COMPARISON OF A WATERCOOLER AND OTHER ALTERNATIVES IN TERMS OF THEIR ENVIRONMENTAL IMPACTS USING THE LCA METHOD

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The environmental impacts of products are evaluated based on an assessment of the influence of material and energy flows that the evaluated product system exchanges with the environment. The University of Southern Denmark is also dealing with this, and from the point of view of sustainable development, drinking watercoolers are being investigated using the Life Cycle Assessment method. This research conducts a Life Cycle Impact Assessment of drinking water supply systems at a university to determine if they fit the institution's sustainability agenda. In the evaluation, the impact of one beverage delivered from watercoolers is compared with beverages from five benchmarked systems. These systems are tap water, ice-chilled water, bottled water, soft drinks and hot drinks. They are set up in scenarios that are directly used for evaluation and subsequent comparison. This study uses a variant of “Cradle-To-Grave” Life Cycle Assessment, where a full assessment occurs from resource extraction to disposal, while using an attributive approach. The results of the life cycle assessment showed which system has the lowest impact and the results are quantified. Finally, based on the results of the life cycle assessment, the most suitable water chiller system is recommended and the University management is provided with information for further decision making.

KEYWORDS

Life Cycle Assessment, Watercooler, Comparison, Sustainability, Drink Supplier

1 INTRODUCTION

Currently, the emphasis is on the development of technologies that are friendly to the environment. It is not just about more energy-saving technologies, but about an overall approach, the aim of which is to minimize all undesirable environmental effects of the operation of the equipment or the production and use of the products themselves. In recent years, there has been an increased emphasis on sustainability, which belongs to the programme of 17 "sustainable development goals" according to the UN organization [Hoosain 2020]. The University of Southern Denmark (SDU) also deals with environmental aspects within its university campus and SDU is among the leading sustainable universities. The ranking is based on the universities’ sustainability activities and efforts [SDU University 2021].

SDU wants to be a sustainable university and has since 2008 reduced energy consumption per full-time equivalent (FTE) by 35% even though in the same period there has been an increase from 2838 to 3816 FTEs, in addition to an increase in the area of SDU from 189102 to 294213 m^2 [SDG´s at SDU 2021]. SDU wants to keep up with this development and therefore wants to look at how it can become even more sustainable and realize its commitment to becoming a sustainable university [SDU Report 2022]. One of SDU's focus points is on reducing CO_2 emissions from today until 2030 [Klimamaal 2021]. The watercoolers on the SDU campus are the subject from the point of view of sustainable development. These watercoolers use energy to cool water that is used by students and staff. At the SDU, there are watercoolers for free use for students and staff. SDU wants to find out what it will mean if the watercoolers are removed from the University, as it is important that both students and staff are well hydrated to get through the day [Static SDU 2021]. It will therefore be necessary to look for other alternative solutions for possible dehydration, such as using hot drinks, soft drinks, bottled water, ice-cooled water, tap water, etc. to reduce energy consumption.

1.1 Case study description

The study described in this article uses theoretical starting points, but it is mainly a "case study" with a specific research subject and it is intended to support the decision making process for determining the fate of the watercoolers on the SDU campus. The intended audience is the management at SDU. The different systems will be compared to find out what the fate of the watercoolers at SDU should be, and how the decision regarding continuation of the watercooler service will affect its potential environmental impact. As all the cases deal with beverages, it enables a comparison using Life-Cycle Assessment (LCA). The LCA should provide the relevant parties at SDU with the information and knowledge needed for the decision regarding the watercoolers’ fate.

LCA is one of the most important information tools used in environmental policy [Jacquemin 2012]. This method is an analytical method for evaluating the environmental impacts of products, services and technologies [Huntzinger 2009, Finnveden 2000]. When evaluating with this method, the entire life cycle of the product is taken into account [Kleinekorte 2020]. The environmental impacts of products are evaluated based on an assessment of the influence of material and energy flows that the evaluated product system exchanges with the environment [Nakano 2011, Hauschild 2018]. The environmental impacts of the product system are always determined in relation to the function of the product or service and thus enable a comparison between alternatives [Azapagic 2000, Ekvall 2004].

An LCA study consists of four basic phases: goal and scope definition, inventory analysis, impact assessment and interpretation. The individual phases of LCA use the results of the other phases. An interactive approach within and between phases contributes to the comprehensiveness and consistency of the study and the presented results [Vinodh 2016, Simion 2013]. The main benefits of the life cycle assessment method are: comparing the environmental impacts of products with respect to their function, assessment of environmental impacts with regard to the entire life cycle of the product, establishing system boundaries to clearly express the scope of the product system, the ability to identify the transmission of environmental problems both in space and between different categories of impact [Azapagic 1999, Pommer 2003].

1.2 Goal and scope definition

Through this LCA, the environmental consequences of using watercoolers to supply drinks are considered. The goal is to determine whether watercoolers are a more environmentally friendly choice or if the alternatives can provide the same service with less impact. The evaluation of impacts is done by comparing four different scenarios. The reference system for this LCA are watercoolers where tap water, ice chilled water, bottled soft drinks, bottled water, and hot drinks, such as coffee or tea are the alternative systems. In this case only coffee is modelled in the hot drinks (the water used for tea preparation is also dispensed from coffee machines, the authors consider this to be interchangeable).

This case study will not be assessing any benefits gained from using the watercoolers such as filtering and sterilizing the water (water quality). Nutritional and other health benefits or consequences provided by the compared systems will also not be considered in this study. **This is because it is an attributional analysis and not a consequential one**. The positive implications to the study and working - environment that the watercoolers may provide to students and staff at SDU due to its free and wide accessibility will not be considered either. The focus of this LCA is solely on the impact of the services the reference and compared systems are providing.

