LIFE CYCLE ASSESSMENT

A comparative LCA of plastic and paper bags

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Abstract

Everybody uses some kind of bag to carry groceries, it is an everyday object that we probably don't give much thought to. However, as each Swedish household uses over 500 bags per year (as estimated in this study) they have a larger impact on the environment than we might think. In this study, the cradle to grave life cycles of two types of bags are investigated and compared: paper and plastic bag.

With a basis on the ISO 14040, a comparative accounting LCA has been performed for evaluating the two alternatives using the SimaPro 8 software and the Ecoinvent 3,0 database. The results from the comparison show that the plastic bag had lower scores in all investigated impact categories under the normalization ReCiPe Midpoint framework, and consequently the conclusion drawn was that plastic bags have a lower environmental impact than paper bag. This somewhat counter intuitive result does not, however take into account the littering of plastic bags, and the effects this has on nature and wild life.

Both paper and plastic bags had the highest scores in the impact categories marine and freshwater ecotoxicity and land use change. The high energy consumption involved in the production of the paper bags is a major contributing factor to the paper bags high impact on the environment.

A recycling scenario where the paper bags were reused three times before incineration was also investigated. This analysis showed that the impact of the paper bag life cycle on climate change could be lowered, enough to have a smaller environmental impact than the plastic bag life cycle, if the paper bags were reused.

In conclusion, plastic bags are less harmful to the environment than paper bags, unless the paper bags are reused at least three times.

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1. Introduction

When buying groceries people have the possibility to choose which type of bag they want to use for transportation purposes. One possibility is to use the paper bag. Since the raw material, trees, is a renewable resource this could be considered as the better option compared to the plastic bag, which is made from petroleum. But is this really the case when factoring in the entire life cycle for the two products?

Paper bags often end up in landfills and should in practice be biodegradable. However, many factors influence the efficiency, for example, temperature and pH (Chaffee and Yaros, 2014). Also, wood need to pass through many different transformation stages before it ends up as paper. These stages require a lot of materials and a high energy- and water demand.

When given the choice in a supermarket, most people in Sweden choose the plastic bag to transport their groceries in. Demand for plastic increase yearly, resulting in more factories but also in an increased focus on energy- and heat recovery in plastic production (Singh, 2009).

Therefore, it is important to analyze the environmental impacts the two products entail during their entire life cycle.

The UK Environment Agency have conducted a comparative life cycle analysis (LCA) study for six different types of grocery bags, the high density polyethylene (HDPE) plastic bag and the unbleached kraft paper bag being two of them. Their study showed that a paper bag has to be reused 3 times to have lower global warming potential than a plastic bag, not being reused and that the life cycles; resource use and production entails the highest environmental impacts (Environment Agency, 2011).

A report written by the ICF International for Green Cities California analyze previously conducted LCA studies comparing plastic and paper bags (ICF International, 2010). All studies analyzed shows that the use of paper bags would result in decreased littering compared to the use of plastic bags. However, paper bags result in higher air emissions, especially concerning greenhouse gases, higher waste production and water pollution compared to HDPE plastic bags. One study showed that paper bag production, use and disposal results in 3.3 times higher greenhouse emissions compare with the same life cycle stages for the plastic bag. Another study showed that the greenhouse emissions are 90% higher for a paper bags life cycle than for the HDPE plastic bag.

2. Purpose of the Study

2.1 Goal of the study

The goal of the study is to investigate and compare the environmental impact of paper and plastic bags, with regard to a number of chosen impact categories, to try to distinguish which of the two alternatives that has the most negative effect on the environment.

2.2 Application

To provide an overview, of some of the environmental impacts associated with paper and plastic bags, to decision makers in order to facilitate informed decision making when offering carriers for groceries and other goods. For consumers to make an informed decision when choosing what type of bag to use as a carrier for groceries.

2.3 Intended Audience

The study is mainly aimed at the organizations and institutions that can make decisions on a regional/local scale and thus have a higher impact than the individual consumer i.e. policy makers and retailers. But also for the consumers of bags.

2.4 Functional unit

Functional unit: plastic bag equivalents/ household and year.

The functional unit is based on the relationship of the weight capacity of the two bag types.
A plastic bag equivalent is defined as the amount of paper bags needed to carry the same weight as in plastic bags. As the weight capacity is 13 kg for a plastic bag and 11 kg for a paper bag (ICA Customer Service, 2016) this results in 1 paper bag is 1,18 plastic bag equivalents. The yearly consumption of bags is based on an average of 5 plastic bags/week, person (Environment Agency, 2011) together with the size of the average Swedish household, 2.2 persons/ household (Statistiska Centralbyrån, 2015).

3. Scope and boundaries

3.1 System boundaries

To analyze the entire life cycle for both bag types the cradle-to-grave life cycle assessment approach is used to define the system boundaries for this study (Figure 1). The initial flowchart below represents both the plastic and the paper bag. The transport is visualized using arrows, consumer transportation to and from the store is excluded from the study and visualized using red arrows.

The system starts at the ‘cradle’ - the raw material extraction - next stages are raw material- and bag production, transportation to bag importer and supermarket. The last stage, the ‘grave’ stage, is the waste management of the bags.

The geographical boundary for the end-of-life stage for both bags is Sweden and since landfilling is not a common practice in Sweden, it is not included in this study. The waste management scenario consists of incineration. The plastic bag is used as a bin liner, to collect garbage in, before incineration.

For the paper bag, wood is extracted and processed in a paper mill to produce unbleached kraft paper. The paper is transported to the bag producer and the finished bags are transported onwards to the supermarket.

Raw material for the plastic bag is crude oil, transformed in the raw material production to polyethylene and further to high-density polyethylene (HDPE) plastic. The plastic product is transported to the bag producer and the finished bags are transported to the supermarket. Included processes are described in more detail in the sections **Process Flow Charts** and **Data**. Processes and material excluded from the study are described in the section **Excluded processes and materials**.

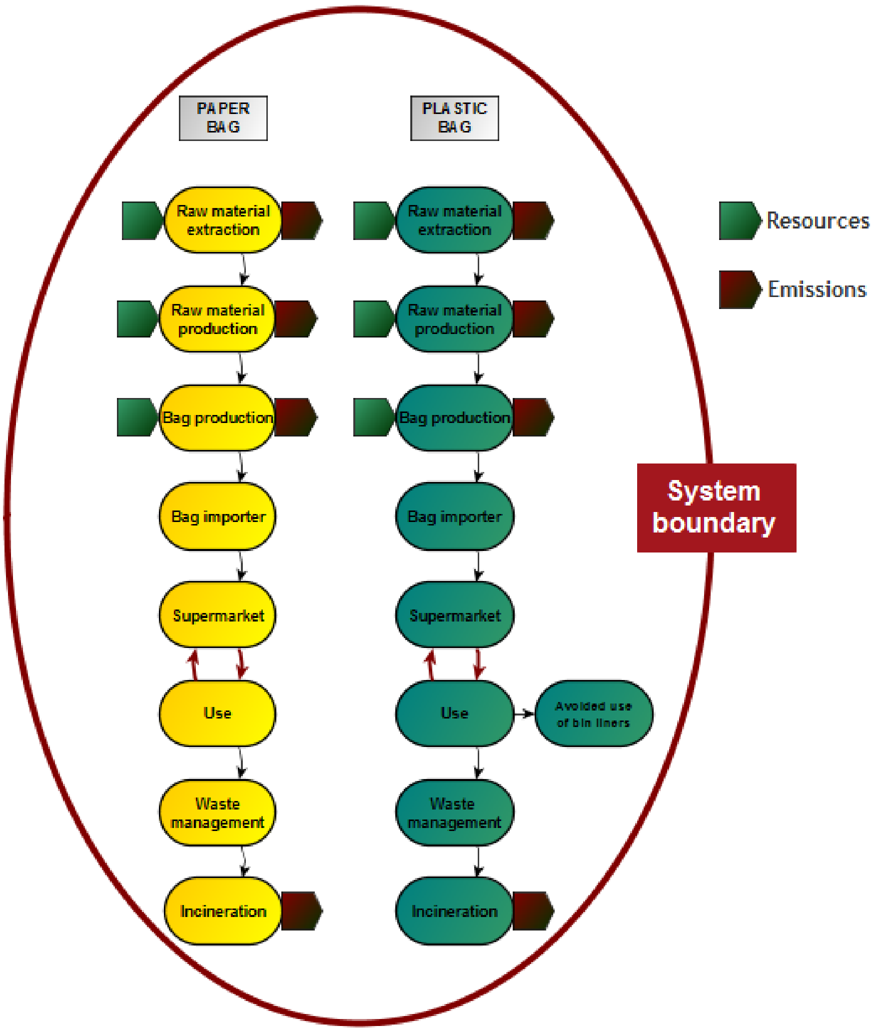

Figure 1. Initial flowchart for plastic and paper bag.

3.2 Time boundaries

- The LCA focuses on the use of bags as carriers for groceries during one year.
- Long term emissions from the incineration is considered.
- Most data in Ecoinvent was collected between 2011-2015.
- The LCA is applicable as long as the bags are produced in the same way as described in the report.

3.3 Geographical boundaries

The paper bags are assumed to be produced in Denmark using Swedish paper pulp. The bags are then imported to Sweden and used in Stockholm.

The Kraft paper production process is described in Ecoinvent using contributions from both Europe and the rest of the world.

The processes of cutting/folding/gluing of the bags are based a global average data as this was the only data available. The data used for waste generated and electricity consumed during production of bags is based on data specific to Denmark. For the glue used in bag production, data specific to Sweden was used when available based on the assumption that the glue was produced in Sweden.

The plastic bags are assumed to be produced in China using Chinese HDPE pellets. The bags are shipped to Sweden and used in Stockholm. HDPE production and Blow-molding processes from Ecoinvent based on global averages were used. For the transport of both types of bag, global average data was used as no country specific data was available.

For the end of life phase which in this scenario takes place in Sweden, data sets for Swiss waste treatment was used as they most resemble the circumstances in Sweden. The heat recovered in this step replaces heat produced from biogas, and is credited to the system using data for heat generated from biogas originating in Switzerland (Svensk Fjärrvärme, 2016). The electricity recovered is credited to the system using data for the Nordic energy mix, as this is what is used in Sweden.

3.4 Allocation procedure

The data sets obtained directly from Ecoinvent contain allocations based on "Allocation at the point of substitution" - APOS (previously named "allocation, default") and "Allocation – recycled content". APOS approach to allocation is the expansion of the system in order to avoid the need to allocate within the system (Ecoinvent, 2016). "Allocation – recycled content" is based on the cut-off system model where the primary production of a material is allocated to the primary product or user. This means that use of recycled material is void of burden associated with material. The recycling processes are however accredited to the process using the recycled material.

Allocations performed in the study:

- Avoided production of bin liners

Then HDPE bags are used as bin liners i.e. waste carriers, which eliminates the need of the bin liners. The relationship of the economic value, of the HDPE grocery carriers and the bin liners they replace, was used as a basis for allocation.

Price per grocery carrier	Price per bin liner	Allocation factor
2 SEK	0,796 SEK*	0,6

*(Clas Ohlson, 2016)

- Allocation of energy used in the production of the paper bag.

Electricity needed is estimated using the electricity input for cardboard box production, excluding printing. Allocation based on assumption listed in section 3.6.

3.5 Excluded processes and materials

- ***Ink and dyes***

  Inks and dyes are not included in the production stage or in this LCA. The increased weight from applying ink and dye to the grocery bags is considered too small to influence the LCA results, in terms of transport emissions. The printing is also similar

  for both types of bag and will not affect the relationship between their respective results.
- ***Storage of grocery bags during import***

  Processes and materials used at bag importer are excluded from this LCA study. For example, the use of wooden pallets and energy consumption for heating facilities etc.
- ***Packaging***

  The packaging of plastic and paper bags after manufacturing stage is not included in this LCA. For plastic bags the amount needed for packaging is too low to impact on the results. Paper bags are mostly transported using wooden pallets. Pallets will not have a significant impact on the results due to their high reuse.
- ***Consumer transportation***

  Consumer transportation to and from a supermarket is excluded from this LCA. The distance travelled to and from the store is not affected by the choice of grocery bag. Furthermore, the weight of the grocery bag is not affecting the amount of emissions released to the air or the vehicle's fuel efficiency.
- ***Capital equipment***

  For all production stages capital equipment (for example machines, equipment and buildings) construction, demolition and reduced efficiency during use, etc. is excluded from this LCA study.
- ***Cutting and sealing of the plastic bags***

The cutting and sealing is not included, as the data needed could not be obtained.

3.6 Assumptions and limitations

For the disposal of the bags it is assumed that both paper and plastic bags are incinerated as, it is the predominant treatment stipulated for household waste in Sweden (Avfall Sverige, 2015)

To simplify the model, the reuse of any of the bags, as a carrier for groceries, by the user is considered to be zero. However, it is assumed that the plastic bags are used as bin liners in garbage cans, avoiding the use of traditional bin liners.

It is assumed that virgin material is used in both paper and plastic bag production, and that no losses of material occur during the production. The paper bags are produced in Denmark using Swedish pulp, and that both the HDPE pellets and the plastic bags are produced in China.

We are assuming that consumption patterns and consequently, use of grocery bags, per household in Sweden and in the UK are the same. This assumption is based on that the average household size is similar, 2.3 people per household in the UK (Office for National Statistics, 2016) and in Sweden 2.2 people per household (Statistiska Centralbyrån, 2015). It is further assumed that the consumer in the UK and Sweden behave similarly since both live in similar contexts of the western developed world.

When allocating energy needed for the production of paper bags, the electricity of a similar process (carton board box production, with offset printing) is used. However, this process includes printing of the boxes and with this an allocation problem arises. It is assumed that the electricity used for printing contributes less than 10% of the total electricity used, and allocation is based on this assumption.

