LCA of office coffee drinking

AG2800 Life Cycle Assessment

(Source: Tingstad AB, 2013.)

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Group 4

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Abstract

It is reasonable to assume a daily coffee consumption of at least two cups per office worker, which means an annual consumption of around 500 cups. These numbers makes it plausible to draw the conclusion that offices have the potential of being large consumers of disposable paper cups, if office workers are given the opportunity to drink their coffee in these instead of reusable cups. It is therefore interesting to analyse which of the modes of drinking that has the largest, or lowest, environmental impact - so that offices can be provided with a decision basis that takes into account not only the financial parameters of the drinking containers but also their environmental performance. This comparative LCA study assesses the environmental impacts of two common drinking containers, a porcelain cup and a disposable cup of liquid packaging board, throughout their lifecycles.

The functional unit was based on a reference flow in form of a reasonable lifespan of a porcelain cup, 1000 servings, together with a reasonable average daily consumption of coffee during two working years of an office worker. The functional unit was therefore set to 1000 servings. Both cups were assumed to be manufactured in the same country, shipped to the same retailer where the office is purchasing them. The end of life of the disposable cup was assumed to be 20 percent incineration and 80 percent recycling while landfilling was the end of life-scenario of the porcelain cup. The disposable cup was modelled without a use phase, while the porcelain cup was assumed to be washed in a dishwashing machine once per day.

The life cycle impact modelling was made in the software SimaPro, using the ecoinvent database and ReCiPe Midpoint (H) as impact assessment method. The characterized results imply that the disposable cup has a larger environmental impact than the disposable cup in 13 out of 18 impact categories (climate change, ozone depletion, terrestrial acidification, freshwater eutrophication, marine eutrophication, human toxicity, photochemical oxidant formation, particulate formation, agricultural land occupation, urban land occupation, natural land transformation, metal depletion, and fossil depletion), whilst the porcelain cup the largest environmental impact in five categories (terrestrial ecotoxicity, freshwater ecotoxicity, marine ecotoxicity, ionising radiation, and water depletion). The weighted results furthermore indicated that the most important impact categories are freshwater eutrophication, freshwater ecotoxicity, marine ecotoxicity, agricultural land occupation, and natural land transformation. A sensitivity analysis was conducted, using the end of life phase of the disposable cup and the use phase of the porcelain cup as parameters. The results from this analysis did not change the total outcome of the analysis in any impact category, accept from water depletion.

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1. Introduction

Life cycle assessment (LCA) is a quantifying tool to estimate the environmental impacts of products from the production of raw materials to the final disposal of the product. The purpose of the LCA is to identify possible improvement areas by viewing the environmental hot spots of in the life cycle of a product. Other important properties of the LCA as a tool is that the analysis of the life cycle stages will give results to environmental loads that can be perceived and investigated in order to make improvements to the products or processes (Goedkopp et.al., 2016).

In general there are four main phases used to conduct an LCA, divided in four different steps; the first step is to define the goal and scope of the study, secondly, creating a model of the product life cycle where all the inputs and outputs are displayed, this is done simultaneously as the data collection which is called the Life Cycle Inventory (LCI) in this case. Thirdly, an understanding of the environmental inputs and outputs are relevant in order to create the Life Cycle Inventory Analysis, where basically the results of the life cycle are displayed with diagrams, pictures and figures of the environmental impact categories and normalized results. Last but not least, is the final step, which included the interpretation of the study (Goedkopp et.al., 2016).

LCA as a tool will provide quantitative scientific basis, but performing an LCA requires to use a LCA specific tool. A great example of an LCA tool is SimaPro, the most used LCA software available. A comparative LCA, which is used in this specific case, has its purpose of comparing the products with each other to a final result of which of the products has the largest environmental impact. From these results conclusions can be drawn to what improvements that needs to be done in order to understand where the largest burden are and what can be done to improve the processes or product (Goedkopp et.al., 2016).

2. Goal and Scope

The relevancy of this study, together with the specific aims and objectives, is presented in this section. The boundaries, assumptions and methodology of the study is also presented.

2.1 Background

Disposable coffee cups are used and consumed daily all over the world. Coffee is the second most consumed beverage after water. In the US, Americans use over 25 billion disposable coffee cups every year, which is equivalent to a consumption of 400 million cups of coffee per day or 146 billion cups of coffee per year in total consumption. To put this in reality, it is equivalent to 10,5 kg waste per year if the consumer buy one cup of coffee or tea contained in a disposable cup (Carry Your Cup, 2010).

If we move from the US to UK, the total coffee consumption is over 70 million cups per day, and around 2,5 billion disposable coffee cups are used in the UK each year. A corresponding figure is that over 500 billion cups of coffee are being consumed each year in the world. These figures imply that it is reasonable to assume that the manufacturing of these coffee cups is a large industry, which makes it interesting to investigate its environmental impacts.
This report is therefore based on a comparative LCA of coffee consumption from a disposable coffee cup made of packaging liquid board, compared to a reusable coffee cup made of ceramic material. The reference flow for this comparative LCA is the average lifetime of a porcelain cup together with a likable daily coffee consumption of an office worker during a

two-year period (Pack2Go Europe, 2016). The disposable paper cup and the porcelain cup are shown in Figure 1, both of the products and the pictures are taken from Tingstad AB.

Figure 1, Shows the disposable paper cup together with the porcelain cup taken from Tingstad AB (Tingstad AB, 2013).

2.2 Goal of study

A comparative LCA will be conducted to examine the environmental burden between disposable coffee cups and reusable coffee cup of porcelain. The result from this comparison study will provide result of which coffee cup has the most environmentally damaging impact in the chosen categories examined.

The goal of this study is to assess the environmental impacts from two representatives of the most common types of coffee cups, one being a porcelain cup and the other a disposable coffee cup, in their life cycle. The aim for this is to conduct a comparative LCA, with a cradle-to-grave perspective, on these two coffee cups, from which the results can be used as decision support for company offices with an interest to reduce their environmental load.

3. Scope of the study

This section describes the functional unit, system boundaries, assumptions and limitations, impact categorizes and impact assessment methods and normalisation and weighting.

3.1 Functional Unit

The reference flow used in this study is a qualified assumption of an average coffee consumption of an office worker, of 2 cups of coffee per day during 500 working days. This is also a reasonable expected lifespan for a ceramic cup (Hocking, M.B, 1994). Therefore, 1000 servings were chosen as functional unit for this study. This entails that the study has a communicative potential toward the intended audience - office workers.

3.2 System Boundaries

The processes included in our systems are raw-material extraction; manufacturing process; use phase; waste collection and disposal. In Figure 1 and 2 the flowcharts of both processes are illustrated. The foreground of the disposable paper cup is the processes that can be viewed, it is the specific data required to describe the system. The background is the data for the system processes such as energy, transport, waste management and generic materials (this is the data that can be found in the SimaPro database) (Goedkopp et al., 2016).

The boundaries in Figure 2 include nine different system processes. One of the boundaries is set over the distribution and the transport to and from the specific location. Due to that this is the same scenario for both of the LCA:s (disposable paper cup and porcelain cup). The second system boundary includes the processes for waste management, and this boundary only shows which processes are included in the waste scenario. The boundaries in Figure 3 are equal to Figure 2.

