Comparative Life Cycle Assessment

Pork vs Tofu

Life Cycle Assessment
1N1800

Stockholm

May 2005

Performed by:
Group 5
Susanne Håkansson
Pavel Gavrilita
Xavier Bengoa

TABLE OF CONTENTS

FIGURES AND TABLES

1. Introduction

1.1 Background

Every activity involves energy, which is obtained from the body store or from the food eaten. It is measured in kilocalories (kcal). To fulfill the energy requirements, the daily human diet must include essential proteins, vitamins, carbohydrates, water, fats and minerals. The Swedish National Food Administration (Livsmedelsverket) recommends people to eat approximately 60 grams of protein per day.

Proteins can be classified in two categories; complete and incomplete proteins. The first ones come from meat, dairy or soybeans, and they contain all the essential amino acids. On the other hand, vegetables, grains, seeds and nuts only provide incomplete proteins, meaning a limited array of amino acids. The body itself can make eleven of these amino acids, while the other nine (called essential amino acids) must be absorbed from food. Out of the recommended quantity of proteins to be consumed daily, 20 grams must be complete proteins that could come either from animal source or soybeans.

In view of the fact that proteins from animal and non-animal products have the same utility for human body it is up to each individual to decide, which diet to choose. Because of population growth and also because of aspiration to sustainable development, attention should be paid not only to major environmental problems such as energy, climate change or air quality, but also to resources depletion and human health. Knowing the impact on the environment of most consumed alimentary products, it become visible which product is more environmentally friendly and it gives the possibility to choose them.

Many people choose a vegetarian diet instead of a conventional one, based on meat. As an LCA study, it was decided to compare the environmental impacts of vegetarian and meat-based food. Pork, which constitutes the largest part of Swedish meat consumption, was taken as non-vegetarian meal. As a vegetarian meal, fresh tofu was chosen because it is the most common substitute to meat. Tofu, also known as soybean curd, is an exceptional food based on soybeans, not only because it is highly nutritious, but also because it can be prepared in a wide variety of ways. It is a good source of protein.

1.2 Goal

The goal of this project is to analyze the environmental impacts of pork and tofu. It is a comparative LCA that gives the information of compared products and their impacts. This LCA does not consider other food values that may be lacking consequently to not eating meat.

1.3 Functional unit

The functional unit is 20 grams of complete proteins per day, which can be found in 100g of pork or in 143g of tofu. Both options contribute to fulfilling the daily protein rations.

1.4 System Boundaries, assumptions and limitations

An LCA should include all processes of the system investigated, which significantly contribute to the environmental impacts. As this is a comparative LCA, only the processes, which are significantly different from pork to tofu in their respective life cycle, are taken into account, see figure 1. Data collection is restricted by the specific assumptions and limitations of the project.

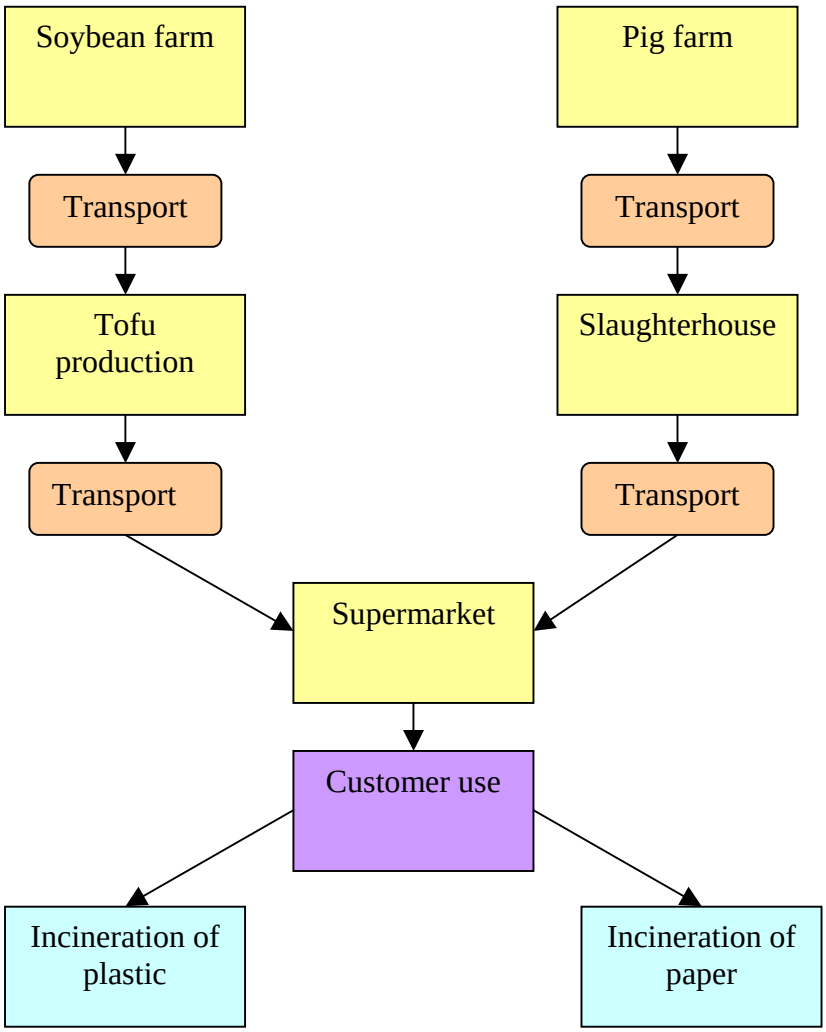

Figure 1: System boundaries

Soybean farm: The European Union imports most of its soybeans from South America (DG Trade, 2004). Besides, Brazil and Argentina are, with 26% and 11% respectively, the second and third soybean exporters in the world after the USA (Soy Stats, 2001). The best available data of soybean production concerns an average Argentinean farm. The assumption was thus made, that importations were from that country. Soybeans grow slower than most garden beans; they require a warmer climate and about three to five months for maturity. Plants need various amounts of nutrients from the soil, such as nitrogen, phosphorus, potassium, calcium, sulphur, etc. All natural components are not considered but the impacts due additional fertilizers and pesticides are counted. Land use was also considered as well as all technical inputs. Land use is particularly relevant is this context, because of the growing issue of deforestation of the Amazonian forest caused by intensive cultivation of soybeans.