3.7 Impact categories and impact assessment methods

- The "ReCiPe Midpoint (Hierarchist)" impact assessment method was used to investigate the following impact categories:
  - Climate change
  - Human toxicity
  - Marine ecotoxicity
  - Freshwater ecotoxicity
  - Natural land transformation
  - Freshwater eutrophication
  - Agricultural land occupation

The choice of impact categories is based on the highest emission scores received when running the model in SimaPro. Climate change was also included, even though the results were relatively low, since this is considered to be an important category.

- The Single-issue impact method "Cumulative energy demand" was used to calculate the energy demand for each life cycle.

3.8 Normalization and weighting

Normalization is needed in order for the impact category scores to be comparable amongst themselves. Normalizing the scores also puts them in a context, showing how the impact from the different categories compares to the reference values (Curran, 2015).

As most of the stages in the life cycles took place within Europe, normalization was based on ReCiPe Europe (Hierarchist).

Weighting was not performed as an addition of value to the chosen categories was implicitly done when excluding the other midpoint impact categories. The chosen categories were considered to be of equal importance.

4. Life Cycle Inventory Analysis

4.1 Process flowcharts

The process flowcharts for the HDPE plastic bag and the paper bag below consists of the processes included in the study and are placed within the system boundaries. Processes not included flowcharts are within the red, dashed line. Description of the symbols included in the process flowcharts below are presented in the legend in the figures.

Process flowchart plastic bag

The process flowchart for the HDPE plastic bag represents processes from the cradle - the raw material extraction – extraction of polyethylene from crude oil and the grave – the end-of-life stage - incineration of the used plastic bags (Figure 2).

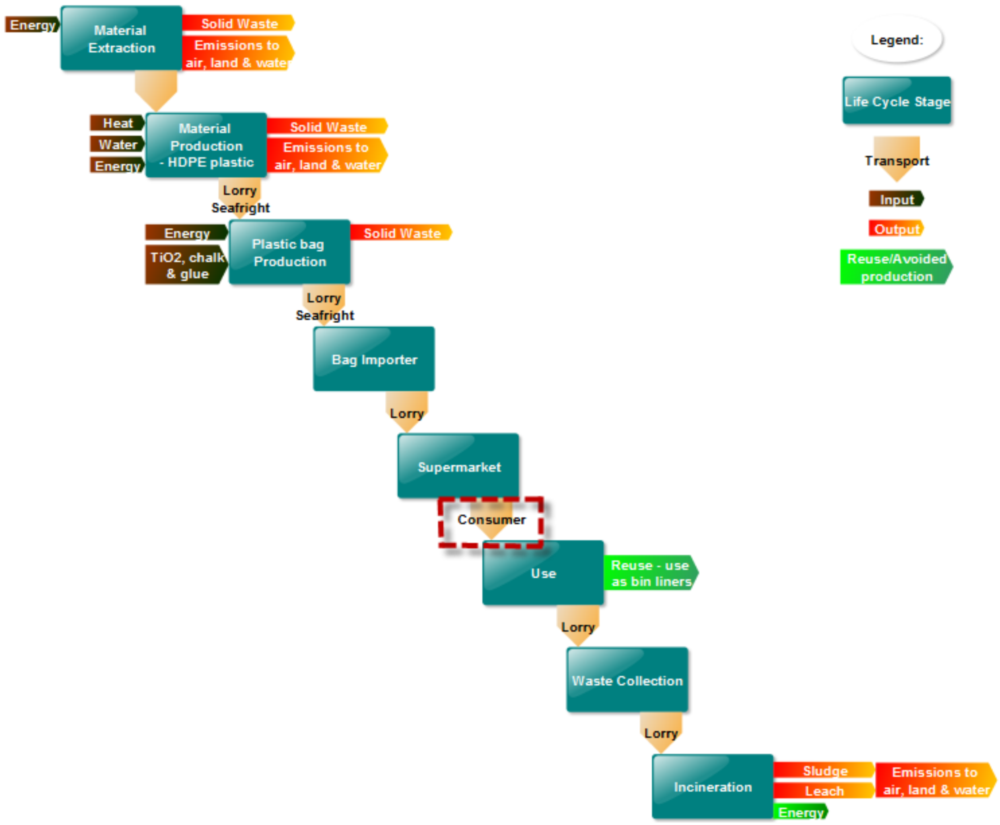

Figure 2. Process flowchart for HDPE plastic bag.

Process flowchart paper bags

The process flowchart for the unbleached kraft paper bag represents processes from the cradle - the raw material extraction – extraction of pulpwood and the grave – the end-of-life stage - incineration of the used paper bags (Figure 3).

Figure 3. Process flowchart for unbleached kraft paper bag.

4.2 Data

Reference flows

For the scenario of only plastic bag use for one year one household would use 1000 plastic bags, and for the scenario of only paper bags one house hold would use 1180 paper bags in one year because 1 plastic bag is equivalent to 1.18 paper bags. This is based on the yearly consumption of bags in 5 plastic bags/week per person (Environment Agency, 2011) and the size of the average Swedish household, 2.2 persons/household (Statistiska Centralbyrån, 2015). See **Appendix 1** for calculations.

Plastic bag production process

Ethylene derived from crude oil is polymerized into HDPE. Pellets of HDPE are then formed into plastic bags through a process called blow-molding (Lee, 2005). The process in SimaPro was modelled after these steps with the related transportation processes from the factory gate in China to the retail point in Sweden. For this, the related Ecoinvent 3 datasets were used and the detail appears in this section.

Plastic bag reference flow

For a reference flow of 572 plastic bags, where one bag weighs 16 grams (weight of an ICA bag) and in accordance with the specifications for data set Blow molding of the Ecoinvent 3 database the amount of HDPE resin required is: 9.15 [Kg]. Analogously the amount needed of Blow Molding process in SimaPro: 9.15 [Kg]. However, with the economic allocation factor of 0,6 those two values turn into 5.491 [Kg]. See **Appendix 1** for calculations.

Data Gaps

The Blow Molding Process dataset for plastics from the Ecoinvent 3 database, does not include the energy used during the cutting, sealing and the associated waste present in the actual manufacture of plastic bags. These specific data could not be produced in the short period of time for the study.

Transport

HDPE pellets are produced by Shijiazhuang Betop Magnesium Zinc Technology Co., Ltd. (Shijiazhuang, China) and the plastic bag production by Jiangyin Yunyuan International Trade Co., Ltd. (Jiangyin, China) the transportation between the manufacturer of resin and plastic bags is taken into account in the data of market for HDPE. The port of Shanghai would be the shipping port and Nynäshamn, Sweden is considered the destination. Transport from importer to supermarket is described by the distance between Nynäshamn and Stockholm. All distances are estimated using google maps. The transportation from supermarket to the consumer's home is considered to be identical for both types of bags, and it is excluded because it offers no differentiated information for comparison.

Use

The plastic bags are reused once as bin liner cover.

Waste management

After use the bags are collected and incinerated together with the rest of the household waste. Heat/electricity is recovered. Waste from the blow molding process is handled internally by the Blow Molding dataset from the Ecoinvent database.

Paper bag production process

The process starts with the intensive cutting of trees mainly from Sweden for the generation of paper pulp. For our process we considered the standard Kraft pulping process from the Ecoinvent 3 database. The kraft process consist of many sub-processes which consumes large amounts of energy, heat and water, sulphur compounds and organic matter are two of the main by-products (U.S. Congress, 1989).

Paper bag reference flow

One plastic bag is equivalent to 1,18 paper bags. In order to establish the reference flow for the paper bags we multiply that factor by 572 the number of plastic bags. Thus 1180 paper bags are needed to fulfil the function of 675 plastic bags. One paper bag weighs 65 grams based on the bags provided by ICA. Thus for the reference flow requires 43,87 [Kg]. of paper bags and according with our assumptions and specifications of the Kraft Paper Unbleached dataset from the database 43,87 [Kg] of Kraft paper is needed. See **Appendix 1** for calculations.

Paper bag process

In a standard production process the Kraft paper is transported to the paper bag production facility where it is cut, glued, printed and pressed. In order to model this, a custom process was crafted using information from studies and datasets. The process is divided in the following:

Glue

The production of glue for the paper bag lifecycle consisted of 32% ABS, 48% phenolic resin and 20% paraffin and used 0.42 kg of steam per kg, 0.25 kWh of grid electricity per kg and generated 0.26 kg of waste per kg which is incinerated (Environment Agency, 2011). This adhesive is assumed to be manufactured in china and transported by freight ship 20,000 Km. The customized data set can be found in **Appendix 2**.

Paper sack forming (Bag forming)

An existing process Carton Board box production was taken as a model to account for the electricity and emissions per Kg of product used in the cutting, folding and gluing process. The data from the aforementioned process, was taken under the assumption that the bag assembly would be less energy intensive, only 90% as it excludes the printing process from the original box production process. See **Appendix 1** for calculations.

Transportation

The pulp is produced in Sweden, here assumed to be produced at Södra Cell Värö (Väröbacka, Sweden), and exported to the paper bag makers located on Jylland, Denmark from the port of Gothenburg to the port of Fredrikshavn (Johansson, 2016). The bags are then imported back into Sweden, via Tingstad Papper AB (Gothenburg, Sweden) via the previously stated ports, and finally transported to Stockholm. All distances are estimated using google maps. The transportation from supermarket to the consumer's home is considered to be identical for both types of bags, and it is excluded because it offers no differentiated information for comparison. The transportation of the pulpwood from Sweden to Denmark is considered to be accounted for in the Ecoinvent's Wood Pulp market dataset for Sweden.

Use
The use phase would only consist of transportation from supermarket to the consumer's home. As mentioned in the transportation section, it is considered that the paper bag goes straight to waste after use.

Waste Management
The paper bags are collected and incinerated. Heat/electricity is recovered.

5. Life Cycle Interpretation

5.1 Evaluation of hotspots in plastic and paper bag LCA

Paper bag LCA
The tree most important impact categories are fresh water ecotoxicity, marine ecotoxicity and natural land transformation (Figure 4).

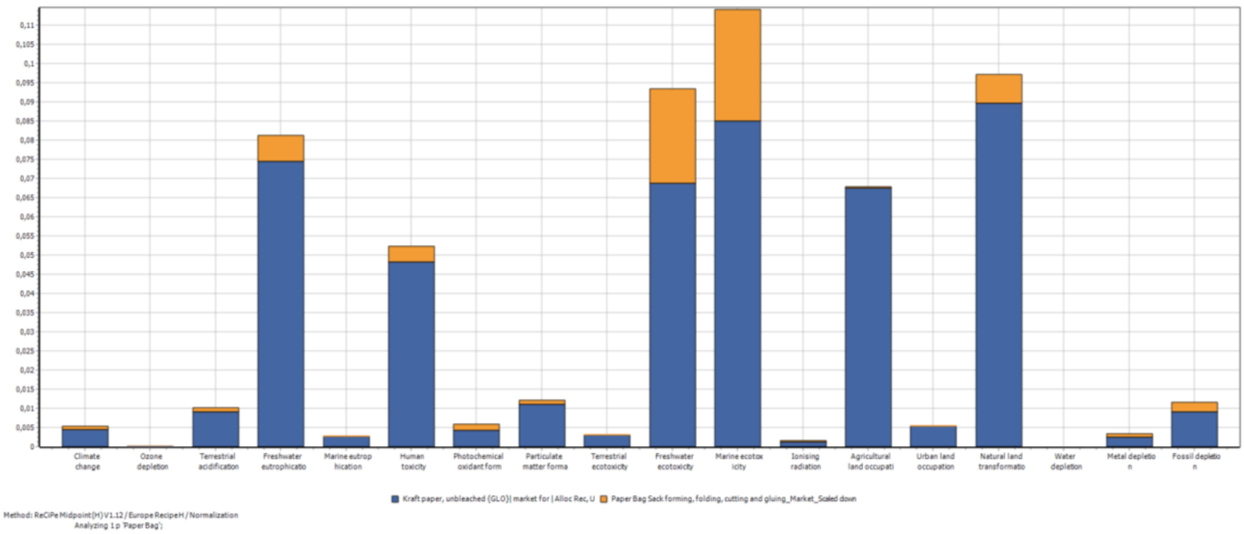

Figure 4. Impact categories for paper bag.

Fresh water and marine ecotoxicity

Overall, the processes that contribute the most to water ecotoxicity are the production of electricity associated with the Kraft paper production and the paper bag incineration stage. Within it the highest impact corresponds to copper dissolved in water second to that is nickel and manganese is third (Figures 5 and 6). Accordingly, a high proportion of the copper emitted comes from paper production processes, the bag forming process and the incineration scenario with heat recovery for the actual paper bag. This can be traced in the network chart (Figure 7).

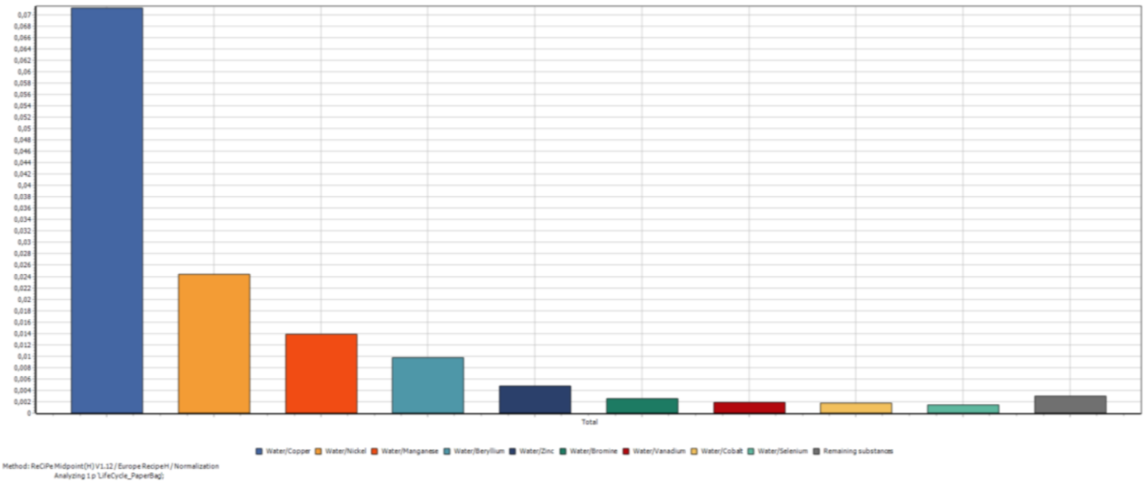

Figure 5. Inventory for fresh water toxicity for paper bag, cut-off 1% normalized.

