Comparative LCA study between Tempe and Seitan

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Abstract

Research has shown that food production, and in particular meat production, has a number of effects on the environment. Some of the impacts that are associated with meat production include water and land consumption, pollution from use of fossil fuels, methane produced from animals, and other greenhouse gas emissions. In this report, we decided to consider two different foods that are often used as meat substitutes. One of the foods was Seitan which is a wheat-based product made from gluten, the main protein of wheat. The other food product that we examined was Tempe, which is a soy-based product and is made from culturing and fermenting soybeans. Both these food products are high in protein and are less resource demanding compared to meat production. Therefore, we decided to conduct a life cycle assessment in order to evaluate the environmental impacts that they have. After normalizing our results, we found the four most significant impact categories to be freshwater eutrophication, freshwater ecotoxicity, marine ecotoxicity and natural land transformation. We concluded that other methods for raw material extraction and cultivation could be considered as well as more renewable energies for electricity production, as this would help to lower the overall environmental impacts for both products.

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1. Goal and scope

The initial stage of our LCA is the goal and scope definition. This is where we state the intended application of our study, the reasons for carrying it out, the intended audience and the main intention for the final results [Curran, 2012].

1.1. Background

There are many environmental problems related to the production of meat. These impacts contribute to the global issue of climate change. Land and water use is one of the impacts caused by animal farming and meat production, depending on the nature of the production process, this can have negative impacts on the land and water sources and cause degradation [Toumisto et al, 2011].

The production of meat also contributes to greenhouse gas (GHG) emissions, current levels for production processes have been shown to account for between 15 – 24% of current GHG emissions [Fiala, 2008]. 15% of all emissions are due to agriculture, half of which come from livestock; this is a significant driver of global warming [Carrington, 2014].

Climate change is a major global problem at the moment, and as populations increase and the demand for food grows, it is necessary to consider other less environmentally damaging methods for food production. With the increase in awareness about the harmful effects of meat production to the environment, more and more people become vegetarians. They look for other meat substitutes that provide the same protein and nutrients as meat but are of plant origin.

The goal of this study is to compare the environmental impacts of two food products (Tempe and Seitan) as meat alternatives, and determine which of them has the lowest carbon footprint. Netherlands were chosen as the geographical location for the study, since it has a equivalent meat consumption to the average value for Europe (PBL, 2011).

1.1.1. Tempe

Tempe is made from soybeans and originates from Indonesia. The soybeans are cracked, dehulled and washed before being soaked in water and boiled to become soft. They are then naturally cultured and fermented, and eventually bound into a cake form [Shurtleff & Aoyagi, 2001].

1.1.2. Seitan

Seitan is a meat replacement food product, which is based on wheat gluten (protein) flour mixed with water. In this study Germany was chosen for wheat cultivation, since it is the only available country of Europe in the database of SimaPro. Netherlands was chosen for milling and processing to gluten flour, where also the final product will be used. The gluten flour is produced by separating gluten from the wheat flour in a industrial process [Smetana, 2015]. The proportion between water and gluten powder for making Seitan is 1/3 powder and 2/3 water (Parsons, 2014).

1.2. Research question

This LCA study has two research questions that will be answered.

- *What are the environmental hotspots of the two products?*
- *Which product has the lowest negative environmental impact?*

1.3. Type of LCA and purpose

This is a comparative and accounting study as we compare two different products as they provide the same function and attempt to determine the potential environmental impacts that they may have.

The intended audience for this study is the public and consumers in the Netherlands. The results of this LCA may be useful for food policy and future work in the food industry, as well as looking at ways to improve the processes involved in their production. The outcomes could also help to contribute to public awareness of where the food we consume comes from, and generally provide more information to consumers.

1.4. Functional unit

The function of the products is to replace meat in a regular meal, or more precis replace the protein in a meal. The Functional unit (FU) was decided to 1 kg ready meal product. This was done in order to allow for a comparison between the two meat replacement products. The functional unit do not consider percentage of protein per one kilogram ready meal, since we believe that the mass of food intake would not change depending on percentage of protein in the product. Seitan (22.5 % protein) is known to have higher content of protein compared to Tempe (16.5 % protein) according to Smetana, S (2015).

1.5. System boundaries

In this LCA study, the Netherlands were chosen as the comparative country in Europe. The wheat and wheat flour used in the production of Seitan are produced in Germany and the gluten flour is produced in the Netherlands.

Tempe is produced in the Netherlands and the soybeans originate in Brazil.

Aspects that are not considered within our LCA include the composition of machinery used during the process, the maintenance of the machinery and the people working within the production of the food products.

Currently the study ranges from the sourcing of the raw materials to the transportation of the materials to the distribution chain in Netherlands, and then to the preparation of the final product. For both food products we have decided to exclude activities concerned with their transportation within Europe, re-packaging and cooking method, as they are similar and will cancel out each other.

1.6. Assumptions and limitations

The source of electricity is from each respective country's grid. Energy consumption for the process of wheat gluten separation has only one reference source.

Cultivation data on soybeans and wheat grains comes from SimaPro data base (ecoinvent 3) Germany was chosen for the cultivation of wheat grains, since Netherlands was not available in SimaPro database.

Allocation problems concerned with wheat grain milling used mass to determine the percentage of allocation, where waste have been chosen to be "unknown use". For the allocation problems we had for wheat gluten separation, we also uses mass to determine the allocation in percentage.

Transportation of wheat from the farm to milling, and of flour to the process industry have been roughly assumed, since we do not have a specific locations for each process step in Germany and in the Netherlands.

CO_2 emissions during the fermentation process in the Tempe production are excluded, since we believe it would not have a significant effect on the result.

1.7. Impact categories and impact assessment method

Out of the 18 impact categories the following 4 categories were chosen as the ones with most significant impact for this study.