Tofu production: The system includes the production process of tofu by the Scandinavian Soya Company in Denmark, which is the main distributor for Sweden.

Pig farm and slaughterhouse: Assumptions were made that the system includes pig production in the South of Sweden with a nearby (less than 200km) slaughterhouse. All the impacts and emissions from the pig farm and the slaughterhouse were considered. As the available data is from Denmark, it was assumed that pig farms and slaughterhouses are the same as in Sweden.

Transportation: The system includes transports of raw materials (soybeans, pig) from the farm as well as final products (tofu, pork) to the supermarket in Stockholm. The LCA does not include the transport between the supermarket and the residence of the customers nor from the customers to the product's waste management site, since the environmental impacts are negligible.

Energy production and use: The system includes the energy production, its use during the production process of pork and tofu, and the energy required for transportation. The assumption was made that tofu and pork are kept at the same refrigeration conditions and for nearly the same period of time. Refrigeration in the supermarket is therefore not considered.

Waste management: The system investigated includes the incineration of the packaging plastic or paper. The system was not expanded to include energy recovery from the incineration plant.

Geographical boundaries: The LCA only concerns pork and tofu that are sold in the supermarkets in Stockholm, Sweden.

1.5 Impact categories and impact assessment method

One of the most challenging current issues, taking into account the finite capacity of the earth's land and water resources, is the urgent need to increase world food production. In the food production cycle, farming has the largest environmental impact, but manufacturing and household consumption also play key roles due to their high use of energy, water consumption and waste production (UNEP, 2000).

The environmental impact categories considered relevant in this LCA are climate change, land use and use of fossil fuels. These impact categories were selected because tofu and pork production contribute more to them than to any other categories, and these are of major importance as global environmental impacts. The total effect on the environment of animal farming can be divided into direct impacts such as gas emissions, water pollution and soil degradation, and indirect impacts from the production of grain and animal feed required for pig nutrition. Climate has and will always vary for natural reasons. However, the concentration of some greenhouse gases is increasing significantly in the atmosphere, which tends to warm the earth surface. It seems obvious that any significant change in climate on a global scale would have impacts on agriculture, and would therefore affect the world's food supply. Land use is not less important since it is very relevant when it is related to crop and animal production, which are fed with the same crop. Since population is growing, there is a need for additional food, which necessitates more land use. This often leads to deforestation, soil degradation or desertification. In view of the fact that fossil fuels are qualified as limited

resources, and their use affects climate change and human health, it is really important to take them in consideration. It is obvious in an LCA that the use of renewable energies leads to positive impact but time is needed until these energies will totally replace fossil fuels, which are essential and mostly used at the moment.

The chosen life cycle impact assessment (LCIA) method is Ecoindicator'99 because it takes the relevant impact categories into account. Ecoindicator'99 is developed to model the average damage in Europe, which also makes this method relevant because the majority of the processes in the pork and tofu LCAs occur in Europe. It is a ready-made LCIA method, which means that the impact assessment procedure is packaged inside. The measurement principal in Ecoindicator'99 are single score indices.

Four stages are included in the Ecoindicator'99:

- Resource, land use and fate analysis
- Exposure and effect analysis
- Damage analysis
- Normalization and weighting

The user submits inventory parameters and the Ecoindicator'99 presents indices.

1.6 Weighting

Weighting is used to determine the seriousness of the damage to the ecosystem, the human health and the resource base. The weighting factors are determined by cultural values; this means that different attitudes determine which environmental problems should be counted for. Ecoindicator'99 represents three cultural perspectives: the individualist (I), the hierarchist (H) and the egalitarian (E) perspectives.

The individualist perspective only takes proven cause-effect relations into account as environmental impacts, and it applies a short-term perspective. The egalitarian perspective applies a long-term perspective, and uses precautionary principle; this means that everything should be included (Baumann and Tillman, 2004).

The hierarchist perspective was preferred because its method is in between the individualist and the egalitarian perspectives. Some scientific and political bodies, which should have sufficient recognition in the environmental community, built it up, and its focus is on traditional air pollutants and resources.

2. Life cycle inventory analysis

2.1 Process Flowcharts

Pork and tofu's processes are presented below in flowcharts. T stands for Transport. This LCA does not include either the electricity consumption or the waste output from the supermarket. The use phase (cooking and eating) of the tofu and pork are considered similar so they are not taken in the account. The customer's transport home and to the waste management facility are not considered either because they are considered equivalent for pork and tofu.