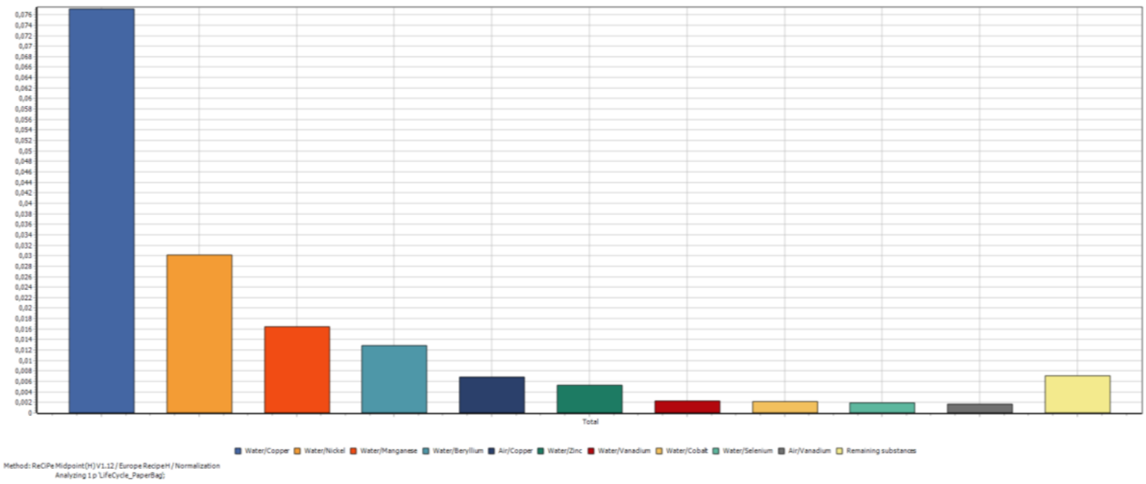

Figure 6. Inventory marine toxicity for paper bag, cut-off 1% normalized

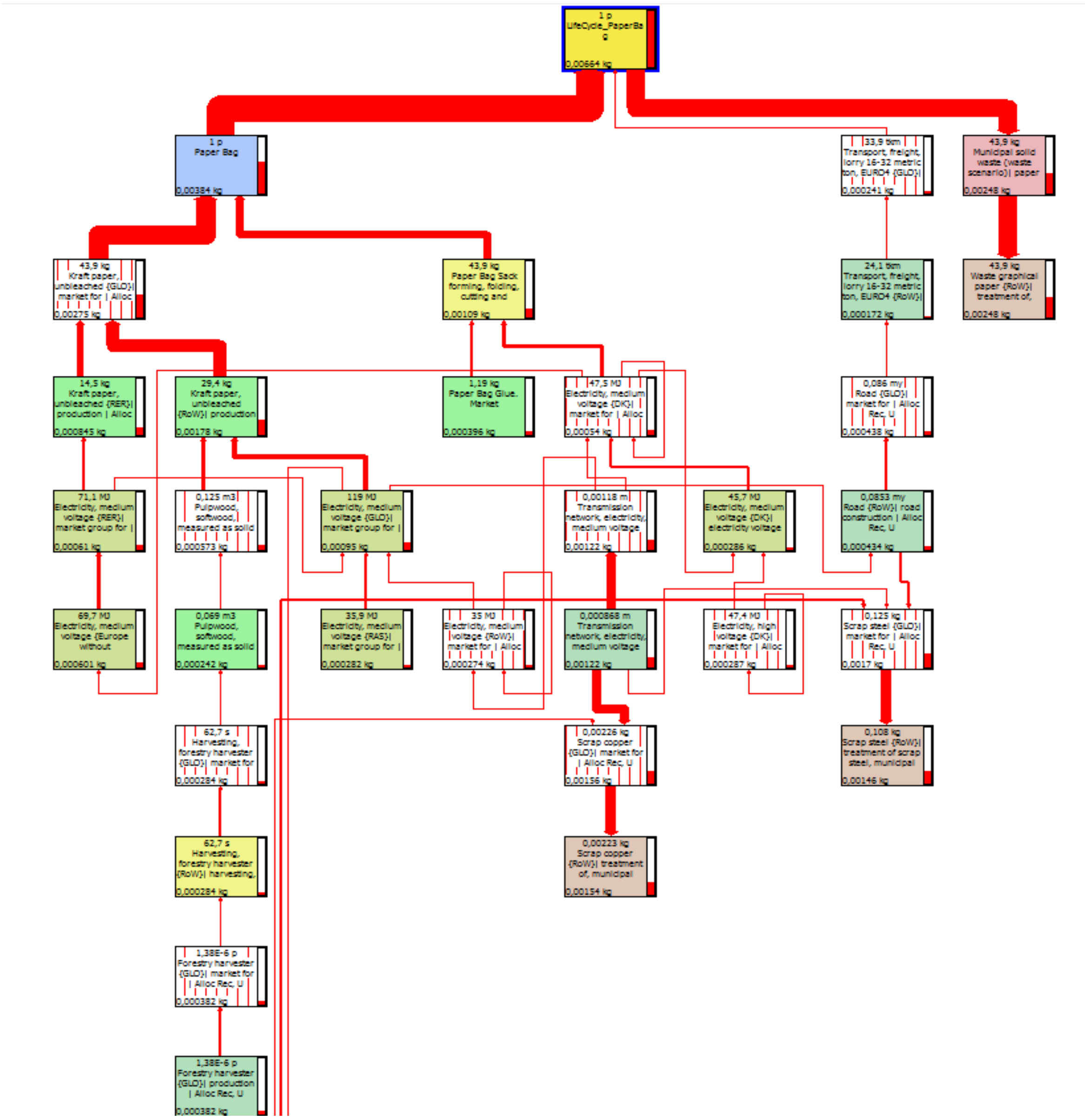

Figure 7. Process network for copper in marine ecotoxicity, for paper bag, normalized.

Natural Land Transformation

In the impact inventory for natural land transformation, the negative and positive impacts regarding forest transformation compensate each other out. So in this case is better to look at the process contribution to the impact on natural land transformation in figure 8, where we can appreciate that the highest contribution is from oil and gas extraction from onshore/offshore wells and land tenure associated.

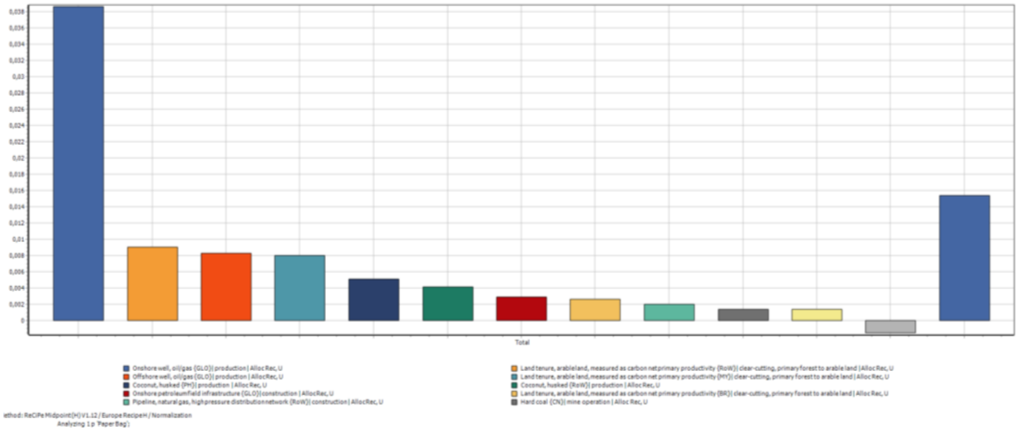

Figure 8. Process contributions on natural land transformation, for paper bag, normalized, cut-off 1%

Climate change

For climate change contribution in CO2eq the processes that contribute the most on their own are the Kraft paper production processes with 12% of the emissions. The rest of the contribution is distributed among smaller processes (rightmost bar on figure 9) which grouped on the basis of a 1% cut off contribute with 68% of the emissions. All this can be appreciated in figure 9.

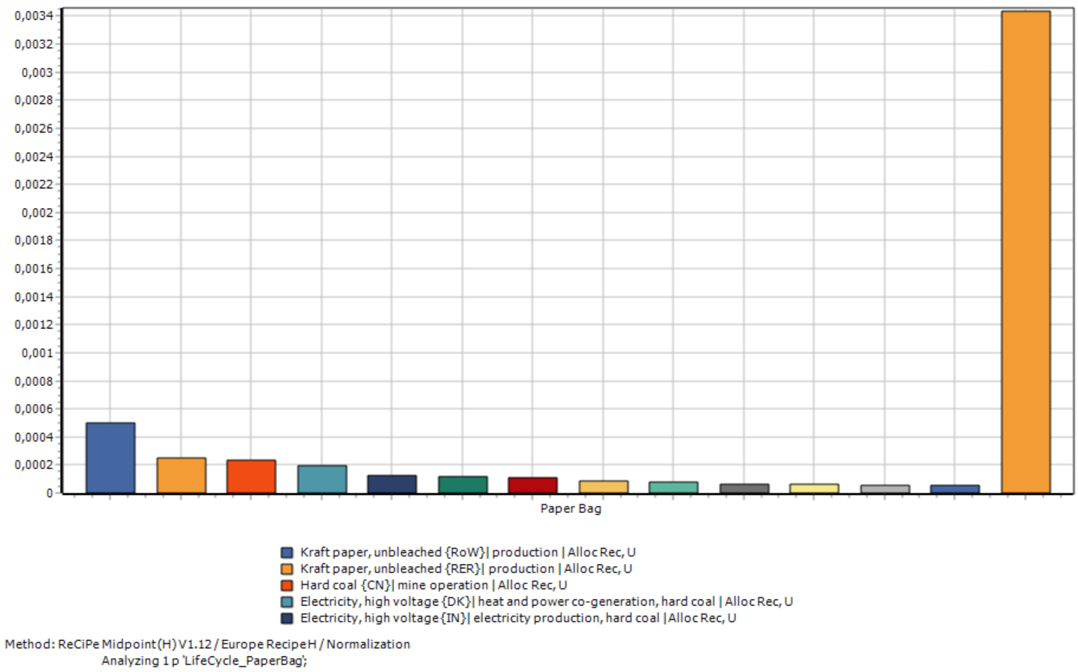

Figure 9 Process contributions on Climate Change Kg CO2eq, for paper bag, normalized, cut-off 1%

Plastic Bag LCA

For the plastic bag life cycle the three categories with a highest impact are marine ecotoxicity, freshwater ecotoxicity and land use change (Figure 10).

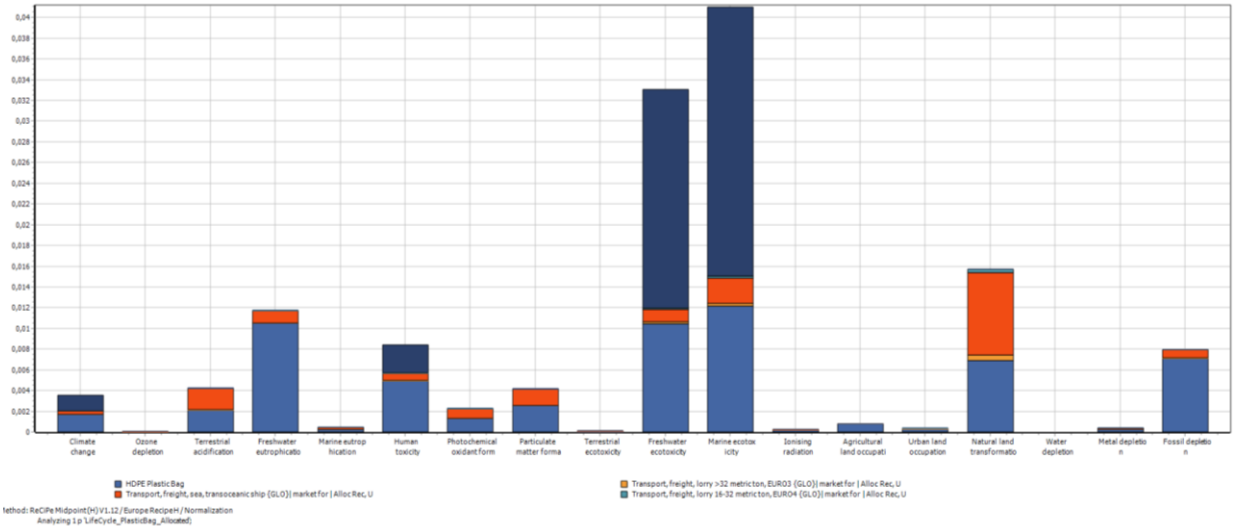

Figure 10. Impact categories for plastic bag.

Marine ecotoxicity and freshwater ecotoxicity

From figure 11 and 12, is noticeable that the main pollutants are heavy metals, vanadium being the highest score, followed by copper. Vanadium to water is traced to the incineration process of the bag and the effect of this can be appreciated in the process network for copper in water (Figure 13). The process network reveals the biggest flow of vanadium is attributable to the waste incineration with heat recovery of the plastic bag.

