Technical University of Denmark

Case Study:
Water Supply at CBS Conference

42372 - Life Cycle Assessment of Products and Systems

Carsten Sherpa Eliasen (s102974)
Mia Heide (s133635)
Naja Kastrup Friis (s133613)
Oskar Peter Geyti (s133638)
Rasmus Nøddegaard (s133604)

Group: 11
Teaching assistant: Niranchana Venkatesh

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1 Introduction

This paper handles a case given by Copenhagen Business School (CBS) who are organizing a conference in 2018 putting focus on sustainability. They want to use their water supply as an environmental statement and have asked for a comparison of different water containers. The overall functional requirement is a container with lid to distribute water. There will be 126 people attending during the 3 days conference.

2 Goal & Scope

In the following section the goal and scope for the water supply are defined.

2.1 Goal

1. *Intended applications of the results*
   The intended application of the results is to compare the environmental impacts of different ways of supplying drinking water at a 3 days conference with 126 people at CBS. Furthermore, the study will be used to document the environmental performance of the containers for CBS to present at the sustainability conference.

2. *Limitations due to methodological choices*
   The environmental impacts of the product systems will be assessed and compared, all following the cradle-to-grave model including midpoint and endpoint LCIA results. Since human behaviour is not accounted for quantitatively in the LCA, it will be taken into account in the definition of the systems in the scope section 2.2. The chosen LCA data base is ReCiPe 2008 (H), which is a limitation, as it is a bit old and does not include all the specific materials and processes.

3. *Decision context and reasons for carrying out the study*
   The study will be used for decision support in small scale: Situation A - "Micro-level decision support" [7]. The reason for carrying out the study is to support an educational institution upon their decision on water supply during a conference hosted by themselves. The study compares different solutions complying with the Functional Unit (FU), and recommends the best environmental performing product. The LCI modelling framework can be seen as "attributional" as the study observes already existing products and no changes to the systems are intended.

4. *Target audience*
   The target audience of the study is CBS (and CBS network) and to a lesser extend the participants at the conference, depending on CBS' use of the results.

5. *Comparative studies to be disclosed to the public*
   The content of this study is not intended for publicity.

6. *Commissioner of the study and other influential actors*
   Sponsors and stakeholders of the project are CBS and SCORAI (Sustainable Consumption Research and Action Initiative) in cooperation with DTU.

2.2 Scope

The following steps describes the workflow, the investigated products, system boundaries and other details that are important for the scope of the assessment.

1. *Deliverables*
   The LCI and LCIA results will be presented as mid- and endpoint categories. The first results will be characterized and compared internally. An external normalization of endpoint results will be carried out as a comparison with a known reference, in this case the contribution from an average world citizen. Finally, the normalized endpoint results will be weighted with the "average" perspective and presented as a single score. These steps will be documented numerically according to ISO 14044.

2. *Object of the assessment*

Table 1: Desired functions

Obligatory Properties	**Positioning Properties**
Dispense and contain drinking water	Design - color - shape
Legislation/safety regarding toxic constituents	Volume/size
	Possible to refill
	Possible/easy to clean
	Easy to dispose
	Reusable
	Closeable
	Nice to hold and drink from

Functional Unit (FU):
Contain and dispense 4 L drinking water per person in an enclosed container of 0.5 L for 126 people at the conference of Sustainable Consumption and Action Research Initiative in Copenhagen.

The requirement for half a liter is decided to make sure that each participant has enough water through the presentations, without having a container too big and unmanageable.

The term 'reuse' is presented several times during this report and defines the number of conference days one container is used by the participants.

3. *LCI modelling framework and handling of multifunctional processes*
   The secondary functions will be handled according to the ISO standard hierarchy for solving multifunctionality for an attributional LCA. Sub-division is not possible as the processes are integrated and mixed. System expansion is thus preferred. If that is not possible, then allocation should be used as presented in Figure 1. When doing system expansion the secondary functions are integrated into the systems. Avoidance of impacts are accounted for and afterwards credited to the initial system. Table 2 shows how the secondary functions will be handled in the systems. The EoL recycling are modeled with the 0:100 approach [9].

The reference flows are presented in Section 3 Life Cycle Inventory Assessment.

LCI modelling framework	Question to be answered	Handling of multifunctional processes when subdivision is not possible		Modelling of background system
		Before ILCD	ILCD	
Attributional	What environmental impact can be attributed to product X?	Allocation	System expansion or allocation	Average processes
Consequential	What are the environmental consequences of consuming X?	System expansion	System expansion	Marginal processes

Figure 1: Attributional and consequential handling,[7], p. 94

4. *System boundaries and completeness requirements.*

Three scenarios, which all comply with the FU will be compared in this analysis. The scenarios are chosen considering availability of data (data sheet transparency and company contact) and what is most likely for CBS to choose. The scenarios are presented in Table 2 with their secondary functions. Several large water containers will be set up to refill the bottles in all the scenarios, where the containers will be reused directly at the conference. This is modeled with an extra system, however, they are only added to the systems that can be refilled. The impact of the large refill containers turns out to be very small (around 1%), thus it is chosen to be neglected. See impacts in Appendix A, Table 6 on page 26.

Table 2: The investigated systems and their secondary functions. Prices are calculated for large purchases and given for one bottle.

No	System	Secondary function	Handling secondary function	Cost
1	Retap glass bottles and rubber lid [10]. Reference flow: 126 pieces	Reuse 50 times Recycled glass open-loop	System expansion: 100% of the recycled glass is credited to the system. Production with virgin glass avoided. Incineration of rubber; credit 100% of the gained heat and electricity to the system.	104 DKK [3]
2	Postevand FSC cardboard [11]. Reference flow: 1008 pieces	Incineration (energy and heat)	System expansion: Credit 100% of the gained heat and electricity to the system (average DK mix).	1,32 DKK [1]
3	Bottle plastic[2]. Reference flow: 378 pieces	Reuse (once a day) Recycled plastic in closed-loop (100% material recycled)	System expansion: Credit the system for reusing the plastic instead of virgin plastic.	0,46 DKK + deposit [1]

In this section the system boundary for each system is presented. The processes included in the study are inevitably connected to many indirect processes in the techno- and ecosphere via elementary flows. Ideally only resources and emissions should flow between the product system and the techno- and ecosphere.
To limit the complexity of the study, certain supporting processes are excluded from the product system. The boundaries for each system are described graphically by Figure 2, 3 and 4. Some flows are considered negligible because of insignificant relevance to the assessed system which is illustrated with a faded color. Except for the Retap system all the processes within the system boundaries are a part of the foreground system, whereas the processes excluded from the system boundaries can be seen as elements in the background system. These are not considered further in the assessment. For the Retap bottle system the packaging process and the water tank included in the system boundary is not a part of the foreground system. Otherwise the rest of the processes within the system boundary are elements in the foreground system. The system boundary for the distribution tank can be found on Appendix A in Table 17, page 26.

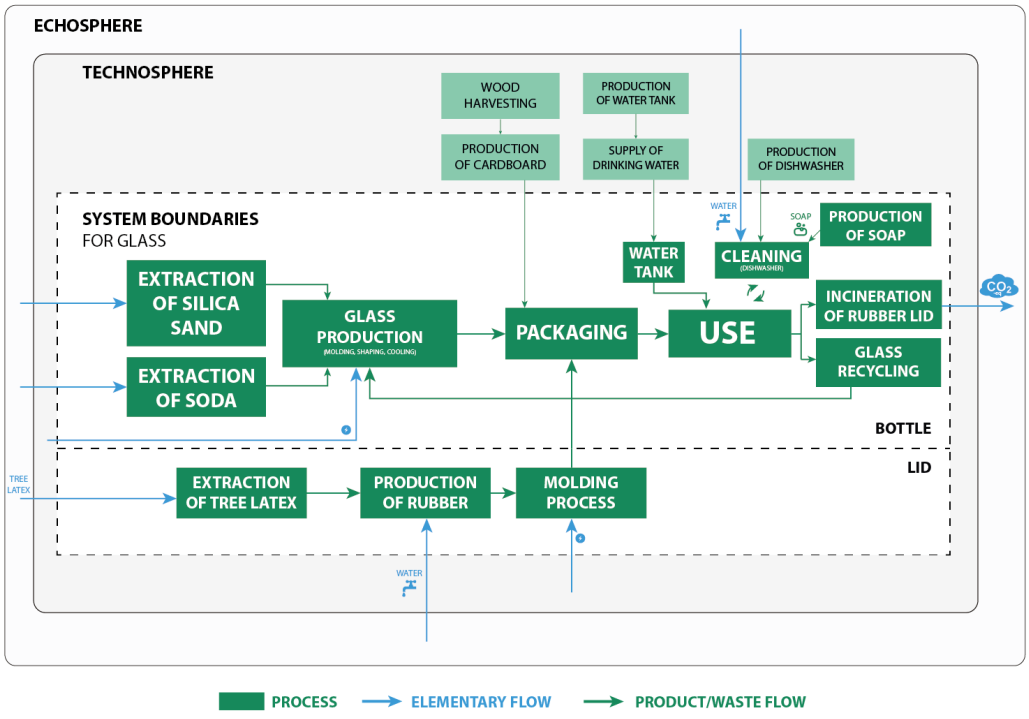

Figure 2: System Boundaries for the product system with glass, Retap (nr. 1 in Table 2).