This research study was intended to be innovative and original. Therefore, the first part of this research was the search and research of similar researches. After the search, only one LCA analysis was found, which deals with the reference system – watercooler. This is a publication Life-cycle assessment methodology: the case study of a water cooler machine. The study considered the impacts from the manufacture, use and disposal of the watercooler at the end of its life cycle, also considering the space required for maintenance parts. The study made it possible to find the main sources of the impact of this appliance on the environment [De Monte 2002].

The results of the search for the application of the LCA method of comparative system analyses have already been successful and several researches have been found. The LCA dealing with the tap water system was Water supply and sustainability: life cycle assessment of water collection, treatment and distribution service, in which the analysis shows the shares of impacts in the entire life cycle chain [Del Borghi 2013]. The publication Environmental life cycle assessment of potable water production compares the environmental burdens of two different methods for the production of potable water using an environmental life cycle assessment [Friedrich 2001].

The study Life cycle assessment of bottled water: A case study of Green 2O products analysed the life cycle assessment of four types of water bottles in an attempt to determine the impact of each bottle on the environment [Horowitz 2018]. Water Life cycle assessment of bottled mineral water for the hospitality industry in Northern Italy deals with a similar topic [Grisals 2001].

The life-cycle environmental impacts of carbonated soft drinks are addressed in publication where the result is that the beverage packaged in 2 L PET bottles is the most sustainable option for most impacts, including the carbon footprint, while the beverage in glass bottles is the worst option [Amienyo 2013]. As part of the publication Life cycle assessment of drinking water: Comparing conventional water treatment, reverse osmosis and mineral water in glass and plastic bottles, a life cycle assessment was carried out with the aim of comparing five drinking water consumption alternatives [Garfí 2016]. No study was found (in the official literature) that would compare the watercooler with any replacement system.

2 MATERIALS AND METHODS

The LCA study should provide the management at the university with the information and knowledge needed for deciding the watercoolers' fate on SDU campus. The establishment of the functional unit is done by determining the watercoolers' obligatory and positioning properties. These properties are drawn up to create a qualitative normalization of the service provided by the watercoolers, see Table 1. The functional unit enables that reference system, the watercooler, to be compared to other systems with the same functional unit.

Table 1: The functional unit defined for the watercooler

	Obligatory Properties	**Positioning properties**
Qualities/ Properties	Supply a drink Safe to drink	Ease of use - Time and distance Temperature ≈ 5 °C
Quantity	One unit of drink = 0.5 L of water dispensed from watercooler	
Duration	200 days/year for 5 years	
Reference flow/ Quantity over lifetime	24300 people * 55% present · 85% using watercoolers · 0.5 L/d/person/88 watercooler ·200d/y · 5 years = 64.547 litres in a lifetime per watercooler or 129.094 units of drink of 0.5 litres	

The data for the reference flow was collected using an author-designed questionnaire on the frequency of use of watercoolers at SDU among students and staff. The lifetime of the machine is given by the producer and the annual usage time was set by the authors. The functional unit used in this study is one unit of drink provided by the reference system or by one of the compared systems. This functional unit is defined in this way to make a comparison between all drinks that the students and staff use. It is known that the SDU campus has 21 000 students, 3 300 staff and there are 88 watercoolers [SDU Odense 2021]. From a questionnaire provided to students, it is assumed that 55% of students and staff are present at the university during the 200 days it is considered populated. It is assumed, from the same questionnaire, that 85% of present people are using the watercooler, and that every person present dispenses 0.5 L of water from the watercooler every day on average. Besides that, it is assumed that the watercooler has a lifespan of five years. This study therefore compares potential environmental impacts of a watercooler that provides 129 094 drinks over the span of five years. All assumptions are averaged estimates, and it must be acknowledged that these will vary over the course of a year.

There are some differences between the systems being compared that distinguish them from each other. The compared systems are found in three different temperature states. Both brewing and keeping the coffee warm is energy consuming, as is cooling. The production of each system differs in complexity, energy and transport complexity. These systems were chosen by the authors because they are the most common and most used in terms of statistics. These systems are the main groups of drinks under which others can be hidden. Table 2 shows an overview of reference flows for the compared systems to deliver the functional unit.

Table 2: Overview of reference flows in compared systems

Product System	Description	Reference flow per functional unit (FU)
Watercooler	Watercooler with water and electricity supply.	0.5 litres of water through watercooler
Tap water	Water dispensed from existing taps. Includes spillage.	0.5 litres + 0.5 litres in spillage
Ice chilled water	Tap water chilled with ice cubes.	0.34 litres of tap water + 0.16 litres from ice
Bottled soft drink	Refrigerated in canteens. Found in bottles of 0.5 litres.	1 unit consisting of 0.5 litres
Bottled Water	Refrigerated in canteens. Found in bottles of 0.5 litres.	1 unit consisting of 0.5 litres
Coffee	0.25 litres served in a paper cup. Kept warm from brewing until use. Two cups are always used for the calculations to maintain equality.	1 unit consisting of 0.25 litres => 2 units for calculations

In this study, we will model different scenarios for comparison of potential environmental impacts. These scenarios and their ratio were defined by the authors as the most appropriate solution:

1. All drinks supplied from the watercooler - Current state
2. Removing all watercoolers:

- All former supply of drinks from watercooler goes to tap water.
- All former supply of drinks from watercooler goes to chilled bottled water.
- All former supply of drinks from watercooler goes to ice chilled water.
- Former supply of drinks is distributed to 45% tap water, 30% to chilled bottled water, 10% to coffee and 15% to soft drinks.

For this study, an attributional approach was chosen. Furthermore, the potential impact of one drink from the watercooler is determined, when wind power certificates are bought to compensate for the electricity use during the use phase of the watercooler. This method was chosen because of the consequential LCA requires knowledge of environmental data and about more processes and economic data on the markets, which are affected by the production, or discontinuation, of the watercooler [Ekvall 2019]. However, the authors consider this knowledge unavailable, hence the attributional approach. In this study, various data sources have been used. The use of primary data has been preferred, since this gives the most accurate results, which is highly needed due to the high completeness requirements. However, primary data is not available in all cases, which has led to the use of databases, scientific articles, and estimations along with primary data, such as masses of the individual parts of the watercooler. The deliverables in this project include a Life Cycle Inventory (LCI) of the compared systems and a Life Cycle Impact Assessment (LCIA). All calculations are done with full transparency [EC-JRC 2010, Huijbregts 2017].

