Life cycle assessment

A comparative LCA of cermic cups and disposal paper cups

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Abstract

Sweden is one of the largest coffee consuming countries in the world and a lot of this coffee is devoured at a work place. The coffee is served in either a ceramic cup or a disposable paper cup. For a company interested in lowering its environmental impact it could be of interest to know which option is to prefer. The goal of this study is to determine if a disposable paper cup or a ceramic cup is the most environmentally sound option for serving coffee. The study is a comparative accounting LCA based on the ISO 14040**.** The functional unit was chosen to be 2070 servings of coffee.

The two alternatives were evaluated in the program SimaPro. In the assessment, the environmental impacts from a ceramic cup and a paper cup were defined, calculated and compared. The focus was on the complete life cycle of the cups, from material extraction to waste management. The study showed that a ceramic cup is the most environmentally sound option as long as it is used more than ten times. It is in the use phase the ceramic cup has the largest impact. For the paper cup it is the production stage that is the most significant one.

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1 Goal and scope

In this chapter the aims and objectives of the study is presented. It also includes a short background, system borders, and methodology of the study.

1.1 Background

Sweden has the second largest coffee consumption per person in the world (Svensk Kaffeinformation, 2011), and a coffee machine can be found in almost every workplace. The most common way of serving coffee is either in a ceramic cup or a paper cup. The ceramic cup needs to be cleaned after every use, either by hand or in a dish washer. This results in energy and water input which is avoided if a paper cup is chosen. On the other hand, the paper cup is thrown in the trash after every use and increases the total waste volume. Both alternatives have clear drawbacks and advantages, so in an everyday situation – which alternative would be the best from an environmental point of view?

1.2 Goal of study

For a company that are interested in lowering their environmental impact it can be of interest to know which alternative that is to be preferred – ceramic cups or paper cups. This question can be answered by performing a life cycle assessment (LCA) of the two options and thereby mapping and comparing the environmental impacts of the two different cups from cradle to grave.

The goal of this study is to determine if a disposable paper cup or a ceramic cup is the most environmentally sound option for serving coffee. Based on the ISO 14040, a comparative accounting LCA is performed by:

- Setting up the goal, scope and system boundaries
- Creating a life cycle inventory for disposable and ceramic cups
- Perform an impact assessment of the two
- Interpreting the results of the LCA

The LCA is of comparative nature and intended to account for the two options environmental impact. The LCA is primarily intended for company managers responsible for internal purchasing decision but can also be of interested to anyone with a general interest in improving their environmental performance, for example employees in the workplace who makes the choice between paper cups and ceramic cups every day.

1.2.1 Product definition

Both the paper cup and the ceramic cup are used in a workplace in Solna, Stockholm. The ceramic cup is washed after use in a dish washer on site and the paper cup is thrown in the garbage.

Ceramic cup

The ceramic cup (see Figure 1) in this study is similar to the cup Färgrik from the IKEA ceramic selection. The studied cup and Färgrik share the same physical properties, for example weight and size. The cup is made of stoneware, which is a non-transparent ceramic material made of clay, feldspar and quarts. The glazing consists of 75 % silica and additional chemical substances such as Na_2O and CaO (Burleson, 2003)

The cup is produced in Gullin, China and transported to Stockholm for distribution. The dish washer installed on the workplace is an Electrolux ESF66814XR (Electrolux, 2011). The detergent is assumed share the same chemical properties as Yes power drops (Procter & Gamble, 2004).

Figure 1. The cup Färgrik from IKEA (IKEA,2011)

Paper cup

The paper cup (see Figure 2) is of a generic model. It is produced in the integrated pulp and paper mill Korsnäs outside of the Swedish municipality Gävle.

Figure 2: Paper cup (Sörmlinds, 2011)

1.2 Functional unit

The function of both the ceramic and paper cup is holding coffee during serving; the functional unit will for that reason be servings of coffee. We assume one person drink three cups of coffee a day every work day, working days are 230 per year and a ceramic cup is used for 3 years. This gives 2070 servings per ceramic cup, the disposable cups are assumed to be used only once. Our functional unit will therefore be 2070 servings of coffee. The sensitivity of the LCA can be checked by analyzing differences that appear when the amount of servings is changed.

1.3 System boundaries

This LCA includes the environmental impacts from cradle to grave. It will account for the environmental impacts of extracting the cup materials, producing and distributing, usage and finally the waste treatment scenarios. In the paper cup and the ceramic cup life cycle, the cradle is the material extraction - clay mining in the ceramic cup case, respectively wood handling for the paper cup. The "grave" is the waste treatment. Both the paper cup and the ceramic cup are being incinerated in the waste treatment, although the ceramic cup is made of incombustible material and will end up on a landfill in the end. Future impacts from the landfill are included in the assessment.

The amount of packaging material will be roughly approximated, since it can be assumed to be a quite small factor in the complete life cycles. Apart from the limitations mentioned, four categories of limitations have been taken into account. Together these four categories provide the considered limits of the life cycle assessment.

1.3.1 Geographical boundaries

Ceramic cups are assumed to be produced in Gullin in China and the disposables in Gävle, Sweden. Both kinds of cups are assumed to be used at a work place in Stockholm; the end of life is in Stockholm as well at the incineration plant Högdalen.

1.3.2 Time Horizon

The study is based on 690 days usage; there is no time limit for future impacts. Since no specific development of improvements of the processes has been seen, older data can be used in the LCA.

1.3.3 Cut-off criteria

The production of the dish washer is excluded in this product system. Only the emissions linked to the use of the dish washer will be evaluated. The reason is that the production of the dish washer itself has a minor contribution to the total environmental impact of a cup.

The whole chain of distribution is neglected in both the ceramic and the paper case. The reason is that it is assumed that both cups are being sold at the same place and therefore the distribution stage will be identical for both cups. Since it is a comparative study this stage can be neglected.

1.3.4 Allocation procedures

The allocation problem in the systems arises in different ways and is also solved with two different methods – system expansion and partitioning.

Paper cup

Energy is recovered in the incineration of the paper cup. This allocation problem is handled by system expansion. The energy recovered from the incineration is presumed to replace residential heat production from biomass (wood/pellets). The positive energy input will be subtracted from the energy consumption in the production phase.

Ceramic cup

Regarding the ceramic cup, there is another type of allocation problem which is resolved with partitioning. The problem arises in the use phase, when the cup is cleaned in the dish washer. Since there are a lot of other potteries dished at the same time, the water consumption and energy demand needs to be allocated in order to find the water and energy need for one single cup.

The used dishwasher is an Electrolux ESF66814XR. Given data is energy demand and water use for one dish. The dish washer has room for 12 IEC dinner-sets, and 1/5 of the set is cups. In order to get requirements for one cup, the amount of water is first divided by 5 and then by 12. (Electrolux, 2011)

1.4 Assumptions and limitations

Both the material extraction and the production of the ceramic cup are assumed to take place in Gullin, China. Since the cup is comparable to the IKEA-cup Färgrik, we have chosen Gullin as IKEAs suppliers have similar extraction and production in that area. The paper cup´s material extraction and production are assumed to take place in Gävle, Sweden, at the pulp and paper mill Korsnäs. A majority of the threes used in the paper production comes from Sweden. (Korsnäs, 2010)

Neither the production nor the waste scenario is assumed to have recycling of paper. Due to sanitary and health reasons, recycled paper is forbidden when producing cups. (SLV, 2011) In both scenarios it is assumed that Swedish municipal waste treatment is used. Also assumed is that both the ceramic and paper cup are thrown with the household waste after usage and thereby is being incinerated in the municipal waste treatment. The residues from incineration are sent to landfill. All of this waste treatment is assumed to take place in Högdalen combined heat and power plant in Stockholm. Since the LCA will be not change oriented, average data will be used in all cases.

1.5 Impact categories and impacts assessment methods

The LCA will be performed with SimaPro, a program that will give the results in a long list of inventory. In order to interpret the results, an impact assessment method will be used. In this case the ReCiPe Midpoint (Hierarchist) assessment tool is used. (LCIA-ReCiPe, 2010) This method uses eighteen indicators which together summarizes the environmental impact of the inventory results in the LCA. Compared to using endpoint indicators, this method provides more certain and robust results.

The midpoint indicators are (1) climate change, (2) ozone depletion, (3) human toxicity, (4) photochemical oxidation, (5) particulate matter formation, (6) ionising radiation, (7) terrestrial acidification, (8) freshwater eutrophication, (9) marine eutrophication, (10) terrestrial ecotoxicity, (11) freshwater ecotoxicity, (12) marine ecotoxicity, (13) agricultural occupation, (14) urban land occupation, (15) natural land transformation, (16) water depletion, (17) metal depletion and (18) fossil depletion.