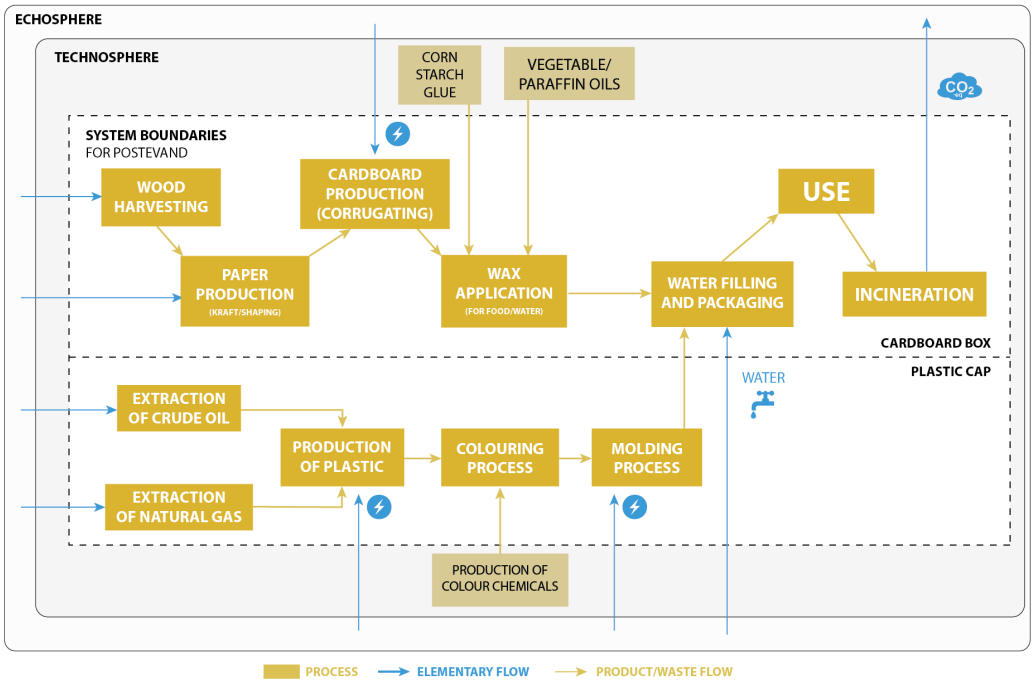

Figure 3: System Boundaries for the cardboard solution, Postevand (nr. 2 in Table 2).

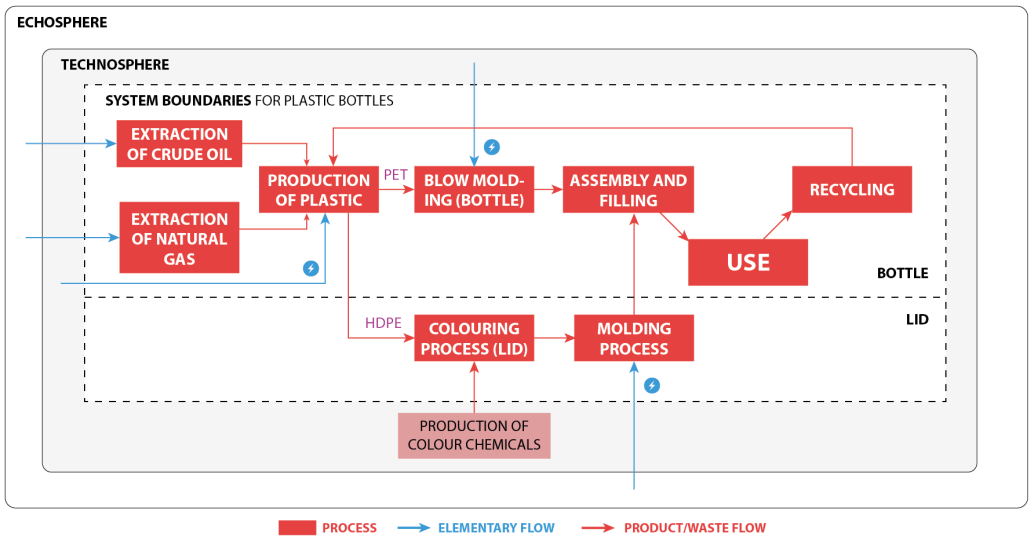

Figure 4: System Boundaries for the plastic system (nr. 3 in Table 2).

5. *Representativeness of LCI data*
   Concerning the representativeness of data, the foreground systems consist of very high or high quality data because the data is gathered directly from the suppliers/manufacturers (first hand data collection) or measured by the group. Furthermore, data collection on the internet is used for one system and categorized as medium level data quality. The quality of all used data are described in Appendix B, Table 7, 8 and 9.

Geographical Representativeness:
The geographical representation of the processes in SimaPro/Ecoinvent are a source of uncertainty, since not all processes contain data from the specific countries. An example is the production of the plastic lid for the Postevand system where data are average European numbers, but the production takes place in Italy. Use and disposal/recycling takes place in Denmark for all systems, which is modelled with Danish data. The production phase in the Postevand system will take place in Italy and in Czech Republic for the Retap system.

Time-related Representativeness:
Temporal representativeness is not a large issue due to the relatively short lifetime of the products and short production period. Hence, the methods will not change significantly before the conference in June 2018. Furthermore, there has not been used any representing data sets with large time related differences from the actual materials and processes studied.

Technological Representativeness:
The technological representiveness can be an issue regarding different production and recycling technologies, however, due to very short lifetime of the systems and relative new/updated processes in SimaPro the technological representativeness is not considered a large issue.

6. *Preparation of the basis for the impact assessment*
   According to our goal definition all environmental impacts are included in the impact assessment. The whole life cycle and all the life cycle phases are considered. The starting point was that all processes should be included, however, the very small amounts that appeared during the inventory, are neglected. In this study a normalization of the results is performed and the single scores are calculated with average weighting. In some cases it is necessary to include the emissions from the different damage categories to make a recommendation, since the single score does not show if there is a huge impact potential in one damage category. This could also be relevant for the midpoint results.

7. *Special requirements for system comparisons*
   In this case the same functional unit is applied to the different products and the methodological aspects will be equally applied to every product system in terms of system boundaries, data quality (first hand data for foreground systems) etc. The systems have uniform boundaries and allocation procedures. The uncertainties in the study will be evaluated in relation to most relevant parameters.

8. *Needs for critical review*
   In this study it is not required to do a critical review, as the results are not planned to be used for marketing or competition in any way. The simple context is for CBS to provide water for a conference with a specific numbers of participants in the most sustainable way possible. This means that the study is for internal use, and that it, as a starting point, will not be used in other contexts.

9. *Planning reporting of results*
   The results are supposed to be used internally by the commissioner of the study, which is CBS.

3 Life Cycle Inventory Analysis

The system boundaries/flow diagrams (Figure 2, 3, 4) show the three product systems. Comparison between the flow diagrams shows that the systems contain different operations. However, many processes are the same for some of the systems (e.g. packaging and use of plastic). Yet, magnitude of the flows varies between the systems (which cannot be seen in the flow diagrams). Therefore, all of the processes are modelled in all the systems, except for the packaging and colouring, which are disregarded due to very small amounts and influence. This will be further discussed in the interpretation section.

3.1 Data collection

The applied data has been carefully collected using product data sheets and interviews/e-mail correspondences/phone calls. The data is reviewed and verified by the respective companies involved in the study. In the beginning there were other interesting products, but they where discarded due to insufficient data and lack of time and will of the suppliers to cooperate. Some estimations have been necessary when data sets from the software tool did not correlate with the data collected. A list of materials with classification of data specificity as well as representative data sets used in the software tool can be found in Appendix B, Table 7, 8 and 9.

System 1 Glass bottle, Retap [13]
Data was retrieved as product data sheets with information about material, mass, production location, distribution method and waste handling. The mass of the glass bottle was missing, thus the weight was measured manually. The data specificity for this product is classified as very high as it is measured for the specific product and the processes/materials are documented from the specific manufacturer. However, data for washing in dishwasher are based on a technical data sheet issued by a supplier and a scientific article [4] [12].

System 2 Cardboard Carton, Postevand [8]
Data was retrieved from an interview and a questionnaire together with direct measurements of the product mass. The questionnaire revealed the distribution methods, material types and waste handling. The data specificity for this product is therefore classified as very high. There was no need for generic data representation for the processes involved with this product. However, when the system was modelled in SimaPro not all of the processes did exist with the right geographical data, thus the process is not of the highest quality.

System 3 Plastic bottle [5]
The data for the plastic bottle is found online concerning which materials it consists of, and the specific bottle from the manufacturer is measured in order to find the specific mass for the different plastic types. The data specificity is therefore separated between high and medium level.

3.2 Inventory

The inventories for the three product systems are shown below. The inventory for the distribution bottle can be found in Appendix C Table 10.

Table 3: Inventory for glass bottles.

Retap
126 pieces

	Materials	**Amount reference flow**	**FU amount**	**Waste flow**	**Transport Mass**	**Transport Distance**	**Transport**
	-	**kg**	**kg**	**kg**	**kg**	**km**	**t.km**
Production							
Glass body	Borosilicate glass	0,19	1,44		1,41	1040	1,46
Lid	Thermoplastic elastomer (TPE)	0,02	0,1512		0,1512	280	0,7056
End of life							
Incineration of lid				0,1512			
Recycling of glass				1,44			

Table 4: Inventory for cardboard bottles.

Postevand
1008 stk

	Materials	**Amount Reference flow**	**FU amount**	**Waste flow**	**Transport Mass**	**Transport Distance**	**Transport**
	-	**kg**	**kg**	**kg**	**kg**	**km**	**t.km**
Production							
Cardboard body	Coated FSC paperboard	0,034	34,27		34,27	2380	81,57
Content	Water	0,5	504		504	168	84,67
Lid	Polypropylene	0,002	2,016		2,016	2380	4,80
End of life							
Credit (incineration)	Coated FSC paperboard			-34,27			
Credit (incineration)	Polypropylene			-2,016			

Table 5: Inventory for plastic bottles.