- Freshwater eutrophication
- freshwater ecotoxicity
- Marine ecotoxicity
- Natural land transformation

1.8. Normalisation and weighting

Normalization enables a more robust understanding of the environmental impact of the evaluated system. The latter puts the results in context by comparing achieved values to the predetermined values e.g. in this case by the average impact of a European and world. The normalization values that was used as the methodology is the ReCiPe Midpoint (H). Weighting is not conducted in this study because the LCA reporting subscribe to the ISO standard.

2. Life cycle inventory analysis

This section will elaborate and illustrate the Life Cycle Inventory Analysis. Elaboration is accompanied with an illustration of conceptual process flow diagram and the diagram generated by Simapro. Conceptual process flow chart illustrates inputs and outputs entered to the model. It is worth mentioning that the generated Simapro process flowchart does not show all the inputs and outputs.

2.1. Process flowchart Seitan

Figure 1 below shows a simple process flowchart of making Seitan starting from wheat production till it is served on the plate and is ready to eat.

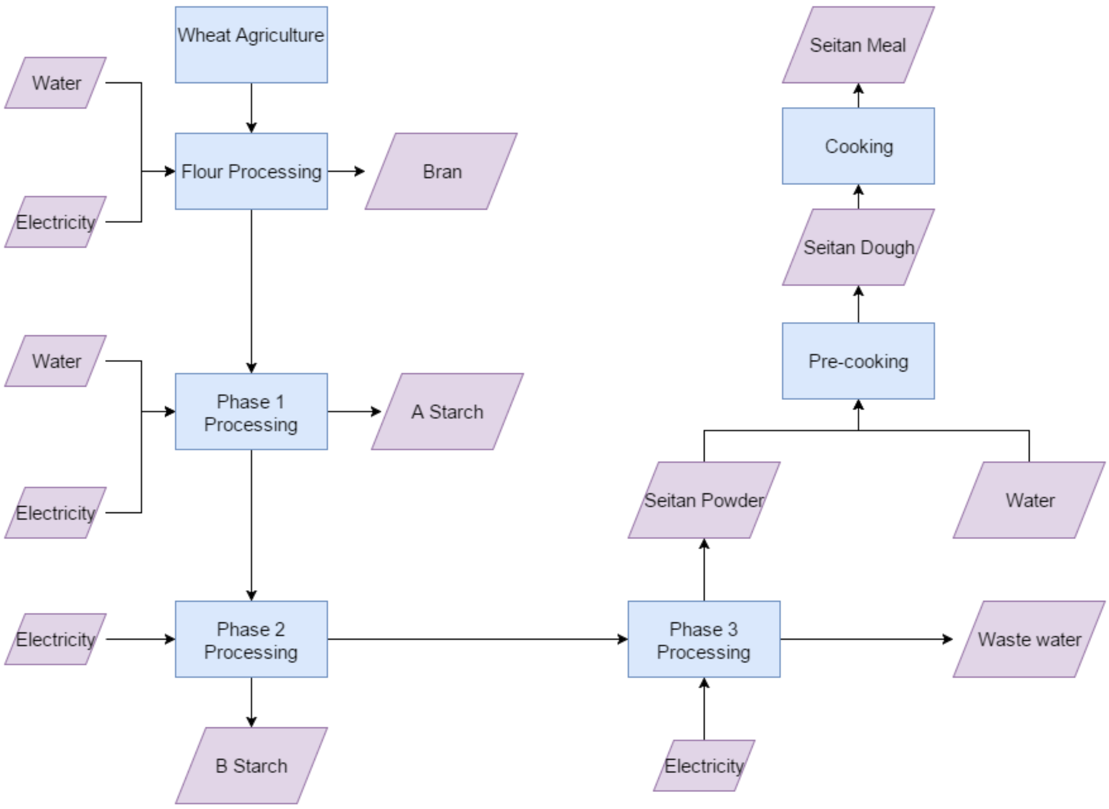

Figure 1 Seitan process flowchart

Flowchart of Seitan from SimaPro. illustrating each process with its impact in percentage and also the impact flow is given below in Figure 2.