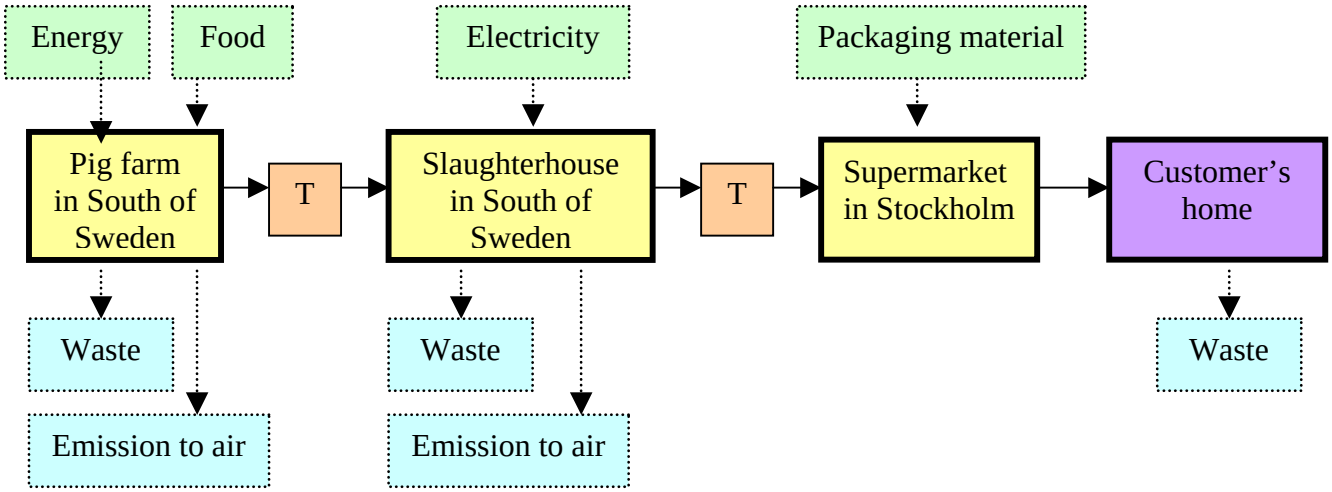

Figure 2: Pork process' flowchart

Pork production starts from the pig farm, which is located in the south of Sweden, where most of the Swedish cattle and breeding takes place. The pigs are fed with Swedish cereals as well as imported beans flours, such as soybean flour. The pigs are then transported by truck to the nearest slaughterhouse, where pork is produced, as well as sausages and blood pudding. The meat is then transported in refrigerated trucks to supermarkets in Stockholm. The packaging material consisting of butcher paper is also brought by truck directly to the supermarket. This is later incinerated as part of the customer's home waste. At all steps, energy is required in the form of electricity or heat. Solid waste, as well as wastewater and emissions to air are produced.

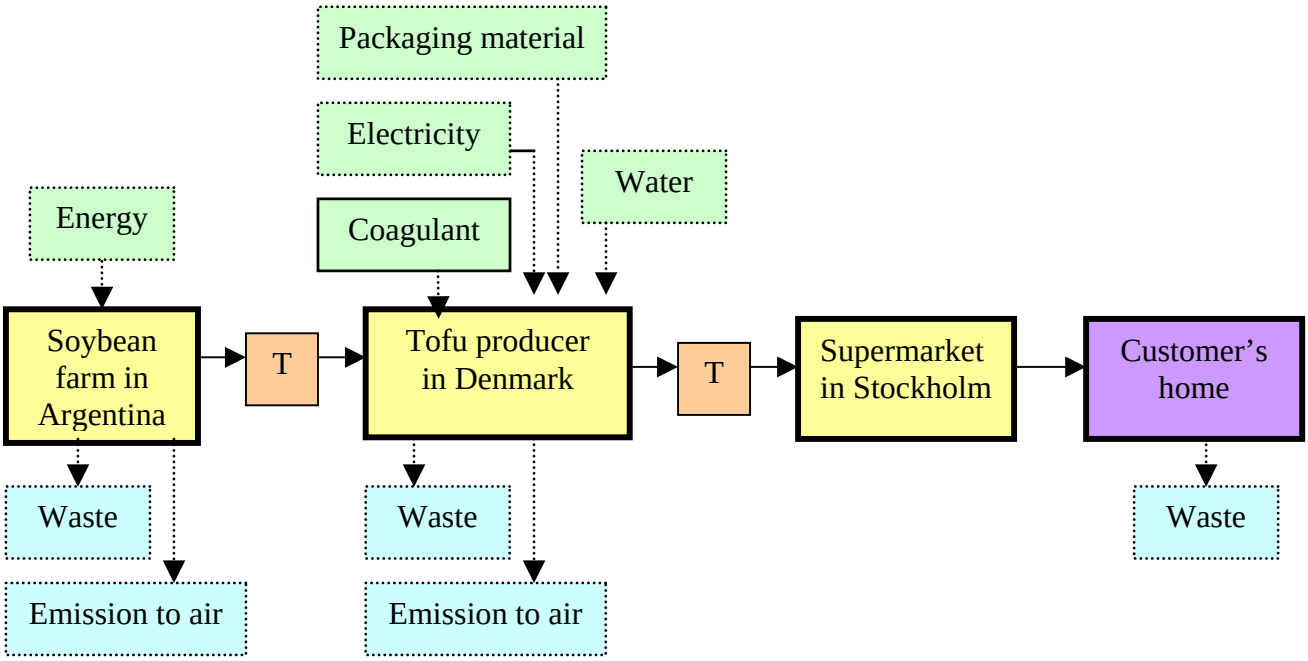

Figure 3: Tofu process' flowchart

Soybean is cultivated in intensive farms in Argentina, where it is harvested and dried. It is then transported by truck to the nearest harbor, and then by cargo to one of the main commercial harbors in Europe. It is then transported on trucks again to the Scandinavian Soya Company in Denmark, where the tofu is manufactured. PP is imported by cargo from Japan as package material for the tofu. The packaged product is then transported in refrigerated trucks to Stockholm, where it is retailed. The plastic packaging material is finally incinerated as part of the customer's home waste. At all steps, electricity is required. Solid waste, wastewater and emissions to air are also produced.