Plastic Bottle
378 pieces

	Materials	**Amount Reference flow**	**FU amount**	**Waste flow**	**Transport Mass**	**Transport Distance**	**Transport**
	-	**kg**	**kg**	**kg**	**kg**	**km**	**t.km**
Production							
Bottle of plastic	PET Resin	0,018	6,84				
Cap	Polypropylene	0,005	1,89				
End of life							
Credit (recycling)	PET + Polypr.	0,023	8,69	-8,69			
Transport							
Distribution					197,69	280	55,35
Recycling					8,69	50	0,43

4 Impact Assessment

4.1 Results

The results are calculated using the impact methods ReCiPe midtpoint (H) 2008 and ReCiPe endpoint (H) 2008 with a comprehensive database from EcoInvent 2016 utilized by the LCA tool, SimaPro. The results below are presented for the three assessed product systems as characterized midpoint impact categories. Figure 5 shows the most and least contributing results from each product system highlighted with red and green respectively. The majority of negative contributions are governed by the cardboard based product, Postevand. The Retap bottle has the smallest impact in 15 out of 18 impact categories.

ReCiPe Midpoint (H)				
Impact category	Unit	Retap	Postevand	Plastic
Climate change	kg CO2 eq	9,27E-01	4,79E+01	6,98E+00
Ozone depletion	kg CFC-11 eq	1,28E-07	7,58E-06	1,44E-06
Terrestrial acidification	kg SO2 eq	1,44E-03	1,73E-01	2,06E-02
Freshwater eutrophication	kg P eq	7,95E-05	1,08E-02	1,83E-03
Marine eutrophication	kg N eq	6,26E-05	6,58E-02	1,39E-03
Human toxicity	kg 1,4-DB eq	1,51E-01	1,36E+01	3,89E-01
Photochemical oxidant formation	kg NMVOC	2,21E-03	2,38E-01	3,77E-02
Particulate matter formation	kg PM10 eq	9,77E-04	1,80E-01	1,23E-02
Terrestrial ecotoxicity	kg 1,4-DB eq	1,28E-04	1,89E-02	3,80E-03
Freshwater ecotoxicity	kg 1,4-DB eq	1,25E-02	8,89E-01	1,41E-01
Marine ecotoxicity	kg 1,4-DB eq	1,11E-02	8,58E-01	1,40E-01
Ionising radiation	kBq U235 eq	2,89E-02	-2,60E-01	2,32E-01
Agricultural land occupation	m2a	-1,34E-01	3,01E+02	-6,04E-01
Urban land occupation	m2a	1,43E-02	3,38E+00	4,71E-01
Natural land transformation	m2	2,81E-04	2,04E-02	3,05E-03
Water depletion	m3	6,63E-03	-1,90E-01	-6,09E-02
Metal depletion	kg Fe eq	4,93E-02	3,54E+00	2,14E-01
Fossil depletion	kg oil eq	3,23E-01	1,69E+01	3,14E+00

Figure 5: Characterized midpoint results, showing the highest(red) and lowest(green) impact in each category.

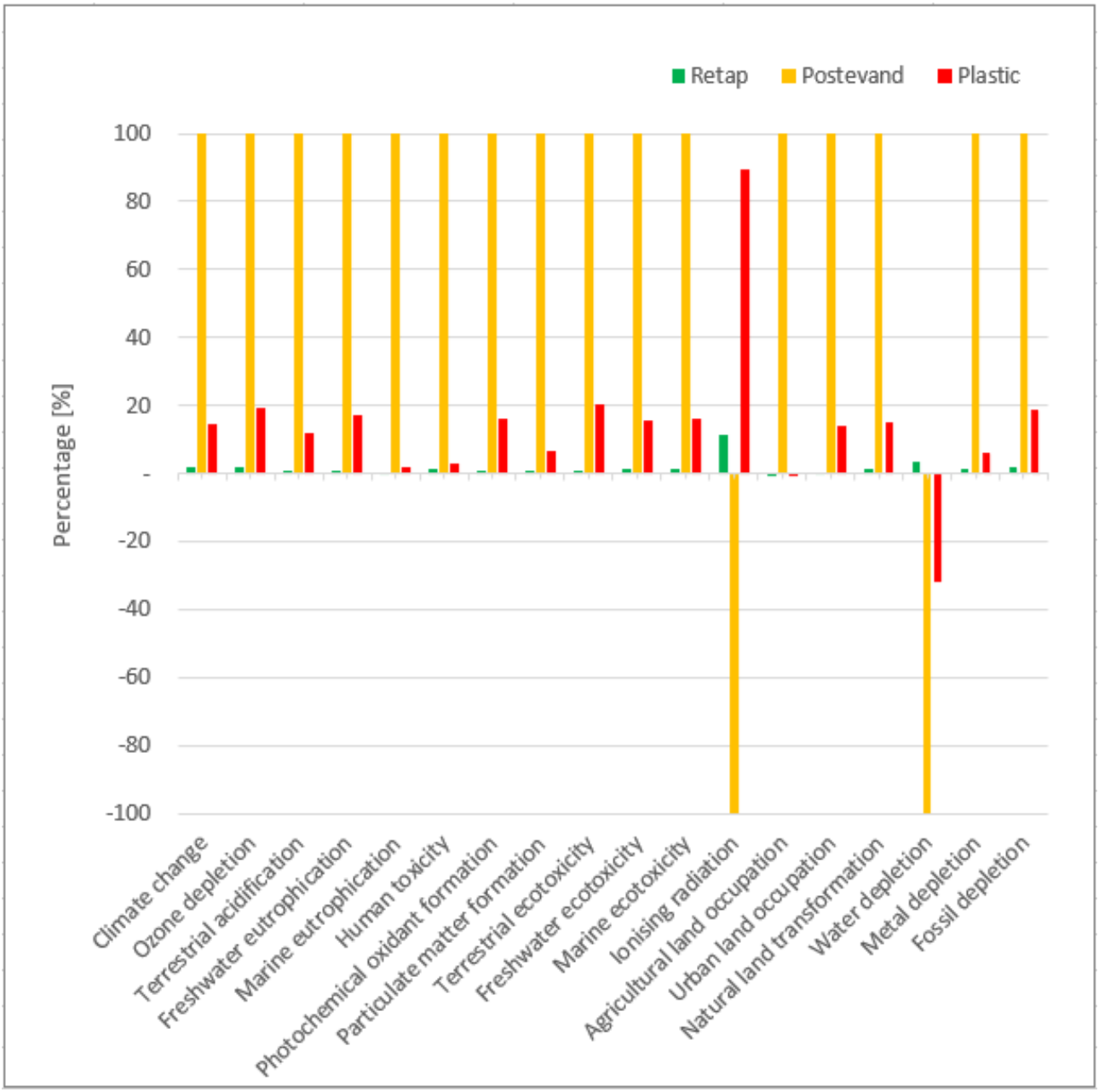

Figure 6: Relative midpoint results with Postevand as reference, calculated with ReCiPe Midpoint (H).

Figure 6 shows a comparison of the midpoint results for the three systems. The comparisons for each impact categories are made related to Postevand, which have the highest impact in all impact categories except for "Ionising radiation" and "Water depletion", where the system has the smallest impacts. Postevand has a negative outcome for the impact category "Ionising radiation" and "Water depletion", which is caused by the incineration process of cardboard.