Cumulative Energy Demand (CED) is another impact assessment method chosen to be considered in the study in order to complement Recipe. The argument for making this choice is that the data for energy demand is the most accurate and detailed data in the model, It also provides a good basis for the sensitivity analysis where the breaking point between the studied products are analyzed. CED calculates the primary energy sources, thus providing an overarching picture of the energy consumption of the different cups. The CED is assessed by the Single-issue impact method. Single issue is based on a methodology by Ecoinvent version 2.0 and is used to compare energy use in the studied processes to get a more comprehensive view of the environmental impacts (Earth Shift, 2011).

1.6 Normalisation and weighting

Normalisation is used in the impact assessment as a way of linking the characterised results to a reference value. The goal with a normalisation is to reach a deeper understanding of the magnitude of the environmental impacts caused by the system under study. (Baumann and Tillman, 200

In this study, the method in ReCiPe Midpoint (Hierarchist) was used to compare the environmental loads from both the ceramic cup and the paper cup. The normalization also shows which indicators have the largest significance for the studied systems. Since the usage of the cups is assumed to be in Sweden the European normalization method in Recipe was used.

Weighting is not included in the study.

2. Life cycle inventory analysis

In this chapter the life cycles of the cups are illustrated in flow charts. Their input and output data are presented, as well as the calculations made from the assumptions.

2.1 Process flowchart - paper cup

Figure 3 illustrates the life cycle of the paper cup and all the processes connected to the product. It also shows which processes related to the product, but not taken into consideration. The slightly transparent parts in the red square are not considered.

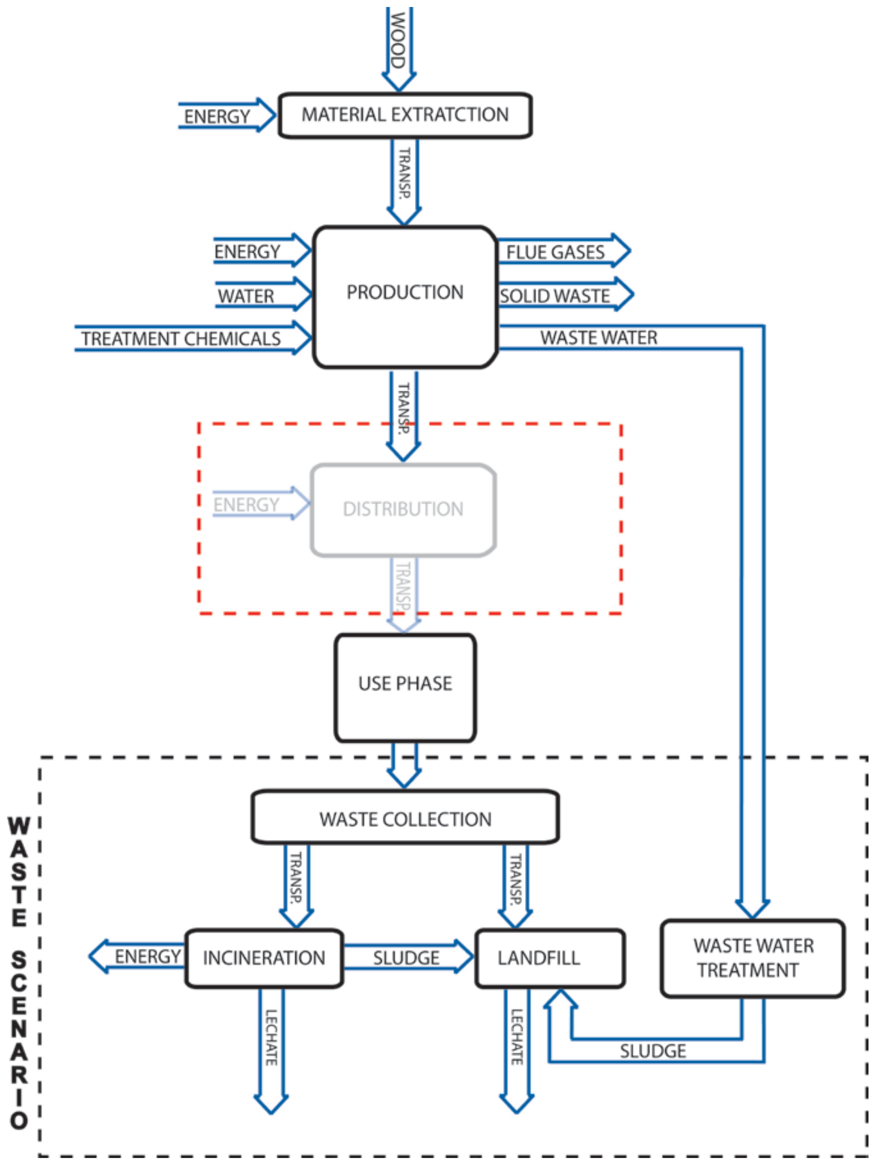


Figure 3: Flow chart displaying flows in the life cycle of a paper cup

The use phase was included in the process but has no environmental impact. The distribution was seen to be identical for the two studied products and would therefore have no impact on the result when performing a comparative life cycle assessment.

Figure 4 shows the same life cycle as above, but in this case demonstrated in a SimaPro model

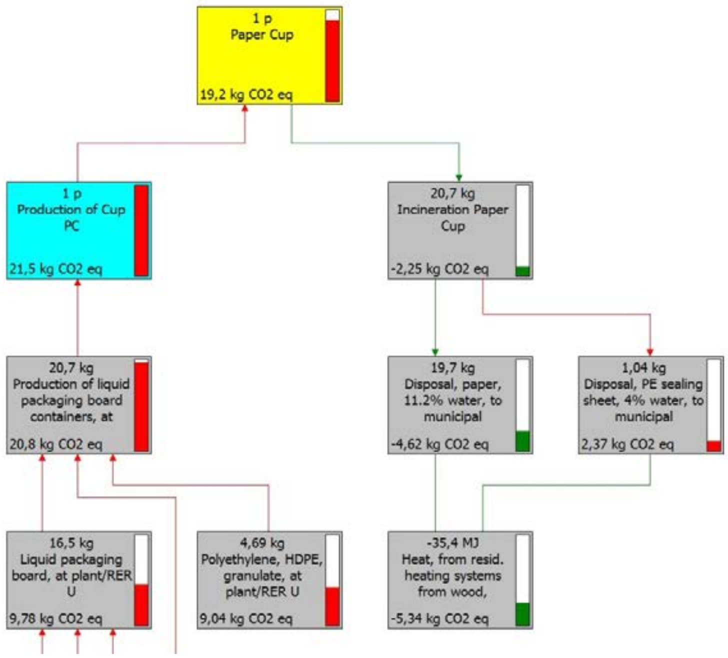


Figure 4: Flow chart displaying flows in the life cycle of a paper cup from SimaPro

2.2 Process flowchart - ceramic cup

In the same way, the ceramic cup life cycle is presented in Figure 5. The production of the dish washer is not included in the assessment, which is illustrated in the flow chart. As in the paper cup flow chart, distribution is not considered.