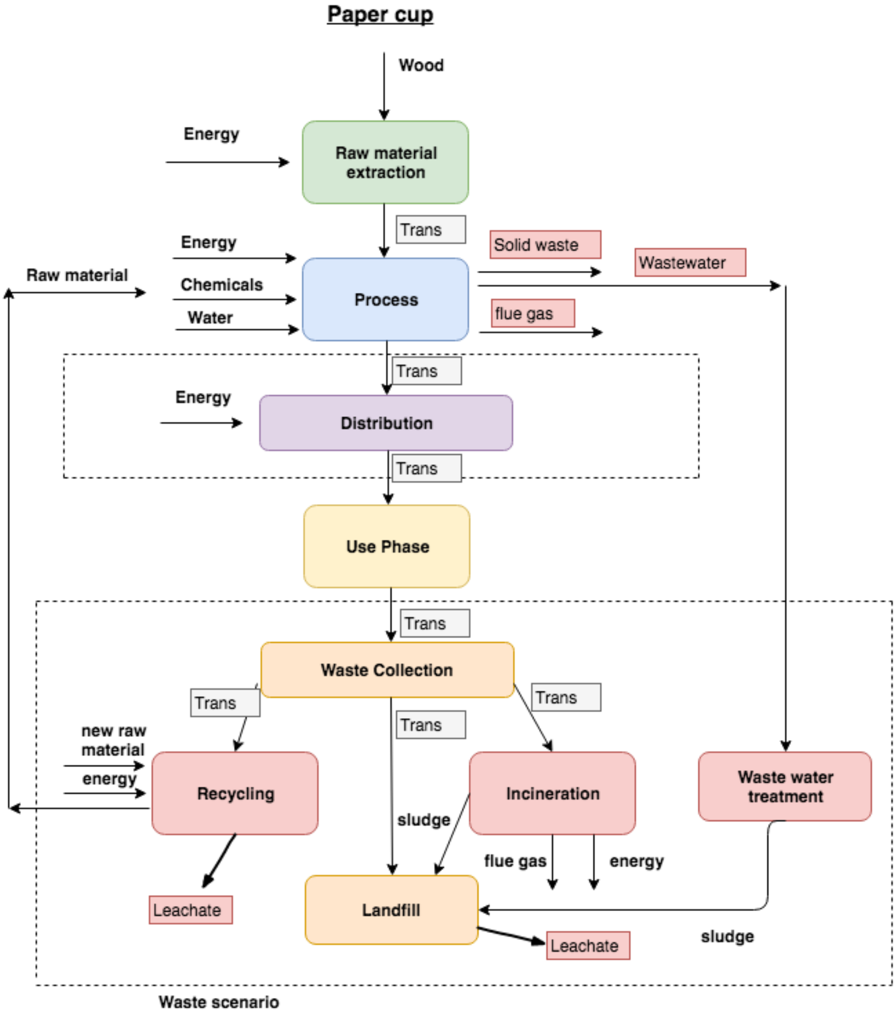

Figure 2, Shows the flowchart of the disposable paper cup and its system boundaries.

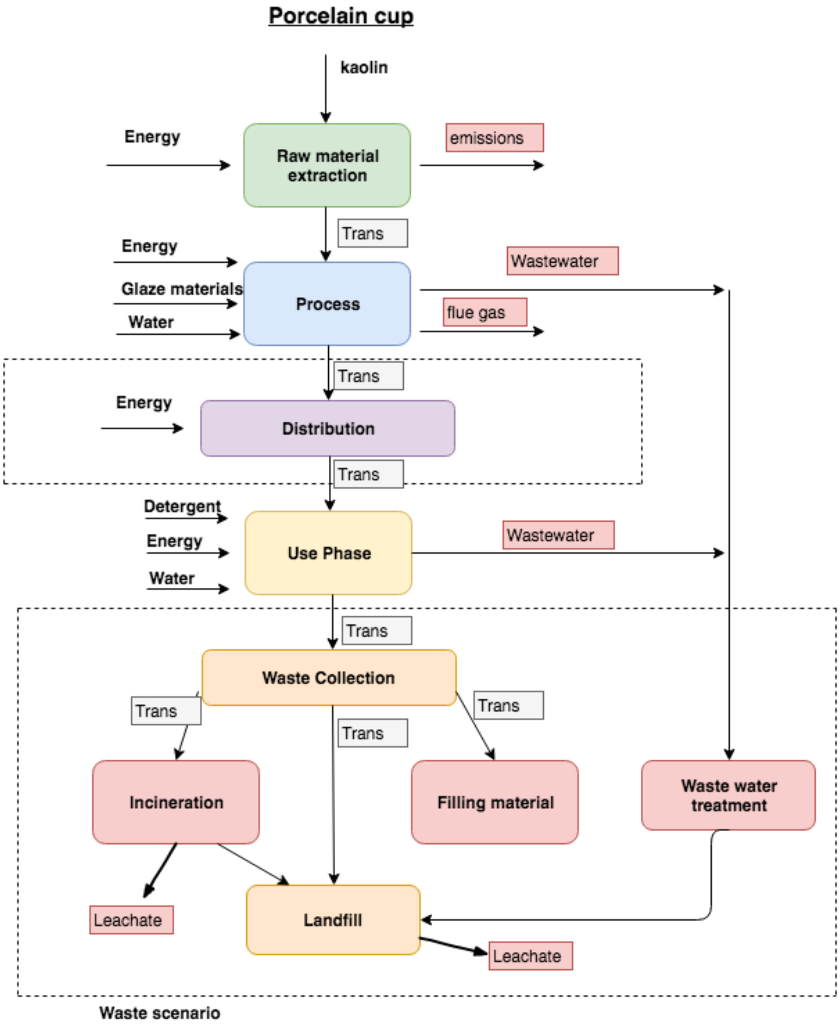

Figure 3, shows the flowchart of the reusable porcelain cup and its system boundaries.

The cradle of resources is located all over the world and the grave of outputs is also globally located, in this study, mostly global data was used.

3.2.1 Geographical Boundaries

The geographical boundaries in this study concern the manufacturing, usage and waste disposal location. Both of the cups are assumed to be manufactured in China, the use phase is placed in Stockholm and the waste disposal is also located in Sweden, but the disposable paper cup is recycled in Norrköping and incinerated in Sweden and the porcelain cup is set to be distributed to landfills all over the world (which includes transportation distance).

3.2.2 Time Horizon

This study compares the environmental loads caused by disposable paper cups and porcelain cups, based on the assumption that the time of usage is two working years. It was decided that the analysis could be carried out without specific requirements on the relevancy of the data, since the manufacturing processes of both products have changed little during the last years.

3.2.3 Cut-off Criteria

- The distribution stage (meaning the chain between production and use phase) can be neglected since the study is a comparative LCA and the transportation route is the same for the products.

- The production of the dishwashing machine used for cleaning the porcelain cup during its use phase is neglected. This due to that it can be estimated that the environmental burden caused by its manufacturing is very low compared to other impacts.
- The coffee making was also excluded from this study since it presumably is the same coffee that the two types of cups will be used for.
- The paper was assumed to be recycled after being turned into pulp (open loop recycling)

3.2.4 Allocation Procedures

Allocation issues were identified both for the porcelain cup and the disposable paper cup, although of different kind.

- Porcelain cup

The porcelain cup is affected by an allocation problem in the use phase, and concerns the cleaning of the cup since the dishwasher presumably is used for more items than coffee cups only. This entails that the water- and energy consumption needs to be allocated between these different items to derive the burdens from the assessed functional unit of porcelain cups.

- The dishwasher

The washer chosen to be incorporated in this project is a (Logik diskmaskin LDW45W16N (vit, Energy class A++)) from Elgiganten which has the following specifications shown in table 1.

Table 1, shows the table of content for the dishwasher.