2.1 Life Cycle Inventory

The inventory is made inside the boundaries set by scope in the previous section. The production of the watercooler is divided into several unit processes that are modelled as inputs to the assembly process, the output of which is the final watercooler. Each sub-process is modelled as a unit process composed of several system processes from the underlying data representing the required materials and manufacturing processes. The watercooler components are assumed to be partly finished products, which are sourced from different suppliers in China and assembled at Waterlogic's plants in China as well. The watercoolers are assumed shipped from China as container freight by ship and then freighted by truck.

The processes that enter the assembly process of the watercooler are the production of electronic components, steel, plastic, rubber, UV filter, solenoid, refrigeration part, carbon filter and of course for transport and electricity consumption for production. The watercooler that the system is modelled after is WL2 FW. The weight of the completely assembled watercooler is 27 kg. The assembly is followed by transport to the point of use, which includes all transport. The transport is by sea from Qingdao by ship, covering 20 639.15 km, which, taking the weight into account, amounts to 557.257 t·km. Transportation is also by land, a total of 145.7 km, or 3.934 t·km when weight is considered.

The watercooler should be packed thoroughly before transport to prevent damage during transportation. For packaging, three-layer corrugated cardboard with a weight of 400 g/m^2 is used [Waps-kart 2021]. The watercooler itself has a surface area of 1.71995 m^2. Because of the residual material that is created during packaging, we use 2 m^2 in our calculations. The weight of the carton is then 0.8 kg. The effect of the pallet is not included in the system since the impact is deemed minimal. 1.

In the use phase, there is an input of tap water, electricity, cleaning, and maintenance. Waterlogic states that the energy required for providing 10 L of water with an inlet temperature is 0.38 kWh [Waterlogic 2021].

Maintenance is done by changing filters and UV lamps. They are replaced regularly once every six months, in total, ten times during five years of use [Waterlogic WL2500 2021]. The watercoolers are assumed to be cleaned once a week with water, detergent, and a cloth. The modelling does not include a container for the drink because it is assumed that everyone brings their own bottle, which they use for a very long time and its impact on the outcome would be negligible.

The outputs of the system are wastewater and waste disposal. The watercooler waste is according to Waterlogic handled by Elretur [Waterlogic Elretur 2021]. Elretur recycles 89% of the electronics they receive [Elretur 2021], and this is modelled in the system. The waste disposal includes transportation of the watercooler to Elretur and the recycling of the major components. Minor components such as activated carbon, silicone, and tin, are excluded due to insignificant impact. The recycling is modelled by using the materials' embodied energy together with the saved energy of the recycled material. Figure 1 below illustrates the process flow diagram (PFD) for the watercooler.

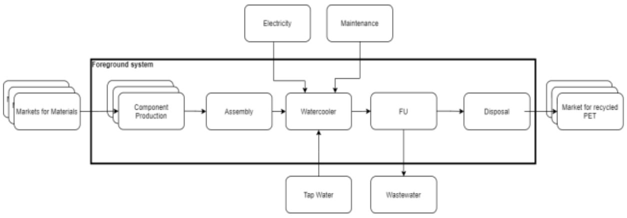

Figure 1: PFD of reference system - watercooler

Compared systems were modelled in the same way. For example, for tap water, an experiment was conducted to see how much water needs to be allowed to drain before the water is at the correct, cool temperature.

Generally, no processes within the system boundaries should be excluded from the LCA, however several things have been excluded:

- Energy consumption of assembling the watercooler has been excluded, since this contributes to a negligible amount of the total impact.
- Impacts from palletizing, included the pallets and the filling of these, has been excluded, since these would amount to an insignificant impact.
- The refrigerators used for bottled water and soft drinks, additional coffee machines, freezers and additional faucets and sinks has not been modelled, as these are considered already in place. An increase in energy consumption in the coffee machines and refrigerators is also neglected, however energy use for the machines has been modelled.
- Cleaning of compared systems has been neglected but has been modelled for the reference system.
- Flavourings used in soft drinks are not used in modelling of soft drinks. The amount of flavourings in soft drinks is negligible.

The data about the consumption habits was gathered through a questionnaire where students and staff were asked about their daily fluid intake on SDU campus. The reason that the specificity is low is because of the small, and possibly biased, sample of the population. The sample may be biased since the questionnaire only reached 50 people. For the compared systems the specificity of the data was generally low. This is because of the somewhat limited information that is available. For instance, the calculations of the electricity consumption of one drink in the different compared systems was mainly based on standard energy consumption of the cooling systems. But in the manufacturing phase of these systems the data is quite specific, especially for the soft drink system.

The variability of electrical energy will be examined based on the electricity consumption. Three different electricity mixes will be used for the sensitivity analysis:

- DK electricity mix from Ecoinvent,
- 2020 DK electricity mix [Energinet 2021],
- 100% Wind.

The LCI models of all the compared systems are modelled using the opensource software OpenLCA [Open LCA 2021]. **Which uses the Swiss Ecoinvent database as a data source.** The article partially describes what ecoinvent contains. They are modelled by creating process flows corresponding to material, energy, and waste flows [Wedema 2013]. The reference system is created first, followed by the compared systems [Stavropoulos 2016]. Parameterization values are used to design different scenarios for sensitivity analysis. To identify the potential environmental impacts of watercooler and reference systems, the "Ecoinvent 3.7.1 apos" attributional database was used to develop the systems and to model the markets. This study uses suppliers from database and therefore marginal suppliers have already been identified in the various system processes. Unique data were used to model individual systems, which were searched so that they fit the given system exactly.