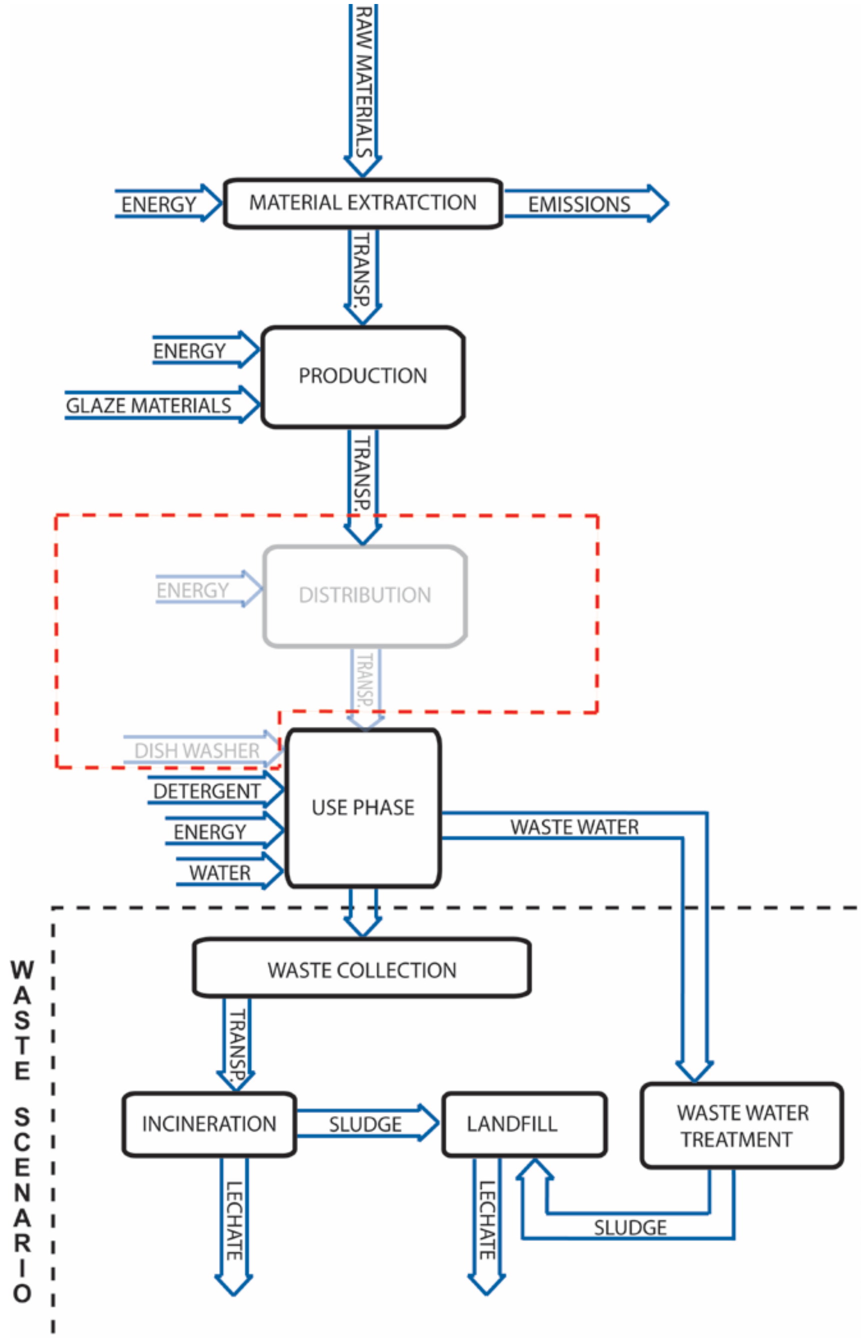


Figure 5: Flow chart displaying flows in the life cycle of a ceramic cup

Figure 6 also shows the life cycle of the ceramic cup, here illustrated in SimaPro.

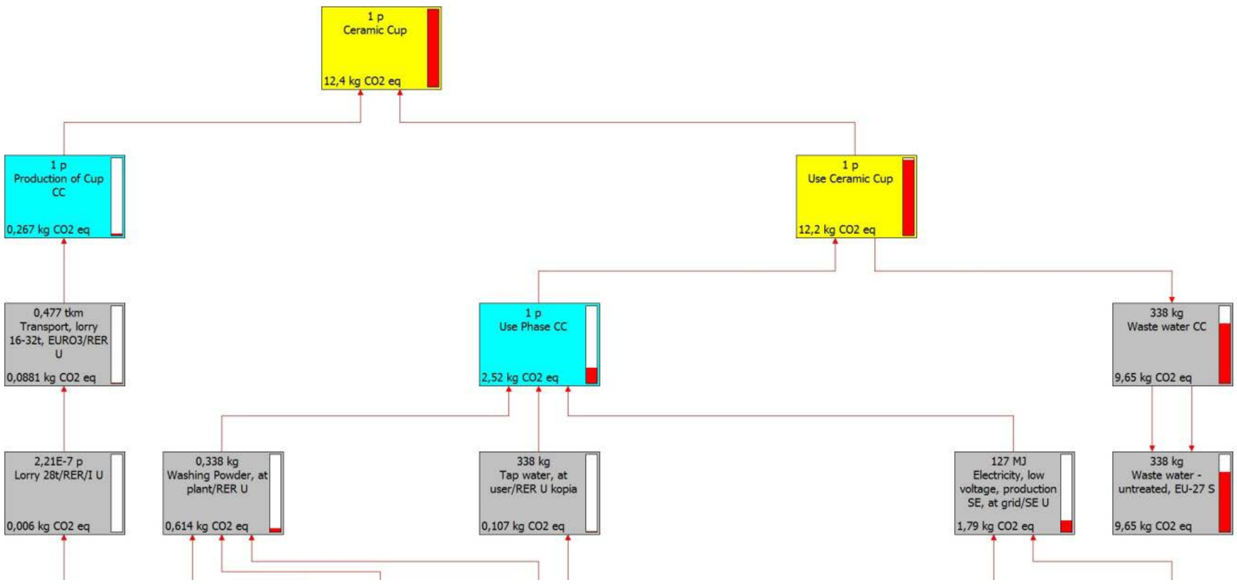


Figure 6: Flow chart displaying flows in the life cycle of a ceramic cup from SimaPro

2.3 Data

The used data mostly originates from databases in SimaPro and product information data sheets. All data has been accessed through Ecoinvent v 2.2, as implemented in SimaPro 7.2.4 unless stated otherwise.

2.3.1 Data for paper cup

The following is a compiled list of inputs and outputs used when modelling the paper cup in SimaPro.

One standard size paper cup weighs 0.01 kg. Since the functional unit is 2070 servings the paper cups will have a total weight of:

$0.01 \cdot 2070 = 20.7$ kg

The material extraction for the paper cup is included in the assembly, finishing and packaging stage. For producing the paper cups 20.7 kg of assembly "production of liquid packaging board containers, at plant/RER U MOD SWE cup" is used. This process includes the raw material extraction as well as laminating, cutting, folding and printing the cups. It is based on the assembly "production of liquid packaging board containers, at plant/RER U and has been modified to better suit Swedish conditions. Changes are made in the electricity production and also aluminium has been exclude since the chosen paper cup does not contain a layer of aluminium foil. The following inputs are used in the process per produced kg of the above-mentioned assembly:

Input	**Amount**	**Unit**
Water, unspecified natural origin	0.000571	m^3
Solvents, organic, unspecified, at plant/GLO U	0.0022	kg
Electricity, medium voltage production SE, at grid/SE/U	0.0004	kWh
Natural gas, burned in industrial furnace >100kW/RER U	0.477	MJ
Heavy fuel oil, burned in industrial furnace 1MW, non-modulating/RER U	0.165	MJ
Printing colour, offset, 47.5% solvent, at plant/RER U	0.0045	kg
Liquid Packaging board, at plant/RER U	0.795	kg
Packaging box production unit/RER/I U	0.0000000014	p
Polyethylene, HDPE, granulate, at plant/RER U	0.226	kg
Transport, Lorry >16t, fleet average/RER U	0.15	tkm

All of the above mentioned inputs have been accessed through Ecoinvent v 2.2, as implemented in SimaPro 7.2.4.

Emissions	Amount	Unit
Heat, waste	0.00144	MJ
Methane, bromotrifluoro-, Halon 1301	0.000000485	kg
Methane, trichlorofluoro-, CFC-11	0.000000485	kg
NMVOC non-methane volatile organic compounds, unspecific	0,00104	kg

Added to the production/material extraction stage above is the transport from Korsnäs where the paper cups are produced to Nacka where they are distributed. This transport has the following input:

Input	Amount	Unit
Operation, Lorry 16-32t, EURO3/RER U	189	km

This input has been accessed through Ecoinvent v 2.2, as implemented in SimaPro 7.2.4.

Since the energy for distributing the products and transport from Nacka to the office where the cups are used is equal for ceramic and paper cups, these inputs has been excluded from the LCA. There are no inputs to the usage of the paper cups. After usage the paper cups are thrown in the household waste and being sent to the waste treatment for incineration. The transportation from the office in Solna to the waste treatment in Högdalen is assumed to be 0.0146 tkm. The following data has been used:

Input	Amount	Unit
Disposal, paper, 11.2% water, to municipal incineration/CH S	95	%
Disposal, PE sealing sheet, 4% water, to municipal incineration/CH S	5	%
Disposal, ash paper prod. Sludge 0% water, to res. material landfill/CH U	100	%
Transport, municipal waste collection, lorry 21t/CH U	0.0146	tkm

All of the above mentioned inputs have been accessed through Ecoinvent v 2.2, as implemented in SimaPro 7.2.4.

When the paper is incinerated, energy is produced. This allocation problem can be solved by system expansion in order to calculate the avoided burdens. In this case it is assumed that the heat produced by incineration of the paper cups can replace heat production from biomass (wood/pellets) since 41 % of the small houses in Sweden is heated with biomass

(Energimyndigheten,2011) The paper cups have a heat value of approximately 0.4 kWh/kg (OVAM, 2006). This can be added as an output to the incineration and one can thereby account for the avoided burdens by using the following information:

Avoided products	**Amount**	**Unit**
Heat, from resid, heating systems from wood, consumption mix, at customer temperature of 70 C E-27S	0.4	kWh

This avoided product has been accessed through European Life Cycle Database (ELCD) v2.0, as implemented in SimaPro 7.2.4.

2.3.2 Data for ceramic cup

The functional unit of the LCA is 2070 servings, it is assumed that only one cup is used and the weight of this cup is 0.3 kg (IKEA, 2011). The materials used to make the cup are clay and glazing. There are no existing data set in SimaPro for production of ceramic cups hence a number of assumptions regarding the manufacturing have been made. The assembly Ceramics, at plant is being used and additional processes are added to it to better represent the production of ceramic cups. The processes that are being added is energy used when burning the clay, silica sand for glazing, transport from mine to ceramic plant and the construction of the plant.