Electricity demand	211 kWh/year
Water use	2 240 liters/year
Measures	H: 81,5, B: 44,8 D: 57 (cm)
Average washing cycles per year	280
Allocated burdens per porcelain cup	1/64 (based on • Diameter of the cup = 8 cm → One cup area = 64 cm^2 • Accessible washing area = 40*52 = 2080 cm^2 • 1 dish = 2080/64 = 32 cups

The data above is essential to have in order to calculate the amount of dishes and allocated burdens connected to the washing of the porcelain cup. The assumption of the calculations are based on that half of the volume in the dishwasher is consumed by the porcelain cups. One porcelain cup takes up a certain amount of space in the washer. Landfilling, which is the most common end of life treatment for ceramics (The Swedish Waste Management Association, 2015), is assumed to be the only waste scenario for the porcelain cup.

- Disposable paper cup

The disposable paper cup is concerned with two allocation problems, which both arise in its waste scenario. The allocation problems are, more specifically, connected with the waste treatment since it involves both multi-input (combustible waste/paper for recycling)- and multi-output flows (energy/paper material).

3.3 Assumptions and Limitations

A range of assumptions and limitations were made in this study, both to keep the complexity of the assessed systems on an achievable level and in cases when data gaps were necessary to fill. Some assumptions were linked directly to one of the products, while others concern the whole study, such as the reference flow and the functional unit. The location of the office is one example of the latter, and it was decided to assume that the office is placed in Stockholm. The study is not change-oriented, which entails that only average data was used.

It was decided to use average market data for the manufacturing processes of both the porcelain cup and the disposable paper cup. Municipal waste collection was assumed to be applied on both products, even though the continuing of the waste scenario differed. A recycling rate of 80 percent was applied on the disposable paper cup, based on data received from the Swedish company FTI AB, which task is to ensure and monitor recycling in Sweden (Förpacknings & Tidningsinsamlingen, 2016). Continuing, it was assumed that the recycling takes place on Fiskeby Board AB, since according to FTI AB, Fiskeby Board AB is taking in roughly 50% of all recycled paper board in Sweden (Förpacknings & Tidningsinsamlingen, 201-).

Another assumption made is that the transport for the disposable paper cup and porcelain cup can be negligible since both are produced in China. A limitation made for the marginal/average source of electricity for the manufacturing was set to global data for the material processes. For the for the use phase Swedish electricity low voltage was used and for the waste disposal Swedish electricity high voltage was used.

3.4 Impact Categories and Impact Assessment Methods

The LCA software SimaPro was used for this LCA, which entailed that the software produced the inventory list for both the disposable paper cup and the porcelain cup. An impact assessment method had to be applied for the interpretation of the results, and it was decided to use the ReCiPe Midpoint (H) assessment tool. Eighteen impact indicators are used in the ReCiPe Midpoint (H) method which are showed in table 2.

Table 2, shows the 18 different impact indicators used in ReCipe Midpoint (H).

1	Climate change	7	Terrestial acidification	13	Agricultural occupation
2	Ozone depletion	8	Freshwater eutrophication	14	Urban land occupation
3	Human toxicity	9	Marine eutrophication	15	Natural land transformation
4	Photochemical oxidation	10	Terrestial ecotoxicity	16	Water depletion
5	Particulate matter formation	11	Freshwater ecotoxicity	17	Metal depletion
6	Ionising radiation	12	Marine ecotoxicity	18	Fossil depletion

3.5 Normalisation and Weighting

The final step in the impact assessment is normalisation of the characterised results, weighting can also be applied but were not made in this study. The reason behind normalisation is to put the characterised results into a broader context through a comparison with a reference value, which can provide a better understanding of the environmental impacts and the sizes of these.

The aim of the normalisation step in this study was to assess 1) the differences in environmental burdens, and 2) determine the most significant indicators, based on the characterized results of the environmental impacts from the disposable paper cup and the porcelain cup. To address the use area of the cups, it was decided to use European normalisation method (In ReCiPe).

4. Life Cycle Inventory Analysis

This section captures the flowcharts of the LCA:s and data collection.

4.1 Process Flowchart 1 - Disposable paper cup

In Figure 4 is the disposable paper cup life cycle shown. Starting from the top, the disposable paper cup life cycle have a carbon footprint equal to 7,45 kg CO2-eq, which comes from the process of 9,95 kg CO2-eq. The reason why this number is higher than the life cycle total footprint is because we have a positive impact of the paper cup's disposal, in a waste scenario equal to 2,5kg CO2-eq. The largest CO2-eq comes from the process of liquid packaging board which stands for 8 kg CO2-eq. Back to the waste scenario, the line on the right side of Figure 4, shows that the disposable paper cup's waste scenario of recycling contributes to a large positive impact of 2,55 kg CO2-eq. Next to the recycling scenario is the municipal solid waste scenario, which is incineration of the disposable paper cup, equal to 0,049 kg CO2-eq.

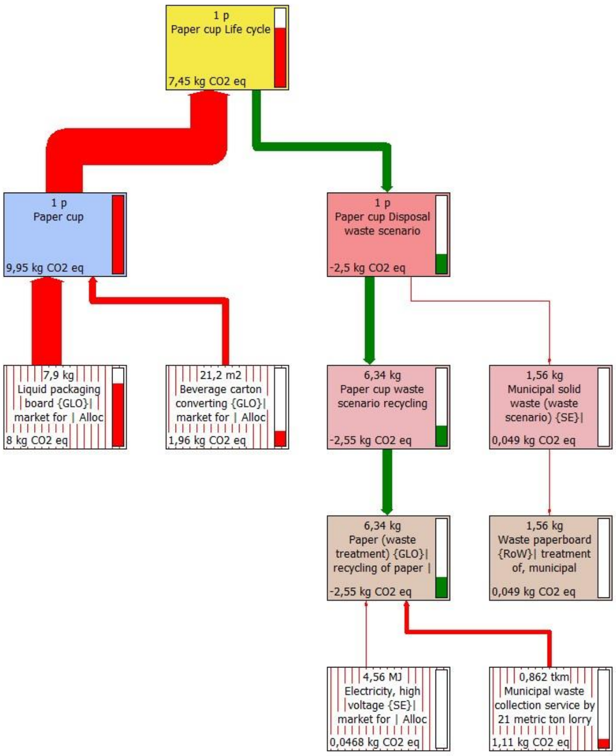

Figure 4, shows the life cycle of the disposable paper cup.

4.2 Process Flowchart 2 - Porcelain Cup

In Figure 4, is the result of the porcelain cup life cycle, which is responsible for 1,17 kg CO2-eq. It has an equal division of production and waste scenario as the disposable paper cup, the differences are however that the porcelain cup production has a negative impact of 0,381 kg CO2-eq, plus the washing cycle which is equal to 0,661 kg CO2-eq. The waste scenario on the right, which is based on landfilling, has a negative impact of 0,116 kg CO2-eq.

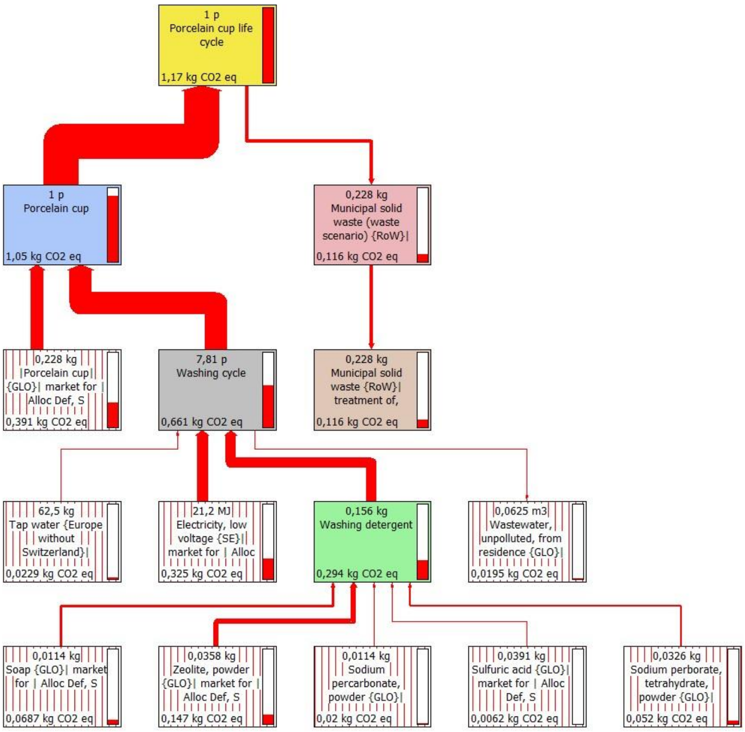

Figure 5, shows the life cycle of the reusable porcelain cup.