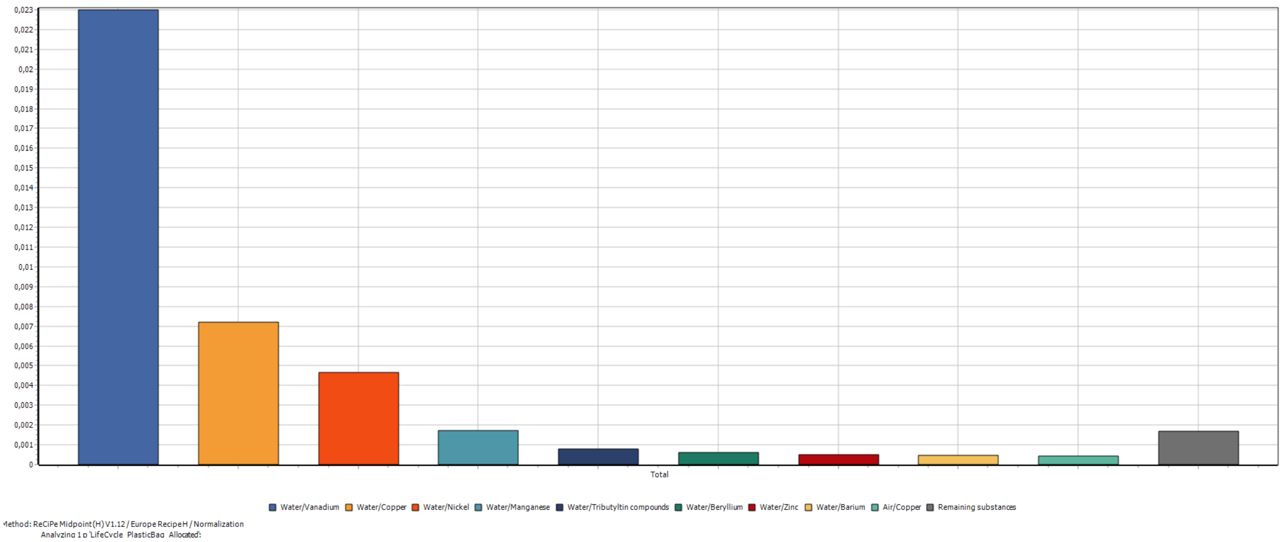

Figure 11. Inventory for marine ecotoxicity for plastic bag, cut-off 1% normalized.

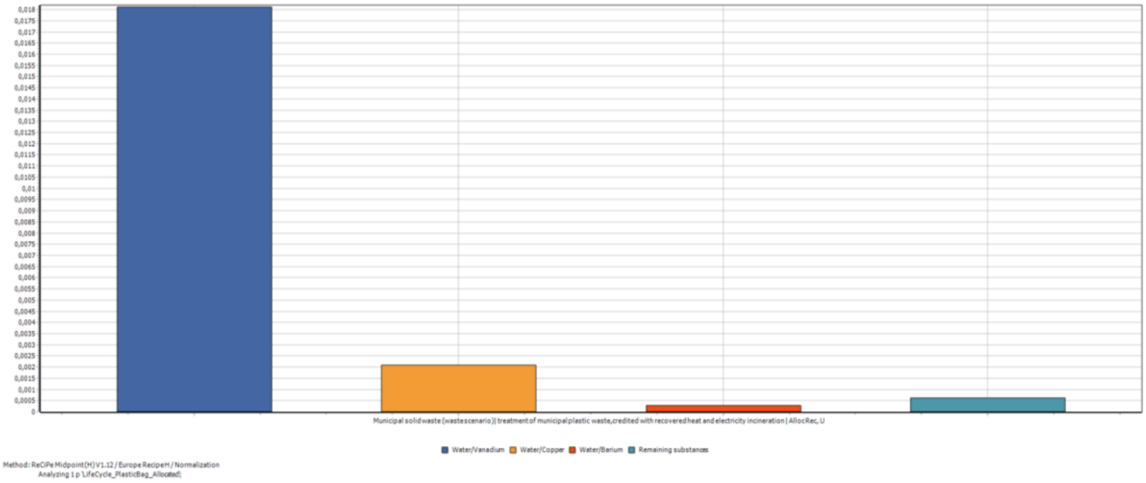

Figure 12. Inventory for freshwater ecotoxicity for plastic bag, cut-off 1% normalized.

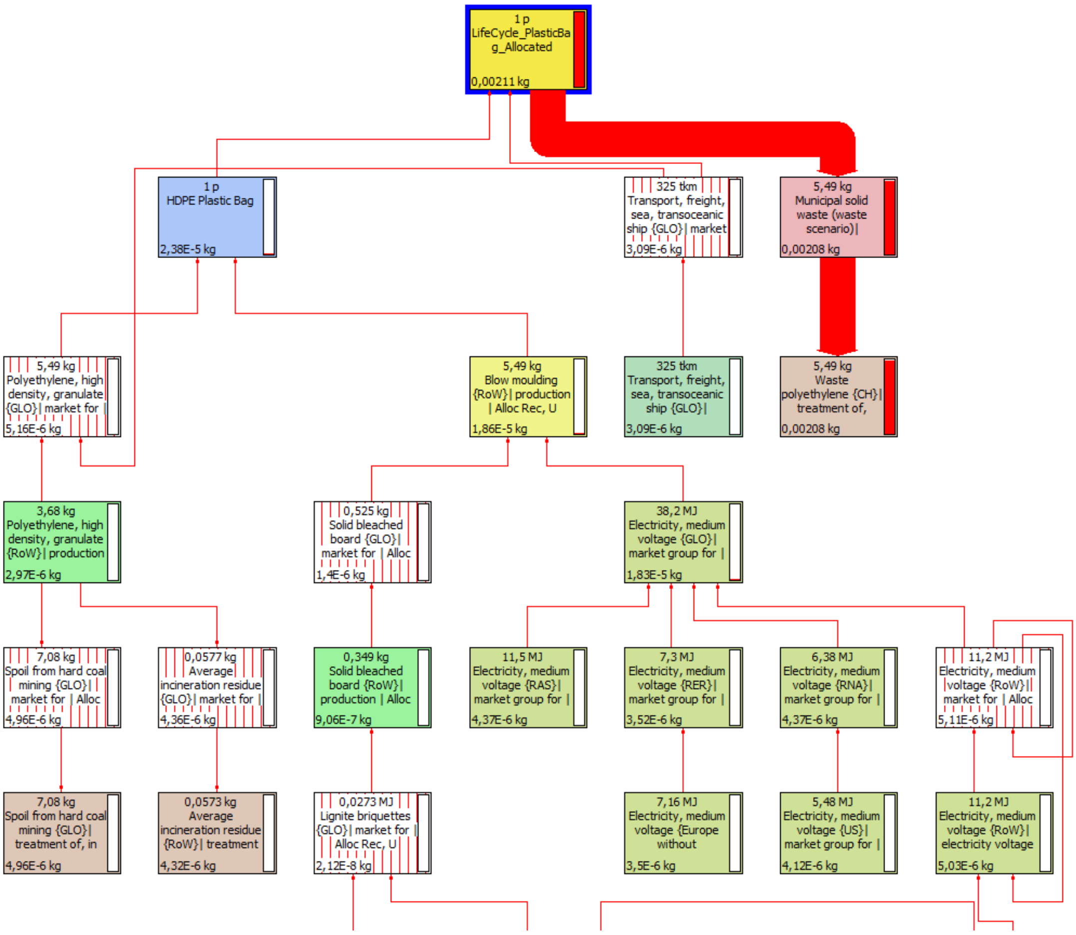

Figure 13. Process network for vanadium in marine ecotoxicity, for plastic bag, normalized.

Natural Land Transformation

For the impacts inventory the forest land transformation categories compensate each other. On this regard however it is worthwhile looking at the processes contributions (Figures 14 & 15), where it can be appreciated that the biggest input to the overall impact of natural land transformation is in the offshore/onshore oil and gas production. Using the associated process network (Figure 16) it can be tracked that such oil and gas production is used for the sea freight transport, additionally it can be identified that an important contribution comes from the electricity for the blow molding process.

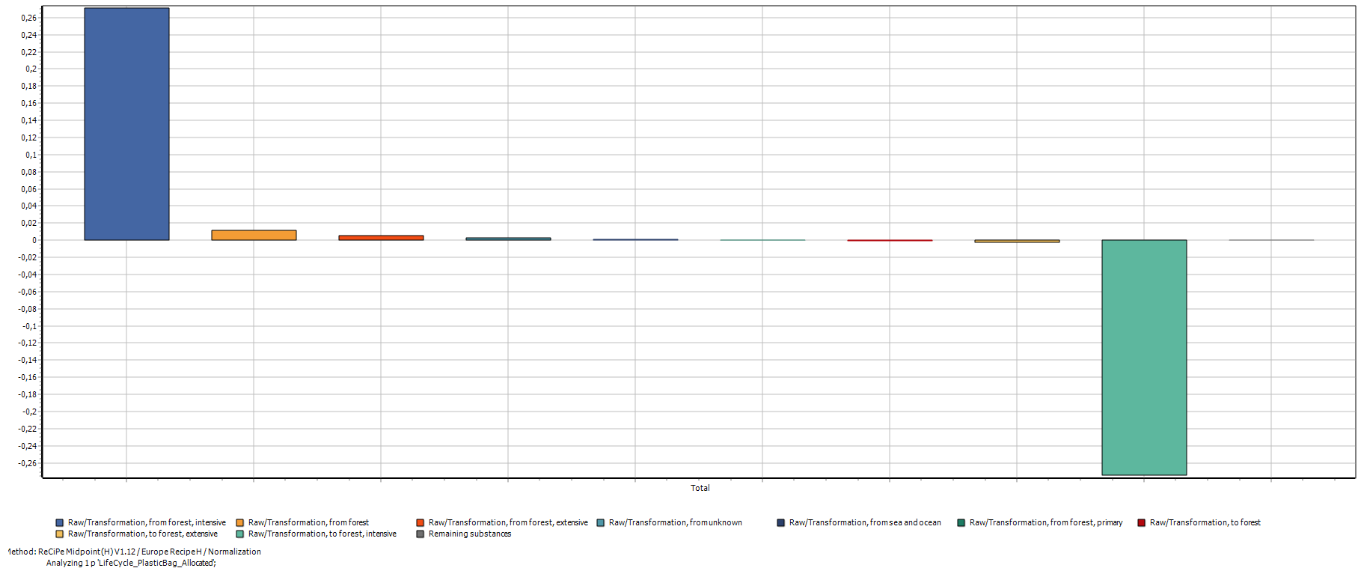

Figure 14. Inventory for natural land transformation for plastic bag, normalized, cut-off 1%

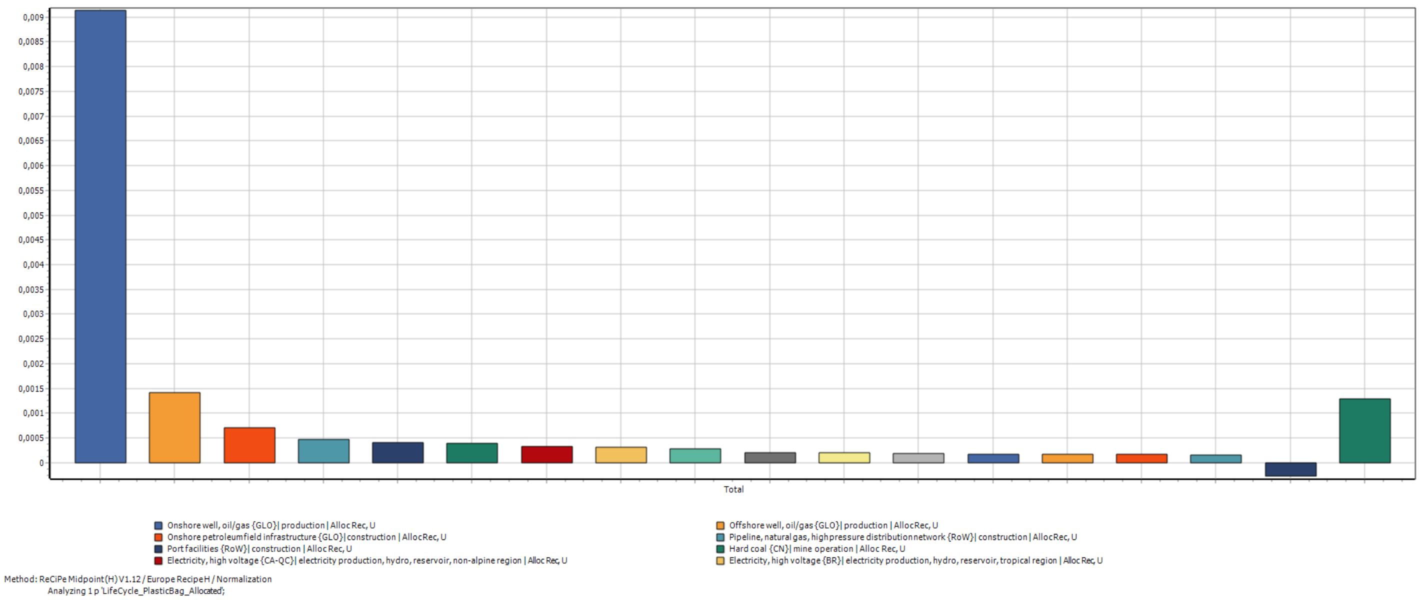

Figure 15. Process contributions on natural land transformation, for plastic bag, normalized, cut-off 1%