2.2 Data collection and interpretation

The information gathered during the inventory analysis is not comprehensive due to time limit and lack of information. Most of the used data come from the Danish LCA Food Database. Some data are inputs-outputs figures, and some others are the result from previous LCAs conducted by LCA-Food with SimaPro 6.0 and with the EDIP 96 life cycle assessment method. This method considers four impact categories:

- Global warming
- Acidification
- Nutrient enrichment
- Photochemical ozone formation (smog)

The LCA practitioner has added an additional category, because of its particular relevance in food products analysis. This additional category is land use, which is provided in "m^2 year" (square meters of land used in one year) without differentiation between different types of land.

Data on agricultural production (soybean farm) have been determined by a "top-down" approach where statistical data on a national level have been broken down to represent specific processes. On the other hand, data on meat processing have been determined by a "bottom-up" approach where data from a limited number of sources have been used to represent the Danish national level.

When using the results from previous LCAs as emissions to a certain processes, it was assumed that the given unit-equivalents for each impact category were effectively emitted as an effect of that process. This could be assumed because none of the given unit-equivalents causes impacts on any of the other categories; it was thus made sure that there was no double counting.

Data for the pork life cycle

For the first box of the pork's flowchart, the *Pig Farm*, the result from a previous LCA was used, concluding with the following given impacts, for the average living time of pig in a Danish farm (the data are provided per kg of living pig):

Table 1: Environmental impacts of pig farm (LCA Food Database)

Impact category	Unit	Pig Farm
Global warming	g CO_2-eq.	2250
Acidification	g SO_2-eq.	40
Nutrient enrichment	g NO_3-eq.	205
Smog formation	g ethene eq.	0.62
Land use	m^2 year	6.8

It was assumed that the pig production in the South of Sweden is similar to the Danish one, and would therefore cause the same impacts.

Regarding the processes occurring in the *slaughterhouse*, inputs-outputs data was used from the same source. The assumption was made that the processing from Danish and Swedish slaughterhouses were equivalent. Inputs and outputs associated with slaughtering and cutting of pigs are shown in table 2. Data are provided per kg cut meat at the gates of the slaughterhouse, without packaging.

Table 2: Inputs and outputs from pig slaughterhouse (LCA Food Database)

		Unit	Quantity
Inputs	Living pigs	kg	100
	Water	liters	200
	Bottled CO_2	g	200
	Dry ice (frozen CO_2)	g	240
	Electricity	kWh	8.4
	Heat	kWh	13
Outputs	Pork	kg	74
	Bowels (incl. content)	kg	8.5
	Scraps	kg	15
	Manure	kg	0.8
Emissions to municipal wastewater treatment plant	COD	kg	0.50
	Tot-N	kg	0.065
	Tot-P	kg	0.010
	Fat	kg	0.071
Solid waste	Bulk waste	kg	1.2

The previous process was analyzed by the LCA-Food practitioners and resulted in the environmental impacts presented in table 3, for a piece of 1 kg of tenderloin in a conventional slaughterhouse.

Table 3: Environmental impacts of pork processing (LCA Food Database)

Impact category	Unit	Slaughterhouse
Global warming	g CO_2-eq.	4520
Acidification	g SO_2-eq.	75
Nutrient enrichment	g NO_3-eq.	413
Photochemical smog	g ethene eq.	1.3
Land use	m^2 year	12

The impacts from the *waste* produced from the slaughterhouse were also taken into account. According to LCA-Food, the waste is reused to produce by-products such as sausages and bacon. Inputs and outputs associated with bone, blood and meat meal are shown in table 4.

Table 4: Inputs and outputs from the reuse of slaughterhouse waste (LCA Food Database)

		Unit	Quantity
Inputs	Slaughterhouse waste	t	1.0
	Electricity	kWh	82
	Heat	MWh	0.53
	Water	liters	900
Outputs	Bone, blood, and meat meal	t	0.39
	District heat	kWh	45
Emissions to aquatic recipients	COD	g	44
	Total N	g	77
	Total P	g	0.10
Emissions to air	Amino compounds	g	15
	Hydrogen sulphides	g	0.65

Data for the tofu life cycle

Data from an LCA conducted by LCA-Food was also used to estimate the potential environmental impacts of a conventional *soybean farm* in Argentina, conventional meaning nom-biological. The data are provided per kg of soybean.

Table 5: Environmental impacts of Argentinean soybean farm (LCA-Food)

Impact category	Unit	Soybean Farm
Global warming	g CO_2-eq.	620
Acidification	g SO_2-eq.	0.70
Nutrient enrichment	g NO_3-eq.	5.99
Photochemical smog	g ethene eq.	0.12
Land use	m^2 year	3.3

Regarding the *tofu production*, it seems that most of the tofu consumed in Scandinavia is manufactured at the Scandinavian Soya Company in Denmark. It is then delivered to Sweden by truck through a Swedish wholesaler. The company could provide the following data:

- 1 kg of soybean is used to produce 1.8 kg of tofu
- 3 liters of water is used to produce 1 kg of tofu
- 20% of 30 DKK/kg is the price for energy usage
- The energy come from Nordic Electricity
- The package material, PP, is bought from Japan

In Denmark, the industries do not pay taxes for electricity, so the usual price they pay is between DKK 0.43 and DKK 0.55 per kWh (Eltra, 2003). We used DKK 0.5 as an average value. It was thus calculated that 20 % of 60 kWh are used to produce 1 kg of tofu, which means a consumption of 12 kWh per kg.

The wastewater and solid waste release at the tofu production could also be calculated thanks to the given inputs-outputs data.

Furthermore, coagulant is used in the tofu production process. The most commonly used one is calcium sulphide ($CaSO_4 \cdot 2H_2O$), or gypsum, and 130 milligrams are needed to produce 1 kg of tofu (Iibushi et al., 1982).