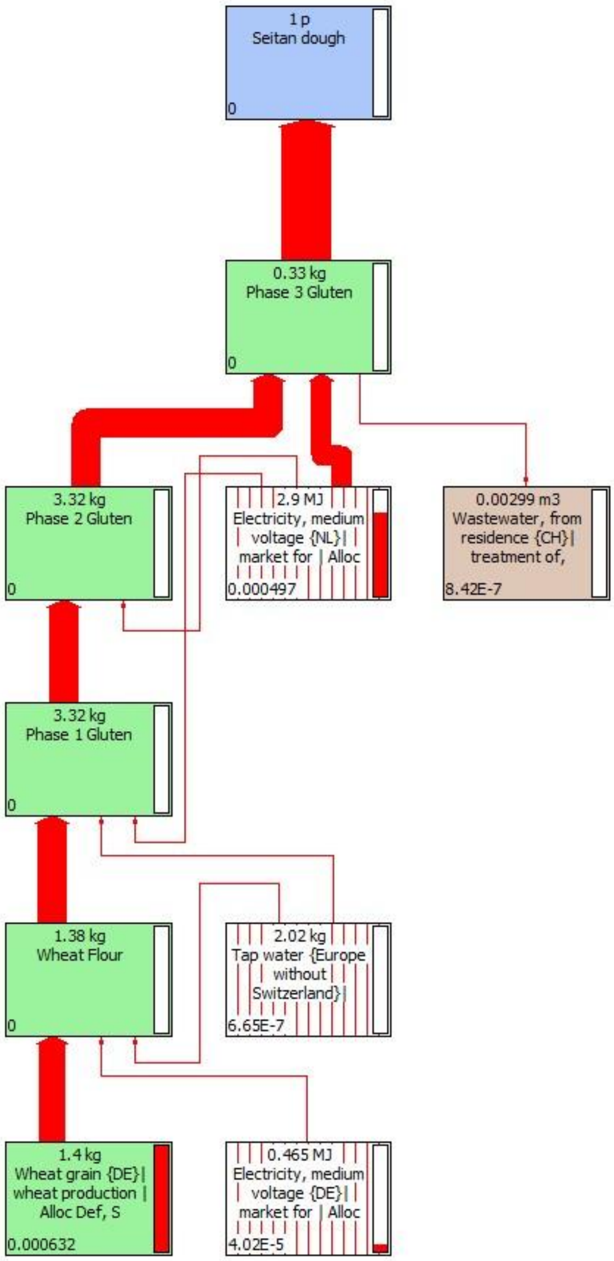

Figure 2 Simapro process flowchart for Seitan

2.2. Process flowchart Tempe

A simple process flowchart of Tempe from soybean production till it is served on the plate and is ready to eat is given in Figure 3 below.

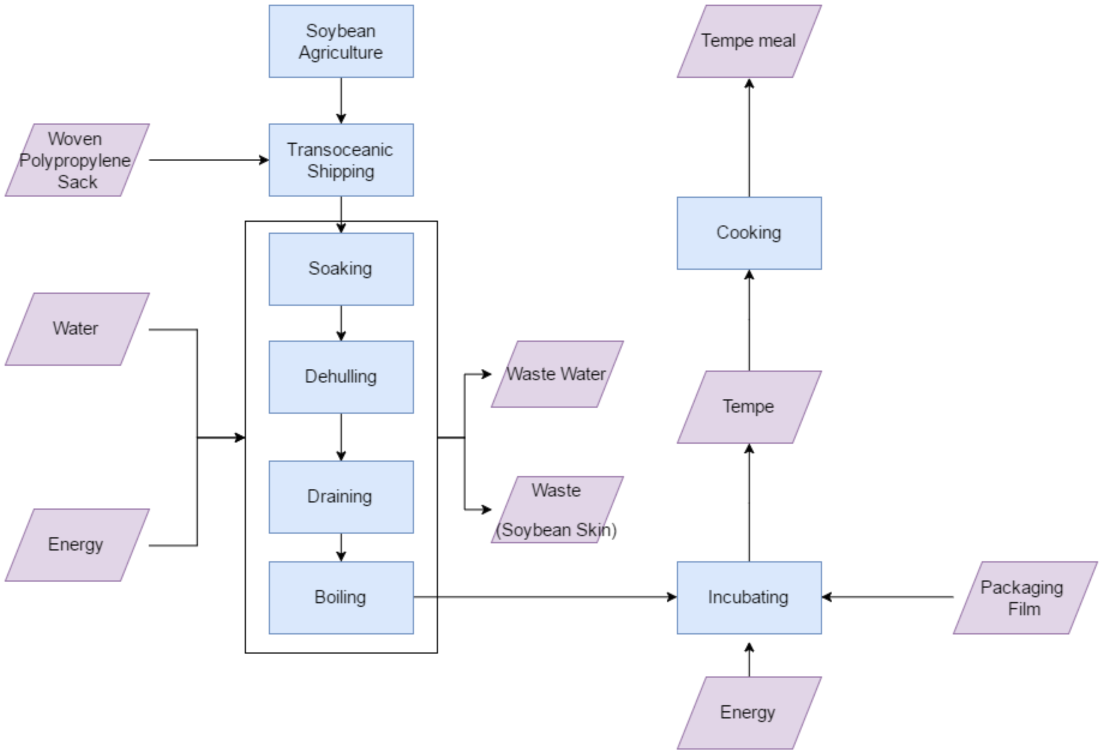

Figure 3 Tempe process flowchart

Flowchart of Tempe from SimaPro. illustrating each process with its impact in percentage and also the impact flow is given below in Figure 4