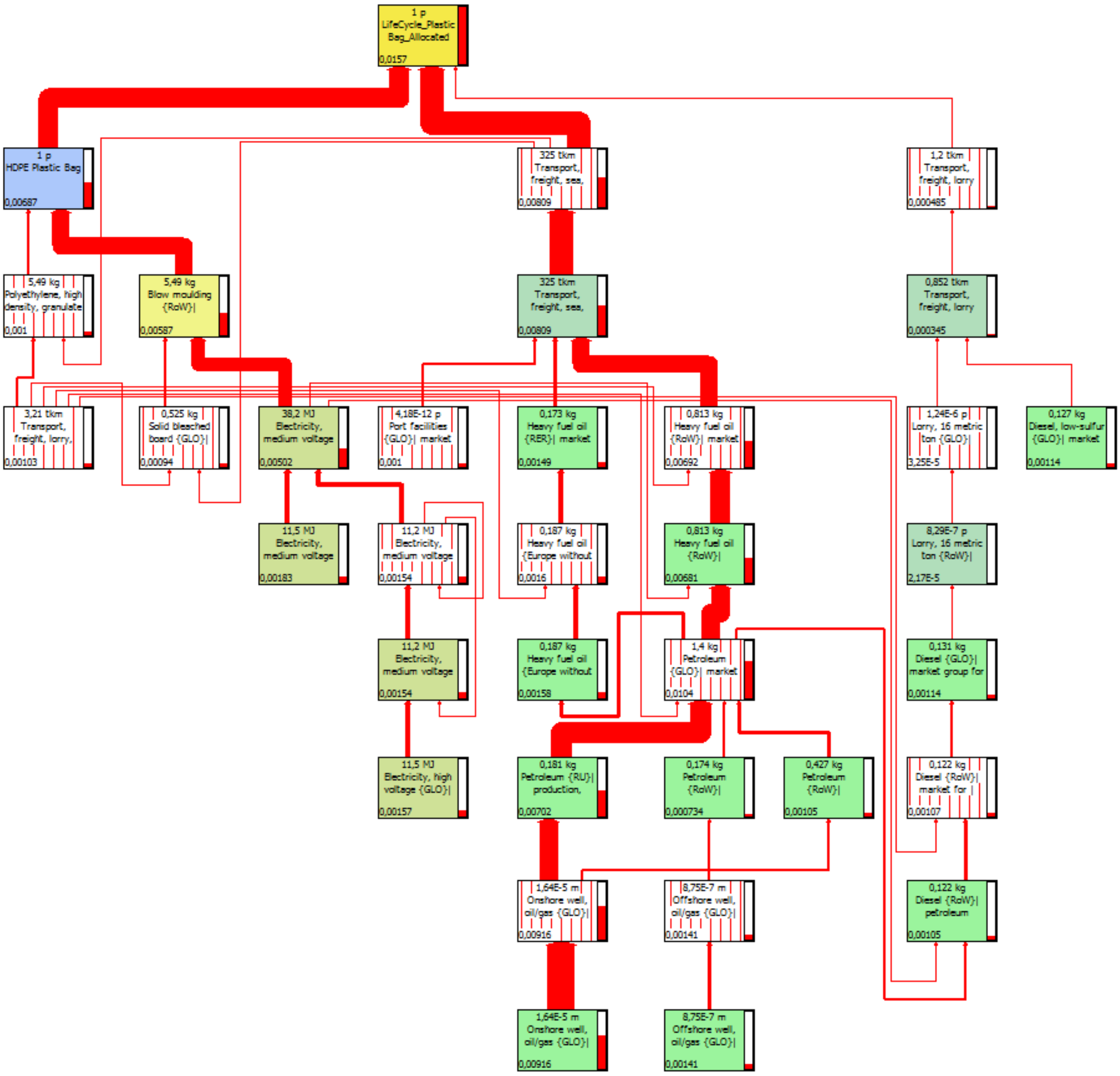

Figure 16. Process network in natural land transformation, for plastic bag, normalized.

Climate Change

For climate change contribution in the plastic bag casein KgCO2eq the processes that contribute the most on their own are the waste incineration for disposing of the plastic bag with 41,3% and both high density polyethylene resin production processes with 26%. The rest of the contribution is distributed among smaller processes (rightmost bar on figure 17) which grouped on the basis of a 1% cut off contribute with 22,6% of the emissions. All this can be appreciated in figure 17.

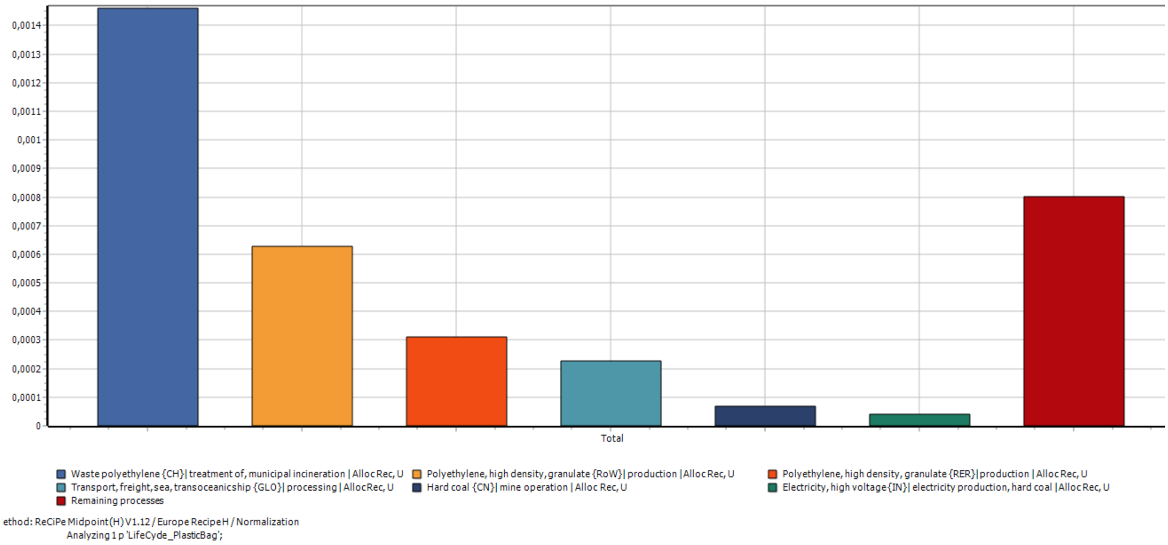

Figure 17 Process contributions on Climate Change Kg CO2eq, for plastic bag, normalized, cut-off 1%

5.2 Comparison of plastic and paper bags LCA

ReCiPe – characterization and normalization

The lifecycle assessment results for the plastic and paper bag are interpreted using ReCiPe Midpoint (Hierarchist). All 18 impact categories included in ReCiPe are analyzed in the characterization step, in the next step normalization is conducted - where the chosen impact assessment categories, presented in section 3.7, are analyzed more in detail.

The characterization visualizes the overall picture for all environmental impacts categories included in ReCiPe Midpoint (Figure 17). The blue staples represent the life cycle of unbleached kraft paper bag and the orange staples the HDPE plastic bag life cycle. Evidently, the paper bag has larger environmental impacts for all categories analyzed in ReCiPe. The impact category most equal for the plastic and paper bag is the fossil depletion. However, the environmental impact to fossil depletion is still relatively lower for the plastic bag, even though the transportation stretch is much longer for the plastic bag. The reason for this is due to the transportation of the plastic bag by freight ship, which has a lower impact on the transportation than transportation of the paper bags, since the low weight of the plastic bags. The least equal impact categories are the agricultural land occupation and the natural land transformation, explained by the high raw material and land use to produce the pulpwood for the paper bags.

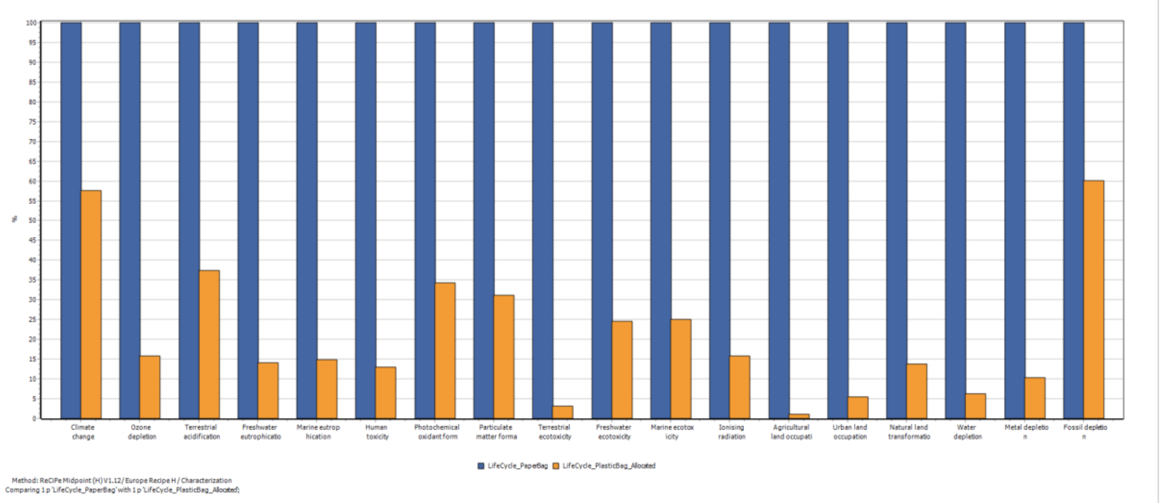

Figure 18. Characterized values for all impact categories included in ReCiPe.

To identify the most significant impacts of the system, further interpretations are made by normalizing the values. By normalizing it is clear that the most significant environmental impact is the marine ecotoxicity, especially for the paper bag which is 0.164 above the reference value. Marine ecotoxicity is also the highest impact category for the plastic bag, 0.041 above reference value. The chosen impact categories – freshwater eutrophication, human toxicity, freshwater ecotoxicity, agricultural land occupation and natural land transformation are significantly higher than the reference values (Figure 18). Freshwater eutrophication is high due to depletion of phosphorous – especially when producing paper bags.

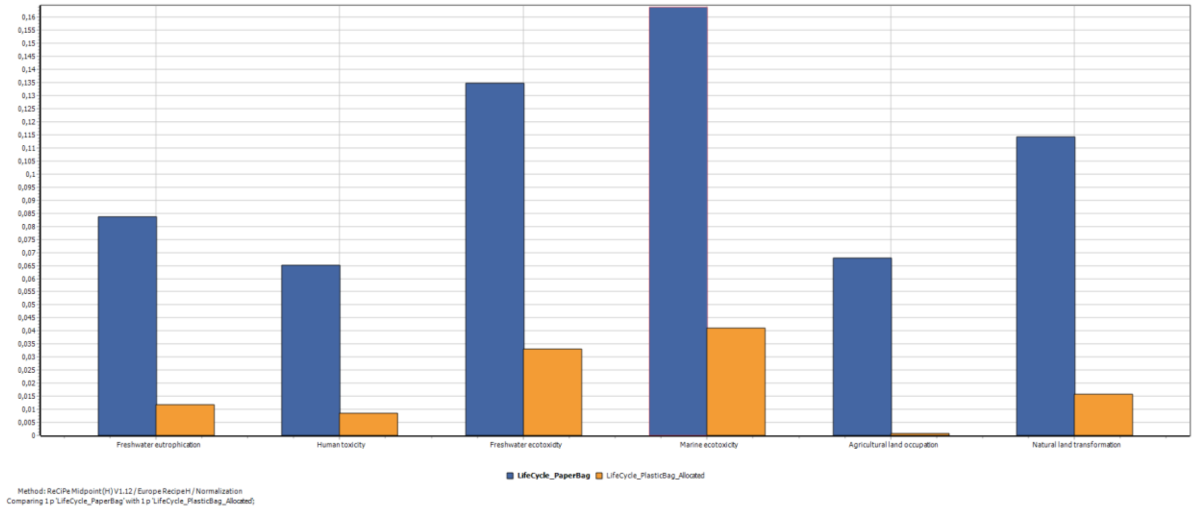

Figure 19. Normalized values for the impact categories with the highest values. With long term emissions included.

When excluding long term emissions, the results are the same for the categories – natural land transformation and agricultural land occupation. Freshwater eutrophication, freshwater ecotoxicity, marine ecotoxicity and human toxicity are significantly lower when excluding the long term emissions (Figure 19).

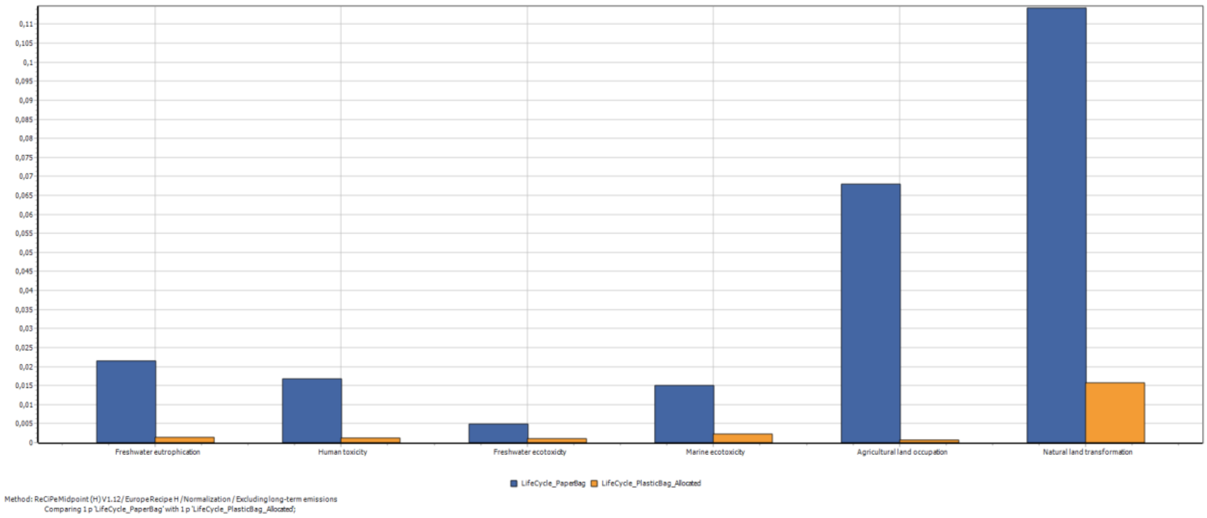

Figure 20. Normalized values for the impact categories with highest values. Without long term emissions.