4.3 Data collection

The data used in this project consist of mostly databases in SimaPro and gathered information about the products originates from the business vendors. The data used is accessed through Ecoinvent version 3.

4.3.1 Data for Disposable paper cup

The weight of the disposable paper cup is 0,0079 kg and the functional unit is set to 1000 servings. This means that the total weight is: 0,0079 * 1000 = 7,9 kg. The raw material extraction for the disposable paper cup is included in the background together with the assembly, and packaging stage. The production of 7,9 kg of disposable paper cups in the assembly is set to “Liquid packaging board {GLO}| market for | Alloc Def, S”.

4.3.2 Data for porcelain cup

First of all it is assumed that only one porcelain cup is used for the functional unit of a 1000 servings. The weight of the porcelain cup is 0,228 kg (Tingstad AB, 2013). The materials used to create the porcelain cup are clay combined with a glazing material. A small obstacle in SimaPro is that there are not available data for production of porcelain cups; however there are similar data with similar properties. In this case sanitary porcelain is used as a data set for the production, since it is made of clay and glazing the properties and assumption is based on the sanitary ceramic.

The reusable cup is being used twice a day but washed in the dishwasher once a day. The dishwasher data and production is being excluded as mentioned earlier from the LCA.

4.3.3 Default life cycles for disposable paper cup and porcelain cup

Collected data for the Paper & Porcelain cup, in- and outflows are collected with the Ecoinvent version 3 database in SimaPro.

Table 3, shows the data or the default life cycles and the sensitivity analysis.

Default life cycles					
Life cycle	Phase	Sub-stage	Name	Unit	Amount
Paper cup	Assembly	Material	Liquid packaging board{GLO}| market for |Alloc Def,S	kg	7,9
		Process	Beverage carton converting {GLO}|market for | Alloc Def, S	m2	21,2
	Disposal	Waste scenario	Paper (waste treatment) {GLO}|recycling of paper | Alloc Def, S [DUMMY]	p	0,8
			Components added to the paper waste treatment		
			Electricity, high voltage {SE}| market for | Alloc Def, S	Wh	200
			Municipal waste collection service by 21 metric ton lorry {GLO}| market for | Alloc Def, S	kgkm	136
		Waste scenario	Municipal solid waste (waste scenario) {SE}|treatment of municipal solid waste, indinceration	p	0,2
Porcelain cup	Assembly	Material	|Porcelain cup|{GLO} |market for | Alloc Def, S	kg	0,228
	Use	Process	Washing cycle [the parts of the washing cycle follows below]	p	500/64
			Tap water {Europe without Switzerland}|market for| Alloc Def, S	kg	8
			Electricity, low voltage {SE}|market for | Alloc Def, S	kWh	0,754
			Washing detergent	g	20
		Material	Components of washing detergent	kg	96
			Soap {GLO}|market for | Alloc Def, S	kg	7
			Zeolite, powder {GLO}| market for | Alloc Def, S	kg	22
			Sodium percarbonate, powder {GLO}| market for | Alloc Def, S	kg	7
			Sulfuric acid {GLO}| market for | Alloc Def, S	kg	24
			Sodium perborate, tetrahydrate, powder {GLO}| market for | Alloc Def, S	kg	20
	Disposal	Waste scenario	Municipal solid waste (waste scenario) {RoW}| Treatment of municipal solid waste, landfill | A	p	1

Sensitivity analysis					
Life cycle	Phase	Sub-stage	Name	Unit	Amount
Paper cup	Disposal	Waste scenario	Municipal solid waste (waste scenario) {SE}|treatment of municipal solid waste, indinceration	p	1
Porcelain cup	Use	Material	Washing detergent	g	16
		Material	Washing detergent	g	24

In the table above the material used for the disposable paper cup was set to *Liquid packaging board [GLO] market for | Alloc Def, S. System* "S" was used in all the categories. The amount was set to 7,9 kg because this is the total amount of weight for 1000 servings of coffee. The process was set to *Beverage carton converting [GLO] | market for | Alloc Def, S* as 21,2 m2, this is the area of the disposable paper cup's when unfolded. For the waste scenario the process *Paper (waste treatment) [GLO] recycling of paper | Alloc Def, S [DUMMY]* was used, this scenario was created and done with the presumption that 80,2 % of the paper waste goes to recycling and 19,8 % goes to incineration in Sweden. The components added to the paper waste treatment was *Electricity, high voltage [SE] market for | Alloc Def, S* with the amount of 200 Wh. *Municipal waste collection service by 21 metric ton lorry [GLO] market for | Alloc Def, S* was set to 136 kg/km. This waste collection included the distribution of the paper waste to an incineration plant. Another component added was the waste scenario of *Municipal solid waste (waste scenario) [SE] treatment of municipal solid waste, incineration for | Alloc, Def, S* and was distributed 0,2 points.

The components for the washing detergent was selected after viewing what the common components of a regular most used washing detergent in Sweden is. Therefore, *Soap [GLO] market for | Alloc Def, S; Zeolite, powder [GLO] | market for | Alloc Def, S; Sodium percarbonate, powder [GLO] market for | Alloc Def, S; Sulfuric acid [GLO] | market for | Alloc Def, S* and *Sodium percarbonate, tetrahydrate, powder [GLO] | market for | Alloc Def, S* was used. In the table above the unit and amount is demonstrated. The components for the washing detergent were taken from a previous study made for the most common washing detergent used in Sweden.

No transportation was added to SimaPro since it is already included in the processes; both products are produced in China and distributed to Sweden. The use phase and disposal phase are included in all the processes since they are preselected in the processes.

4.3.3 Allocation procedures

For all the allocation procedures in this project system was used to make the calculations faster and easier. Instead of using unit, which is based on other units the allocations of system was better to use since all the impacts are already calculated, several units have been included to create a system.

To draw a conclusion for the allocations procedures the issues of allocations is taken care of by the Ecoinvent 3 - allocation, default - system database. This database contains LCI data from different sectors, for instance, energy production, transport, building materials, production of chemicals, metal production etc. This database system model is based on two methodological choices, first of all it used the average supply of products, secondly it used partitioning in order to convert multi-product datasets to single-product datasets. More simplified described this means that the flows in this database are allocated relative to their true value (PRé Sustainability, 201-).

4.3.4 Data gaps

Possible data gaps may have occurred when creating the washing detergent for this project. A template from another project done by Bundesanstalt für Materialforschung und -prüfung (BAM), which is a German federal institute for material research and science (Ecolabelling Denmark, 2011). Since the data used in that particular LCA was extracted from a previous version of the Ecoinvent database, as well as an additional database, some data may have been changed or missing when the process was built for this project.

Since the data in this LCA is extracted from a database which is constructed and made for the particular reason of LCAs, any gaps in the data is assumed to be covered by the creators of the database. In addition, the data that has been used in this case are approximate data, which is not set to a specific geographical location.