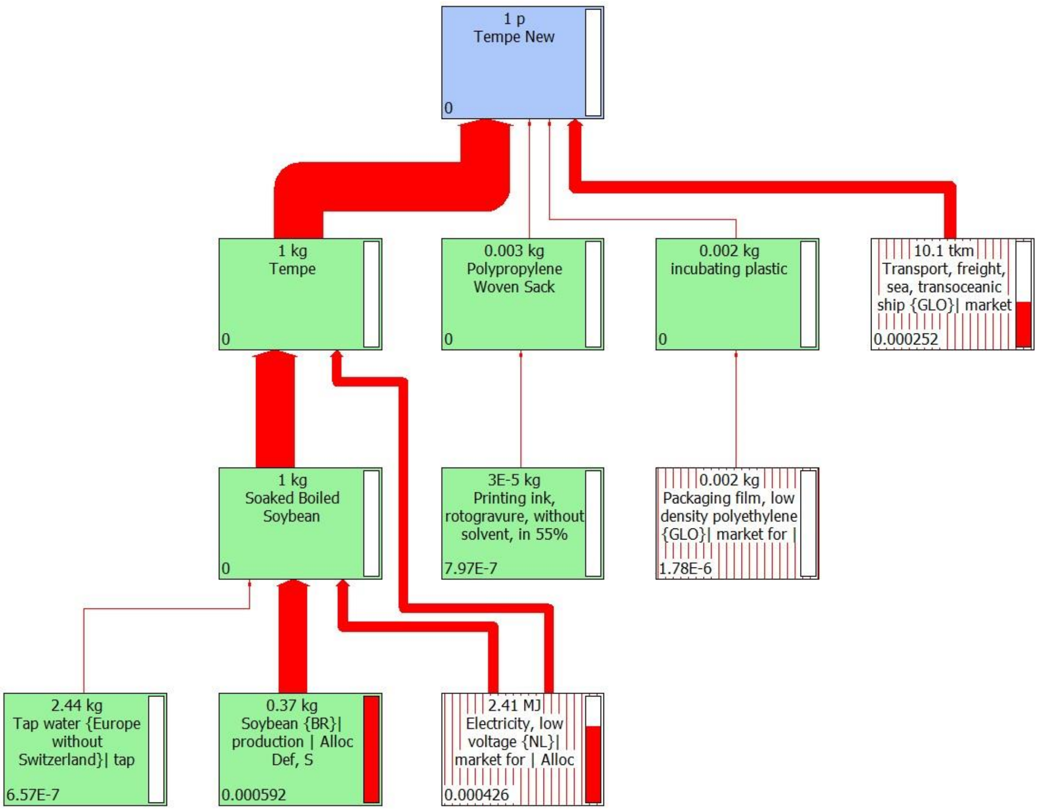

Figure 4 Simapro process flowchart for Tempe

2.3. Data

Background data is used from Eco invent 3 default database if nothing else is mentioned. All data used is in the model is also presented in table 7 in the appendix . The foreground data for Seitan are the processes milling wheat and producing Gluten powder (Smetana, S. 2015). For Tempe, the foreground data were aggregated from various sources, such as the following: soybean import origin (Kessler et al., 2013), the distance of transoceanic transport (sea-distance.org, 2016), the woven polypropylene sack (Daman, 2016; Precise 2016; QTL Bags, 2016); the amount of water for soaking and boiling (Tempe.info, 2016); the electricity to boil the soybean and water (confusedaboutenergy.co.uk, 2016); and the duration, as well as the method to ferment the soybeans into precooked Tempe (Tempe.info, 2016).

Table 1 Data

	Tempe	Seitan
Origin of ingredients	Soybean – Brazil	Wheat grains - Germany
Assemblies	Process of preparing Tempe cake – Netherlands (home)	Process of making wheat (gluten) flour - Netherlands
Transportation	Transportation of soybeans, from agriculture to store	Transportation of wheat grains from Germany to Netherlands. Transports of wheat gluten flour from factory to store
Waste	Packaging	Packaging

The used data in the model will be presented in tables as input and output data. This project is a comparative study that uses average data and looks into the burden for producing a unit of goods. Seitan has multioutput allocation problems in its processes, where mass is used when dividing the burden between the outputs, while Tempe does not have an allocation problem.

2.3.1. Data for Seitan

Tables 2a till 2f provide the input and output data for different processes in the making of seitan. These data were assigned in the Simapro software in the custom processes created for the making of seitan.

Table 2a Input data for milling

Input Milling	Amount	Unit
Wheat grain	1.4	kg
Tap water	$8.693\ 10^{-2}$	kg
Electricity	0.129	kWh

Table 2b Output data from milling

Output Milling	Amount	Unit
Wheat flour	1.38	kg
Bran	0,393	kg
Waste	0,133	kg

Table 2c Input data for gluten

Input Gluten	Amount	Unit
Wheat flour	1.958	kg
Electricity	2.11 10-2	kWh
Tap water	1.93	kg

Table 2d Output data for gluten

Output Gluten	Amount	Unit
Starch A	1.01	kg
Starch B	0.585	kg
Gluten flour	0.33	kg
Waste water	2.99	L

Table 2e Input data for seitan preparation

Seitan Input	Amount	Unit
Gluten flour	0.33	kg
Tap water	0.66	L

Table 2f Output data for seitan preparation

Seitan Output	Amount	Unit
Seitan	1	kg

Allocation problems for Seitan arise during milling of wheat grains and separating gluten from wheat flour. Both processes are multioutput allocation problems, where mass is used when dividing the burden between products and waste. See Table 3

Table 3 Allocation problem for outputs

Milling wheat grain	Mass (kg)	Percentage %
Bran	0.393	22.2
Wheat flour	1.395	77.8

Phase 1 output	Mass (kg)	Percentage %
Phase 1 Gluten	3.32	76.6
Starch A	1.01	23.4

Phase 2 output	Mass (kg)	Percentage %
Phase 2 Gluten	3.32	85
Starch B	0.585	15

2.4. Data for Tempe

Tables 4a and 4b provide the input and output data for process of production of Tempe respectively. These data were assigned in the Simapro software in the custom processes created for the making of seitan.

Table 4a Input data for tempe

Input Tempe	Amount	Unit
Soybeans	0.37	kg
Tap water	2.44	kg
Electricity	0.348	kWh

Table 4b Output data for tempe

Output Tempe	Amount	Unit
Tempe	1	kg
Waste	0.3	kg
Wastewater	4.6	l

Other data used beside the production process include the packaging of soybeans in Brazil and their transportation from Brazil to Europe, given in Table 5.

Table 5 Data used in assembly

Other input Tempe	Amount	Unit
Transportation	10.1	tkm
Incubating plastic (Packaging Film)	2	grams
Woven Polypropylene Sack (WPS)	3	grams

Woven polypropylene sack is a foreground data composed of several inputs and outputs. The tables below (Table 6a and 6b) show the input and output of this material.

Table 6a Input data for WPS

Input WPS	Amount	Unit
Unspecified Water	1.67 10-5	kg
Polypropylene	2.1 10-3	kg
Printing ink	3 10-5	kg
Electricity	1.75 10-4	kWh

Table 6b Output data for WPS

Output WPS	Amount	Unit
Woven Polypropylene Sack	3	gr
Waste incinerated plastic	3	gr

3. Life Cycle interpretation

3.1. Result

The two created assemblies that were presented in the Life cycle inventory section: Seitan (Figure 4) and Tempe (Figure 2) were compared. This produced the result illustrated in Figure 5. The result is in percentage using characterization, where Seitan is represented in orange and Tempe in blue. Overall, by looking at the characterization result, Seitan seems to have a higher environmental impact compared to Tempe.