The processing of tofu is resumed on figure 4:

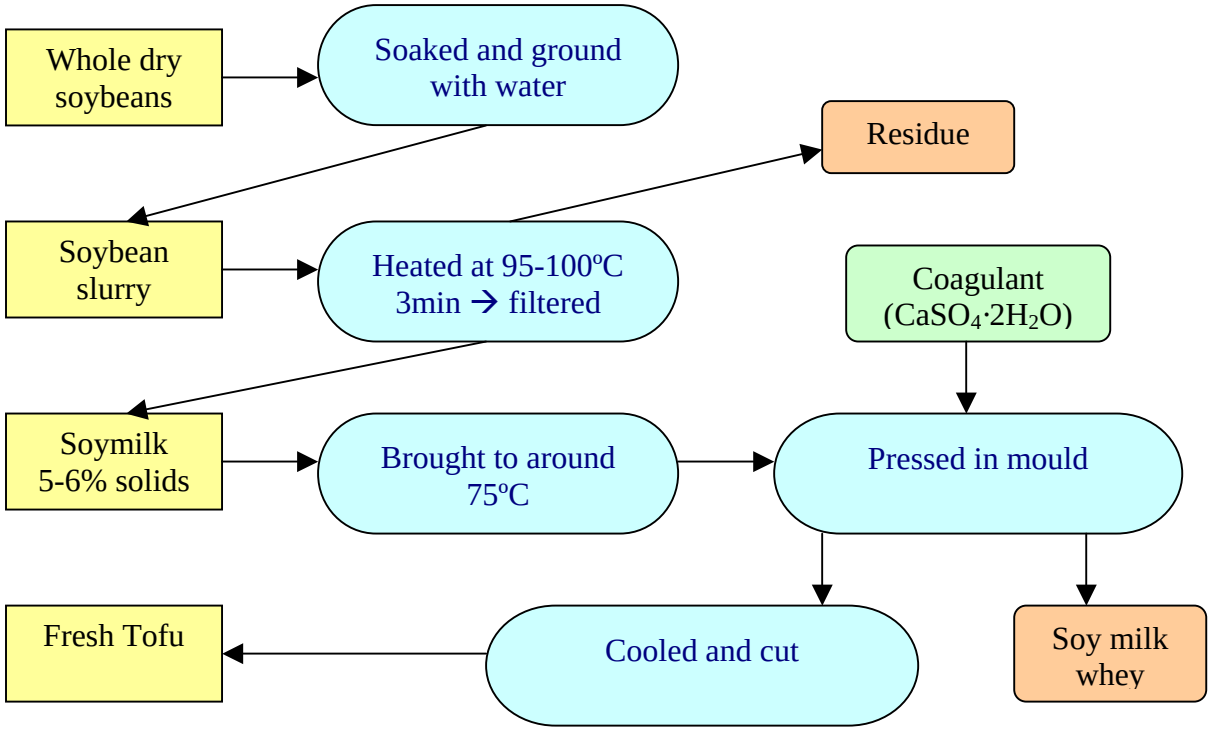

Figure 4: Fresh tofu processing (Berk, 1992)

The complete data used for the production of 1 kg of tofu is presented in table 6:

Table 6: Inputs and outputs from tofu production industry

		Unit	Quantity
Inputs	Soybeans	kg	0.56
	Water	liters	3
	Coagulant	mg	130
	Nordic Electricity	kWh	12
Outputs	Fresh tofu	kg	1
Emissions to WWTP	Wastewater	liters	2.21
Solid waste	Residues	kg	0.35

All the remaining data used for this LCA come from the various databases accessible from SimaPro 6.0.1

3. Life cycle interpretations

3.1 Results

Tofu life cycle

The environmental impacts' flowchart of the tofu life cycle is shown below in figure 5. The gray boxes represent the different processes, the blue boxes the assemblies and the yellow ones the life cycle itself. Only the processes with an environmental impact higher than 1 % of the total impact are displayed.