5. Life Cycle Interpretation

This section presents the analysis of the result, sensitivity analysis, conclusions and recommendations.

5.1 Result

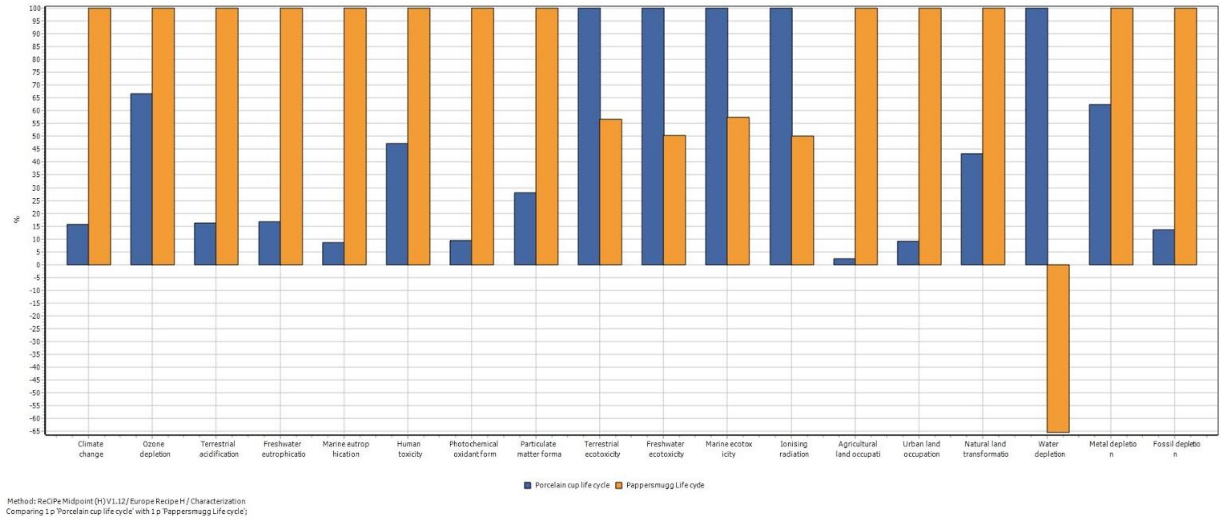

Figure 6, shows the characterized result of the porcelain- and paper cup.

As can be seen in Figure 6, the disposable paper cup has the largest impact in 13 of the 18 impact categories, whilst having a positive impact on the environment in the water depletion category (shown as a negative value in the bar graph). This positive impact is due to the calculations made in the ecoinvent database in which all recycled processes has a positive impact on the environment. This result clearly shows that the absolute value of the recycled process used in the disposable paper cup life cycle is higher than the production processes and material, with regards to the water depletion category. This does not, however, show which product has the highest environmental impact that is better deducted from considering both normalized and characterized results.

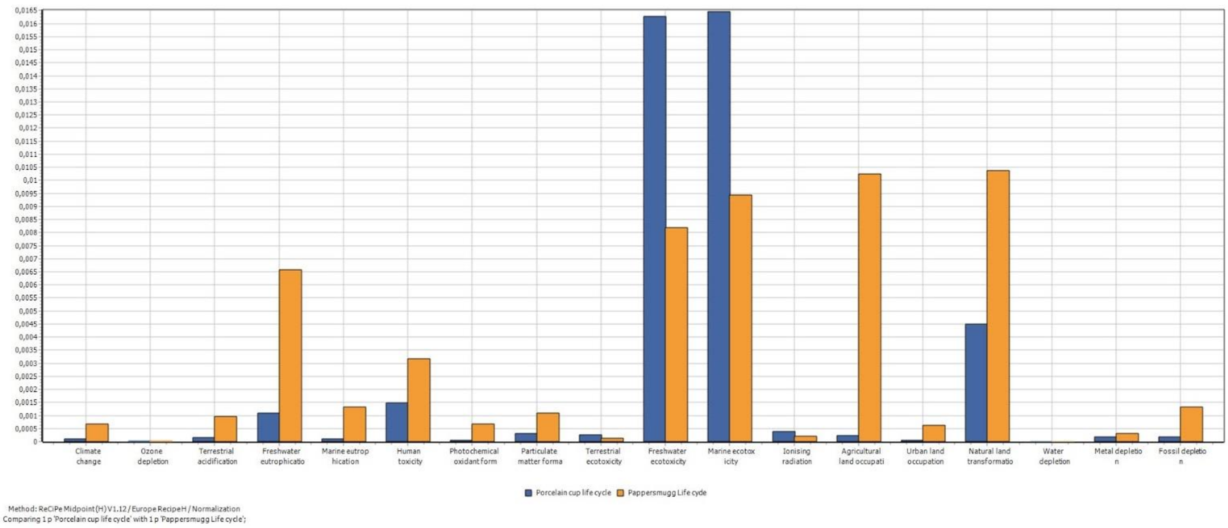

Figure 7, shows the normalized result of the porcelain- and paper cup.

As can be seen in Figure 7 the disposable paper cup has it largest environmental impact on land area and water systems, while the porcelain cup has it largest environmental impact on the water system. The most affected impact categories in this study are freshwater ecotoxicity, marine ecotoxicity, natural land transformation, agricultural land occupation and freshwater eutrophication. The reason for the high impact from the porcelain cups life cycle on the freshwater ecotoxicity and marine ecotoxicity is the contribution from the washing machine and its detergents during the use phase. From the life cycle of the disposable paper cup, the five main categories in which the disposable paper cup has a large impact, most is due to the production of the disposable paper cup and the substantial contribution to the natural land transformation, agricultural land occupation and freshwater ecotoxicity. Freshwater eutrophication and marine ecotoxicity comes from the raw material extraction, since it is a substantial part of the disposable paper cup's production phase. As could be generally concluded from this section is that the production phase is the phase with the most substantial environmental impact in the disposable paper cup scenario, whilst the user phase is the phase with the most substantial environmental impact in the porcelain cup life cycle. What could be interpreted from our normalized results is that the two main impact categories are freshwater toxicity and marine ecotoxicity.

5.2 Sensitivity Analysis

The result from a sensitivity analysis can show how the assessment could be modified in order to get different results for the environmental impacts from each product. Several parameters could be modified in order to affect the results from the impact assessment, such as:

- The functional unit, meaning the amount or servings
- The frequency of washing the reusable porcelain cup
- The water, energy and detergent demand of each washing cycle
- The allocation of burdens per cup during each washing cycle
- If hand washing or dishwashing is used for cleaning the cup
- The weight of the disposable paper cup
- Allocation will be based on economic values for recycling of plastic and paper
- The waste scenario for the disposable paper cup

Two parameters were used in this sensitivity analysis, the waste scenario for the disposable paper cup and the amount of washing detergent in each washing cycle for the porcelain cup. It was decided to analyse these parameters since assumptions were made concerning this data in the original impact assessment. Following cases were analysed:

- 100 % incineration as waste scenario for the disposable paper cup
- 20 % Less detergent per washing cycle in Porcelain cup life cycle
- 20 % More detergent per washing cycle in Porcelain cup life cycle