Cumulative energy demand - Energy demand

The cumulative energy demand methodology in SimaPro has been used to analyze the energy demand for the different life cycle stages and to compare between the bag types (Figure 21). The energy demand for the production stage of the paper bag is much higher than the energy needed to produce plastic bags. In fact, the energy demand for plastic bag production is almost 42% lower. The chart representing the results from using "Cumulative energy demand" is divided into three categories:

- Production: raw material extraction, raw material production and bag production.
- Transport: all transport stages represented in the process flowchart, section **Process flowcharts**.
- Waste management: the incineration of the bags.

From the chart it is clear that the energy contribution from the waste management (dark green) is significantly lower than the other two categories. Here, it is also clear, that the energy used for transport is quite similar even though the plastic bags are transported a longer distance than the paper bag. As mentioned above this is because of the transport method, the ability to package them effectively and the low weight of the plastic bags.

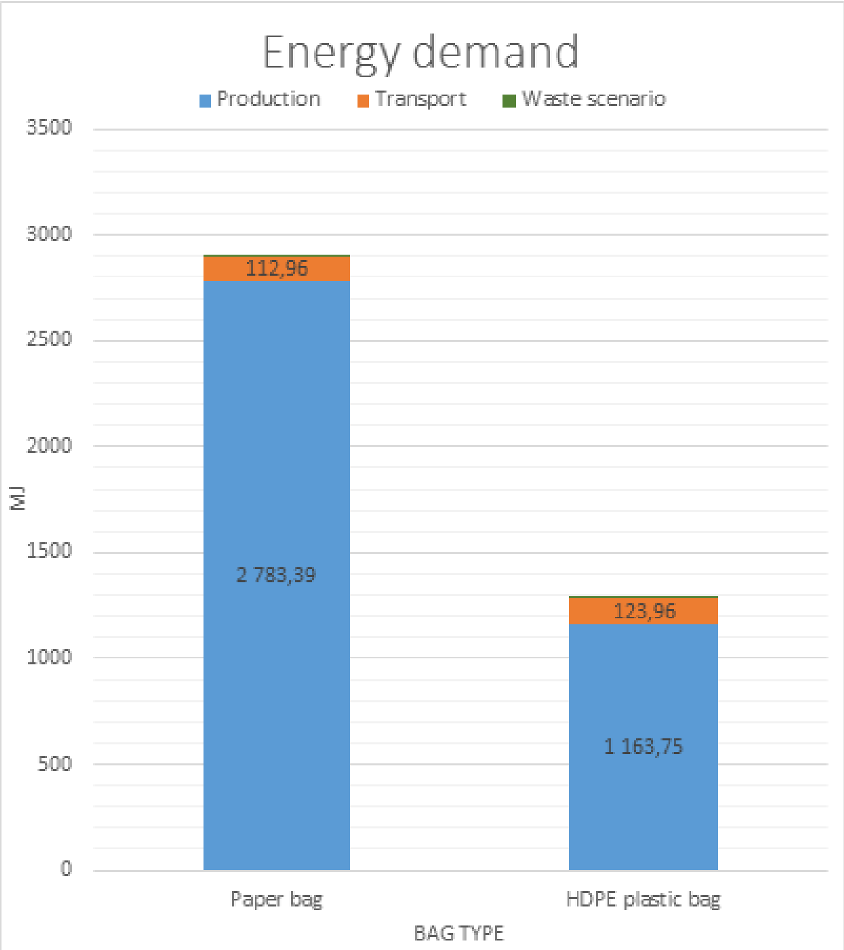

Figure 21. Chart representing the energy demand for the production, transport and waste management for the plastic and paper bags. The energy demand for the waste management is significantly lower it makes it difficult to observe in the chart.

5.3 Sensitivity analysis

Since the allocation of avoided burdens for production of bin liners and the allocation of electricity used for folding and cutting of the paper bags were based on assumption, the impact of changes in the allocation factors were tested in a sensitivity analysis. This was performed by changing the allocation factor ± 10%, and investigating the subsequent changes.

Secondary use of plastic bags as bin liners

The allocation factor in the study was set at 0.6 and based on the relationship of the economic value of the bags two functions. In order to test the effect of this allocation factor on the overall system, it was changed ±10%. The results from the changes can be seen in figure 22.

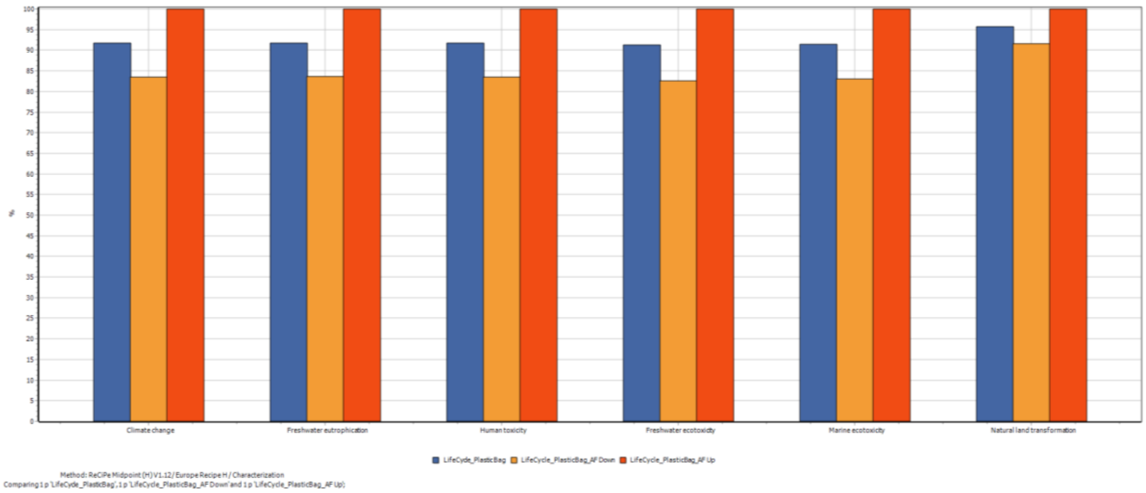

Figure 22. Lifecycle of plastic bag with original AF =0,6 (blue) compared to 10% increase in AF (red), and decrease 10% (orange). Characterized impact category scores.

As the impact on the environment of the paper bag is remarkably higher than that of the plastic bag, an increase in allocation factor has very little effect on the overall relationship between the impact category scores of the two types of bag, shown in figure 23.

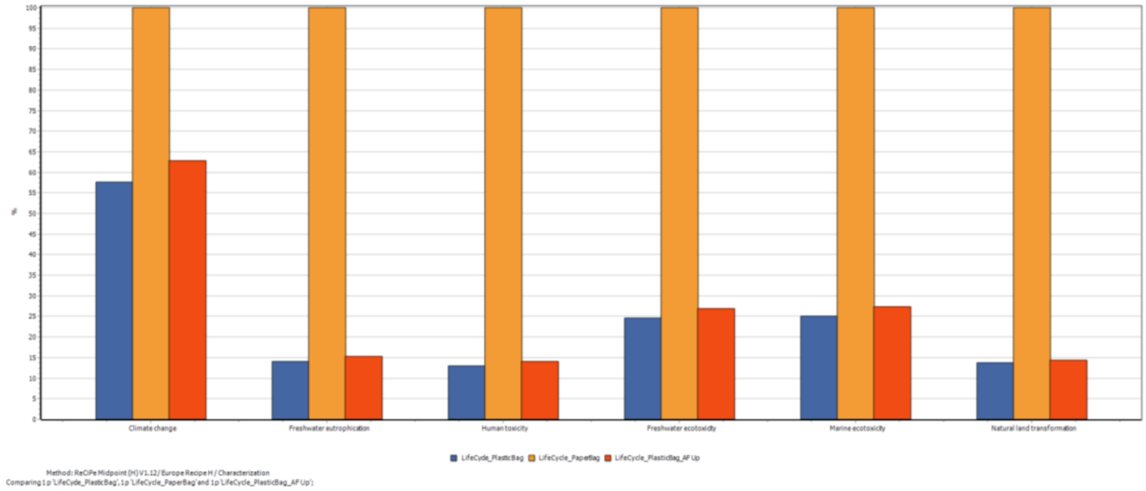

Figure 23. Comparison of Plastic bag (blue) and plastic bag with increased AF (red) to paper bag (orange). Characterized impact category scores.

It is concluded that the model is stable with regard to the allocation factor for reuse of plastic bags as bin liners.

Allocation of electricity for the paper bag production process

The allocation factor used when estimating cutting, folding and gluing of the paper bags was chosen rather arbitrarily. The importance of this AF was also investigated by an increase/decrease of 10%. The results can be seen in figure 24 below.

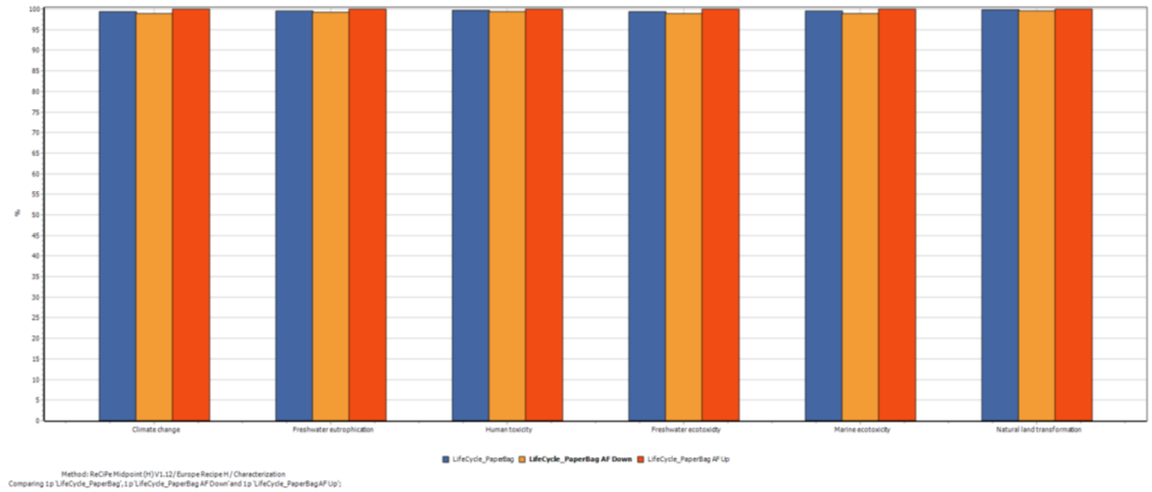

Figure 24. Comparison of paper bag allocation factor; initial AF = 0.9 (blue), 10% decrease (orange) and 10% increase (red). Characterized impact category scores.

Decreasing the AF for the paper bag shows little impact on the overall results, as seen in figure 25.

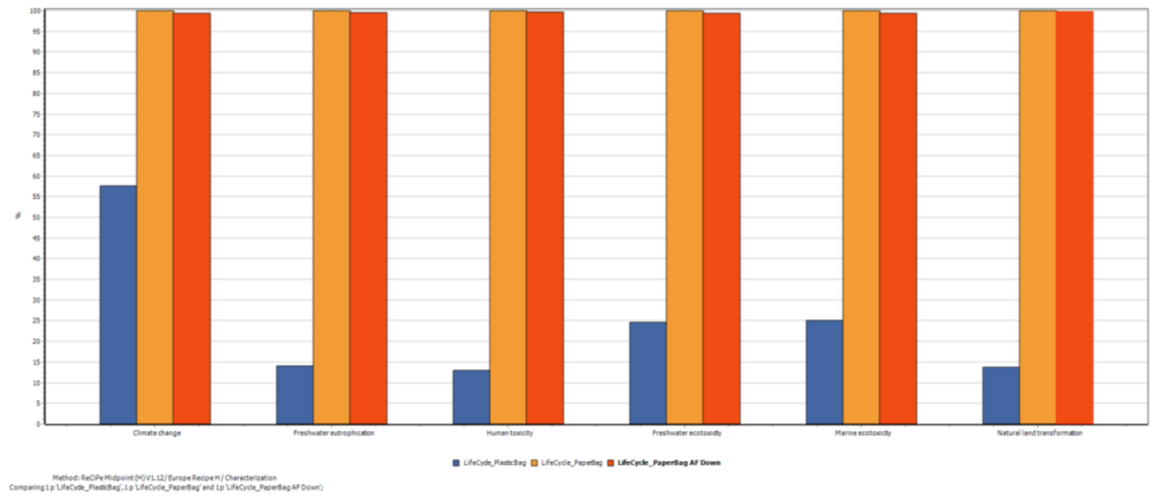

Figure 25. Comparison of paper bag with initially assumed AF (orange), AF decreased with 10% (red) and plastic bag (blue). Characterized impact category scores.

