason for that is the treatment of the wastewater in the slaughterhouse; it represents 54.8% of the total NO3 emissions for the sewage treatments.

7.4 Future research

As mentioned above, improvements can come from very different areas, and can lead to various results.
First of all, one can extend the system boundaries by including for example pesticides used in agriculture in the analysis or by working on the waste management scenario after the household. These changes will not give more precisions in the results but can lead to different conclusions.
Moreover the data collection could be improved, by collecting more accurate data. This could be done by including the Spanish data for pork production for example. This would put the study in a situation closer to reality. For the other ingredients, Spanish data could be included, like for tomato production.
To finish it could be interesting to have more information about other impact categories included in the EDIP methodology, as land use (or ecotoxicity which is a very relevant factor for the food industry).

8 Conclusions and recommendations

The goal of this study was to assess the environmental impact of four products with different protein sources. To compare these products four meals have been studied in which the protein source has been changed. The difference of environmental impact between the meals is significant and this is mainly due to the proportions of vegetable and animal protein. Hence, the first conclusion is that vegetable protein is better than meat for the various environmental impacts. The increased consumption of grain legume in the alimentation of animals and humans is so highly recommended from an environmental perspective.

One can also notice that agriculture takes an important part in the environmental impact. Effort could be put there in order to decrease the impacts of feed production for example. Less intensive agriculture or improvement in crop rotations, more efficient irrigation are possible solutions to study.

Industrial processing of peas are important, the composition of the pea burger is quite energy demanding and could be improved. The solution of a frozen burger could be maybe rethink

Home transportation is a hot spot and should be made more efficient. A lot of alternative solutions already exist and could be implement, as for example the home delivery or better public transport network to the shops… But data on Spanish transportation are scarce and could be improved as well.

An important point to consider is the product quality. This is the reason why beef is present in the sausage recipe. This in turn affects the results significantly but is a sine qua non ingredient for the customer. It is important to try to make environmentally friendly products but one doesn’t have to forget that to implement such products in the market the have to be economically viable.

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