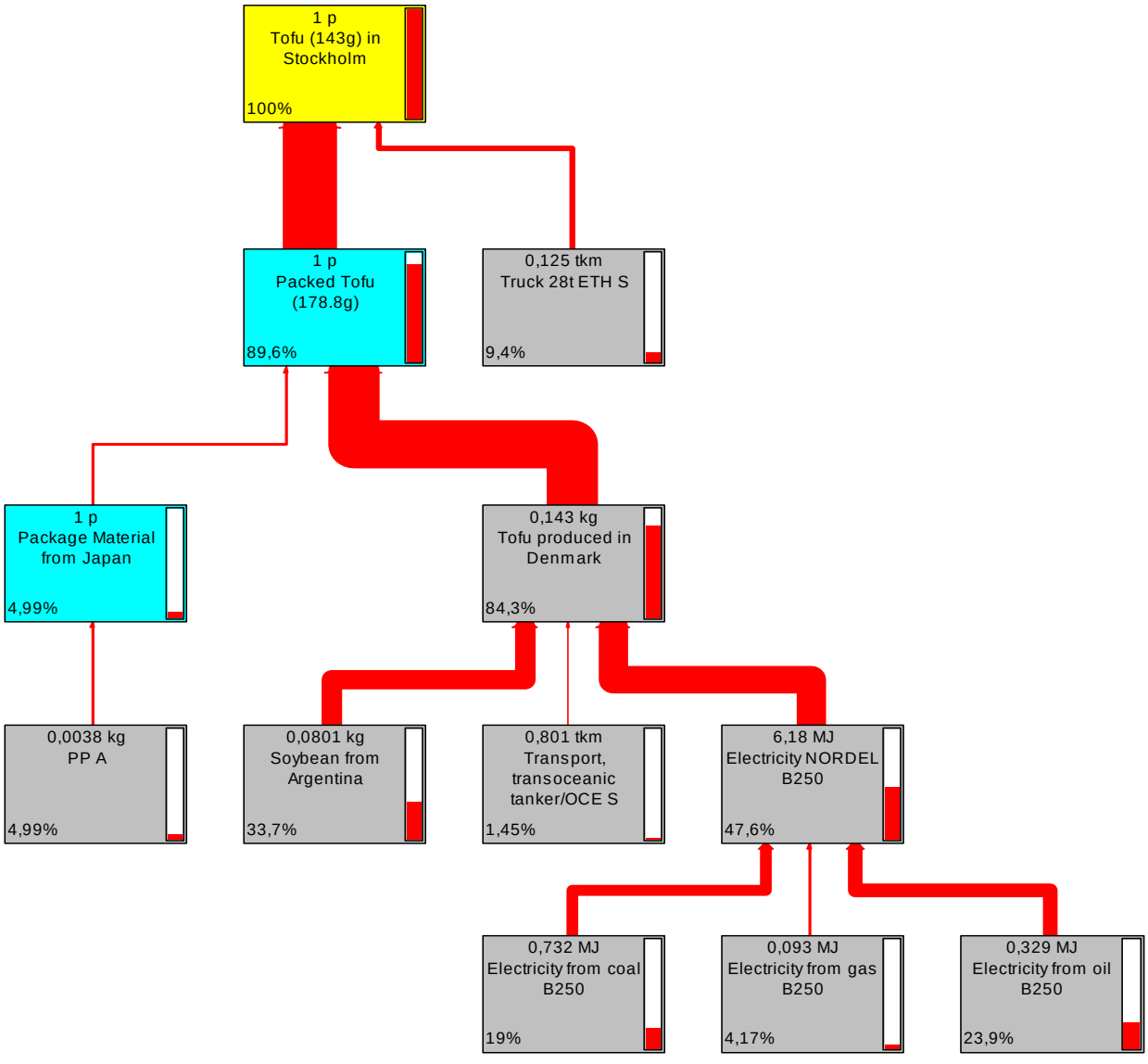

Figure 5: Environmental impacts' flowchart for the life cycle of 143g of tofu

It appears that the repartition of the total environmental impacts is rather equitable, between the soybean farm and the tofu processing itself. While 33.7% are caused by the agricultural production of soybeans, their drying and all sorts of associated processes, almost 50 % of the total impact comes from the tofu processing, out of which 47.6% is the energy usage. The rest of the environmental impacts are caused by the package material production (5%) and the transport (10%).

Pork life cycle

The environmental impacts' flowchart of the pork life cycle is shown below in figure 6. Only the processes with an environmental impact higher than 0.5 % of the total impact are displayed.