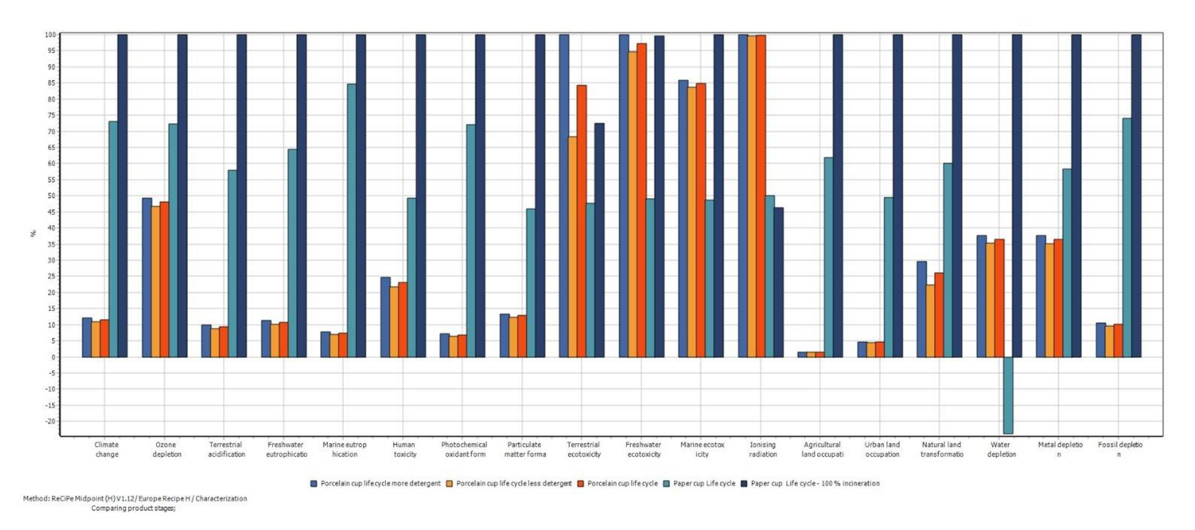

Figure 8, shows the characterized result of the sensitivity analysis.

Figure 8 illustrates a comparison of the characterized results per impact category for each product, including both the original product scenario and the sensitivity scenarios. When compared, it can be seen that the waste scenario for the disposable paper cup has a significant influence on its environmental impact since the 100 percent incineration alternative has the highest impact level in fifteen out of eighteen impact categories. Another observation is that the amount of detergent used in the use phase of the porcelain cup has an influence on its performance in not only its significate impact categories (Terrestrial ecotoxicity, Freshwater ecotoxicity, Marine ecotoxicity and Ionizing radiation), but also in all other impact categories.

Furthermore, the sensitivity analysis shows that the choice of waste scenario for the disposable paper cup has the ability to change the relative environmental performance of the two products in two impact categories - both Freshwater ecotoxicity and Marine ecotoxicity, where the disposable paper cup obtains a higher impact than the porcelain cup instead of lower as earlier. The sensitivity analysis also clearly show that the original waste scenario of the disposable paper cup included allocation of avoided burdens, which are taken away in the 100 percent incineration waste scenario. It is therefore safe to argue that the design of the comparative study in itself has a significant impact on the results.

5.3 Conclusions and Recommendations

The general conclusions that could be drawn from the results of this comparative LCA is that the disposable paper cup generally has a larger environmental impact than the porcelain cup (in 13 out of 18 impact categories). Seen from this perspective, it could be argued that the porcelain cup is the preferable choice from an environmental point of view, in this particular case. What could be considered surprising was that the difference between the environmental impacts of the two products was expected to be larger than it turned out to be. The reason behind this might be an unexpected impact magnitude from the user phase of the porcelain cup - since the disposable paper cup had a lower environmental impact in three categories that relates to environmental toxification.

For the waste scenario one assumption was made that 80% of the disposable paper cups were recycled and 20% were incinerated. In reality, a larger share of the disposable paper cups might be incinerated/recycled than in this LCA, which would affect the environmental impacts from the disposable paper cups depending on which recycling-/incineration-ratio is used . A higher recycling rate would presumably result in a higher positive environmental impact, while a higher incineration rate would give a higher negative environmental impact.

The assumption regarding the lifespan of the porcelain cup, 1000 servings, is based on an earlier, similar study. For the porcelain cup the lifespan was estimated to be 1000 servings, which is based on an earlier, similar study. Thus, an assumption has been made that the earlier study is correct when assuming this amount of servings for a porcelain cup. If that assumption is incorrect, it would affect the validity of this comparative outcome of the LCA. In real life the cup could have both a longer or a shorter lifespan, which means that the total environmental impact potentially could be both smaller or larger, break before the assumed number of servings has been reached, which would therefore affect the comparative LCA due to the that a new cup must be made or the number of disposable paper cups will decrease. If it is the other way around that the cups lifetime will increase the environmental impact will decrease for the porcelain cup compared to the disposable paper cups. The assumptions regarding the transport distance from China to Stockholm (which was the assumed office location) that is neglected can also have an effect on the outcome of the LCA due to that the type of transport can be different for the products, for example it can be by train, airplane, boat or truck.

Since this study is done with the case of a workplace in Stockholm in mind, this could be used as an underlying basis for any decisions regarding choice of cups in the fictive workplace. If a workplace would like to apply measurements to improve their everyday environmental performance, this could be used when collecting data for impacts on different types of environmental problems. As an example, the data could be used from this LCA to estimate the kgs of CO2-equivalents that could be saved if transcending from disposable paper cups to porcelain cups.