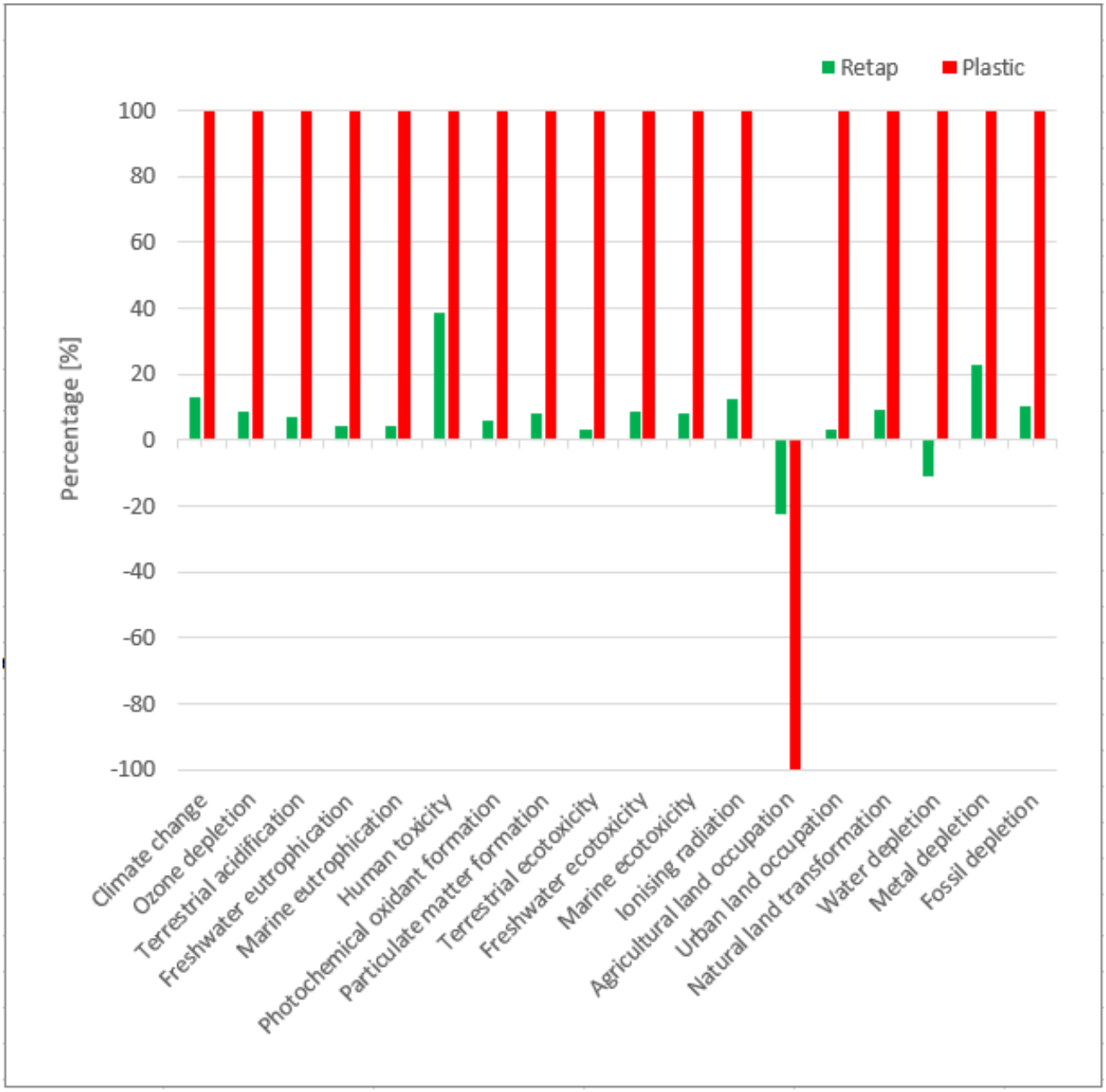

Figure 7: Relative midpoint results for the two best performing systems, with the plastic system as reference.

Figure 7 also illustrates the relative midtpoint results as Figure 6. However, Postevand is excluded and the results are shown relatively to the plastic bottle. Figure 7 illustrates how much better the Retap bottle performs compared to the plastic bottle. The impact caused by the Retap bottle is less than 40% of the impact in all categories compared to the plastic bottle. The Retap system accounts for around 20% of the impact from the plastic bottle system in a few impact categories, though most of the categories only account around 10% or less of the impact from the plastic bottle.

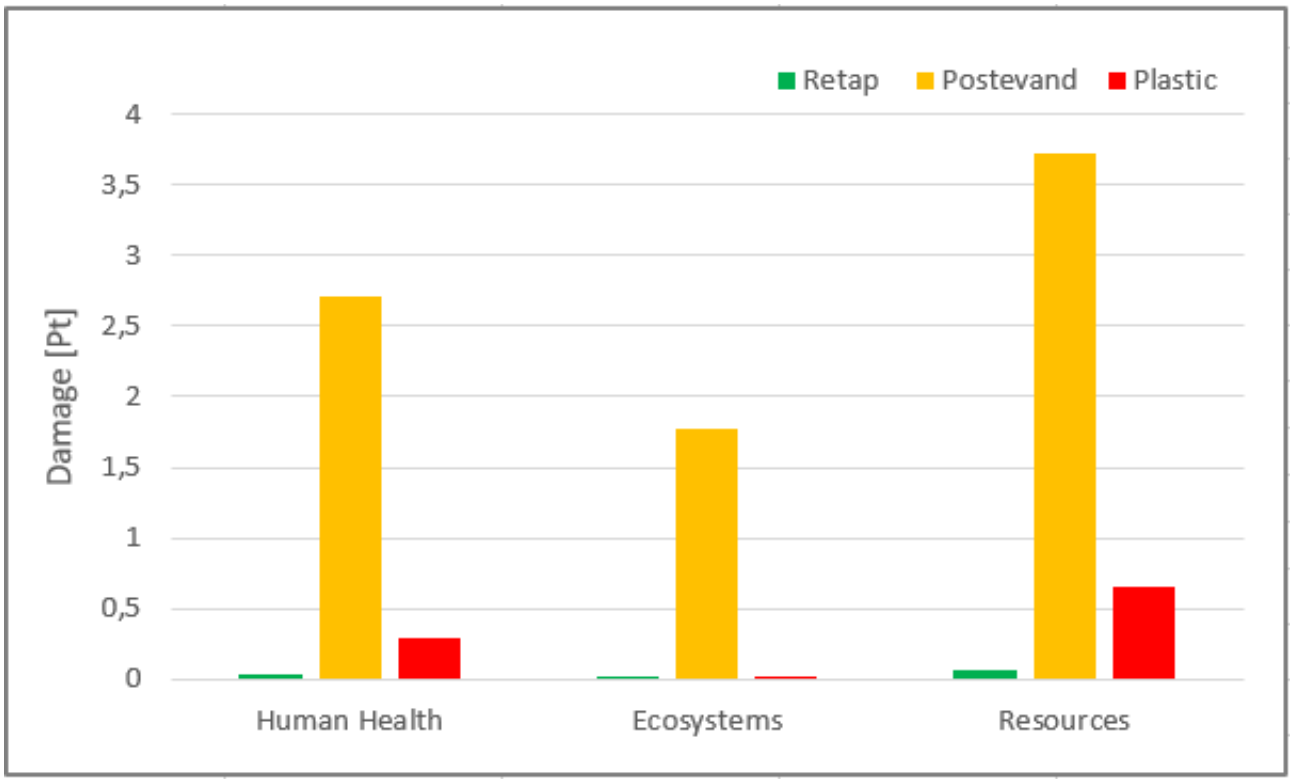

Figure 8: Normalized Endpoint results for each system, weighted with world citizens.

The normalized endpoint impacts of the three product systems are presented in Figure 8 in relation to an average world citizen. It emphasizes the large difference between the Postevand system and the two others in all categories. The Postevand system has a contribution to the three endpoint categories with around 2 to 3 times of an average world citizen's yearly impact. Whereas the other two systems show significantly less than 0.5 times an average world citizen's yearly impact in all damage categories except for plastic in "Resources".

A single score has been generated using the external normalized endpoint results weighted by the 'Average' methodology. The Retap bottle system reaches a score of 0.1 Pt, which is ten times smaller than the second best system; the plastic bottle system, which has a score of 1.0 Pt. The Retap system is around 80 times smaller than the Postevand system with a score of 8.2 Pt.

4.1.1 System 1 Retap bottle

Figure 9 illustrates the climate change network for the Retap system with midtpoint characterized results. The borosilicate glass has the biggest impact on climate change as presented in Figure 9, hence, a sensitivity analysis of this part of the product system is relevant. The transport do not have a major impact despite the long transport distance from Czech Republic, this is due to that the bottles are transported empty all the way to Copenhagen. The recycling of the glass have a large negative impact on the system.

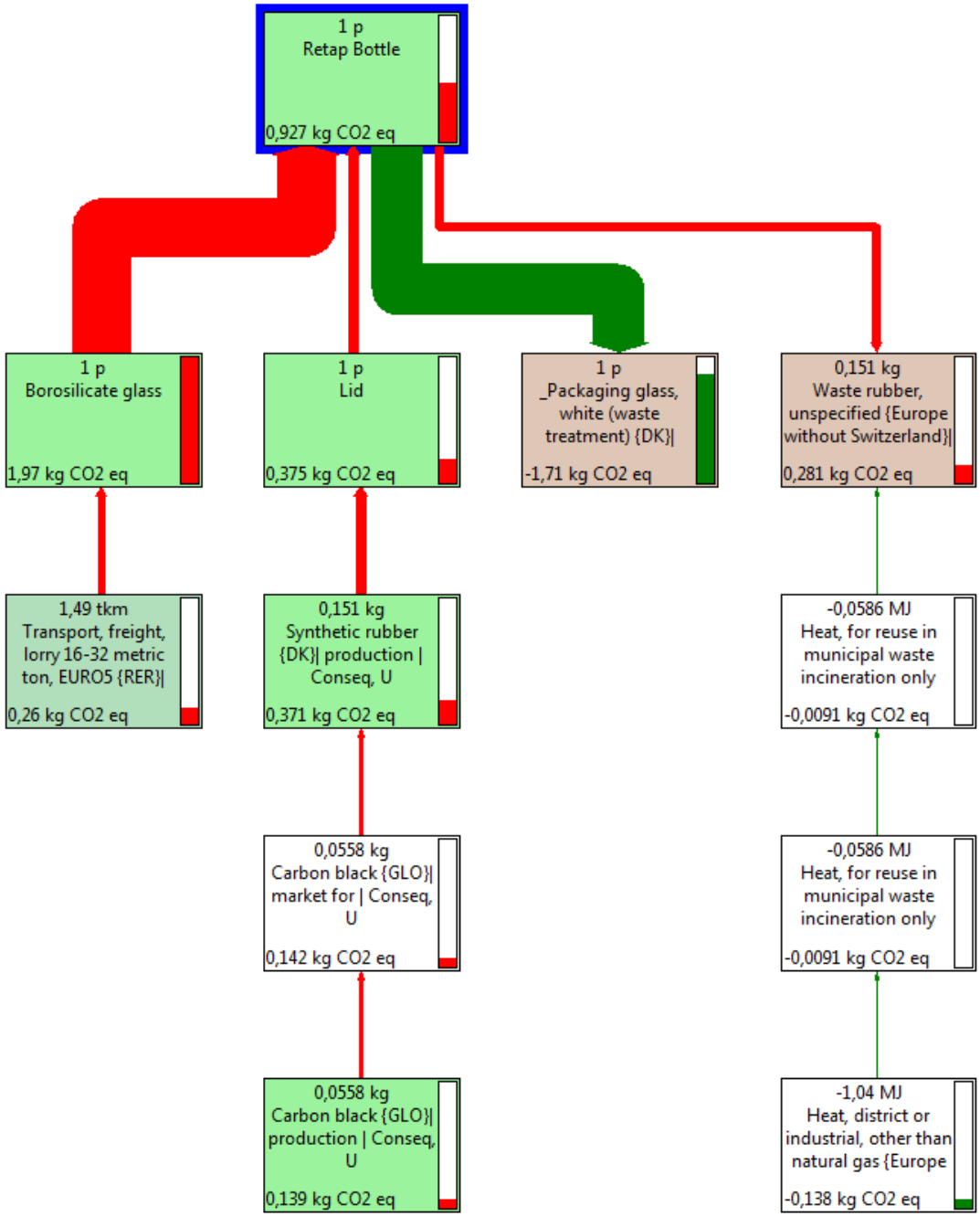

Figure 9: Network for Retap, Climate Change ReCiPe midpoint, characterized results.