2.2 *Life Cycle Impact Assessment*

In the LCIA, the elementary flows will be assessed to determine their contribution to the environmental impact categories, which will be interpreted. The environmental impacts are defined as changes, either positive or negative, in the environment due to anthropogenic intervention [Hauschild 2018, Bjørn 2018].

The impact assessment method chosen is ReCiPe 2016 (H) mid and endpoint. The main reasons for choosing ReCiPe 2016 (H) are that it is well recognized in Europe and is very commonly used. Everything that ReCiPe does from assessment midpoint and conversion to endpoint is well documented and choices of impact indicators and value choice modelling are presented. The ReCiPe 2016 method uses 17 different midpoint impact categories indicators and three areas of protection, three different social perspectives are also considered. These social perspectives are E: Egalitarian, H: Hierarchical, I: Individualistic. The hierarchical approach is chosen as it is based on scientific consensus, it is the most balanced approach regarding time scale at 100 years, which experts agree is suitable for assessment impacts such as climate change. Figure 2 shows the pathways from midpoint to endpoint, for ReCiPe 2016.

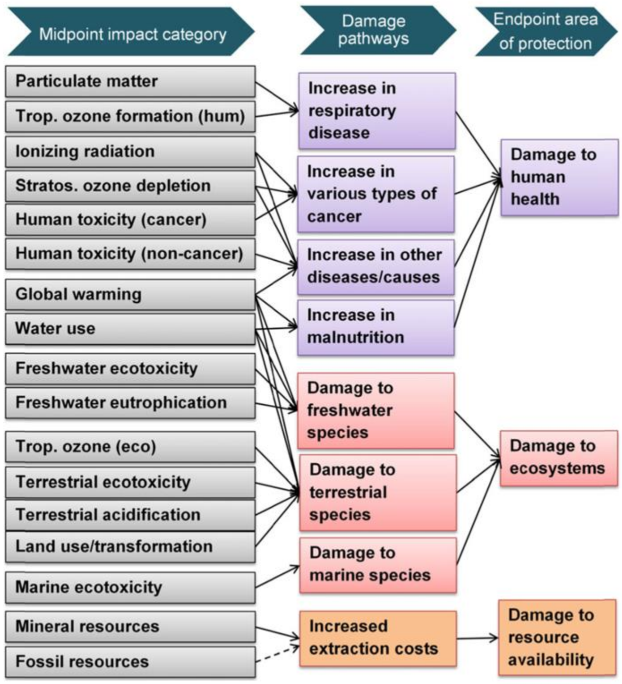

Figure 2: The pathways from midpoint to endpoint for ReCiPe 2016 [Silva 2017]

The characterization transforms the elementary flows into the impact categories mentioned in the earlier section through derivations of characterization factors (CF). The ReCiPe models can use both main ways to derive these CFs, at the midpoint and endpoint level. Midpoint CFs show a stronger relation to the environment because they are more specific, but the endpoint can easily be interpreted from elementary flows into damage of the areas of protection.

During the derivation of characterization factors, the impact assessment method uses reference substances to enable comparison through a dimensionless number which is relative to the strength a substance has compared to that reference substance. Such as CO_2 eq. where the strength of other greenhouse gases can be compared with a single number.

Since assumptions of various flows and scenarios have been made in this LCA, a sensitivity analysis has been done to test the influence on the results. This is followed by uncertainty analyses. The most influencing impacts have been identified, and normalized sensitivity coefficients have been calculated. The method used for calculating the sensitivity coefficient follows the method described in "Life Cycle Assessment - Theory and Practice" [Hauschild 2018, Bjørn 2018]. Considering the background processes in the modelled systems, a Monte Carlo simulation has been done, using the OpenLCA software. Ecoinvent has uncertainty information regarding the background processes which are utilized in the simulation. Here repeated calculations are run with various changes in the input parameters within the uncertainty intervals stored in Ecoinvent. The numerous calculations lead to an output of several impact scores, and in the software it will be presented as a probability distribution of possible outcomes [Hauschild 2018, Bjørn 2018].

Using external normalization relates the impact scores to a common scale by using normalization factors supplied by the LCIA method [Nunes 2019]. ReCiPe 2016 uses World 2010, meaning that the scores are normalized to an average world citizen in the year 2010. By this normalizing the impacts, it is more apparent if the impacts are high or low relative to an average citizen.

3 RESULTS

The biggest impacts in relation to the overall impact assessments of contributions regarding midpoint impact categories have fossil resource scarcity, marine eutrophication, global warming, marine ecotoxicity, and fine particulate matter formation. This is shown in Figure 4, which is the internally normalized midpoint comparison between all systems. Due to its size and subsequent readability, the figure 4 has been inserted into the appendix of this article.

The mixed scenario has a higher land use when examining the midpoint impact score than the other, this is likely because of the growing of the coffee beans included in the scenario. In relation to the scenarios, one drink from the bottled water system has the greatest impact on fossil resource scarcity. Of this, the soft drinks system has the largest contribution. The significant impact stems from the materials used for making the plastic bottle, which are PET (PolyEthylene Terephthalate), HDPE (High Density PolyEthylene), and LDPE (Low Density PolyEthylene). The process of moulding the bottle also has a significant impact.

For marine eutrophication the mixed scenario has the largest impact. This is because of the large impact of both the soft drink and hot drink systems. In the soft drink system, it is mainly the beet sugar production and the citric acid production that are the source of the impact. For the hot drink system, it is the coffee bean production.

For global warming the bottled water system has the highest impact, closely followed by the mixed scenario. Same as for global warming, marine ecotoxicity the bottled water system, as well as the production of plastics has the largest impact.

The impact from fine particulate matter formation is higher for the mixed scenario. Here, again, ingredients are the source of the higher impact from the soft drink system, although the bottle materials also have a significant impact as well. And for the hot drink system it is again the coffee bean production that is the main cause of the impacts.