The production of the cup demands 53.2 kJ of energy, based on production in England (Hocking, 2006). The source of energy is replaced to match Chinese energy consumption which is 66.1% coal, 20.5% oil, 5.3% natural gas, 0.9% nuclear power, 6.8% Hydropower and 0.4% other renewable energy (Reuters, 2010). The amount of energy consumed is however assumed to be the same as in England. The following inputs include raw material extraction and production of the 1 kg ceramic cups (approximately 3 cups):

Input	**Amount**	**Unit**
Clay, unspecified, in the ground	1	kg
Occupation, mineral extraction site	0.000167	m^2a
Transformation, form unknown	0.0000167	m^2
Transformation, to mineral extraction site	0.0000167	m^2
Transformation, to unknown	0.0000167	m^2
Diesel, burned in building machine/GLO U	0.0297	MJ
Re cultivation, bauxite mine/GLO U	0.0000167	m^2
Silica sand, at plant/DE U	0.05 kg	kg
Electricity, production mix CN/kWh/CN	0.014777778	kWh

In the production there is also some transport from the clay mine to the factory:

Transport, lorry>16 fleet average/RER U	0.01	tkm

Based on the environmental impacts of a ceramic plant that produces 50 000 products annually for 50 years the share of one ceramic cup in this plant is:

1/(50 000·50) = 0.0000004

The input from the ceramic plant is therefore:

Input	**Amount**	**Unit**
Ceramic plant/CH/I U	0,0000004	p

When the ceramic cup has been produced, it is transported from Guilin in China to the distributer in Nacka, Sweden. The cup takes the following route: first of it is transported 1.525 tkm by truck from Guilin to Shanghai. It is then shipped 22.224 tkm from the port of Shanghai to the port of Rotterdam. From there it is transported by truck for 1.590 tkm to central storage in Västerås and from there by truck for 0.117 tkm to the distribution in Nacka. Based on this rout, the following transportation inputs are added to the process:

Input	**Amount**	**Unit**
Transport, lorry>16t, fleet average/RER U	1.525	tkm
Container ship ocean, tech. mix, 27.500 dwt pay load capacity RER S	22.224	tkm
Transport, lorry 16-32t, EURO 3/RER U	1.590	tkm
Transport, lorry>16t, fleet average/RER U	0.117	tkm

As previous mentioned, the energy for distributing the products and transport from Nacka to the office where the cups are used is equal for ceramic and paper cups, these inputs has therefore been excluded from the LCA. Since only one ceramic cup is used, it has to be washed 2070 times during the use phase. An allocation problem occurs since the coffee cups cannot be accounted for all of the usage, this is solved by partioning. For one wash, 9.8 l of water, 9.8 g of washing powder and 1.02 kWh of electricity is being used (Electrolux, 2011). The dishwasher takes 12 IEC dinner sets, where one fifth is assumed to be ceramic cups. One coffee cup is therefore assumed to account for 1/60 part of the dishwashing. During the cups lifecycle these figures gives the following information on the cups usage:

(9.8·2070)/60= 338.1 kg of water per life cycle

(0.0098·2070)/60= 0.3381 kg of washing powder per life cycle

(1.02·2070)/60= 35,19 kWh of electricity per life cycle

The following inputs have been used:

Input	Amount	Unit
Tap water, at user/RER U	338.1	kg
Electricity, low voltage, production SE, at grid/SE U	35.19	kWh

No washing powder existed in the databases of SimaPro and has therefore been constructed as new material data. The washing powder shares the chemical properties with Yes power drops (Procter & Gamble, 2004). Based on the following figures and assumptions the washing powder has been constructed. The complete flowchart can be found in Appendix 1. In order to build a model of the washing powder, the concentration of the components was used. The concentrations were found in the data sheet from Procter & Gamble (2004). The washing powder consists of:

Common name	Amount	Unit
Alcohols	1 – 5	%
Sodium Carbonate	10 - 20	%
Sodium Percarbonate	5 - 10	%
Sodium Silicate	5 - 10	%

This gives the following inputs/kg produced washing powder:

Input	Amount	Unit
Water, cooling, unspecified natural origin/m3	0.0000517	m^3
Water, unspecified natural origin/m3	0.00102	m^3
Sodium silicate, hydrothermal liquor, 48% in H20, at plant/RER U	0.35	kg
Sodium carbonate from ammonium chloride production, at plant/GLO U	0.75	kg
Chemicals organic, at plant/GLO U	0.0000862	kg
Electricity, medium voltage production UCTE, at grid/UCTE U	0.135	kWh
Heat, natural gas, at industrial furnace > 100kW/RER U	1.03	MJ
Steam, For Chemical processes, at plant/RER U	0.384	kg
Chemical plant, organics/RER/I U	0.0000000004	p
Transport, Freight, rail/RER U	0.649	tkm
Transport, lorry>16t, fleet average/RER U	0.108	tkm

Ethoxylated alcohols, unspecified, at plant/RER U 0.175 kg

3. Life cycle interpretation

This chapter gives an overview of the paper- and ceramic cup's environmental consequences by presenting characterised environmental impacts of the life cycle inventory. The relevant impact categories will be analysed further in order to identify significant impacts and stages of the lifecycle. By comparing the studied alternatives, important differences in the life cycle can be identified. This will provide the basis for discussion that will lead up to the conclusions.

3.1 Results

In order to interpret the results, ReCiPe Midpoint (Hierarchist) is used. Figure 7 presents the overall picture of the environmental impacts (a larger picture can be seen in Appendix 2). In this picture the green bars represent the paper cup and the red bars represent the ceramic cup. The figure shows that paper cups generally have a larger environmental impact compared to a ceramic cup.

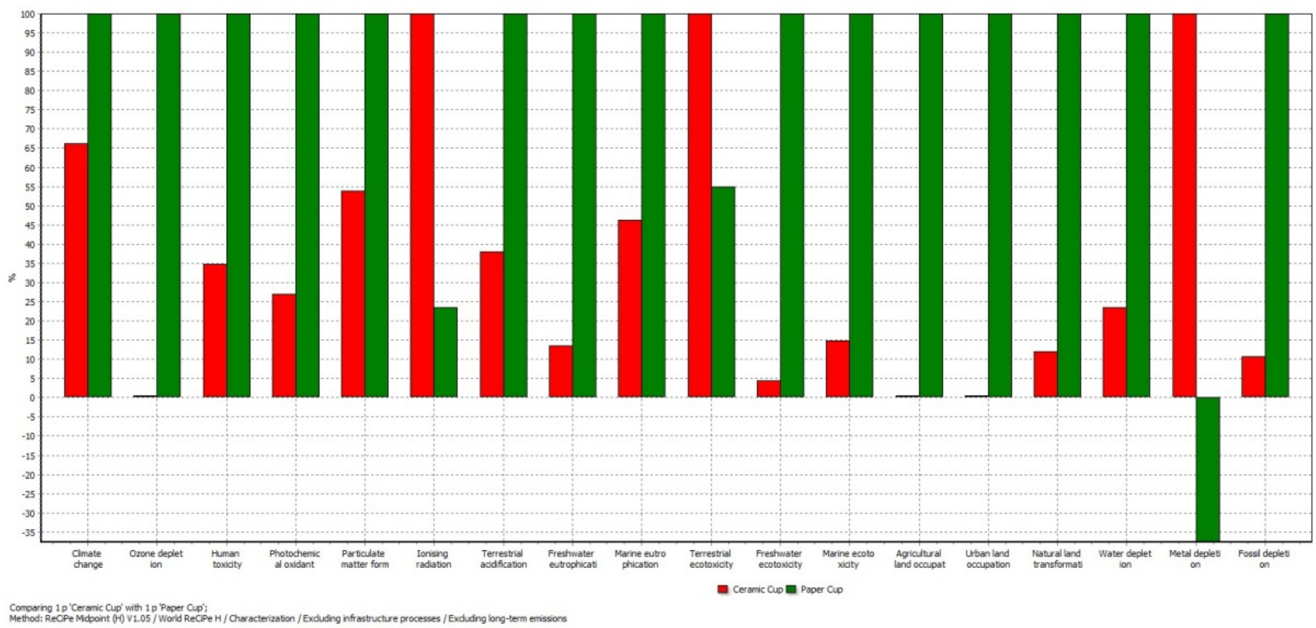


Figure 7. Chart displaying the characterised impacts of the life cycles of paper cup and ceramics cup

The results are normalised in order to identify the most significant impacts of the system, see Appendix 3. The impact categories that have one bar over 0.01 are chosen to be further analysed. This results in three categories which are displayed in Figure 8; human toxicity, freshwater ecotoxicity and agricultural land occupation.