A "worst case scenario", where the allocation factor used for the reuse of plastic bags as bin liners was underestimated and the allocation factor for the paper bag production was overestimated, was also investigated. This was done by a comparison of the results given by increasing the allocation factor for paper bags while simultaneously decreasing the allocation factor for the plastic bags. Even in this case, there was no change in the overall relationship between the impact scores for the two types of bag. It is however possible to distinguish that it is the allocation factor used for the plastic bag that has the highest impact of the two. (figure 26)

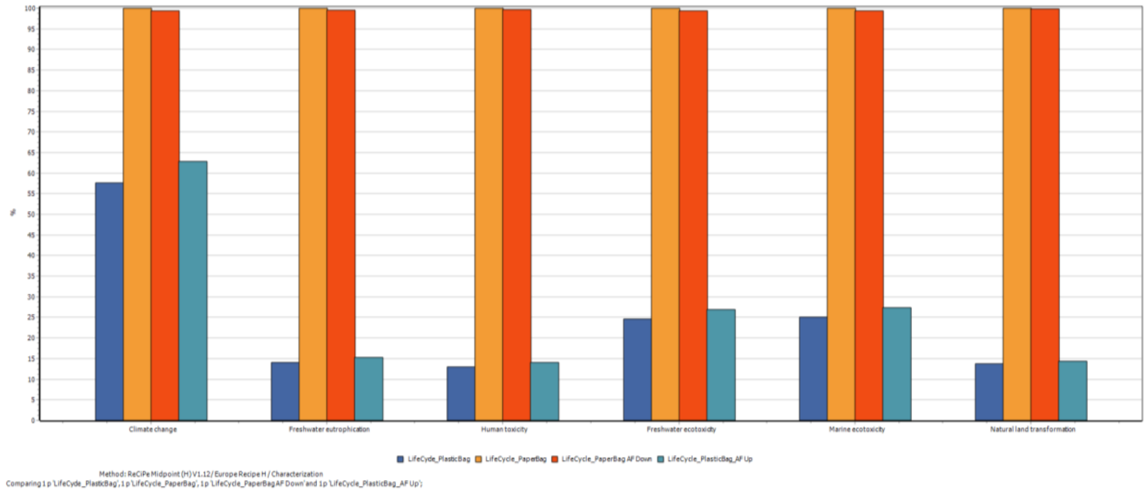

Figure 26. Comparison of the results of the LCA, Plastic bag (blue) vs Paper bag (orange), and the "decreased paper bag AF (red) - increased plastic bag AF (light blue)" - scenario. Characterized impact category scores.

Reuse of paper bags

The scenario described in the study, where all paper bags are used only once and then incinerated is not a probable scenario in Sweden. The reuse of paper bags is quite common, and therefore the effects of the reuse was investigated. This was done by changing the reference flow to represent the reuse of paper bags three times. Below the comparison of the results for the plastic bag LCA and the LCA of paper bags that are used three times can be seen (Figure 27). No reuse of the plastic bags (except for their secondary use as bin liners) was considered.

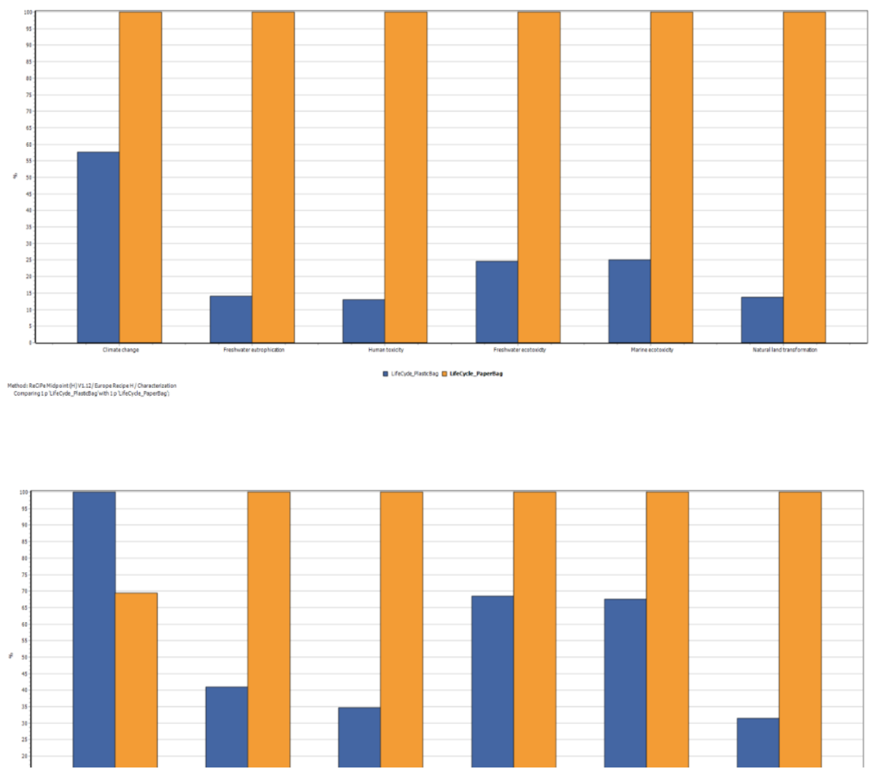

Figure 27. Top: Plastic bag vs Paper bag (no reuse)
Bottom: Plastic bag vs paper bag (3 times reuse. Plastic bag (blue), Paper bag (orange). Characterized impact category scores

As can be seen from figure 27, the reuse of the paper bags three times brings the climate change impact of the paper bags below the level as of the plastic bag. For the other impact categories, however, further reuse is necessary in order to lessen the gap between the two types of bag.

6. Discussion

For the paper bag, it was identified that the contributors of marine water and freshwater ecotoxicity, are paper production processes and the incineration of the bag, mainly because of the copper emission into the water fraction. The third most significant impact is natural land transformation; the greatest contributor to this impact is the onshore/offshore extraction of fossil fuels to feed the different processes. For climate change, the processes that contribute the most on their own are the ones related to Kraft paper production.

The high level of copper emissions to water from the production of Kraft paper can be traced to electrical installations involved in the paper making processes that use copper in an intensive way; i.e. production and transportation of electricity, these and other production related processes drive the emission of copper up to a 41% of the total. The incineration of the paper is also accountable because heavy metals are commonly present in the municipal solid waste incinerators (Brunner & Mönch, 1985). Incineration accounts for 37% of the total emission of copper in the whole life cycle.

In the case of the plastic bag life cycle, the main contributor of marine water and freshwater ecotoxicity is the emission of vanadium by incineration processes. The incineration of the plastic bag, is accountable for the release of the 98% of the vanadium emitted throughout the entire life cycle. Vanadium is known to be present in the emissions of municipal solid waste incinerators (íbid.). Natural land transformation is mainly affected by the onshore production of oil demanded by the sea shipping from China to Sweden, in this way oil extraction accounts for 51% of the impact on land transformation. On the other hand, the electricity required by the production process of the bag contributes to natural land transformation category on a 32%. In terms of climate change the process that contributes the most is the incineration of the plastic bag for waste disposal.

The paper used to produce the paper bags is made by using the kraft pulping process (U.S. Congress, 1989). This pulping process produces stronger paper than for example using a mechanical pulping process. However, the kraft pulping process is much less resource effective than other processes – only 47-52% pulp is recovered from the raw material in comparison with the use of a mechanical pulp process where the recovery is up to 95%. If a more resource friendly process could be used to produce the paper needed for the bags this would be a great improvement for the paper bag since it is clear above that most of the environmental impacts can be traced back to the production stage.

The sensitivity analysis performed, to test the robustness of the model with regard to the allocations made, showed no change in the relationship between the impact category scores of the bags. This indicates that the uncertainties introduced to the model through the assumed allocation factors, does not significantly affect the model, and that the model for comparison is stable in the ±10% range of the allocation factors. It was however concluded that the factor for the allocation of secondary use of the plastic bags, as bin liners, had a higher impact on the model, than that of the electricity used for paper bag production.

As could be seen in the sensitivity analysis, the reuse of the paper bags greatly reduced the environmental impact. This is of course also true for the plastic bag. However, in Sweden it is common to use the plastic grocery bags as a bin liner, and this secondary use might reduce the reuse of the plastic bag in its primary function - as a carrier for groceries. The use of recycled material, instead of virgin material as was the case in this study, can also reduce the negative impact on the environment, and in Sweden it is common to produce bags from recycled material. In this study the use of virgin material was assumed in order to simplify the model, but it is important to take the use of recycled material into consideration when evaluating the results from this study, to keep in mind that the results shown might not reflect the real life situation.

One aspect not addressed in this LCA study, is the littering the bag materials cause to the environment, if not managed correctly in their end-of-life. One of the biggest environmental issues today is the health of the world's marine ecosystems. Climate change and pollution are two influencing factors leading to deteriorating marine ecosystems. Another highly contributing factor is littering – especially littering of plastic materials. Most of the unwanted content in the oceans are transported there due to poor waste management. Since plastic is not biodegradable, it can cause create damage for at least hundreds of years, probably even longer.

As this study is an attributional assessment, no conclusions can be drawn regarding the consequences that might occur if the Swedish population would use only plastic or only paper bags. It is tempting to speculate that the use of resources, i.e. oil and wood respectively, would decrease, but in order to find out and to make further conclusions possible, regarding the changes in environmental impacts, a consequential life cycle assessment has to be made.

7. Conclusions and recommendations

7.1 Conclusions

The conclusions drawn from this comparative life cycle assessment is that plastic bags are the lesser of two evils. This can be said to be valid as long as virgin material is used for production and no recycling is taken into consideration.

The sensitivity analysis showed that the model is robust in regard to the allocations based on assumptions.

The importance of reuse was also shown in the sensitivity analysis, where it could be seen that the reuse of the paper bag three times, lowered the paper bags impact on climate change below that of the plastic bags.

Hotspots were identified for the three largest impact categories, marine and freshwater ecotoxicity and land use transformation as well as climate change in the paper bag and plastic bag life cycles. Where incineration of the paper bag and production of the paper account for a great proportion in these impact categories. In the case of the plastic bag the main contributing processes identified were incineration, sea transportation and to some extent electricity generation.

7.2 Recommendations:

- Plastic bags should be favored over paper bags.
- A more in depth model, taking recycling into consideration, should be developed and investigated.
- A consequential LCA should be performed to explore the effects on the environment with regard to scenarios where only paper or plastic bags are used.
- Emphasis should be put in the reuse of either paper or plastic bag carriers.

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Appendix 1 - Calculations

Table 1. Calculations for consumption of plastic bags

Consumption of plastic bags		
Average consumption	5 [plastic bags/week and person]	
Size of household	2.2 [persons/household]	
Number of bags/ household and week	5 [plastic bags/week and person] * 2.2 [persons/household]	11 [plastic bags/week and household]
Number of bags in a year	11 [plastic bags/week and household] * 52 [weeks/year]	572 [plastic bags/household and year]

Table 2. Calculations for consumption of paper bags

Consumption of paper bags
1 plastic bag are equivalent to 1,18 paper bag
572 plastic bags are equivalent to 675 paper bags.

Table 3. Calculations for plastic bag reference flow

Plastic bag reference flow
Weight of 1 plastic bag = 16 [g]
Weight of 572 plastic bag = 9,152 [kg]
Assumed blow molding process input to output ratio approx. 1:1 (according to Ecoinvent dataset)
Weight of HDPE resin required = 9,152 [kg]
Economic allocation factor = 0,6
Reference flow for HDPE = 9,152 [kg] * 0,6 = 5,491 [Kg]

Table 4. Calculations for paper bag reference flow

Paper bag reference flow
Weight of 1 paper bag = 65 [g]
Weight of 675 paper bag = 43,875 [kg]
Assumed sack forming assumed process input to output ratio approx. 1:1
Weight of Kraft paper required = 43,875 [kg]

Table 5. Calculations for electricity in paper sack forming process.

Energy for paper sack forming
Energy for 1 [kg] of cardboard box forming = 0,325 [kWh]
Allocation 90%
Energy for 1 [kg] of paper sack box forming = 0,325 [kWh] * 0,9 = 0,2925 [kWh]

Table 6. Calculations for transport burdens for stages of plastic bag transport.

Transport for plastic bag		
Road transport from manufacturer to port (China)	140 [km] * 0,005491 [ton]	0,768 [tkm]
Sea transport from China to Sweden	20000 [km] * 0,005491 [ton]	109,82 [tkm]
Road transport from port to retailer	50 [km] * 0,005491 [ton]	0,27455 [tkm]

Table 7. Calculations for transport burdens for stages of paper bag transport.

Transport for paper bag		
Road transport from manufacturer to port (Denmark)	200 [km] * 0,043875 [ton]	8,775 [tkm]
Sea transport from Denmark to Sweden	95 [km] * 0,043875 [ton]	4,16 [tkm]
Road transport from port to retailer	400 [km] * 0,043875 [ton]	17,55 [tkm]

Appendix 2 – Used datasets

Used datasets from Ecoinvent 3.0 database as implemented SimaPro 8 (Frischknecht et al., 2007).

Table 8. HDPE Plastic bag for 5,491 [kg] "HDPE Plastic Bag" assembly

Materials	Amount	Input in SimaPro	Database in SimaPro
Polyethylene high density	5,491 [kg]	Polyethylene, high density, granulate {GLO}| market for | Alloc Rec, U	Ecoinvent 3.0
Process	**Amount**	**Input in SimaPro**	**Database in SimaPro**
Blow molding	5,491 [kg]	Blow molding {RoW}| production | Alloc Rec, U	Ecoinvent 3.0

Table 9. Transport for the reference flow in LifeCycle_PlasticBag_Allocated

Process	Amount	Input in SimaPro	Database in SimaPro
Road transport from manufacturer to port (China)	0,76874 [tkm]	Transport, freight, lorry >32 metric ton, EURO3 {GLO}| market for | Alloc Rec, U	Ecoinvent 3.0
Sea transport from China to Sweden	109,82 [tkm]	Transport, freight, sea, transoceanic ship {GLO}| market for | Alloc Rec, U	Ecoinvent 3.0
Road transport from port to retailer	0,27455 [tkm]	Transport, freight, lorry 16-32 metric ton, EURO4 {GLO}| market for | Alloc Rec, U	Ecoinvent 3.0

Table 10. Waste Scenario for HDPE Plastic Bag "Municipal solid waste (waste scenario) | treatment of municipal plastic waste, credited with recovered heat and electricity incineration | Alloc Rec, U".