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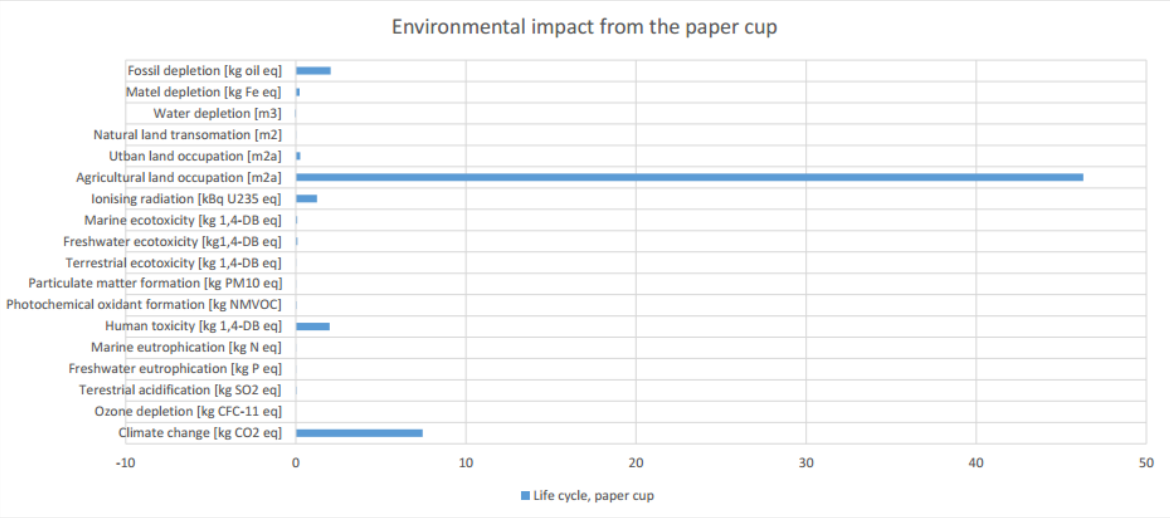
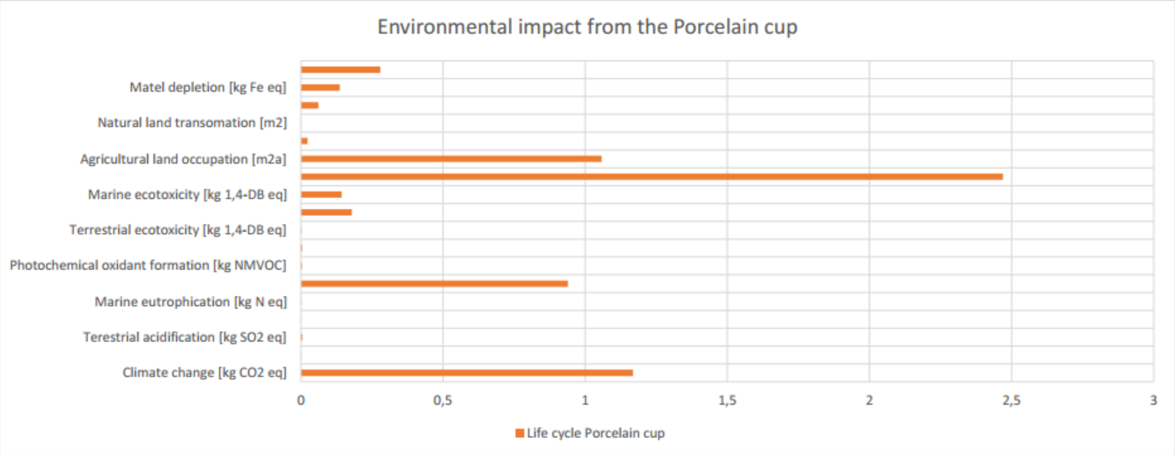
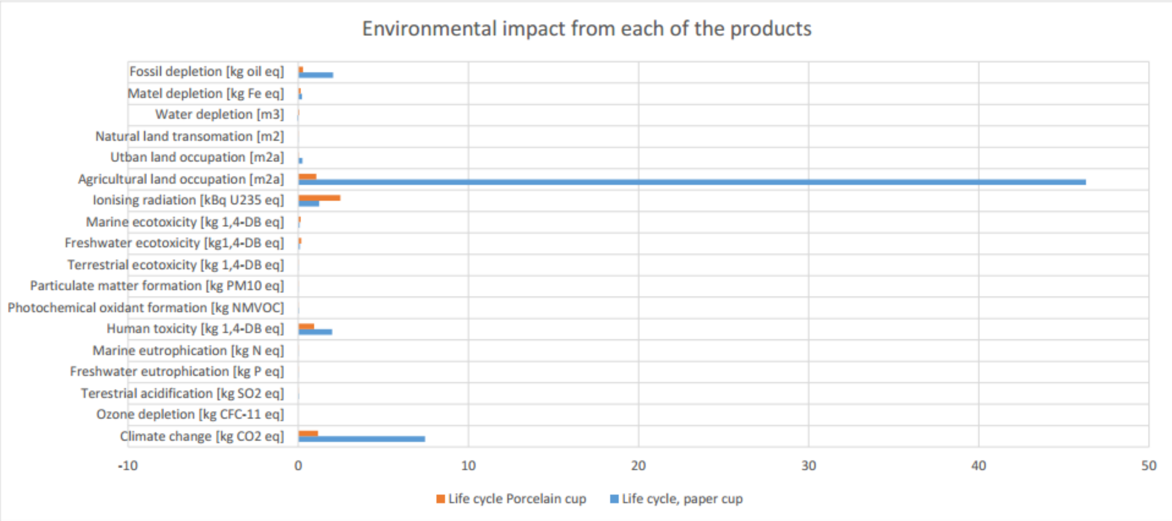
Appendix 1

Environmental impact from the different products

Impact category and unit	Life cycle, paper cup	Life cycle Porcelain cup
Climate change [kg CO2 eq]	7,45319777	1,167939273
Ozone depletion [kg CFC-11 eq]	6,49314E-07	4,31935E-07
Terestrial acidification [kg SO2 eq]	0,0331162	0,005349085
Freshwater eutrophication [kg P eq]	0,002734016	0,000455688
Marine eutrophication [kg N eq]	0,013469778	0,001175172
Human toxicity [kg 1,4-DB eq]	1,988880005	0,93897387
Photochemical oxidant formation [kg NMVOC]	0,037801057	0,003583315
Particulate matter formation [kg PM10 eq]	0,016351549	0,004565701
Terrestrial ecotoxicity [kg 1,4-DB eq]	0,001165067	0,002058466
Freshwater ecotoxicity [kg1,4-DB eq]	0,090169997	0,179109979
Marine ecotoxicity [kg 1,4-DB eq]	0,082137863	0,143104532
Ionising radiation [kBq U235 eq]	1,237265406	2,469650944
Agricultural land occupation [m2a]	46,29174815	1,057485404
Utban land occupation [m2a]	0,250368913	0,023085053
Natural land transomation [m2]	0,001674489	0,000724739
Water depletion [m3]	-0,040065755	0,061207838
Matel depletion [kg Fe eq]	0,218554441	0,136640028
Fossil depletion [kg oil eq]	2,048298656	0,278886815






Environmental impact from each of the products
Fossil depletion [kg oil eq]
Matel depletion [kg Fe eq]
Water depletion [m3]
Natural land transomation [m2]
Utban land occupation [m2a]
Agricultural land occupation [m2a]
Ionising radiation [kBq U235 eq]
Marine ecotoxicity [kg 1,4-DB eq]
Freshwater ecotoxicity [kg1,4-DB eq]
Terrestrial ecotoxicity [kg 1,4-DB eq]
Particulate matter formation [kg PM10 eq]
Photochemical oxidant formation [kg NMVOC]
Human toxicity [kg 1,4-DB eq]
Marine eutrophication [kg N eq]
Freshwater eutrophication [kg P eq]
Terestrial acidification [kg SO2 eq]
Ozone depletion [kg CFC-11 eq]
Climate change [kg CO2 eq]
-10
0
10
20
30
40
50
Life cycle Porcelain cup
Life cycle, paper cup

Appendix 2

Paper cup life cycle

This is a document regarding the steps taken when modeling in SimaPro. All materials, methods, and processes used in this life cycle can be found in the libraries "Ecoinvent 3 -allocation, default - system", "Ecoinvent 3 -allocation, default - unit" and "Methods".

Creating the life cycle of the paper cup

The materials used in this life cycle are

- Liquid packaging board {GLO}|market for corrugated board box | Alloc Def, S

The processes used in this life cycle are

- Beverage carton converting {GLO}|market for | Alloc Def, S
- Paper (waste treatment) {GLO}| recycling of paper | Alloc Def, S [DUMMY]

The scenarios used in this life cycle are

- Municipal solid waste process (waste scenario) {SE} treatment of municipal solid waste, incineration | Alloc Def, S
- Paper cup waste scenario recycling (*This is created for the sole purpose of this project, description is found further down in this document)*

Assembly

The assembly includes the Liquid packaging board and the Beverage carton converting. In this stage, the estimation is that the total weight of the liquid packaging boards that are being processed in this scenario is 7,9 kg since that is the weight of 1000 cups of the type "pappersmugg, brun, 23cl" fromt the company Tingstad AB (Tingstad AB, 2016). 1000 cups is also the unit in which the cups are sold, I.e. one unit = 1000 cups. The area of the cup that is being processed in this case is calculated with the formula of a cone with the top cut off. The diameters of the two ends are given by the product declaration, as is the height and the volume. The calculations for the area of the cup is showed in the table below.
The integer values are rounded off to two decimals.

	Source/calculation	**Value**
Height (mm)	Product declaration	92
Bottom radius (mm)	Product declaration	26
Bottom area (sqmm)	26*26*pi=	2123,72
Bottom circumference (mm)	2*26*pi=	163,36
Top radius (mm)	Product declaration	40

Top Area (sqmm)	40*40*pi=	5026,55
Top circumference (mm)	2*40*pi=	251,33
Mantle area (sqmm)	(251,33-163,36)/2=43,99 163,36+43,99=207,35 207,35*92=	19 076,2
Total area (sqmm & sqm)	Bottom area + mantle area 2123,72+19 076,2=	21 199,92=21,2sqm for 1000 cups

Table 1, paper cup data.