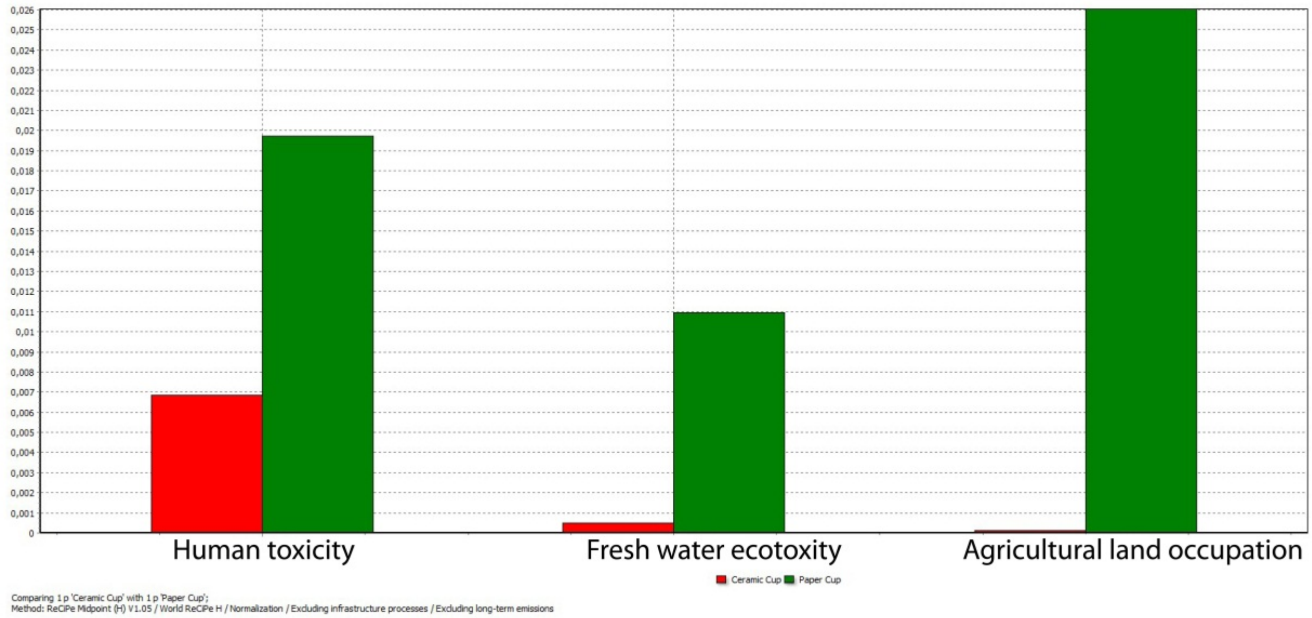


Figure 8. Normalised impacts of human toxicity, freshwater ecotoxicity and agricultural land occupation.

If human toxicity and fresh water ecotoxicity is analysed further one can trace the causes of the high normalisation values. Manganese is one major substance that has a large impact on the human toxicity as well as the fresh water ecotoxicity. This substance exists in the production stage of the process and can be traced back to construction of the plants where the paper and ceramics cups are produced. It is however significantly larger for the paper cup. Apart from this substance there are several other that are worth mentioning in the subject. For human toxicity Arsenic, Barium and Selenium also has a high influence. For water toxicity Nickel, Phosphorus and Vanadium has high influence. These mainly exist within the paper cup production and the production of paper and pulp.

Regarding the agricultural land occupation, there is a vast difference between the ceramic and paper cup. This can be traced back to the production of the pulp. Producing paper demands large amounts of cellulose, which is extracted from trees. The land use is basically the occupational area of the wood devastation.

In addition to these three impact categories, cumulative energy demand is used to compare the energy used in the processes in order to provide a comparative and comprehensive picture of the environmental impacts, see Figure 9 (Earth Shift, 2011). By studying this figure it is clear that the paper cup has a significantly larger energy demand, this in spite of the energy production during incineration.

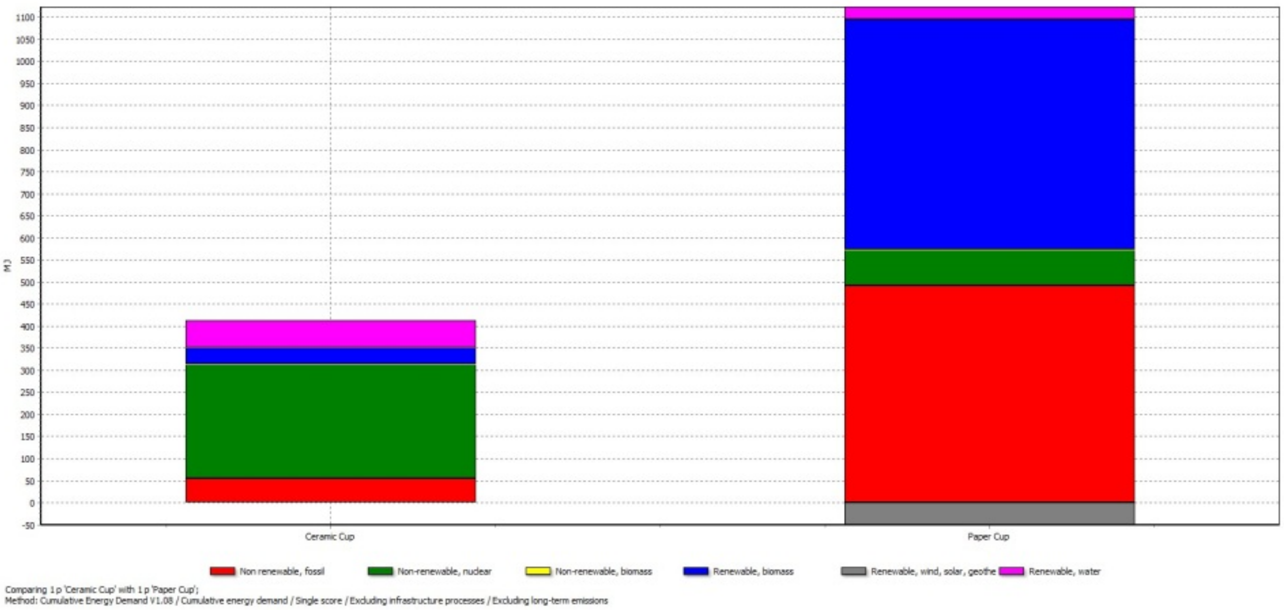


Figure 9. Energy demand of Ceramic (left) and paper cup (right)

A large part of the energy consumed by the paper cup is biomass (blue field). This is can be traced to the production of the paper, the wood inputs consists of large amounts of potential energy that is not used. The Fossil fuels (red field) consists of the second largest energy consuming area. This can be traced to the plastic coating of the paper cup which is based on fossil fuels and crude oil for production. Some of it can also be traced to the transport of the of the paper cups from Korsnäs to Stockholm. If looking at the Ceramic cup, the largest energy consumption is nuclear electricity (green field). This can be traced to the usage phase of the cup, which can be accounted for a majority of the energy consumption.

There are several significant differences in the energy balances of the two different life cycles. Due to the functional unit the life cycle of the paper cup consumes more energy than the life cycle of the ceramic cup. The affect can be seen in all stages of the life cycles.

To analyze what stage of the products life cycle that has the largest impact cumulative energy demand is used to assess the impacts for the different stages in the SimaPro flow chart model. Cumulative energy demand is used for the same reasons that are stated previously. The results are shown in Figure 10 and 11 below.