4.1.2 System 2 Postevand

Figure 10 shows the network for the the Postevand system with respect to the climate change impact category. The main impact is caused by the cardboard production. The transport also have a noteworthy impact, this is different from the Retap system hence the bottles are transported from Odense to Copenhagen containing water in addition to long distance without water. The incineration (waste paperboard) has a negative impact, since it is incinerated in Denmark, thus use of other fossil fuels are avoided.

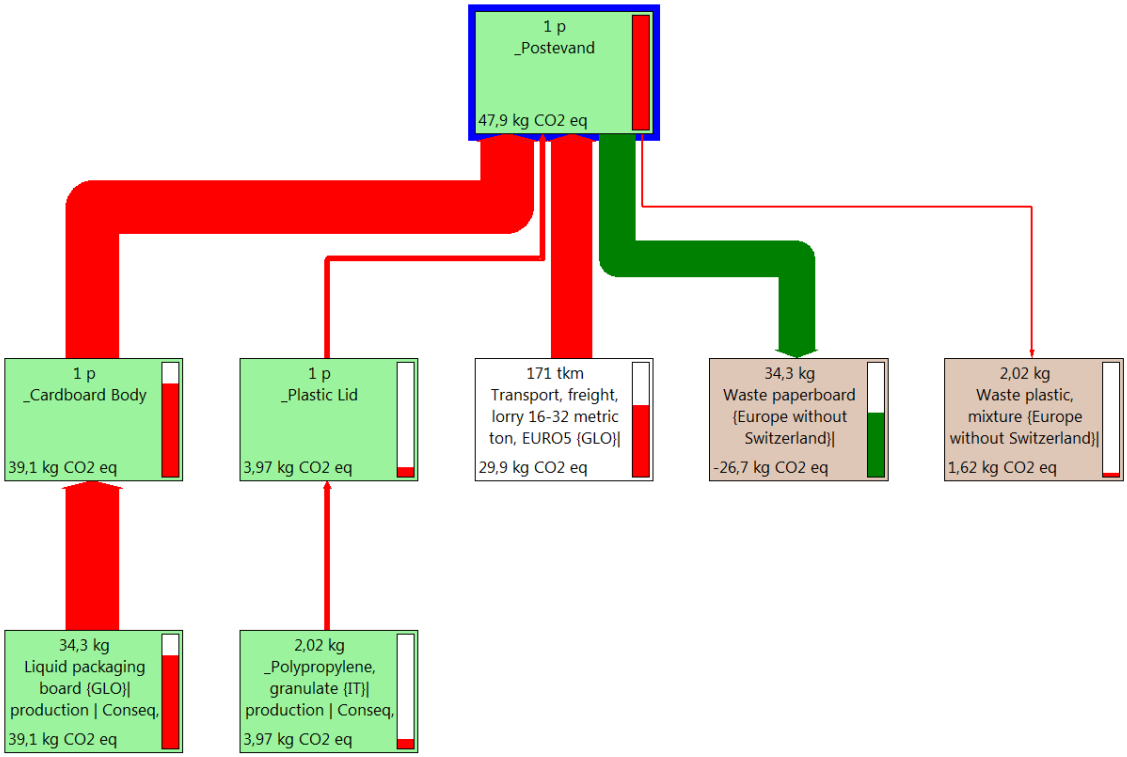

Figure 10: Network for Postevand, Climate Change ReCiPe midpoint, characterized results.

4.1.3 System 3 Plastic bottle

The network diagram in figure 11 shows that the bottle body of polyethylene contributes most to the environmental impact on climate change. On the other hand the EoL for the polyethylene impacts climate change negatively when the bottles are recycled. The transport contributes to the impact on climate change despite the short distance, because the bottles contain water during transport.

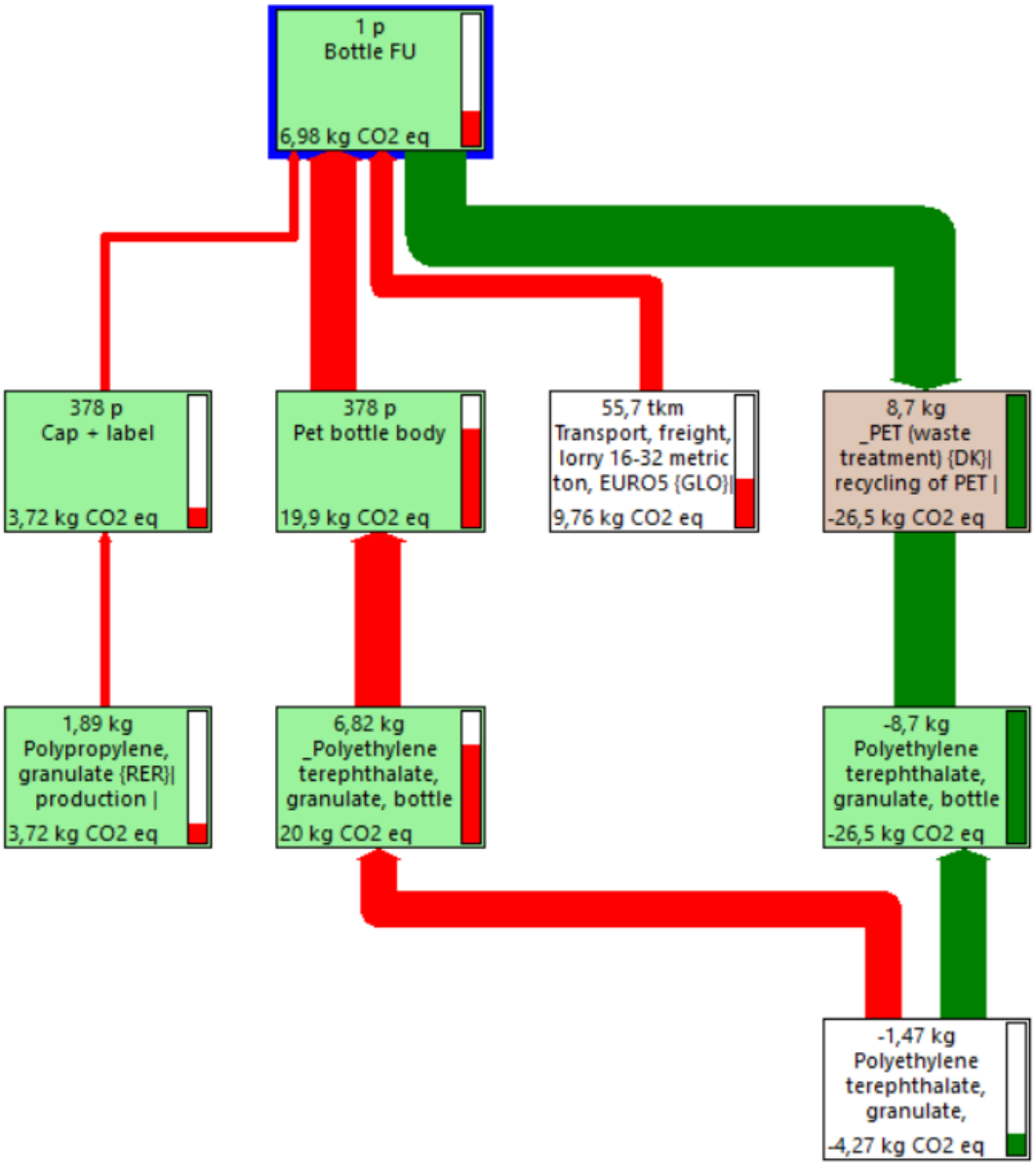

Figure 11: Network for Plastic, Climate Change midpoint, characterized results.

4.2 Sensitivity Analysis

To determine the most sensitive parameters of the model systems, a sensitivity analysis has been performed. It investigates what the consequences of a small change in input values are on the respective impact categories. A positive change of 10% in mass of the most significant material has been studied using following equation.

$$[S] = (\Delta output/output)/(\Delta input\ n/input\ n)$$

If the average sensitivity coefficient |S| is higher than 0.3 (across scenarios) or if the highest sensitivity coefficient is higher than 0.5, the parameter is considered important.

System 1 Glass bottle, Retap
The average sensitivity coefficient across impact categories is larger than 0.3 namely about 0.44 which means the mass and the process for the borocilicate for the glass body are two important parameters to the system regarding possible uncertainties. See the sensitivity analysis in figure 12. Further, six of the impact categories are subject to values higher than 0.5, underlining that the mass of and process for borosilicate are important parameters.