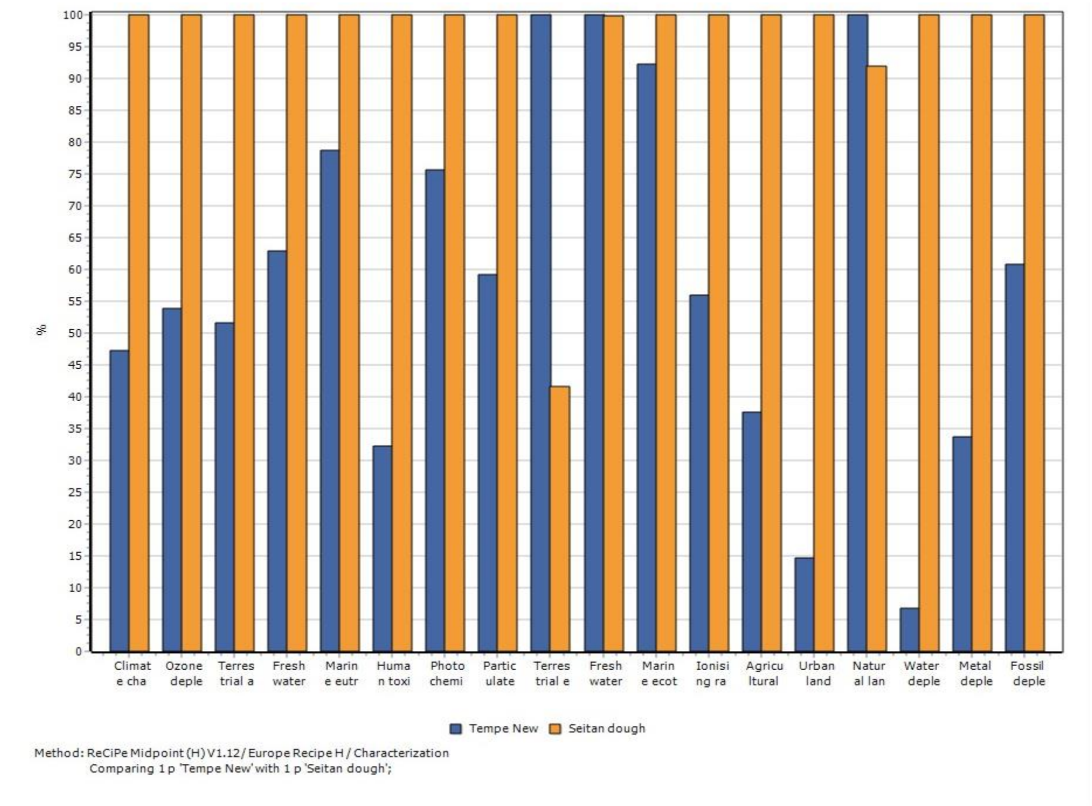

Figure 5 Comparison between Tempe and Seitan

3.2. Most significant impacts

From the presented results in Figure 5, four significant impact categories were identified through normalization of the results, using the method in SimaPro: ReCPe Midpoint (H) V1,12. The normalization of all categories can be seen in Figure 9 in the appendix. Four significant categories have been selected (Figure 6) for further investigation in order to identify environmental hot spots and its original source. The four selected categories are:

- Freshwater eutrophication
- freshwater ecotoxicity
- Marine ecotoxicity
- Natural land transformation

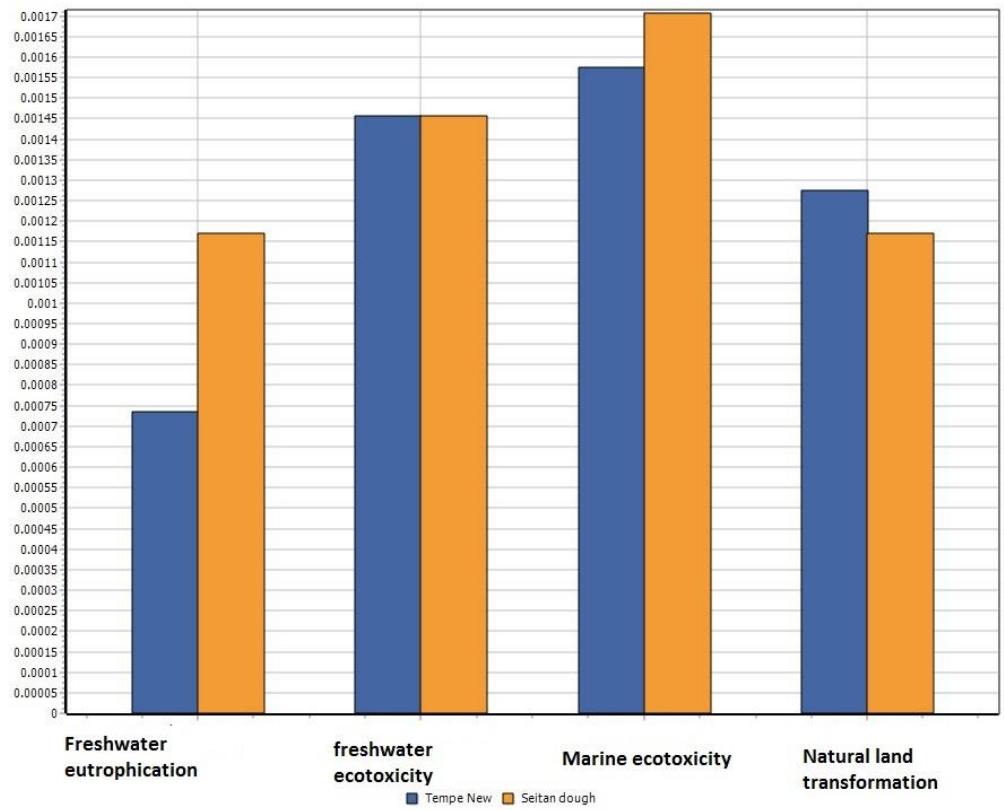

Figure 6 Comparison of significant impacts between Tempe and Seitan

The category 'freshwater eutrophication' has a small number of contributing substances. Tempe has a lower total impact, but has a higher impact on Phosphorus to water, significant parts of which can be traced back to cultivation of soybeans in Brazil (BR). Seitan has a significant higher impact on phosphate to water, where a significant amount can be traced back to the cultivation of wheat grain in Germany (DE) and electricity use in both Germany (DE) and the Netherlands (NL).