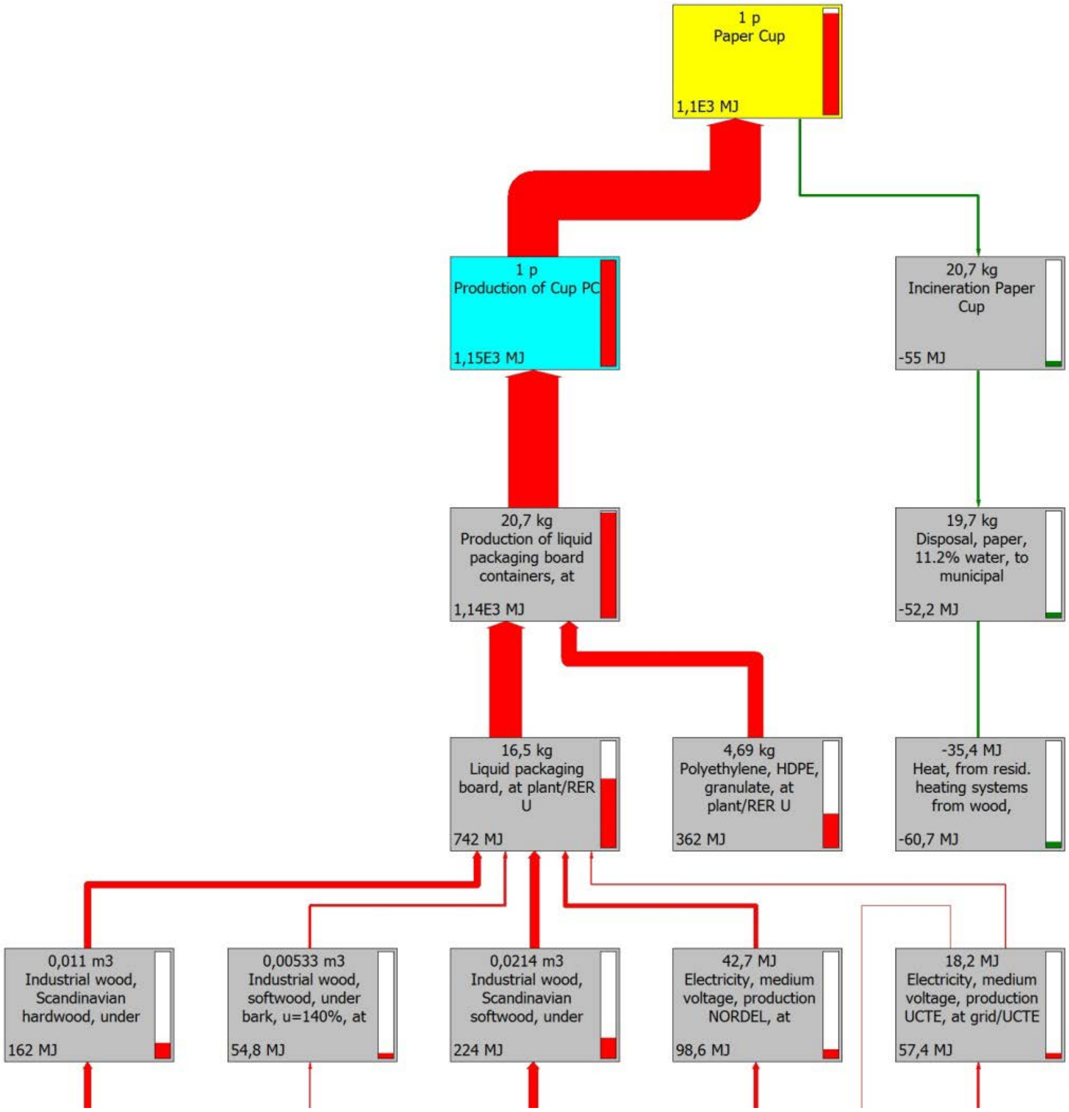


Figure 10. Cumulative energy demand for different stages in the paper cup life cycle

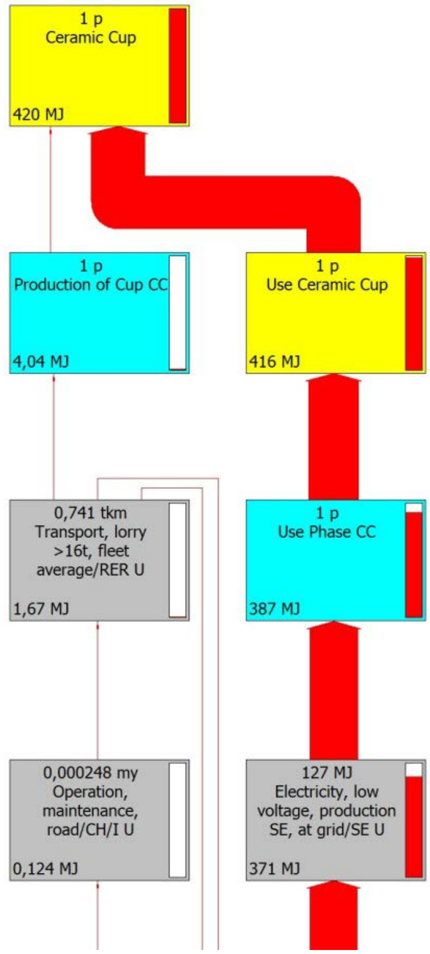


Figure 11. *Cumulative energy demand for different stages in the ceramic cup life cycle*

As can be observed the largest impact from the ceramic cup is from the use phase. This is primarily due to the energy and water use when washing the cup. For the paper cup it is the production phase that is the most dominate one. This is explained by the fact that the production of pulp and paper is a very energy and water intensive process. Also the paper cup does not consume any energy in its use phase.

Another significant observation that can be done in the differences between the two life cycles is found in the waste scenarios. In this stage the paper cup cancels other energy production by providing energy from its incineration to district heating while the ceramic cup does not.

3.2 Sensitivity analysis

When the number of servings of coffee is reduced the impact from the use phase will gradually become less significant for the ceramic cup. At this stage the production and transport will be the most dominate one. Since the paper cup is not affected to the same extent by reducing the number of servings it is reasonable to believe that there exists a point at which the impact from the paper cup is equal to that of the ceramic cup.

To find this point the number of servings of coffee, i.e. the functional unit, is gradually reduced in the model. Through this iterative process the point of break-even can be determinate. The impact category chosen for this comparison is cumulative energy demand. The reason for this is that the data on energy consumption is the most accurate of all the data in the model. Energy demand is also a category which is sensitive to change in input. In addition a single impact category comparison is necessary to find a single point of break-even.

According to the analysis the point of break-even occurs for ten (10) servings of coffee. The resulting energy demand at this point is presented in Figure 12 below.

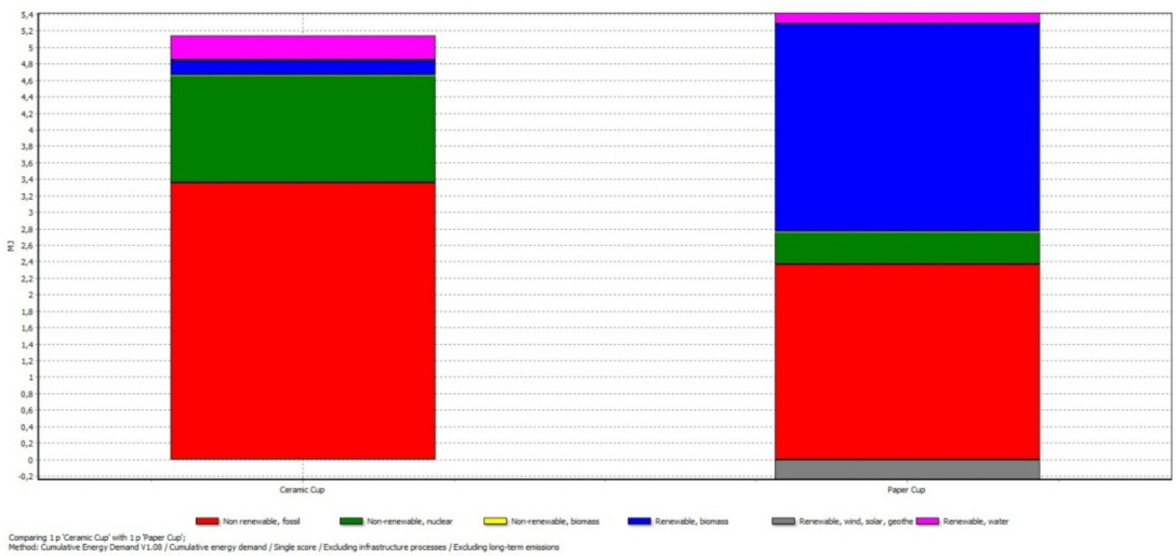


Figure 12: Resulting energy demand at ten servings

Note that the paper includes the avoided burdens from energy production through incineration which needs to be deducted in order to have a fair comparison. If this is done the two bars will be approximately equal. This result shows that if more than ten cups of coffee is to be served it is energy-wise more beneficial to use a ceramic cup.

3.3 Conclusions and recommendations

The study shows that a ceramic cup is the most environmentally sound option for serving coffee in an office environment. The sensitivity analysis shows that this is true as long as the ceramic cup is used more than ten times. It is in the use phase the ceramic cup has the largest impact. For the paper cup, the production stage that is the most significant phase.