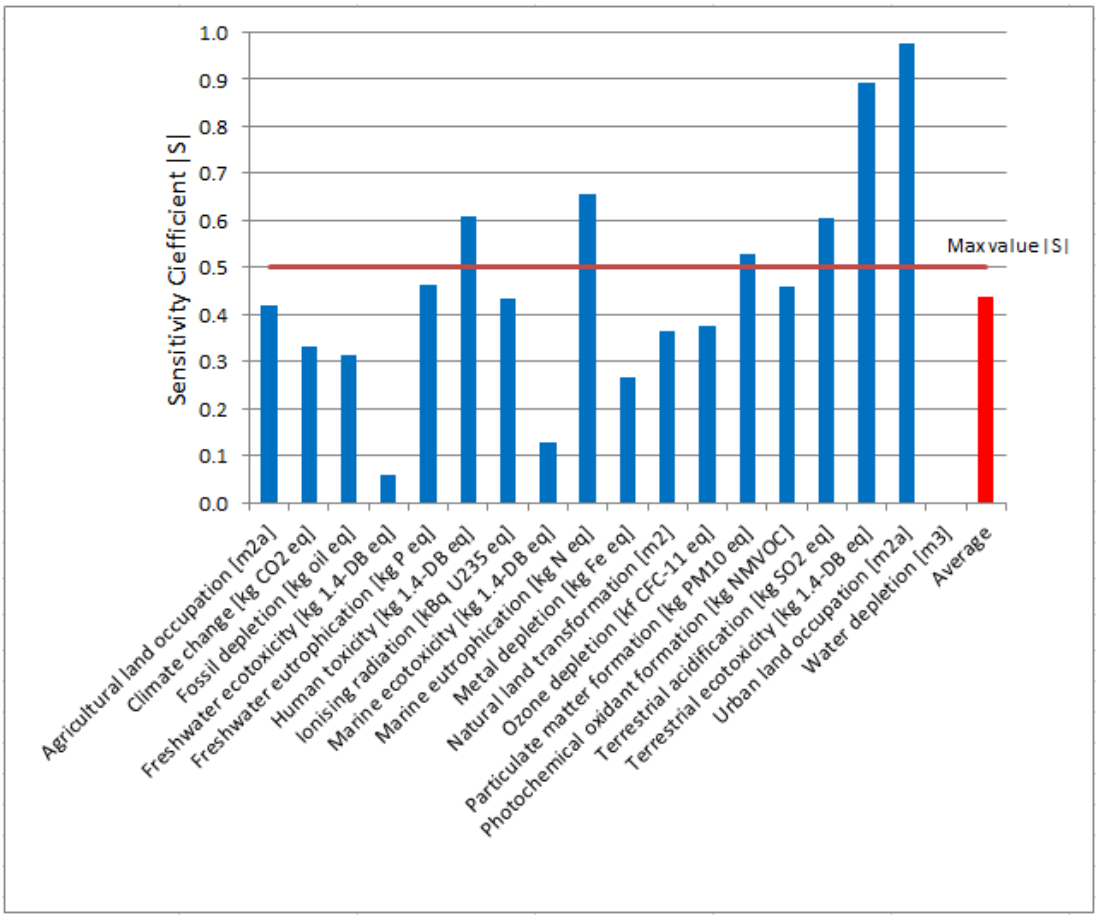

Figure 12: Sensitivity analysis of the Retap system with red bar showing the average sensitivity coefficient across impact categories at about 0.44 and the horizontal line displays the max value the respective impact categories must exceed to be considered an important parameter to the product system.

System 2 Cardboard Carton, Postevand

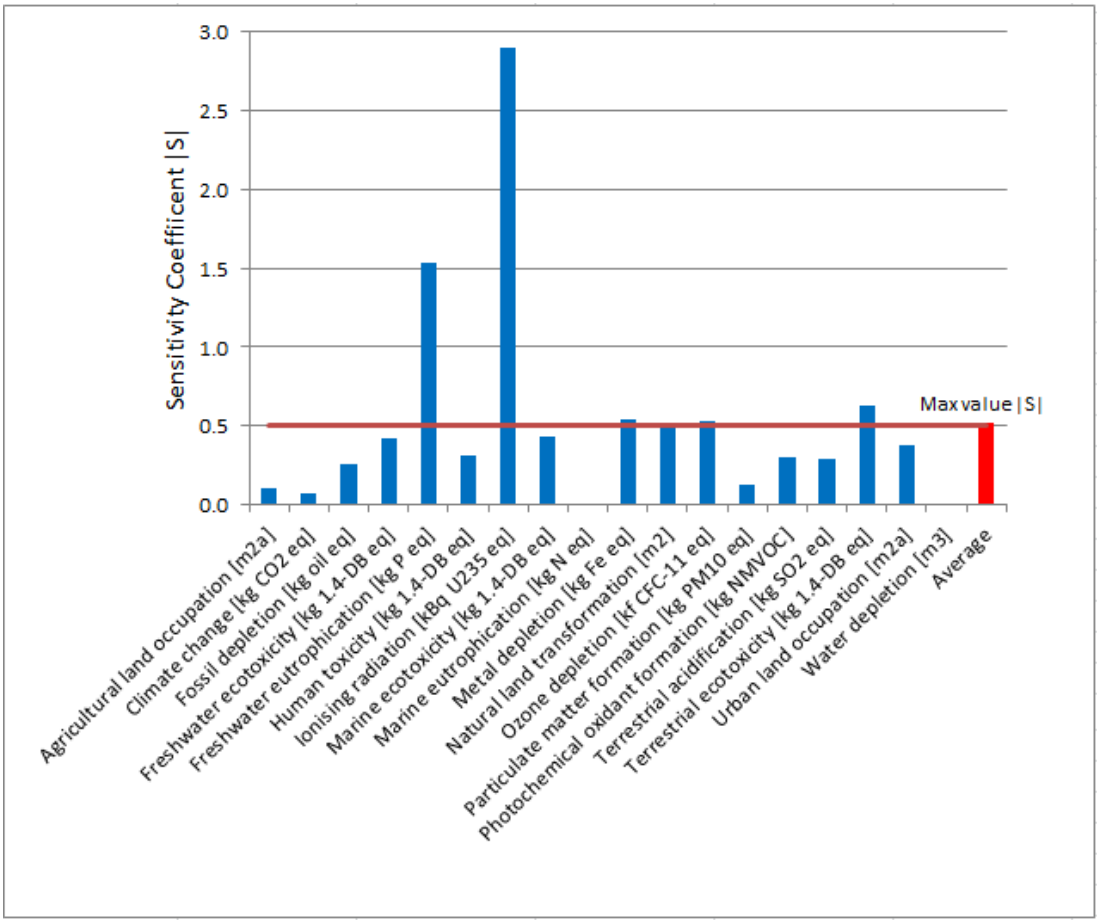

Figure 13: Sensitivity analysis of the Postevand cardboard bottle with red bar showing the average sensitivity score across impact categories at about 0.9 and the horisontal line displays the max value the respective impact categories must reach otherwise they are considered as an important parameter to the product system

Ecoinvent does not include FSC certified cardboard in any datasets, which might create some uncertainty, see Appendix B for further data detailing. Five impact categories exceeds the maximum value of 0.5 and the average is about 0.52 across categories. It can be seen that Freshwater eutrophication and Ionizing radiation are affected the most by a change in cardboard mass. The majority of the Postevand bottle consists of FSC cardboard, harvested from European wood. The applied data set representing this flow does not comply technically with the real system, the best alternative process is chosen to be a generic liquid packaging cardboard. The energy source for this process is not modified to meet the Italian means of producing electricity, hence this resulted in explainable data output.

System 3 Plastic bottle
Since the PET bottle body impacts Climate change the most in Figure 11, a sensitivity analysis is completed for this process. The sensitivity analysis can be seen in figure 14. There is a large division in how severely the impact categories are affected by the change in plastic mass. Figure 14 displays that seven impact categories are well above 0.5. In average the sensitivity coefficient reaches 0.33 which means that the PET bottle body has a significant importance to the uncertainty of the system.