Of all the scenarios, the tap water system and the watercooler system have significantly the lowest environmental impacts. Marine eutrophication is the only impact between the two systems where the tap water system has a higher impact. This is because of the remission of 0.5 L water that is included in the tap water system, which essentially doubles the impact from the wastewater.

The comparison of the internally normalized endpoint of systems is shown in figure 4. This graph is a followup to figure 2 described above. Each bar represents one region of protection. The first column is disability adjusted life year (DALY), the second is time integrated species loss per year, and the last is surplus cost in dollars. Here it is seen that tap water, watercooler and ice chilled water have lower impacts than bottled water and the mixed scenario. Bottled water and the mixed scenario systems have the highest impact scores. This is most likely because of the plastic production and transport of the bottles and cups.

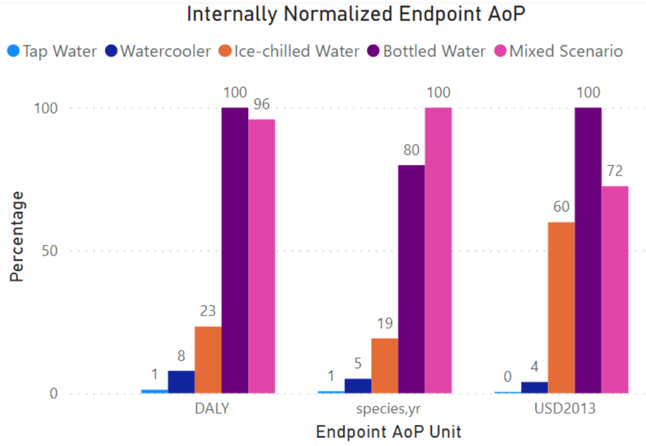

Figure 3: Internally normalized endpoint AoP

3.1 Significant issues

To find the environmental difference between the different products and identify the major contributing life-cycle stages, a process contribution analysis has been made. Based on the process contribution analysis, the process with the greatest environmental impact can be found.

The life cycle stages that are included in the analysis are: production, transportation, use, and disposal, which can be seen in Figure 5, which is inserted in the appendix of this article due to its size and subsequent readability. The analysis is done for five different impact categories, namely marine ecotoxicity, water consumption, global warming, fine particulate matter, and freshwater eutrophication. The tap water system is not included because all contributing processes are in the use stage.

The result of the process contribution analysis showed that the production stage has the greatest contribution to environmental impact for all systems except for the watercooler system. The production process contributes to the total impact of marine ecotoxicity, global warming and fine particulate matter are around 90% for all the systems except for the watercooler system. There it is only about 50% for marine ecotoxicity and 20% for global warming and fine particles. Tap water has no production, therefore the taps that are already on the university premises will be used. Tap water and watercooler systems have the biggest impact in the stage of use. Hot drinks are the only system without any negative impact. The reason is that nothing is going into recycling in the process.

The disposal phase has the lowest impact for almost all systems, which is around 20% of the overall impact. The exception is icecold water because of the ice cube bags. The small percentage of impact is due to the fact that a large part of the material goes to recycling and a large part of the plastic from the plastic bottles goes to the Danish PANT system for returnable plastic bottles. The reason way the disposal is positive for the impact of water consumption is that the amount of water used is the same for recycling a bottle and making a new bottle. Transport does not have a significant impact on some of the processes.

3.2 Sensitivity

Sensitivity analysis can be used to identify what parameters are most sensitive to change. The sensitivity analysis calculation was also performed using OpenLCA software and can be found in detail in the Annex as supplementary material. (The listed percentage values are based on the total watercooler volume.) From the results of the sensitivity analysis it becomes clear that several impact scores are highly sensitive to changes in the recycled percentage of the watercooler. These results mean that the assumptions made for the recycling percentage could affect the conclusions of this work, since a change in the disposal stage could affect the environmental impact negatively. Figure 6 shows a comparison of normalized impact scores of the impact categories which have the highest sensitivity to changes in the percentage of recycling, normalized sensitivity coefficients is greater than 0.3. The figure 6 shows that less recycling will affect the impact categories in most of the categories. Only four impact scores are lower with less material recovery.

Due to the size and readability of the displayed data, figures 6 and 7 are part of the appendix of this article.

Figure 7 shows how the reference scenario, where electricity to the watercooler is modelled after the current Danish electricity mix in the grid, compares to scenarios where electricity is supplied from the standard Danish electricity market from Ecoinvent and a modelled scenario of 100% wind energy.

From the results it follows that wind power has a lower overall impact, except when it comes to marine and freshwater toxicity and in mineral resource scarcity. When it comes to comparison between the Ecoinvent database and actual data from the 2020 Danish electricity mix there is a bit of variation [Energinet 2021]. The reason for this is most likely that the Ecoinvent database is more or less static, and the Danish mix is very affected by the amount of wind energy present in the system, which again depends on the weather.

3.3 Uncertainty

A Monte Carlo simulation has been run for the compared systems - watercooler, tap water, ice chilled water and bottled water. This study uses 100 iterations for each system [Thomopoulos 2014, Kroese 2014].

Figure 8 shows the standard deviation of the uncertainty of the impacts of the compared systems. The average standard deviation of watercooler system is 0.003 which is quite low, and therefore the data is considered reliable overall. In general, the standard deviation is low in most of its impact categories with some exceptions - human non-carcinogenic toxicity, water consumption, ionizing radiation, terrestrial ecotoxicity and human toxicity. The tap water system results showed an average standard deviation of 0.0002. This standard deviation is even lower than the watercooler system when compared to their means, and therefore considered more reliable. This lower standard deviation is most likely due to the very simple system. The ice chilled water simulation shows overall reliable data but as with the watercooler scenario where are still impact categories with more uncertain data. The results of the bottled water system are already a little more wobbly. Especially the human non-carcinogenic toxicity and water consumption has a high uncertainty. These higher uncertainties are likely because there is an equal amount of water in the use and disposal life-cycle stages and a small change in one of these stages can result in a drastic change in the overall water consumption. Overall, the biggest uncertainty is about the impact - human non-carcinogenic toxicity. This impact reaches a value of up to 0.17 for system bottled water (this value is not shown in the figure 8 for better visualization of the other values).