The impact category Freshwater ecotoxicity has a high number substances that contribute to it. The four most significant substances were selected for further investigation. Both products have almost equal value of total contribution. The significant difference between the products are that Tempe has a higher value of copper to water and diflubenzuron to soil. The Copper can be traced back to the electricity use (NL), while diflubenzuron can be traced to the cultivation of the soybeans. Seitan has a higher value of Manganese to water. All four most significant substances for Seitan can be traced first to wheat grain and second to electricity use (NL) and (DE).

Seitan contributes slightly more than Tempe in the impact category Marine ecotoxicity. The most significant substances for Seitan are Copper, Nickel and Manganese. All three substances can be traced back to the significant contributing processes as: cultivation of wheat grains and electricity use (NL and DE). The two most significant substances contributed from Tempe are Copper and Nickel and can be traced back to electricity use (NL).

Tempe has a slightly larger contributing impact on the category Natural land transformation. Tempe's most significant substance is "Transformation, from forest, intensive", which can be traced back to the electricity use (NL). Seitan's most significant contributing substances are "Transformation, from forest, intensive" and "Transformation, from forest", which can be traced back to wheat grain production (DE) and electricity use (NL).

3.3. Sensitivity analysis

3.3.1. Tempe

Sensitivity analysis in Tempe is conducted based on the two uncertain findings in the references. The first condition is the uncertainty that is derived from the amount of raw soybean needed to produce one kilogram of precooked Tempe (Nordic Food Lab, 2015). The other is due to the uncertainties in the time needed to ferment the boiled-soaked soybeans (Nordic Food Lab, 2015). The change in time is reflected in the amount of energy needed from the Netherland's grid. Figure 7 below shows that the duration of the fermentation spiked the impact of freshwater ecotoxicity and marine ecotoxicity.

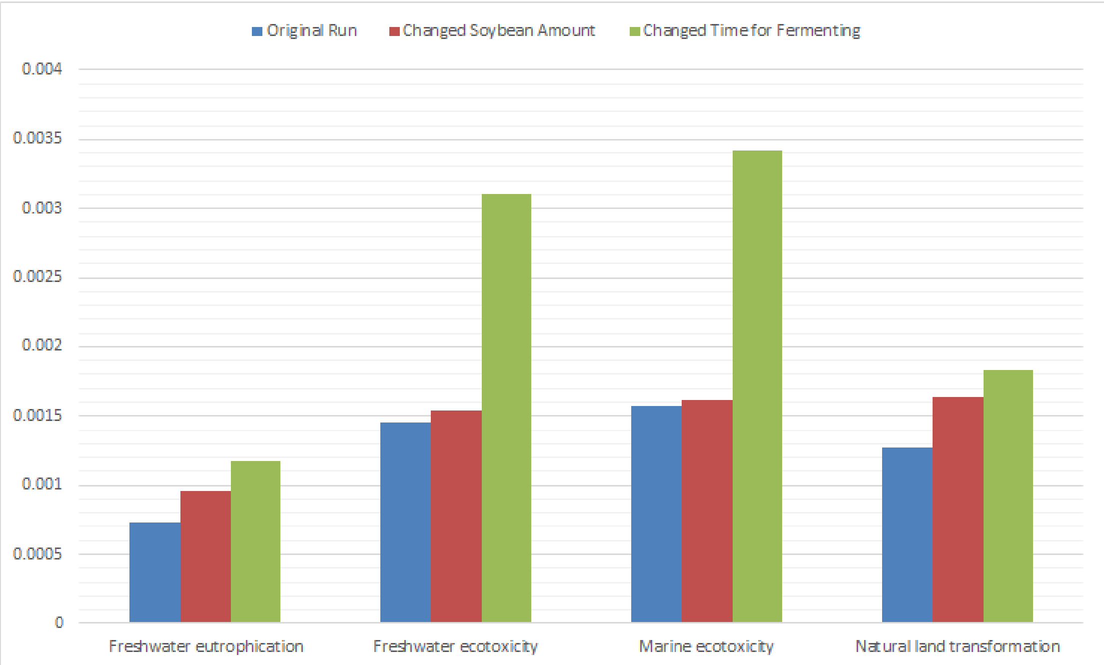

Figure 7 Sensitivity analysis for Tempe

3.3.2. Seitan

Sensitivity analysis in the precooked seitan is derived from its confounding uncertainties within the recipe to make the Seitan dough. In this case, it is the amount of corresponding Seitan powder and water. A recipe from Isa Chandra (2009) suggests that the amount of Seitan powder should be increased while the amount of water should be decreased. The result can be seen in Figure 8, which shows almost same proportional change in al four categories, due to increased use of gluten powder.