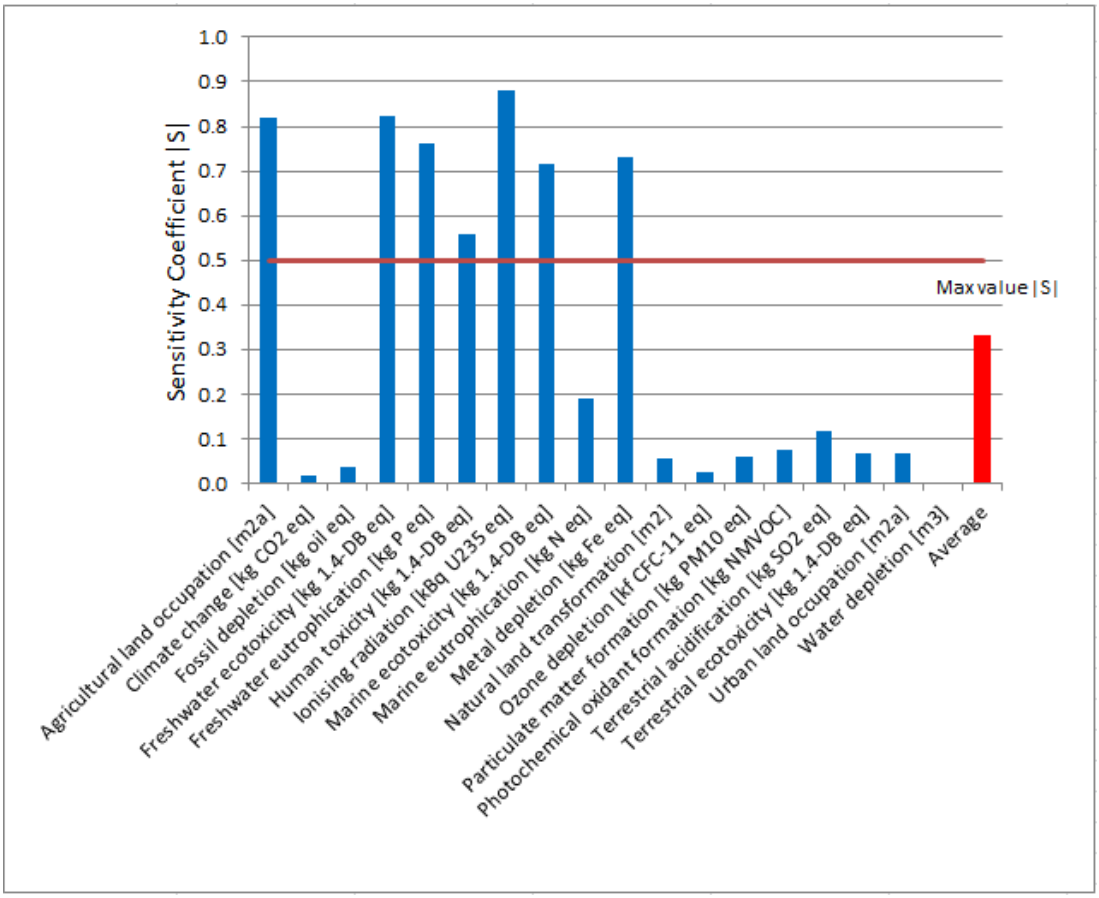

Figure 14: Sensitivity analysis of the plastic bottle 10% more mass (18g changed to 20g). Red bar showing the average sensitivity score across impact categories and the horizontal line displays the max value the respective impact categories must exceed to be considered an important parameter.

4.3 Break Even Point

The Retap system's environmental performance is remarkably better than the two other systems. These results are highly dependant on the number of times the bottle is reused.

In the Retap system it was defined that the bottle would be used three days at the conference and further reused 47 days after the conference (50 times in total).

For every time the bottle is reused the impacts are divided out on the total number of uses. This means the second time a bottle is used the impacts are divided in half. The third time it is used it will only be credited for 33% of the total impact. This relationship forms an exponentially decreasing function, which can be seen at Figure 15. The calculation is based on the weighted endpoint results, which is presented in single scores.

To clarify the number of times the Retap bottle must be reused in order to perform better than the plastic bottle system, a 'break-even point' has been calculated. The break-even point indicates the intersection between the two single-score/use-graphs for the plastic and Retap systems.

The Retap bottle must be reused seven days to perform better than the plastic bottle, this is shown in Figure 15.

A great deal of uncertainty is connected to this practice if the participants get the bottles. It is therefore recommended that CBS gather the bottles when the conference is over, furthermore because the price of the Retap bottle encourage to reuse it many times internally at CBS.

Furthermore, the break even point is based on weighted results where the methodology carries a great deal of uncertainty, therefore the results should be carefully presented according to ISO 14044.

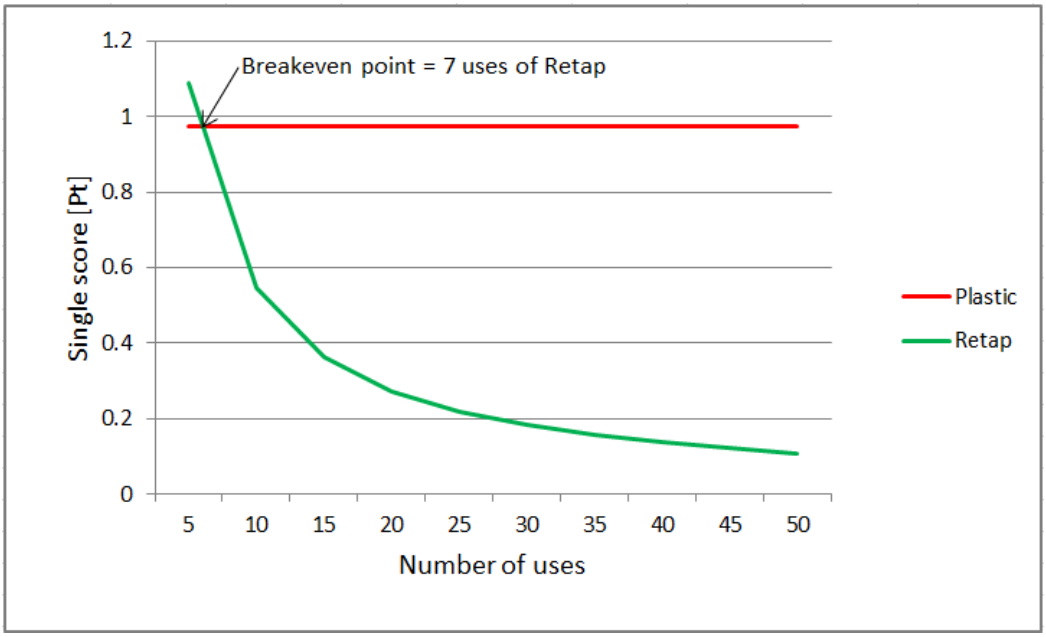

Figure 15: The x-axis divert in number of bottles for the two systems. The red graph contains one plastic bottle per. number of use per person and the green graph shows the decreasing impact for the Retap bottles. The break-even point is illustrated where the two graphs intersect after 7 uses of the Retap bottles.

5 Interpretation and uncertainty

This study has been carried out using gathered data and applies a number of assumptions. There will always be uncertainties when performing a LCA and these will be elaborated in this section. The LCA results derived through SimaPro are interpreted with the uncertainties in mind.

The results are not applicable to other situations or conferences, hence the study examines a specific FU defined for a particular conference at CBS.

The methodology and the model follow the cradle-to-grave approach, however do not include assumptions according to the social perspective. The behaviour of the participants is taken into account concerning whether the containers will be reused and how many times they will be used. The social perspective is used to define how many reference flows will fulfill the FU for each system (number of bottles). It is assumed that the Postevand bottle will not be reused as it is associated with a milk carton. Even though, it can be refilled it does not invite you to do so.

The secondary functions for each system are identified in the scope phase. There are always some uncertainty associated with the assumptions concerning how the secondary functions are handled. System expansion is used in all of the systems. This specific study depends on CBS and the participants behaviour concerning the EoL of the bottles. Since the people who will use the bottles participate at a conference about sustainability, it is assumed that they must have some interest in doing the best for the environment and therefore choose the best EoL option. It is assumed that 100% of glass in the Retap system is recycled, thus the system is credited for the glass and production of glass with new virgin material is avoided.

100% of the Postevand bottles will be incinerated, this is almost inevitable in Denmark therefore no further uncertainties are associated with this system expansion.

It is assumed that 100% of the plastic bottles will be recycled, therefore no incineration process is included in the system boundaries for the plastic system due to the fact that the Danish recycling system recycles 98% of all plastic bottles. Other waste scenarios have been discussed for this. In SimaPro two situations have been modelled representing 100% recycling and 50% recycling where the other 50% are incinerated.

Damage category	100% Recycle 0% Incineration	50% Recycle 50% Incineration	Factor
Human Health	9,7E-04	3,1E-03	3,2
Ecosystems	7,0E-05	1,2E-04	1,8
Resources	2,2E-03	5,9E-03	2,7

Figure 16: ReCiPe Endpoint normalized (World) results for the plastic bottle system where 100% is recycled and where 50% is recycled and 50% is incinerated respectively

As Figure 16 shows the 50%-scenario performs worse than the 100%-scenario with human health being markedly different with a factor of 2.9. Recycling is therefore preferable when it comes to waste handling of the plastic bottles.

It is important that the plastic bottles are recycled, after use at the conference, otherwise the system does not perform as well as this study states.

The packaging is not included in any of the systems. The system boundaries 2, 3 and 4 illustrate that packing exists in all of the three systems, however data accessible about the amounts and types of

packaging is limited. The packaging materials and amounts are not the same for all of the systems. This results is an uncertainty since the glass bottles most likely need more protection during transport, however the system has the least number of bottles.

The printing process exists in two of the systems (plastic and Postevand). The printing color has been investigated using SimaPro, which reveals a multitude of different hazardous chemicals. The results showed that the printing process has a high impact per g compared to plastic and cardboard. The color quantities are extremely small compared to the total mass of the systems and is therefore disregarded.

From Figure 5 it can be stated that the Retap system overall has the least environmental impact, thus this system could be recommended at this point in the analysis. Figure 5 also shows that the Postevand has the largest impact in almost all of the midpoint impact categories. Figure 6 illustrates the relative midpoint results in relation to Postevand which once again shows that it has far higher contribution. In order to get a more detailed view of of the two best performing systems, Postevand was left out and Figure 7 shows the relative contribution in relation to the plastic system. From this illustration it can be concluded that Retap performs markedly better in all categories except Agricultural land occupation.

The Network-function in SimaPro showing the results for climate change is used to give an overview of potential processes with high uncertainty and large influence on the system (Figure 10, 9 and 11). Since the systems only contain a few materials it is easy to identify the most essential processes for the sensitivity analysis. The sensitivity analyses for the bottle body for all three systems showed that the mass and process of the bottle materials are important parameters since all show an average |S| above 0.3 and several impact categories have max |S| above 0.5. Therefore, it is necessary to do an extra check of the bottle bodies in terms of which processes that are used and the mass. This analysis showed only smaller issues since the data quality for all bottle bodies are very high or high. See Appendix B, Table 7, 8 and 9.