Due to its size, this figure 8 is again placed in the appendix of this article for clarity.

3.4 Completeness and Consistency Checks

The report ends up with low specificity and high sensitivity, because there are too many assumptions throughout the report. The overall consistency of the systems is fairly good, except for with the cooling appliances used. Since the watercooler system includes the cooling device, and the compared systems do not, there is a lack of consistency. So, to increase consistency, the ice-chilled water, bottled water, soft drink and hot drink system should include modelling of freezers, refrigerators, and coffee machines, respectively.

The calculations were processed in OpenLCA software and are available in the appendix as supplementary material. The calculations/results presented in the weighting with the externally normalized endpoint have been done by hand and not by OpenLCA. This is due to an error in the current version of OpenLCA (1.10.3) where the calculation of going from impact scores to normalized/weighted score is wrong. Taking the inverse value of what OpenLCA presents gives the correct results [Waps-kart 2021].

At the end of the article, an overall summary of the results is made and the main evaluated attributes, including the results, are listed in Table 3.

Table 3: Overall summary of the results

Evaluated attribute	Result
The most environmentally friendly system	Tap Water
The least environmentally friendly system	Mixed Scenario – Midpoint Bottled Water - Endpoint
The process with the greatest impact	Production
Parameters with the greatest sensitivity to change	Recycling parameters for Watercooler
The most environmentally friendly type of electrical energy that was compared	Wind Energy
The system with the least uncertainty of results	Tap Water
The system with the greatest uncertainty of results	Bottled Water
Impact category with the greatest uncertainty of results	Human Non-Carcinogenic Toxicity

4 DISCUSSION

A total of 5 scenarios were modelled in this study. Four of these scenarios represent different ways that students and staff on campus may respond to the removal of the reference scenario - watercoolers.

The modelled scenarios show that tap water generally has the lowest impact in most impact categories and all areas of protection. The potential impact compared with the watercooler scenario is not that different, considering the other scenarios which were analysed. There is one slight trade-off between the watercooler and tap water scenario when considering marine eutrophication due to the remission of 0,5 L of water when using tap water.

The main objective is to reduce CO_2 emissions. Tap water has the lowest impact in this category. Compared to the watercooler, this is also due to the fact that the faucets and sinks are not considered and there is almost no energy used for cooling the tap water. This is very different from the reference system, where the water cooling device is modelled and the electricity that is used to cool the water.

For the watercooler system the major contributor for impact was the use stage in the life cycle. Most of the impact stems from the energy consumption of the watercooler. For all the compared systems, the largest contribution comes from the production stage, which is mainly due to the impact from the materials used for manufacturing.

The watercooler system is highly sensitive to changes in the recycling efficiency. The amount of material of the watercooler which is recycled instead of incinerated will highly affect the impact scores of virtually all impact categories. Waterlogic provides recycling through Elretur, but if the recycling was done through a service with higher recycling efficiency, it would positively affect the potential environmental impact. In the next phase of the research, the role of transportation could be included in the sensitivity analysis, which could have interesting effects for the local economy.

From comparing and assessing the impacts of scenarios with different energy mixes, it can be concluded that the use of 100% wind power instead of the current Danish electricity mix reduces the impact, both considering the conservation end areas and especially in the midpoint with several trade – offs lack of mineral resources, marine and freshwater ecotoxicity.

The likelihood of reaching the scenarios is undetermined as the people behaviour is difficult to predict, and the results are considered as only potential results as these scenarios may not be met. For example, if the watercoolers were to be removed it is uncertain that there would actually be a lower impact on the environment, because that can only be the case if a large number of people started using the tap water. If people migrated from using watercoolers to, for example, bottled water, there would be an increase in environmental impact. Also there is the possibility that water consumption on campus could decrease as more students and employees may reduce their intake of water on campus and/or bring water with them from home. If only the results of the Monte Carlo simulation were taken as the probability of achieving these scenarios, the overall uncertainty would be very small. It would range from an average standard deviation of 0.0002 for tap water to 0.0193 for bottled water. The impact category with the greatest uncertainty of results is by a wide distance Human Non-Carcinogenic Toxicity. This is probably due to the high use of plastics in the systems.

This LCA is calculated in Denmark using the Danish electricity grid and transport to Danish ports. Therefore, with a dose of reserve and perspective, it can be said that these results and recommendations may be applicable in other parts of the world. The results are based on Danish standards, laws and electrical mix, which are among the strictest and cleanest in the world.

For example, elsewhere in the world the backup system and emphasis on recycling is not as widespread. For that reason, it can even be assumed that the differences between the individual scenarios would be far greater elsewhere in the world and with worse ecological impacts, but compared to each other they would end up more or less the same. But without an LCA analysis, these are just assumptions of the authors.

5 CONCLUSIONS

Motivating people to change their behavior towards environmental friendliness is a difficult task, but if successful, it can lead to energy savings in the long term. One of the best environments for the dissemination of sustainability ideas is the university environment, as this is where these ideas will have the greatest impact. Technical change and behavioral change approaches complement each other and their effect is amplified, as changes in the behavior of staff and students are often necessary to make good use of new technologies. The LCA method has been successfully used for many years, and one of the best-known best practices is the Danish study Life Cycle Assessment of packaging systems for beer and soft drinks from 1998. Based on these results, a backup system for plastic and glass bottles and cans was introduced. At the same time, a law was defined that stipulated that manufacturers must only use bottles that can be collected and refilled for reuse [Miljøministeriet 1998, InforMEA 2022].