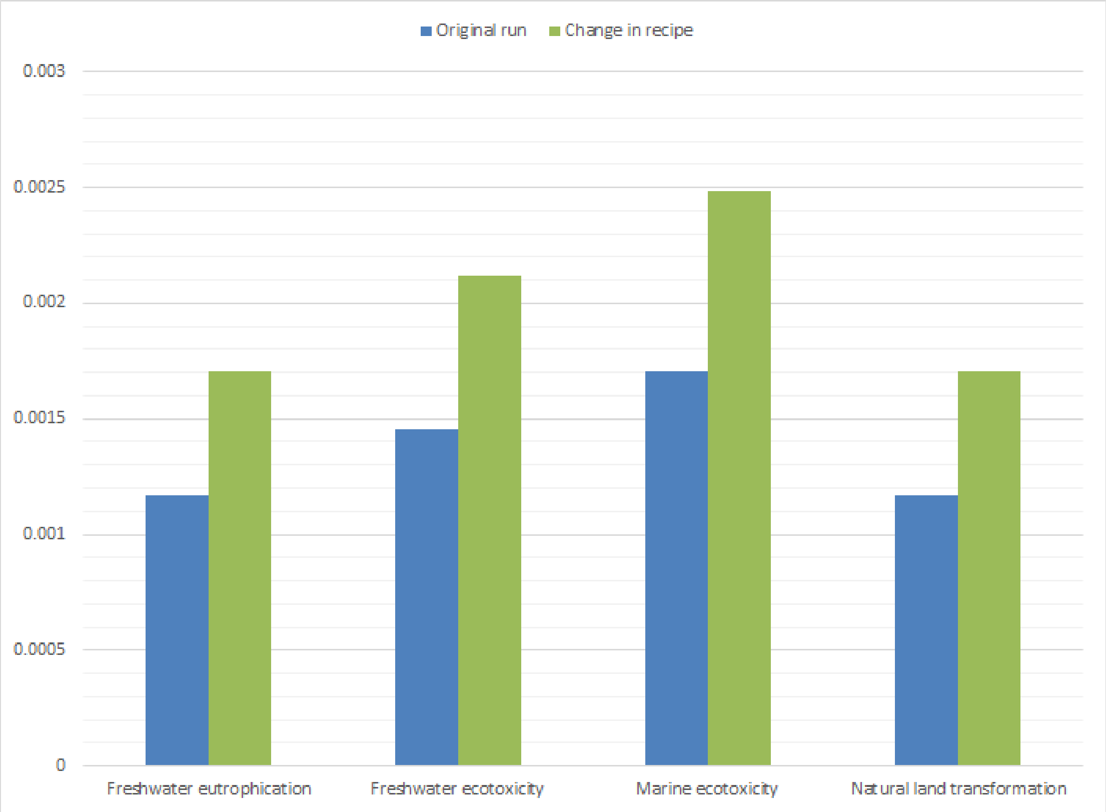

Figure 8 Sensitivity analysis for Seitan

4. Conclusions and recommendations

The results from the study show that Tempe has in general less environmental impacts than Seitan. The results from both flowchart trees in SimaPro and inventory analysis have pointed out significant environmental hotspots for both products. Seitan's most significant hotspots are cultivation and electricity use. The hotspots for Tempe was cultivation of soybeans, electricity use and transportation.

We could look at other countries that cultivate wheat in order to identify which have the fewest environmental impacts. We could also consider other methods for electricity production, such as renewables like wind or solar. This would help to reduce the environmental impacts that result from Seitan production.

With regards to Tempe, we could look at locating soybean production that is closer to the area where it is needed for consumption. This would greatly reduce the amount of transportation required, and lower the environmental effects of this part of the process. As with the Seitan product, we could also consider renewable methods for electricity production.

With regards to the methodology used and the models themselves, we found several strengths and limitations. One of the strengths of the methodology and of using SimaPro was that there was a large and comprehensive amount of existing data within Ecoinvent database. This as very time-saving as we didn't have to find all the relevant information for our LCA ourselves. In addition to this, as SimaPro is a highly-used program, the software itself has been thoroughly tested and thus is very robust. The graphical representations of the results were very useful and helped us to analyse the data from many different angles

4.1. Limitations:

Background data from SimaPro (ecoinvent 3) is rather limited when it comes to ability to choose origin location and other parameter within the raw materials, in this case wheat grains and soybeans. Both raw materials have a significant impact on the final result of the study. Since the background data cannot be changed, we can only modify the amount of used raw material in the sensitivity analysis.

We can see from looking at the sensitivity analysis for Seitan that the choice of recipe, proportion between water and gluten powder, has a large impact on the final result. Tempe in other hand shows a more robust result in the sensitivity analysis, when changing amount of used soybean and electricity.

Many assumptions have been made in the model, for example that we determine the allocation problem by mass for Seitan. The quality of the forward data for the process from wheat grain to gluten powder can be questioned, since it depends on only one source, which could be incorrect. But we can see in the same time that the process itself is not the most significant environmental impact. The forward data quality for the producing Tempe from soybean can also be questioned, since it is roughly estimated. Tempe is also homemade compared to Seitan that is industrial made, or at least the gluten powder. If Tempe would have been industrial made it would most likely be more energy efficient.

4.2. Recommendations

The main recommendations that we suggest in order to make further improvements to process and product are:

- Energy efficiency of producing the products
- Change to using renewable energy
- Raw materials sourcing (as agriculture seems to be an environmental hotspot)