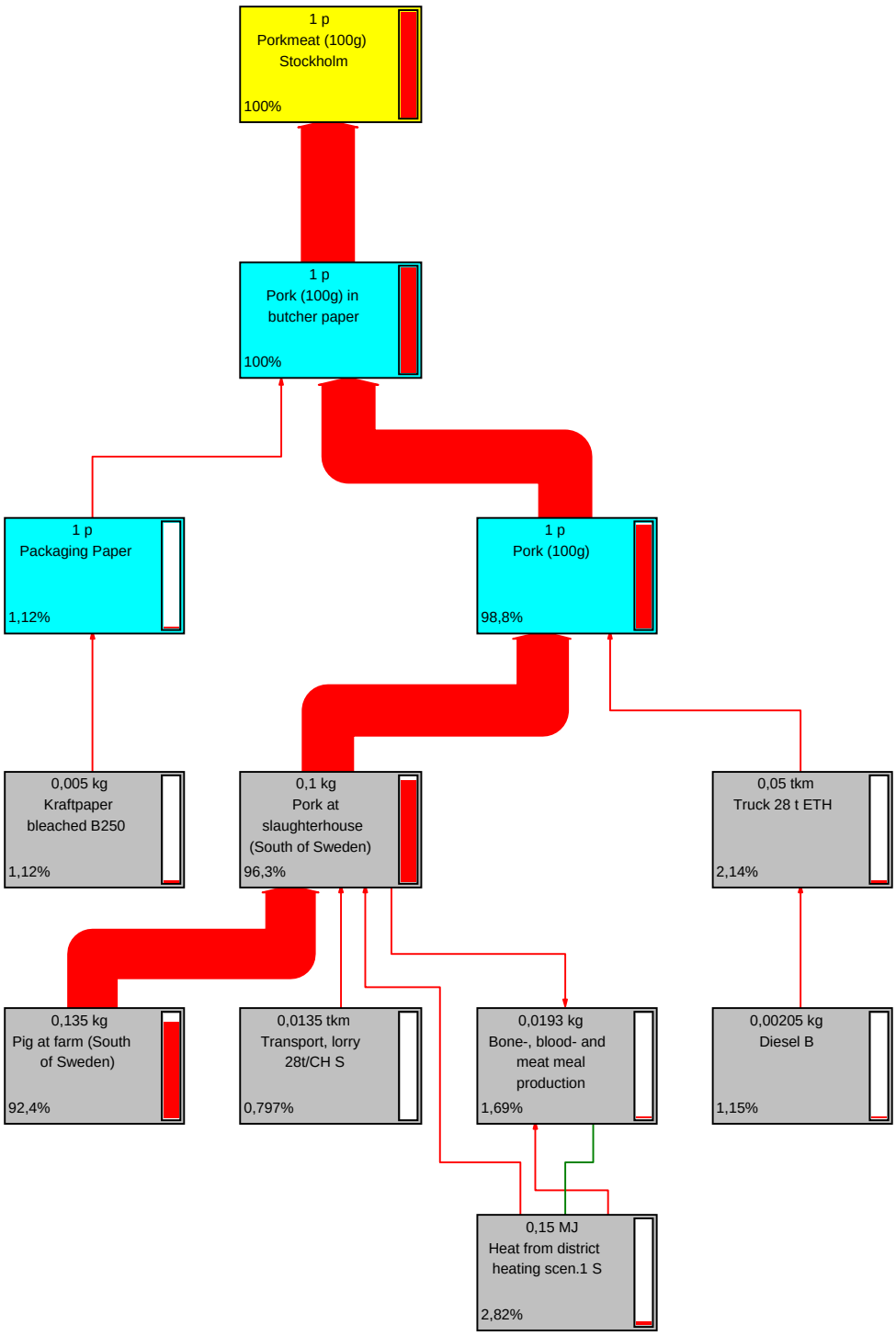

Figure 6: Environmental impacts' flowchart for the life cycle of 100g of pork

In this case, the pig production at the pig farm is clearly responsible for most of the total environmental impact (92.4%). The processes occurring at the slaughterhouse have comparatively very low impacts (3%), transport also takes about 3% and the package material only 1.27 % (with incineration, not shown on the flowchart).

Comparative impacts

The chosen impact assessment method, Ecoindicator'99 (H), displayed comparative impacts results for eleven impact categories: carcinogens, respiratory inorganics, respiratory organics, climate change, radiation, ozone layer, ecotoxicity, acidification/eutrophication, land use, use of minerals and use of fossil fuels. As explains before, only climate change, land use and use of fossil fuels are considered in this LCA.

Figure 7 shows the graphical results after weighting of the different environmental impacts. Only the chosen categories are displayed and the weighting method follows the hierarchist perspective. From left to right, the impact categories are climate change, land use and use of fossil fuels. The impacts linked to the pork life cycle are in red; the ones from tofu, in green.

Different conclusions can be drawn from this result:

Regarding climate change, the impacts are quite similar. This can be logically explained; even though the CO2-equivalents emitted by the pig farm are much larger than the soybean farm's, the high energy consumption for tofu production balance the total emissions of greenhouse gazes.

Concerning land use, it appears that the pork causes more than 300% of tofu's impacts. This is, because the land use of the pig farm includes the effects of crops cultivation, as food for the pigs. Among the most common food used to feed pigs is soybean flour. Yet, a pig eats a few hundreds of kilograms of soybeans, together with other beans and seeds, during its lifetime, before being sent to the slaughterhouse. This explains the considerable difference between the two products.

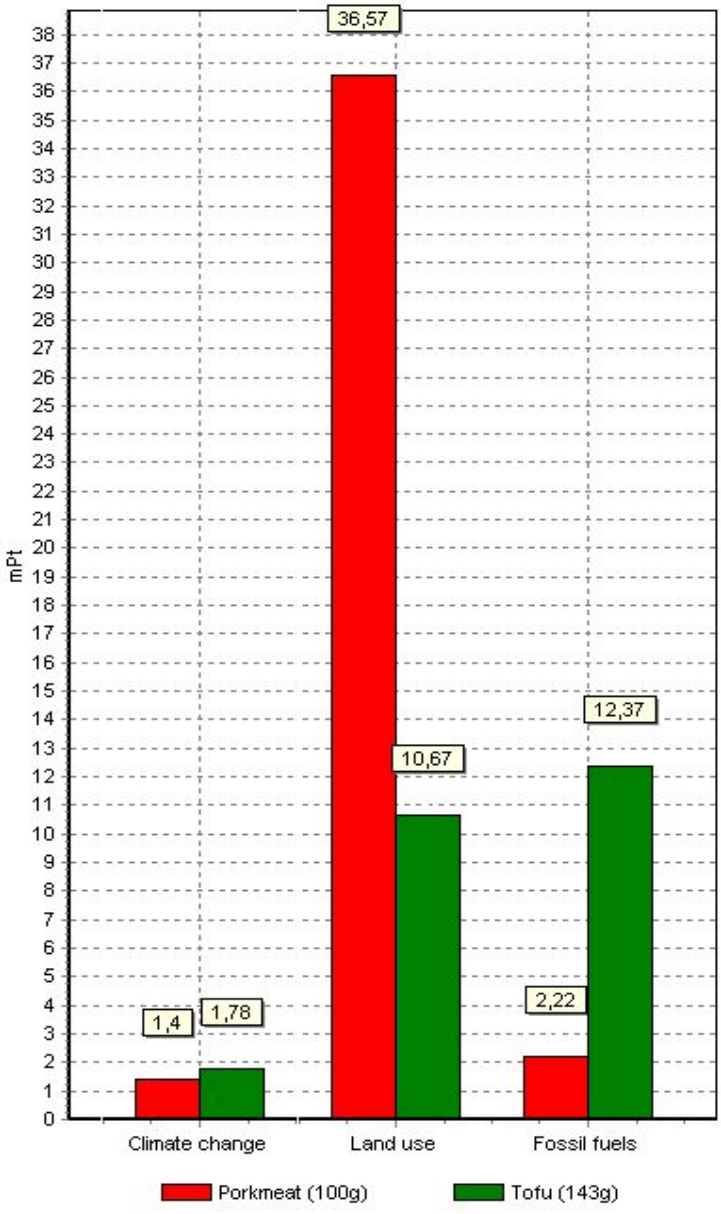

Figure 7: Comparative impacts of pork and tofu

The impact on use of fossil fuels is very low for pork as it is six times higher for tofu. This can be explained by the data gap concerning the energy demand in the pig farm. The data obtained for the pig farm was presented in equivalent. Lack of accurate data and knowledge made it impossible to make a relevant assumption for the energy demand. This results in that energy consumption is not included in the modeling for the pork, apart from the part already included in the CO2-equivalent. The energy demand for the tofu production is included in the model for tofu, and this makes the result vague. The energy consumption added to the tofu life cycle contributes to both climate change and use of fossil fuel, and the CO2-equivalent added to the pork life cycle contributes only to the climate change. The result shows that tofu has a bigger fossil fuel part, although this is may not be the case in reality. This LCA cannot determine the correct balance between pork and tofu's impact on fossil fuel. Other sources for fossil fuels are transport, which is included in both pork's and tofu's life cycle. Transportation runs for much longer distances in the tofu life cycle.