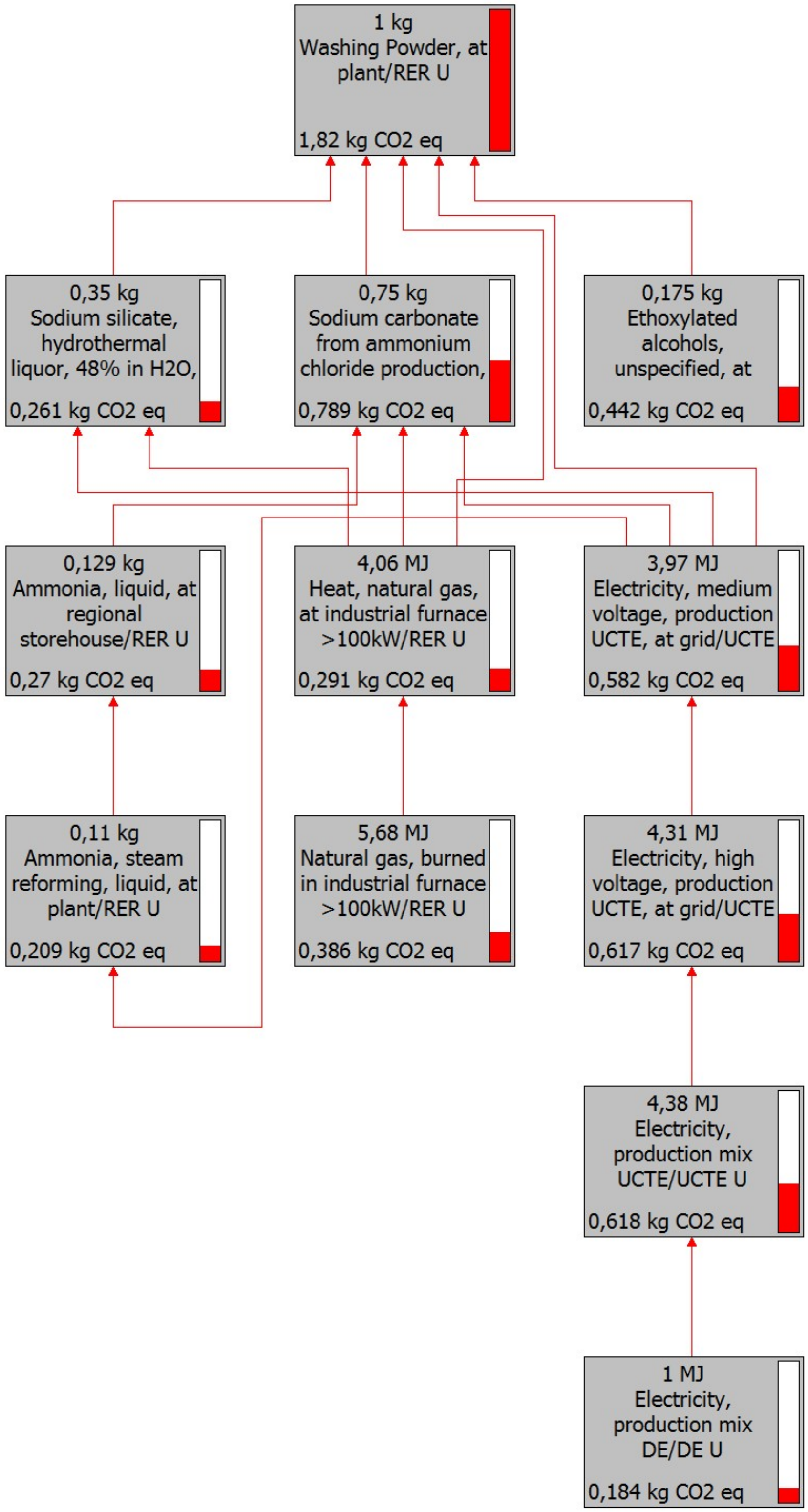
The fact that the manufacturing and transport had such a small significance for the result of the ceramic cup came as somewhat of a surprise, especially since the ceramic cup is being transported from China. However, if examined closer it quite clear that it is a natural consequence of the fact that the use phase is of such great importance. Energy and water used in the washing of the cups proved to be the most important factors affecting the environmental performance.

There are a number of assumptions made that have a large impact on the results, for example the choice of method for washing the ceramic cups. If a less efficient method is chosen, rather than the one used in the study, or if the allocation at this stage is handled differently, this would potentially increase the impact from the ceramic cup. Another assumption that greatly affects the result is the waste management of the paper cup. If the cup is not sent to incineration or if the avoided burdens is calculated differently it would possibly increase the impact of the paper cup. The quality of the data is also an issue has affected the result. Generic data out of standard databases based on European conditions is primarily used which needs to be considered when interpret the results. If more specific data is used the results will be affected.

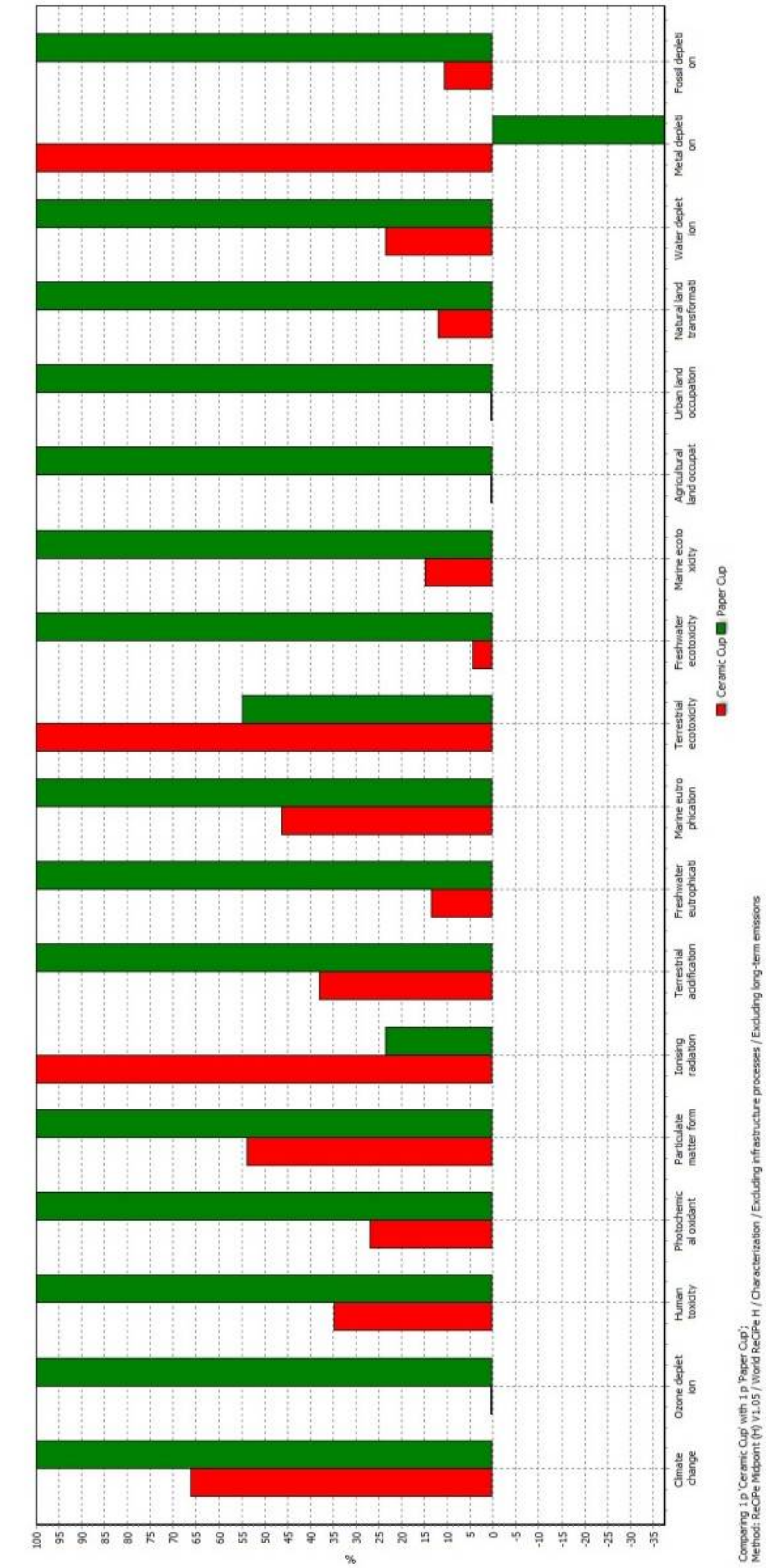
The paper cup has its largest energy demand in the production. Pulp- and paper mill have in general an extremely high energy and water demand and in order to decrease the paper cups environmental impact, production improvements in the paper mill should be made. A strategy to decrease both energy and water is to “close the material and energy loop” in the factory. For example, if the water is recirculated and reused as much as possible, less water goes to water treatment and less energy is needed.

A recommendation to company managers facing the decision of purchasing coffee cups is to opt for ceramic cups. It is however important to point out that the way the cups are being washed is going to be of great importance for the final environmental performance of the cups. It is of substantial significance to choose a method that minimizes water as well as energy use. The purchase of a modern dish washer to accompany the ceramic cups is therefore recommended.