It is assumed that the Retap bottles will be used 50 times in total where the three days at the conference accounts for three out of the 50 times. This number is based on an assumption made after long discussions in the group. It carries a great deal of uncertainty. The number of uses could be greater or lower depending on the user behaviour. The user behaviour have a huge influence on the overall impact of the system. A break-even point (based on the weighted single score) between the Retap system and the plastic bottle system shows that CBS needs to reuse the Retap bottles seven times to even out the impact for the plastic bottle system. This means that every reuse after the seventh will enhance the sustainability compared to the other systems, but also indicates that if CBS only host one conference the plastic bottle is the most sustainable solution.

6 Conclusion and recommendation

Recommendations for CBS

This study documents that the most sustainable option for water distribution at the CBS conference is to use containers which encourage refilling.

The Postevand bottle cannot be recommended to use at the conference, even though the uncertainty is greatest in this system.

The two other systems perform markedly better than the Postevand system. When looking at the single scores, assuming 50 times reuse of the Retap bottle, the Retap system performs a factor of 10 better than the plastic bottle system. However, if the systems were modelled only containing the three days at the specific conference the plastic bottles would have the smallest impact.

The break-even point for the plastic and Retap system has been calculated in order to figure out how many times the Retap bottles should be reused to even the impact from the plastic bottle system. The break-even point calculation shows that it is a better solution to use the Retap bottles compared to the plastic bottles if they are used more than 7 conference days.

The recommendation for CBS is to use the Retap bottles, provided that they keep the bottles for future conferences. This also makes sense according to the price of the bottles since a single Retap bottle costs 104 DKK while a generic plastic bottle costs 0.5 DKK + deposit. In an economical view the Retap bottle will however have to be used at approximately 75 similar conferences in order to reach the price level of the plastic bottles.

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A Appendix - Distribution bottle

Table 6: Impact from distribution bottles.

Damage category	System with distribution bottle	Without distribution bottle
Human health	1.0582 E-03	1.0579 E-03
Ecosystems	7.656 E-05	7.657 E-05
Resources	2.387 E-03	2.386 E-03

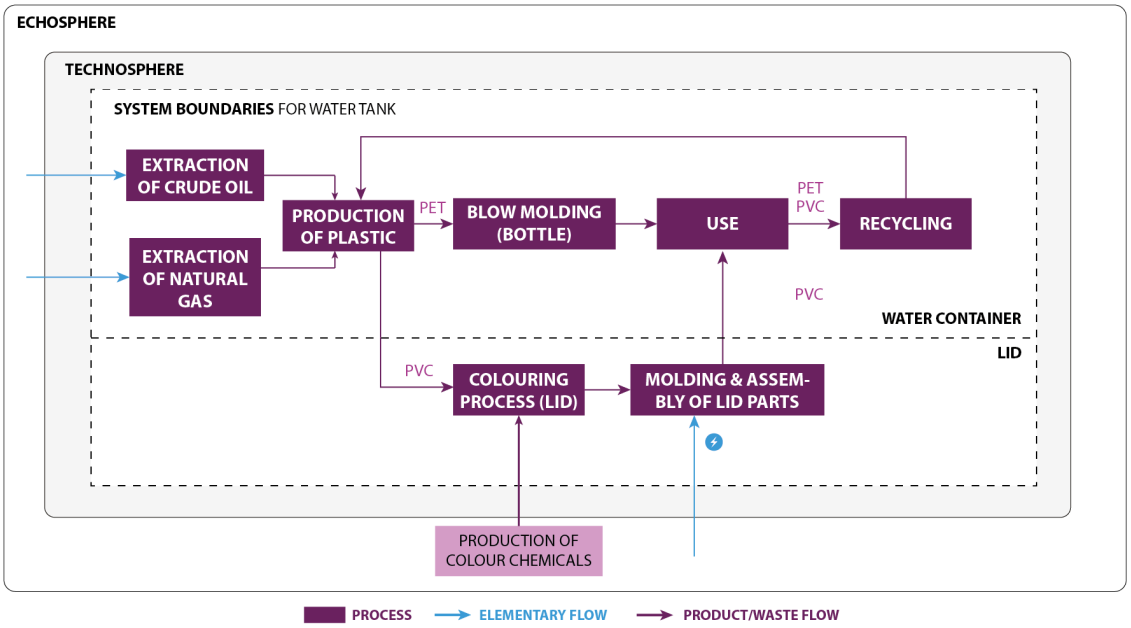

Figure 17: System Boundaries for distributing water tank.

B Appendix - Data quality

Table 7: Description of data quality

Postevand			
Process In SimaPro	Quality of Process	Quality of mass/amount	Note
Liquid packaging board {GLO}| production | Conseq, U	Data collected from the 4 main European mills that produce more than 95% of European LPB production volume Last edited: 2013-03-20	Mass of bottle body has been measured on a scale.	Firstly, modelled with changed water data from GLO to IT. That yielded unrealistic results for water depletion so the GLO was thus used instead. Original cardboard is FSC-certified but it was not possible in this modelling.
Polypropylene, granulate {IT} | production | Conseq, U (GLO)	28 European production sites.Some emissions are not included along recyclable wastes. Last edited: 2015-10-15	Mass of lid has been measured on a scale.	All types of water input are changed to Italian (IT).
Transport, freight, lorry 16-32 metric ton, EURO5 {GLO}| market for | Conseq, S	Last edited: 2011-08-02	Transport is the measured distance from the known location provided by the respective companies.	
Waste paperboard {Europe without Switzerland}| treatment of waste paperboard, municipal incineration | Conseq, S	Technology is Swiss, data are Europe. Last edited: 2016-07-11	100 % is assumed incinerated. There is uncertainty related to this regarding some Postevand bottles may be recycled.	
Waste plastic, mixture {Europe without Switzerland}| treatment of waste plastic, mixture, municipal incineration | Conseq, S	Technology is Swiss, data are Europe. Last edited: 2016-07-08	100 % is assumed incinerated.	

Table 8: Description of data quality

Retap Bottle			
Process in SimaPro	Quality of Process	Quality of mass/amount	Note
Packaging glass, white {DK}| packaging glass production, white, without cullet | Conseq, U	A mix of GLO, RoW and RER data. Mix of present used technologies in Europe. Last edited 2013-03-26		Water and Natural gas have been changed to Danish values. Otherwise the data is GLO, RoW and RER.
Transport, freight, lorry 16-32 metric ton, EURO5 {RER}| transport, freight, lorry 16-32 metric ton, EURO5 | Conseq, S	A mix of Swiss and European data. Last edited 2016-06-15		
Synthetic rubber {DK}| production | Conseq, U	ESTM used for technical products but has many applications. Created: 2010-07-28		Water for cooling and electricity mix are changed to Danish values. Otherwise the data is GLO and one RER
Ethoxylated alcohol (AE7) {GLO}| market for | Conseq, U	Expert judgement for product specific transport distances. Undefined technology level. Created: 2011-08-02		Only alcohol is a ccounted for in the cleaning detergent.
Tap water {DK} market for | Conseq, U	Assumed that no additional energy needed to compensate loss of load. Last edited: 2014-05-27		Water emission is Danish data. The others are Europe w.o. Switzerland and GLO
Packaging glass, white (waste treatment) {DK}| recycling of packaging glass, white | Conseq, U	Created by PRé consultants. Electricity and transport not included.		Avoided product is the first row of this table.
Waste rubber, unspecified {Europe without Switzerland}| treatment of waste rubber, unspecified, municipal incineration | Conseq, U	Average of Swiss plants in 2010. Last edited: 2016-07-08		

Table 9: Description of data quality

Plastic Bottle			
Process in Sima Pro	Quality of process	Quality of mass/amount	Note
Polyethylene terephthalate, granulate, bottle grade {DK}| production | Conseq, U	Danish, European and global data. Process contains the right technology for moulding. No concerns according to time	Mass of bottle has been weighted, which is very high quality.	The flow has been changed to contain Danish electricity - otherwise the inputs are global or European data.
Polypropylene, granulate {RER}| production | Conseq, U	Average European data, should be Danish. Time and technology okay for this process.	The mass is measured, however some uncertainty caused by the small mass, which is difficult to measure precise. The quality is high.	Process for label and cap. Do not constrain Danish data.
Transport, freight, lorry 16-32 metric ton, EURO5 {GLO}| market for | Conseq, S	New data (2009 to 2016). Global data is ok.	The distance(locations) and mass is very certain. Very high quality.	The size is chosen from an average Danish truck size perspective.
PET (waste treatment) {DK}| recycling of PET | Conseq, U	High quality. Avoids the right process - however European data in flow. Allocate the electricity in the recycling process.	100% of mass is recycled (some uncertainty to this assumption).	Electricity changed to Danish data. Avoids new production of this process: Polyethylene terephthalate, granulate, bottle grade {RER}| production | Conseq, U

C Appendix - Inventory

Table 10: Inventory for distribution bottles

Distribution bottle
6 pieces

	Materials -	**Amount - reference flow** kg	**FU amount** kg	**Waste flow** kg
Production				
Bottle of plastic	PET	0,35	0,014	
Lid of plactic	PVC	0,164	0,0066	
Credit (recycling)				
Bottle (recycling)	PET			0,014
Lid (recycling)	PVC			0,0066