Waste Type	Amount	Input in SimaPro	Database in SimaPro
Plastics	100 [%]	Waste plastic, mixture {CH}| treatment of, municipal incineration | Alloc Rec, U	Ecoinvent 3.0
Polyethylene, PE	100 [%]	Waste polyethylene {CH}| treatment of, municipal incineration | Alloc Rec, U	Ecoinvent 3.0
Process	**Amount**	**Input in SimaPro**	**Database in SimaPro**
Waste incineration of polyethylene with energy	100 [%]	Waste polyethylene {CH}| treatment of, municipal incineration credited with heat	PaperVsPlasticB

recovery		and electricity recovery) | Alloc Rec, U	

Table 11. Waste incineration of polyethylene with energy recovery for 1 [kg] "Waste polyethylene {CH}| treatment of, municipal incineration credited with heat and electricity recovery) | Alloc Rec, U"

Avoided Products	Amount	Input in SimaPro	Database in SimaPro
Heat	1,69 [MJ/kg]	Heat, central or small-scale, other than natural gas {CH}| treatment of biogas, burned in micro gas turbine 100kWe | Alloc Rec, U	Ecoinvent 3.0
Electricity	1,54 [kWh/kg]	Electricity, high voltage {NORDEL}| production mix | Alloc Rec, U	Ecoinvent 3.0
Materials	**Amount**	**Input in SimaPro**	**Database in SimaPro**
All other inputs, emissions and outputs stay the same as in the process Waste polyethylene {CH}| treatment of, municipal incineration | Alloc Rec, U			Ecoinvent 3.0

Table 12. Kraft paper bag for 76,7 [kg] for paper bag assembly.

Materials	Amount	Input in SimaPro	Database in SimaPro
Kraft paper, unbleached	43,875 [kg]	Kraft paper, unbleached {GLO}| market for | Alloc Rec, U	EcoInvent 3.0
Process	**Amount**	**Input in SimaPro**	**Database in SimaPro**
Sack forming	43,875 [g]	Paper Bag Sack forming, folding, cutting and gluing market scaled down	PaperVsPlasticB

Table 13. Transport for the reference flow in LifeCycle_PaperBag.

Process	Amount	Input in SimaPro	Database in SimaPro
Road transport from manufacturer to port (Denmark)	8,775 [tkm]	Transport, freight, lorry >32 metric ton, EURO4 {GLO}| market for | Alloc Rec, U	Ecoinvent 3.0
Sea transport from Denmark to Sweden	4,168125 [tkm]	Transport, freight, inland waterways, barge {GLO}| market for | Alloc Rec, U	Ecoinvent 3.0
Road transport from port to retailer	17,55 [tkm]	Transport, freight, lorry 16-32 metric ton, EURO4 {GLO}| market for | Alloc Rec, U	Ecoinvent 3.0

Table 14. Sack Forming Process for 1 [Kg] "Paper Bag Sack forming, folding, cutting and gluing Market_Scaled down" adapted from "Carton board box production, with offset printing {CH}| carton board box production service, with offset printing | Alloc Def, U" from the Ecoinvent 3.0 database as implemented SimaPro 8

Input material	Amount	Input in SimaPro	Database in SimaPro
Glue	0,0271 [kg]	Paper Bag Glue. Market	PaperVsPlasticB
Packaging box factory	1,43E-9 [p]	Packaging box factory {GLO}| market for | Alloc Rec, U	Ecoinvent 3.0
Electricity input	0,29 [kWh]	Electricity, medium voltage {DK}| market for | Alloc Rec, U	Ecoinvent 3.0
Emissions to air	**Amount**	**Input in SimaPro**	**Database in SimaPro**
NMVOC	0,00134 [kg]	NMVOC, non-methane volatile organic compounds, unspecified origin	Ecoinvent 3.0
Ammonia	7,15E-5 [kg]	Ammonia	Ecoinvent 3.0
Water	3,75E-7 [m^3]	Water/m^3	Ecoinvent 3.0
Emissions to water	**Amount**	**Input in SimaPro**	**Database in SimaPro**
Oxygen demand bio.	0,000189 [kg]	BOD5, Biological oxygen demand	Ecoinvent 3.0
Carbon	3,5E-5 [kg]	TOC, Total organic carbon	Ecoinvent 3.0
Dissolved carbon	3,5E-5 [kg]	DOC, Dissolved organic carbon	Ecoinvent 3.0
Oxygen demand chem.	9,4E-5 [kg]	COD, Chemical oxygen demand	Ecoinvent 3.0
Water	2,125E-6 [m^3]	Water, Europe without Switzerland	Ecoinvent 3.0
Waste	**Amount**	**Input in SimaPro**	**Database in SimaPro**
Municipal waste	0,038 [kg]	Municipal solid waste {RoW}| market for | Alloc Rec, U	Ecoinvent 3.0

Table 15. Glue process "Paper bag glue. Market" for 1 [kg] crafted using datasets from the Ecoinvent 3.0 database as implemented SimaPro 8

Inputs	Amount	Input in SimaPro	Database in SimaPro
ABS	0,32 [kg]	Styrene-acrylonitrile copolymer {GLO}| market for | Alloc Rec, U	Ecoinvent 3.0
Phenolic resin	0,48 [kg]	Phenolic resin {GLO}| market for | Alloc Rec, U	Ecoinvent 3.0
Paraffin	0,20 [kg]	Paraffin {GLO}| market for | Alloc Rec, U	Ecoinvent 3.0
Transport from China to Denmark	20 [tkm]	Transport, freight, sea, transoceanic ship {GLO}| market for | Alloc Rec, U	Ecoinvent 3.0
Steam	0,42 [kg]	Steam, in chemical industry {RER}| production | Alloc Rec, U	Ecoinvent 3.0

Electricity	0,25 [kWh]	Electricity, medium voltage {SE}| market for | Alloc Rec, U	Ecoinvent 3.0
Waste	**Amount**	**Input in SimaPro**	**Database in SimaPro**
Municipal waste	0,26 [kg]	Municipal solid waste {DK}| treatment of, incineration | Alloc Rec, U	Ecoinvent 3.0

Table 16. Waste scenario for kraft paper bag "Municipal solid waste (waste scenario) | paper waste recovered electricity and heat, incineration | Alloc Def, U"

Waste type	Amount	Input in SimaPro	Database in SimaPro
Paper	100 [%]	Waste graphical paper {RoW}| treatment of, municipal incineration | Alloc Def, U	Ecoinvent 3.0
Cardboard	100 [%]	Waste graphical paper {RoW}| treatment of, municipal incineration | Alloc Def, U	Ecoinvent 3.0
Packaging paper	100 [%]	Waste graphical paper {RoW}| treatment of, municipal incineration | Alloc Def, U	Ecoinvent 3.0
Newspaper	100 [%]	Waste graphical paper {RoW}| treatment of, municipal incineration | Alloc Def, U	Ecoinvent 3.0
Process	**Amount**	**Input in SimaPro**	**Database in SimaPro**
Waste incineration of paper with energy recovery	100 [%]	Waste graphical paper {CH}| treatment of, municipal incineration credited with energy (electricity and heat) recovery	PaperVsPlasticB

Table 17. Waste incineration of paper with energy recovery for 1 [kg] "Waste graphical paper {CH}| treatment of, municipal incineration credited with energy (electricity and heat) recovery"

Avoided products	Amount	Input in SimaPro	Database in SimaPro
Heat	2,77 [MJ/kg]	Heat, central or small-scale, other than natural gas {CH}| treatment of biogas, burned in micro gas turbine 100kWe | Alloc Rec, U	Ecoinvent 3.0
Electricity	0,367 [KWh/kg]	Electricity, high voltage {NORDEL}| production mix | Alloc Rec, U	Ecoinvent 3.0
Materials	**Amount**	**Input in SimaPro**	**Database in SimaPro**
All other inputs, emissions and outputs stay the same as in the process Waste polyethylene {CH}| treatment of, municipal incineration | Alloc Rec, U			Ecoinvent 3.0

Appendix 3 – Print outs of proprietary processes/materials/life cycles

Processes were either adapted from an existing process or created using datasets from the Ecoinvent 3.0 database as implemented in SimaPro 8

Plastic Bag

Life Cycle of Plastic Bag

SimaPro 8.2.0.0	product stage	Date:		Time:	12:55:24
Project	PaperVsPlasticB				
Product stage					
Category type	Life cycle				
Status					
Products					
LifeCycle_PlasticBag	1	p	Others		
Assembly					
HDPE Plastic Bag	1	p	Undefined		
Processes					
Transport, freight, lorry >32 metric ton, EURO3 {GLO}| market for | Alloc Rec, U	2,24	tkm	Undefined		
Transport, freight, sea, transoceanic ship {GLO}| market for | Alloc Rec, U	320	tkm	Undefined		
Transport, freight, lorry 16-32 metric ton, EURO4 {GLO}| market for | Alloc Rec, U	0,8	tkm	Undefined		
Waste/Disposal scenario					
Municipal solid waste (waste scenario)| treatment of municipal plastic waste,credited with recovered heat and electricity incineration | Alloc Rec, U			Undefined		
Additional life cycles					
Input parameters					

Calculated parameters						

Paper Bag

Paper Bag Life Cycle

SimaPro 8.2.0.0	product stage	Date:	2016-12-15	Time:	12:21
Project	PaperVsPlasticB				
Product stage					
Category type	Life cycle				
Status					
Products					
LifeCycle_PaperBag	1	p	Others		
Assembly					
Paper Bag	1	p	Undefined		
Processes					
Transport, freight, lorry >32 metric ton, EURO4 {GLO}| market for | Alloc Rec, U	15,34	tkm	Undefined		
Transport, freight, inland waterways, barge {GLO}| market for | Alloc Rec, U	7,29	tkm	Undefined		
Transport, freight, lorry 16-32 metric ton, EURO4 {GLO}| market for | Alloc Rec, U	30,68	tkm	Undefined		
Waste/Disposal scenario					

Municipal solid waste (waste scenario)| paper waste recovered electricity and heat, incineration | Alloc Def, U			Undefined		
Additional life cycles					
Input parameters					
Calculated parameters					

Paper Bag Forming Process. (Paper Sack Fomring) adapted from Carton board box production, with offset printing {CH}| carton board box production service, with offset printing | Alloc Def, U from the Ecoinvent 3.0 database as implemented SimaPro 8

SimaPro 8.2.0.0	process	Date:	2016-12-15	Time:	12:11		
Project	PaperVsPlasticB						
Process							
Category type	Processing						
Process identifier	KTH03518000038168400007						
Type							
Process name							
Status							
Time period	Unspecified						
Geography	Unspecified						
Technology	Unspecified						
Representativeness	Unspecified						
Multiple output allocation	Unspecified						
Substitution allocation	Unspecified						
Cut off rules	Unspecified						
Capital goods	Unspecified						
Boundary with nature	Unspecified						
Infrastructure	No						
Date	2016-12-01						
Record							

Generator							
External documents							
Literature references							
Collection method	All emissions to air and water were copied from the cardboard box forming process.						
Data treatment							
Verification							
Comment							
Allocation rules							
System description							
Products							
Paper Bag Sack forming, folding, cutting and gluing_Market_Scaled down	1	kg	100	not defined	Paper+ Board	Electricity, waste and emissions based on the cardboard box production process.	
Avoided products							
Resources							

Materials/fuels								
Paper Bag Glue. Market	0,0271	kg	Undefined					
Packaging box factory {GLO}| market for | Alloc Rec, U	1,43E-09	p	Undefined					
Electricity/heat								
Electricity, medium voltage {DK}| market for | Alloc Rec, U	0,2925	kWh	Undefined					Allocated based on the energy used for the process of cardboard box forming subtracting 10% because that process includes offset printing.
Emissions to air								
NMVOC, non-methane volatile organic compounds, unspecified origin	high. pop.	0,00134	kg	Undefined				
Ammonia	high. pop.	7,15E-05	kg	Undefined				

Water/m3		3,75E-07	m3	Undefined			
Emissions to water							
BOD5, Biological Oxygen Demand	river	0,000189	kg	Undefined			
TOC, Total Organic Carbon	river	0,000035	kg	Undefined			
DOC, Dissolved Organic Carbon	river	0,000035	kg	Undefined			
COD, Chemical Oxygen Demand	river	0,000094	kg	Undefined			
Water, Europe without Switzerland	river	2,13E-06	m3	Undefined			
Emissions to soil							
Final waste flows							
Non material emissions							
Social issues							
Economic issues							
Waste to treatment							
Municipal solid waste {RoW}| market for | Alloc Rec, U	0,038	kg	Undefined				
Input parameters							
Calculated parameters							

Glue for paper bag, process crafted using datasets from the Ecoinvent 3.0 database as implemented SimaPro 8

SimaPro 8.2.0.0	process	Date:	2016-12-15	Time:	12:10
Project	PaperVsPlasticB				
Process					
Category type	Material				
Process identifier	KTH03518000038168400003				
Type					
Process name					
Status					
Time period	2010 and after				
Geography	Europe, Western				
Technology	Unspecified				
Representativeness	Unspecified				
Multiple output allocation	Unspecified				
Substitution allocation	Unspecified				
Cut off rules	Unspecified				
Capital goods	Unspecified				
Boundary with nature	Unspecified				
Infrastructure	No				
Date	2016-11-30				
Record					
Generator					

External documents					
Literature references					
Collection method					
Data treatment					
Verification					
Comment					
Allocation rules					
System description					
Products					
Paper Bag Glue. Market	1	kg	100	not define d	Chemicals\Othe rs
Avoided products					
Resources					
Materials/fuels					
Styrene-acrylonitrile copolymer {GLO}| market for | Alloc Rec, U	0,32	kg	Undefine d		
Phenolic resin {GLO}| market for | Alloc Rec, U	0,48	kg	Undefine d		
Paraffin {GLO}| market for | Alloc Rec, U	0,2	kg	Undefine d		
Transport, freight, sea, transoceanic ship {GLO}| market for |	20	tkm	Undefine		

Alloc Rec, U			d		
Electricity/heat					
Steam, in chemical industry {RER}| production | Alloc Rec, U	0,42	kg	Undefine d		
Electricity, medium voltage {SE}| market for | Alloc Rec, U	0,25	kWh	Undefine d		
Emissions to air					
Emissions to water					
Emissions to soil					
Final waste flows					
Non material emissions					
Social issues					
Economic issues					
Waste to treatment					
Municipal solid waste {DK}| treatment of, incineration | Alloc Rec, U	0,26	kg	Undefine d		
Input parameters					

Calculated parameters						