Appendix 1

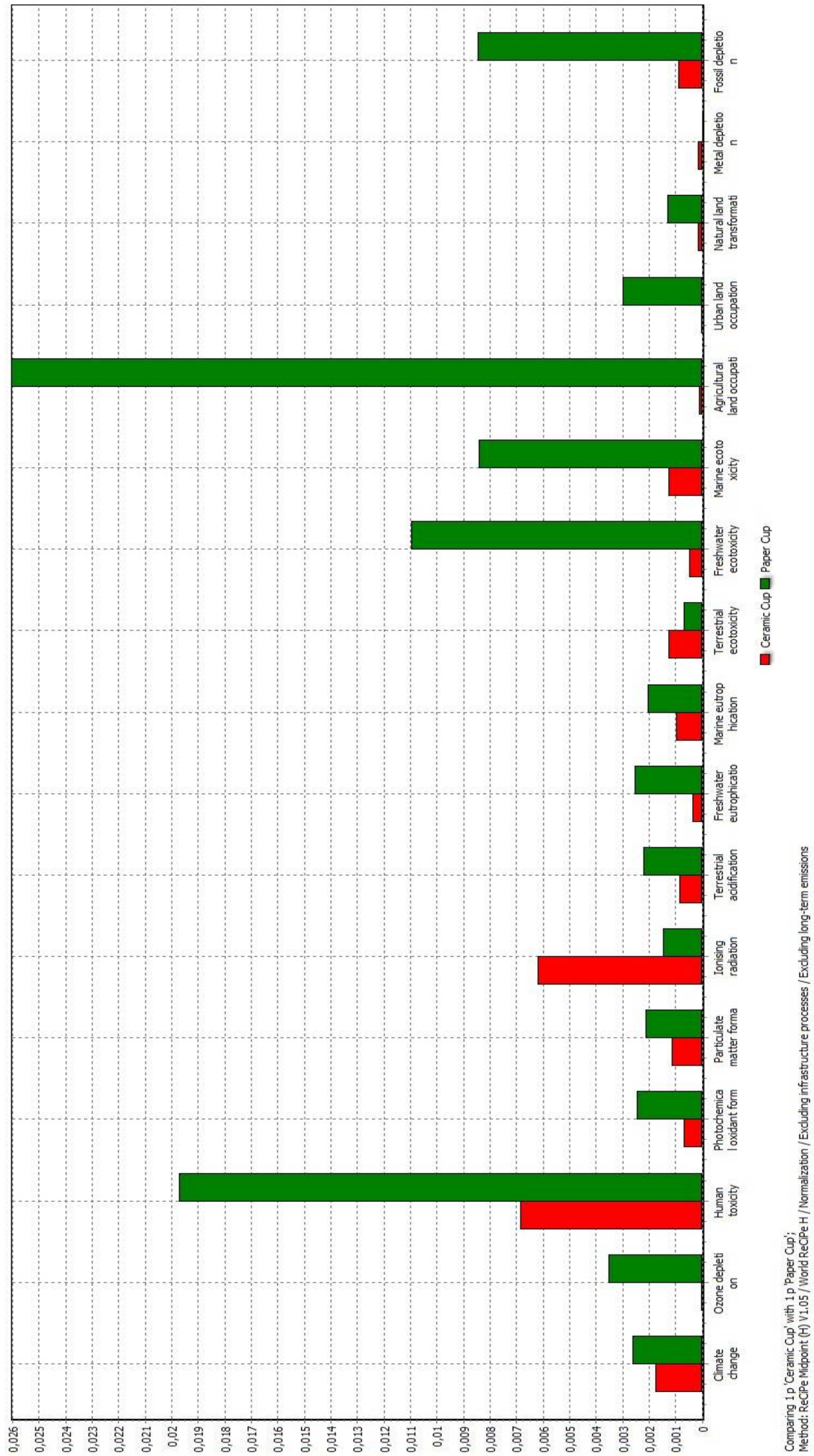

1 kg
Washing Powder, at plant/RER U
1,82 kg CO2 eq
0,35 kg
Sodium silicate, hydrothermal liquor, 48% in H2O,
0,261 kg CO2 eq
0,75 kg
Sodium carbonate from ammonium chloride production,
0,789 kg CO2 eq
0,175 kg
Ethoxylated alcohols, unspecified, at
0,442 kg CO2 eq
0,129 kg
Ammonia, liquid, at regional storehouse/RER U
0,27 kg CO2 eq
4,06 MJ
Heat, natural gas, at industrial furnace >100kW/RER U
0,291 kg CO2 eq
3,97 MJ
Electricity, medium voltage, production UCTE, at grid/UCTE
0,582 kg CO2 eq
0,11 kg
Ammonia, steam reforming, liquid, at plant/RER U
0,209 kg CO2 eq
5,68 MJ
Natural gas, burned in industrial furnace >100kW/RER U
0,386 kg CO2 eq
4,31 MJ
Electricity, high voltage, production UCTE, at grid/UCTE
0,617 kg CO2 eq
4,38 MJ
Electricity, production mix UCTE/UCTE U
0,618 kg CO2 eq
1 MJ
Electricity, production mix DE/DE U
0,184 kg CO2 eq

Appendix 2



100
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
-5
-10
-15
-20
-25
-30
-35
%
Climate change
Ozone deplet ion
Human toxicity
Photochemic al oxidant
Particulate matter form
Ionising radiation
Terrestrial acidification
Freshwater eutrophicati
Marine eutro phication
Terrestrial ecotoxicity
Freshwater ecotoxicity
Marine ecoto xicity
Agricultural land occupat
Urban land occupation
Natural land transformati
Water deplet ion
Metal depleti on
Fossil depleti on
Ceramic Cup
Paper Cup
Comparing 1 p 'Ceramic Cup' with 1 p 'Paper Cup';
Method: ReCiPe Midpoint (H) V1.05 / World ReCiPe H / Characterization / Excluding infrastructure processes / Excluding long-term emissions

Appendix 3


0,026
0,025
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0,023
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0,013
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0,009
0,008
0,007
0,006
0,005
0,004
0,003
0,002
0,001
0
Climate change
Ozone depletion
Human toxicity
Photochemical oxidant form
Particulate matter forma
Ionising radiation
Terrestrial acidification
Freshwater eutrophicatio
Marine eutrophication
Terrestrial ecotoxicity
Freshwater ecotoxicity
Marine ecotoxicity
Agricultural land occupati
Urban land occupation
Natural land transformati
Metal depletion
Fossil depletion
Ceramic Cup
Paper Cup
Comparing 1 p 'Ceramic Cup' with 1 p 'Paper Cup';
Method: ReCiPe Midpoint (H) V1.05 / World ReCiPe H / Normalization / Excluding infrastructure processes / Excluding long-term emissions

References

Baumann, H. & Tillman, A.-M., 2005. The Hitch Hiker's Guide to LCA. An orientation in life cycle assessment methodology and application. s.l.:s.n

Burleson, M., 2003. *The Ceramic Glaze Handbook.* Lark Books. USA.

Electrolux, 2011. *ESF66814XR* [Online]. Available at http://www.electrolux.se/Produkter/Product-details/?pId=20878b51-4b60-4268-a053-22805ebb07cc [accessed 2011-11-12]

Energimyndigheten, 2011. *Biobränslen – ved och pellets* .[Online] Available at http://energimyndigheten.se/sv/Hushall/Din-uppvarmning/Biobransle---ved-och-pellets/ [accessed 2011-11-29]

Earth Shift, 2011. *SimaPro Impact Assessment Methods.* [Online]. Available at http://www.earthshift.com/software/simapro/impact-assessment-methods#ced [accessed 2011-12-01]

Hocking, M.B., 2006. *Reusable and Disposable Cups: An Energy-Based Evaluation*. [pdf] Available at http://www.design4x.com/misc/bus183/handouts/Hocking.SpringerVerlag.Energy%20Use%20of%205%20Different%20Cups.pdf [accessed 2011-11-04]

IKEA,2011. *Färgrik.* [Online] Available at http://www.ikea.com/se/sv/catalog/products/40143993/ [accessed 2011-12-01]

Korsnäs, 2010. *Sustainability report.* [pdf] Available at http://dmweb.v-tab.se/webpages/Korsnas/Sustainability2010.html [accessed 2011-11-30]

LCIA-reCIPE, 2011. *Introduction.* [Online] Available at http://www.lcia-recipe.net/ [accessed 2011-11-04]

Procter & Gamble, 2004. *Säkerhetsdatablad: Yes power drops.* [pdf]. Available at: http://www.dahl.se/vd/909227.pdf [accessed 2011-11-12]

Reuters, 2010. China's NDRC forecasts for energy mix in 2010. [Online] Available at: http://uk.reuters.com/article/2007/04/11/china-energy-reserves-idUKSP24148420070411 [accessed 2011-12-18]

Sörmlinds, 2011. *Pappersmuggar*. [Online] Available at http://www.sormlinds.se/pappersmuggar.html [accessed 2011-12-01]

Svensk kaffeinformation, 2011. *Statisk.* [Online] Available at http://www.kaffeinformation.se/Statistik2/Kaffekonsumtion-i-Sverige/[accessed 2011-12-01]

SLV,2011. *Returpapper och kartong.* [Online] Available at http://www.slv.se/sv/grupp1/Risker-med-mat/Kemiska-amnen/Forpackningsmaterial/Returpapper-och-kartong/ [accessed 2011-11-15]

OVAM, 2006. *Comparative LCA of 4 types of drinking cups used at events.*[pdf]. Available at http://www.natureworksllc.com/the-ingeo-journey/eco-profile-and-lca/life-cycle-analysis/~/media/The_Ingeo_Journey/EcoProfile_LCA/LCA/OVAM_Cup_ComparativeLCA_FullReport_0206_pdf.pdf [accessed 2011-11-04]