The impact assessment method could also display the single score for both pork and tofu life cycles. These are presented in Figure 8, with only the considered impacts visible.

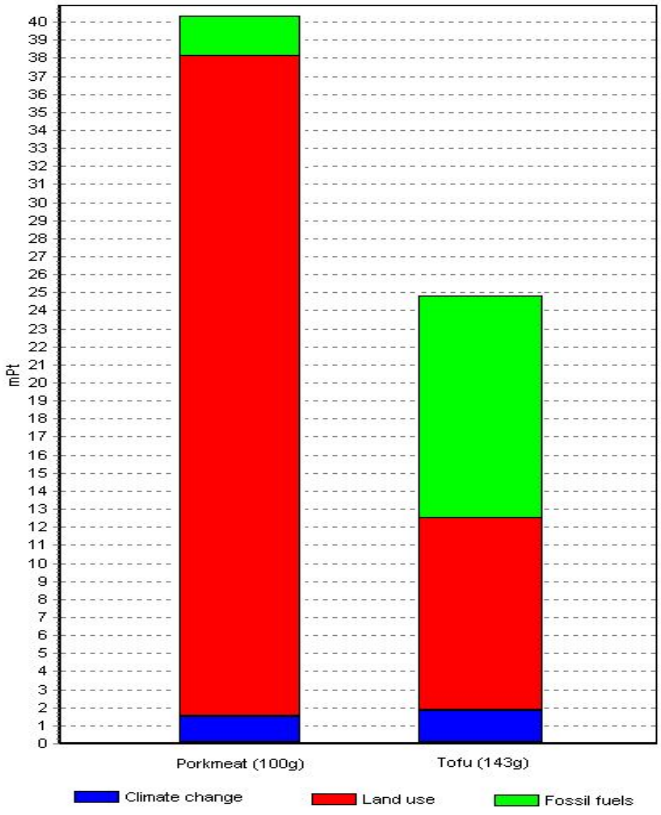

Figure 8: Single scores for pork and tofu

The diagram displays the impacts on climate change in blue, on land use in red and on use of fossil fuels in green. On the left, the impacts are related to pork life cycle; on the right, to tofu.

The single score points out that the tofu life cycle has a total environmental impact corresponding to 62.5% of the pork life cycle. It also shows the importance of land use compared to the other impacts, and consequently the effect that animal breeding indirectly has on the environment.

As an overview, it seems that the data used for the impact assessment of tofu vs. pork result in an advantage for tofu. It might even show a bigger advantage if the correct part of use of fossil fuel for the pig farm was included.

3.2 Conclusion

This LCA was performed with a very limited access to data. The data choices and the assumptions certainly have a huge influence on the final result. It was expected that pork would cause more environmental impacts than tofu, because of the basic biological rules of the food chain and its recurrent losses of energy and matter from one level to another. It seemed obvious that eating meat would have a larger impact than consuming any type of vegetal product, even when the later required an energy demanding processing stage. It is nevertheless interesting to observe how a scientific tool like the LCA can lead to an acceptable result, corresponding to the most subjective expectations. It would however be very pretentious to draw strict conclusions from this LCA, especially regarding the importance of specific impacts. The analysis has drastically simplified the different processes and access to specific and complete data is required.

4. References

Baumann, H. and Tillman, A.M. (2004). *The Hitch Hiker's Guide to LCA, An orientation in life cycle assessment methodology and application*. Studentlitteratur AB. Lund. ISBN 91-44-020364-2

Berk, Z. (1992). *Technology of production of edible flours and protein products from soybeans*. Food and Agriculture Organization -FAO-. Israel Institute of Technology. Haifa. ISBN 92-5-103118-5. Chap 9.

Directorate General Trade of the European Commission. (2004). *Trade in agricultural and fishery products, Agricultural policy and Trade: Trade partners, MERCOSUR*.
http://trade-info.cec.eu.int/doclib/docs/2004/december/tradoc_120309.pdf

Eltra. (2003). *Reduction in the Price of Electricity – Theme 1 for the System Plan 2002*. Doc. No.: 148394 v1. Retrieved from http://www.eltra.dk on 29.04.05

Iibuchi, S., Yano, T., Kawashima, M. and Nakagawa, K. (1982). *Energy analysis of a Kori-Tofu plant*. Journal of Food Engineering 1, pp. 17-29.

LCA Food Database. http://www.lcafood.dk

SimaPro 6.0.1. (2004). PRé Consultants. Netherlands. http://www.pre.nl

Scandinavian Soya Company. Jægerspris. Denmark. http://www.scandinaviansoya.dk

Soy Stats, (2001), *World Soybean Exports 2000*.
Retrieved from http://www.unitedsoybean.org/soystats2001/ on 20.04.05

United Nations Environment Programme. (2000). *Current food consumption patterns and global sustainability*.
Retrieved from http://www.agrifood-forum.net/issues/consumption/paper.asp on 03.05.05