The information shown in this table are used to calculate the area of liquid packaging board to be processed in the beverage carton converting process.

One part of the assembly that is neglected is the transport form the producer to the distributor. According to the distributor, the producer is located in China, just as the producer of the porcelain cup. Therefore, all transportation of the products are neglected in both life cycles.

Waste Scenario Description

The waste product stage is using the waste scenario named "Paper cup waste scenario recycling", as well as the incineration scenario for municipal solid waste handling with specified Swedish (SE) scenario. This scenario uses the distribution of 80,2% recycled waste and 19,8% waste sent to municipal solid waste incineration.

In the waste scenario of "Paper cup waste scenario recycling" the materials and/or waste types separated from waste stream we used Paper (waste treatment) (GLO) | recycling of paper | Alloc Def, S [DUMMY] with the material / waste type of liquid packaging board container (GLO) market for | Alloc Def, S with a percentage of 100 %. In the section of waste streams remaining after separation the same paper (waste treatment) used as described above with a percentage of 100 %.

Life cycle results

The general results that are shown in the SimaPro program shows that main climate change impact is allocated in the liquid packaging board material, when looking at normalisation and kg CO2-eq.
The process tree is shown below.

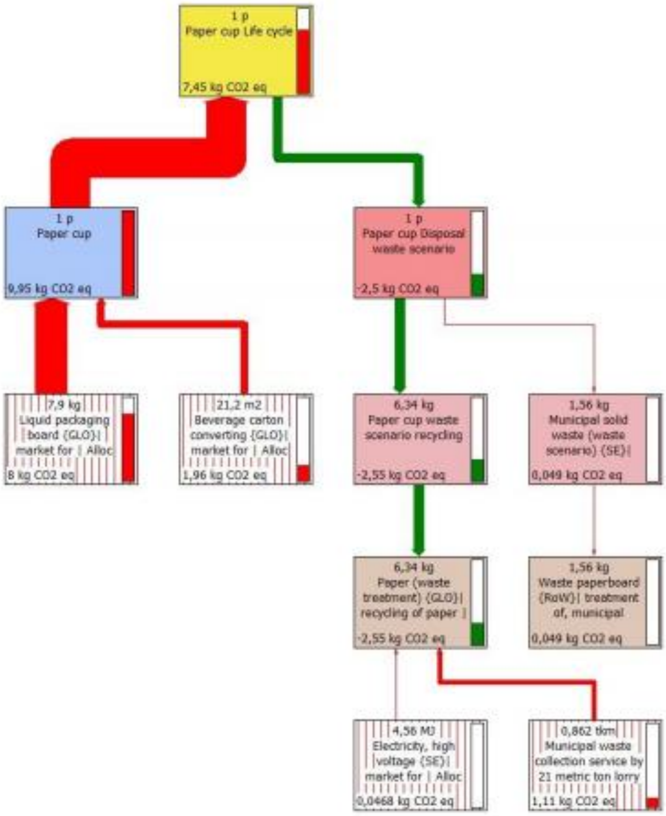


Figure 1, Paper cup life cycle process tree

Appendix 3

Porcelain cup life cycle

This is a document regarding the steps taken when modeling in SimaPro. All materials, methods, and processes used in this life cycle can be found in the libraries "Ecoinvent 3 -allocation, default - system", "Ecoinvent 3 -allocation, default - unit" and "Methods".

Creating the life cycle of the porcelain cup

The materials used in this life cycle are

- |Porcelain cup| {GLO} |market for | Alloc Def, S (*This is created for the sole purpose of this project, description is found further down in this document*)

The processes used in this life cycle are

- Washing cycle (*This is created for the sole purpose of this project, description is found further down in this document*)

The scenarios used in this life cycle are

- Municipal solid waste (waste scenario) {RoW} treatment of municipal solid waste, landfill | Alloc Def, S

Assembly

The assembly consists of the assembly of the product as well as the use phase of the product.

Assembly of product

The assembly includes the Porcelain cup material only, making it rather simple in this case. The material "|Porcelain cup| {GLO} |market for | Alloc Def, S" was created from a copy of the material "Sanitary ceramics {GLO}|market for | Alloc Def, S", with no major changes made but changing the actual name to porcelain cup. This due to the reluctance to portray the porcelain cup as a sanitary ceramic, even though both consists of the same materials.

Use

When creating the user phase of the porcelain cup, the only aspect that is considered is the washing of the cup. Considering the choices made regarding this phase, the cup is expected to uptake roughly 1/64th of the impacts and resources connected with one washing cycle. This due to that the washing machine chosen for this project has two trays of on which dirty dishes could be loaded on, while the area of each of the trays are approximately 2080 cm2. The calculations made in this case are based on that the approximate area that the porcelain cup takes up in the dishwasher is a square with the sides equal to the diameter of the cup. Therefore, the area of one cup was expected to take up approximately 1/32nd of the area of one tray, and thus 1/64th of the area of both trays. To model this in SimaPro, the process "Washing cycle" was created to represent this stage of the user phase. This stage consists of the water, energy, and the materials being used when washing the cup, however

neglecting the life cycle of the dishwasher itself, and rather just consider the input of the process.
The washing detergent being used in this process needed to be created since it was missing from the simaPro database. This was done by creating a material that consists of all the materials that are needed for the tablets used in the washing machine, based on a report from the german federal institute for material research and science (BAM, 2016). The weight of the washing detergent was determined simply by checking the weight of an average washing detergent tablet.

Waste Scenario Description

The waste product stage used in this part is the municipal solid waste, landfill-process. Since this process uses data regarding landfill of ceramics, with no other added processes or materials, this concludes the life cycle of the porcelain cup. 100% of the porcelain cup is sent to landfill.

Life cycle results

The general results that are shown in the SimaPro program shows that main climate change impact is allocated in the washing cycle of the porcelain cup, when looking at normalization and kg CO2-eq.
The process tree is shown below.

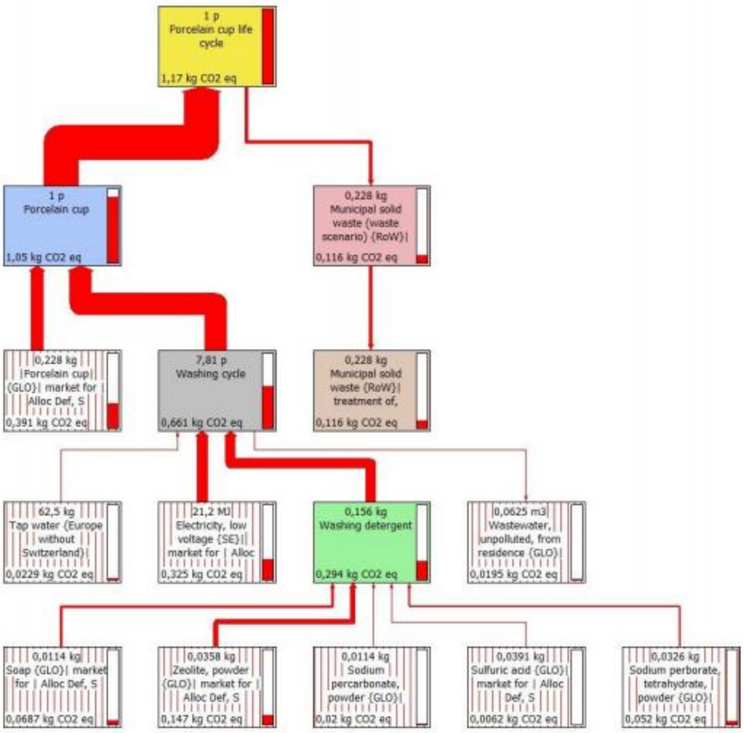


Figure 1, Porcelain cup life cycle process tree