5. References

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6. Appendix

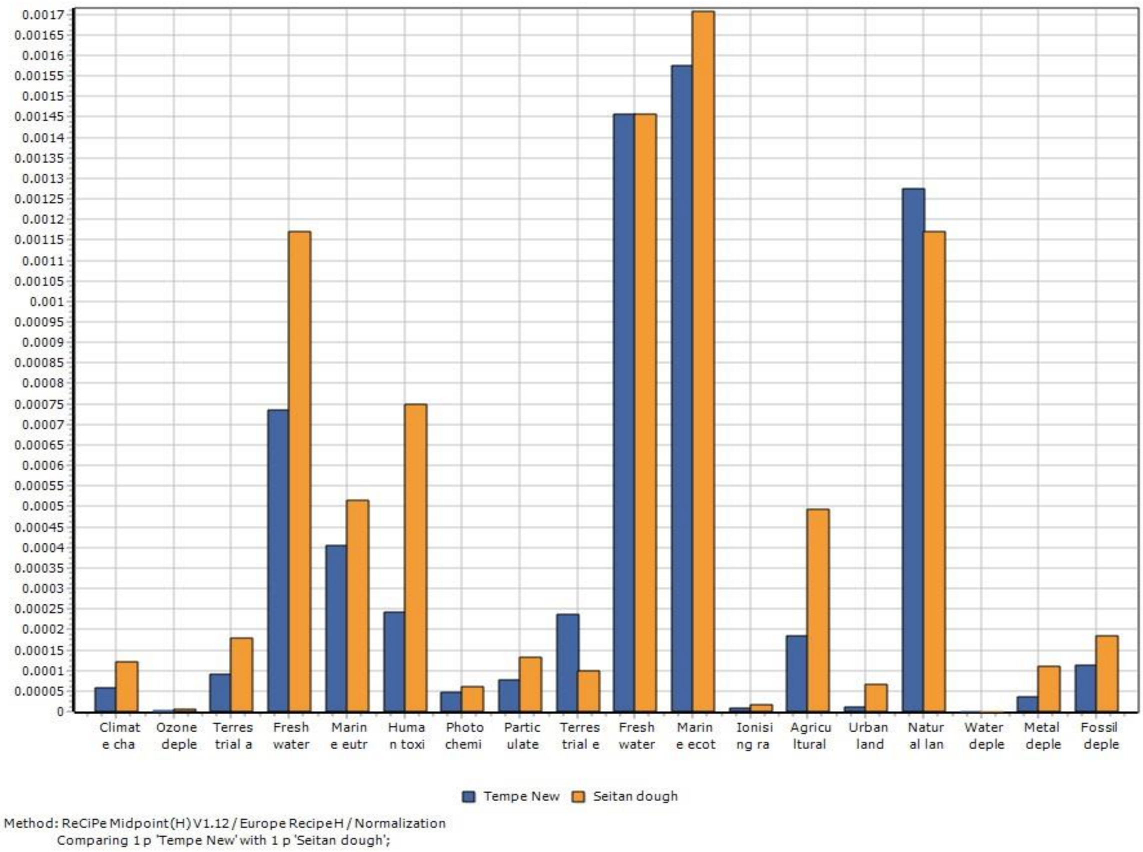

Figure 9 : Illustrates Normalized result from comparing Seitan and Tempe

Table 7: Inventory list from SimaPro

No	Process	Project	Unit	Tempe	Seitan
1	Wheat grain {DE}| wheat production | Alloc Def, S	Ecoinvent 3 - allocation, default - system	kg	0.00	1.40
2	Wheat Flour	Project_Meat_Replacement	kg	0.00	1.38
3	Wastewater, from residence {CH}| treatment of, capacity 1.1E10l/year | Alloc Def, S	Ecoinvent 3 - allocation, default - system	l	1.70	2.99
4	Waste plastic, mixture {CH}| treatment of, municipal incineration | Alloc Def, S	Ecoinvent 3 - allocation, default - system	g	4.64	0.00
5	Transport, freight, sea, transoceanic ship {GLO}| market for | Alloc Def, S	Ecoinvent 3 - allocation, default - system	tkm	10.11	0.00
6	Tempe	Project_Meat_Replacement	kg	1.00	0.00
7	Tap water {Europe without Switzerland}| tap water production, conventional treatment | Alloc Def, S	Ecoinvent 3 - allocation, default - system	kg	2.44	0.66
8	Tap water {Europe without Switzerland}| market for | Alloc Def, S	Ecoinvent 3 - allocation, default - system	kg	0.00	2.02

No	Process	Project	Unit	Tempe	Seitan
9	Soybean {BR}| production | Alloc Def, S	Ecoinvent 3 - allocation, default - system	g	370.37	0.00
10	Soaked Boiled Soybean	Project_Meat_Replacement	kg	1.00	0.00
11	Printing ink, rotogravure, without solvent, in 55% toluene solution state {RoW}| printing ink production, rotogravure, product in 55% toluene solution state | Alloc Def, S	Ecoinvent 3 - allocation, default - system	mg	30.00	0.00
12	Polypropylene, granulate {RoW}| production | Alloc Def, S	Ecoinvent 3 - allocation, default - system	g	2.10	0.00
13	Polypropylene Woven Sack	Project_Meat_Replacement	g	3.00	0.00
14	Phase 3 Gluten	Project_Meat_Replacement	g	0.00	330.00
15	Phase 2 Gluten	Project_Meat_Replacement	kg	0.00	3.32
16	Phase 1 Gluten	Project_Meat_Replacement	kg	0.00	3.32
17	Packaging film, low density polyethylene {GLO}| market for | Alloc Def, S	Ecoinvent 3 - allocation, default - system	g	2.00	0.00
18	incubating plastic	Project_Meat_Replacement	g	2.00	0.00
19	Electricity, medium voltage {NL}| market for | Alloc Def, S	Ecoinvent 3 - allocation, default - system	MJ	0.00	2.90
20	Electricity, medium voltage {DE}| market for | Alloc Def, S	Ecoinvent 3 - allocation, default - system	kJ	0.00	464.52
21	Electricity, medium voltage {BR}| electricity voltage transformation from high to medium voltage | Alloc Def, S	Ecoinvent 3 - allocation, default - system	J	630.00	0.00
22	Electricity, low voltage {NL}| market for | Alloc Def, S	Ecoinvent 3 - allocation, default - system	MJ	2.41	0.00
23	DummyWasteTreatment	Methods	g	111.11	0.00