One of the newer cases of using LCA in practice is, for example, the Volkswagen car company, which uses LCA analyses to assess the impact of its products on the environment.

The study evaluated the environmental consequences of using watercoolers to supply drinks on a university campus and compared them with alternatives. From the above analysis, it follows that the most environmentally friendly way is to drink tap water, and on the contrary, the worst possible option is the bottled water system. This is due to the materials used to make plastic bottles, which are PET, HDPE and LDPE. But the resulting recommendation is that watercoolers should be retained for the present and the future, for two reasons. The potential for environmental impacts from watercoolers is close to the best overall scenario, and people's behaviour in finding a replacement for watercoolers is difficult to predict. However, it is important to ensure that watercoolers are disposed of with high recycling efficiency. This study also compared the replacement of electricity from the public grid with wind energy in the use phase of watercoolers. The finding is that buying wind energy certificates to supply green electricity would bring a significant reduction in impacts, especially on global warming. This study should also be applied to industrial water cooling, which is used in many industries in operations using laser technology for cutting, plastic production plants, welding operations, paint shops or engineering production. Industrial liquid cooling is important in most engineering operations, especially in summer, when high outdoor temperatures can lead to overheating of production equipment. Here, the transition to ecological energy would bring a great benefit to the environment.

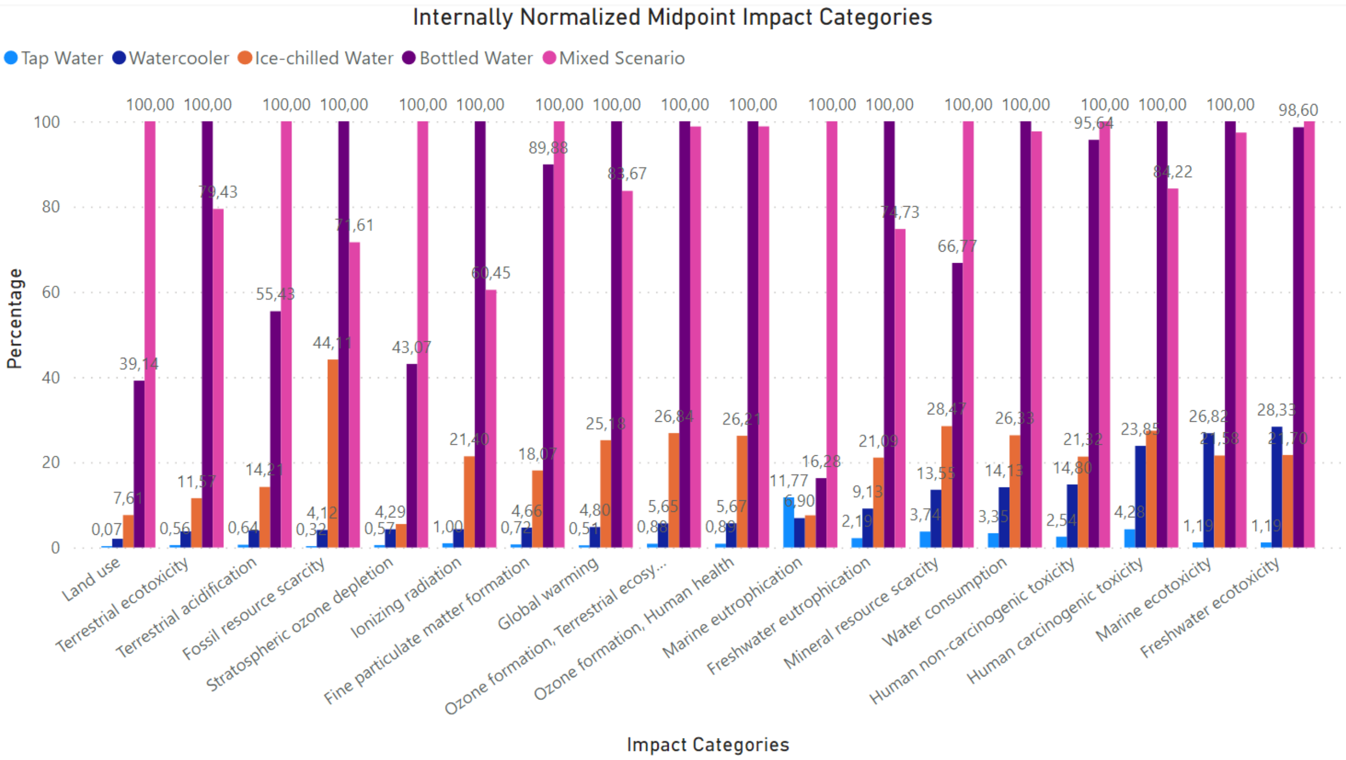

Figure 4: Internally normalized midpoint impact categories

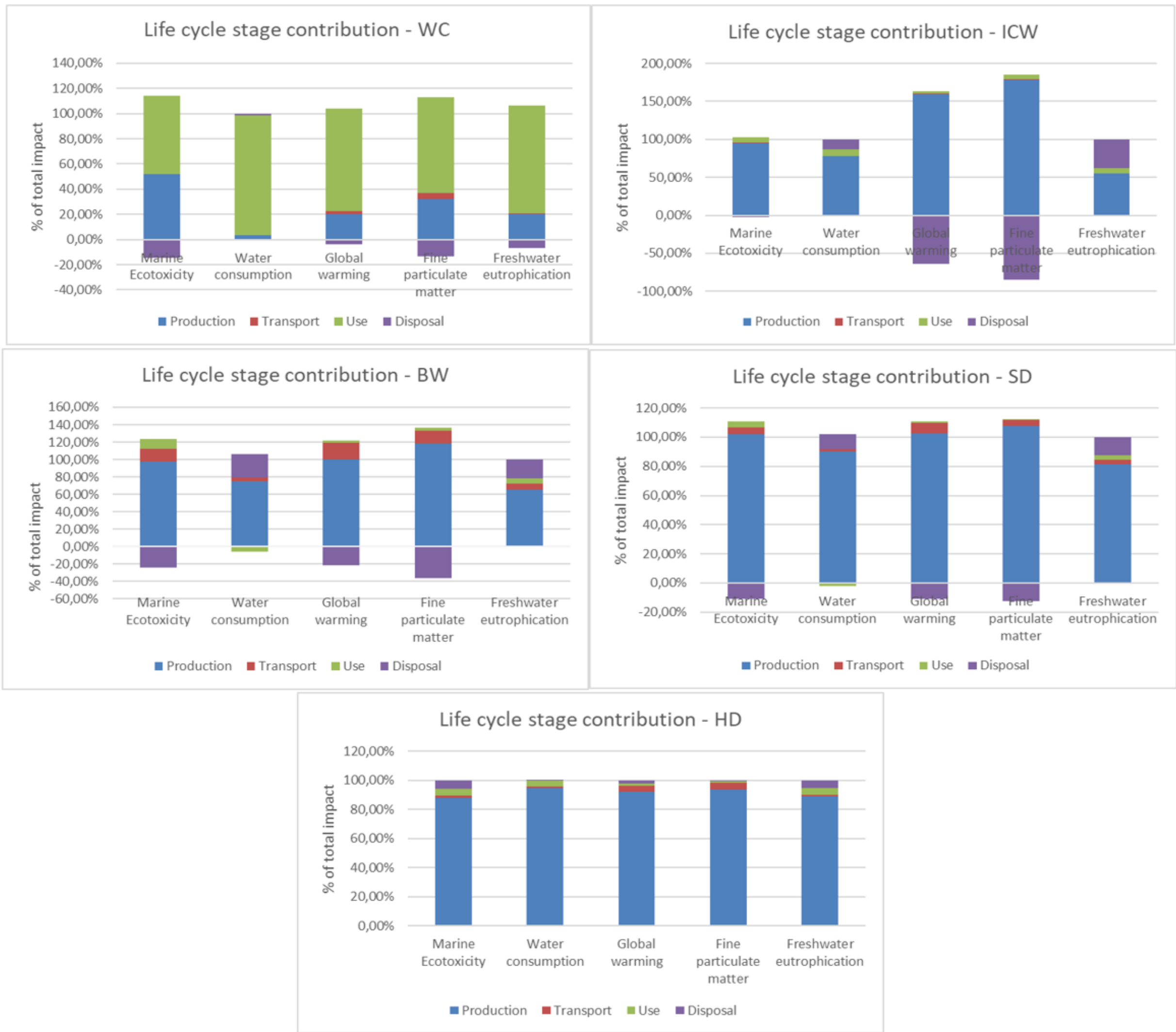

Figure 5: Life cycle stage contribution of all systems

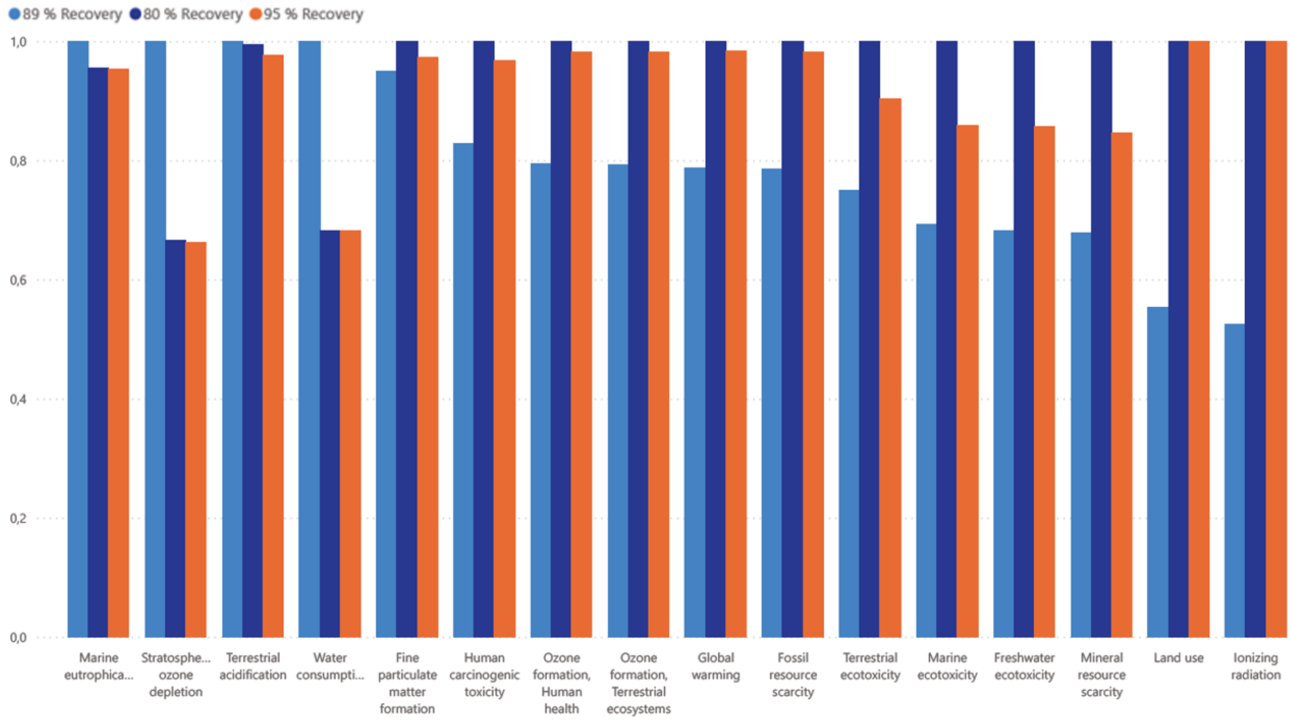

Figure 6: Normalized presentation of impact categories highly sensitive to recovery efficiency

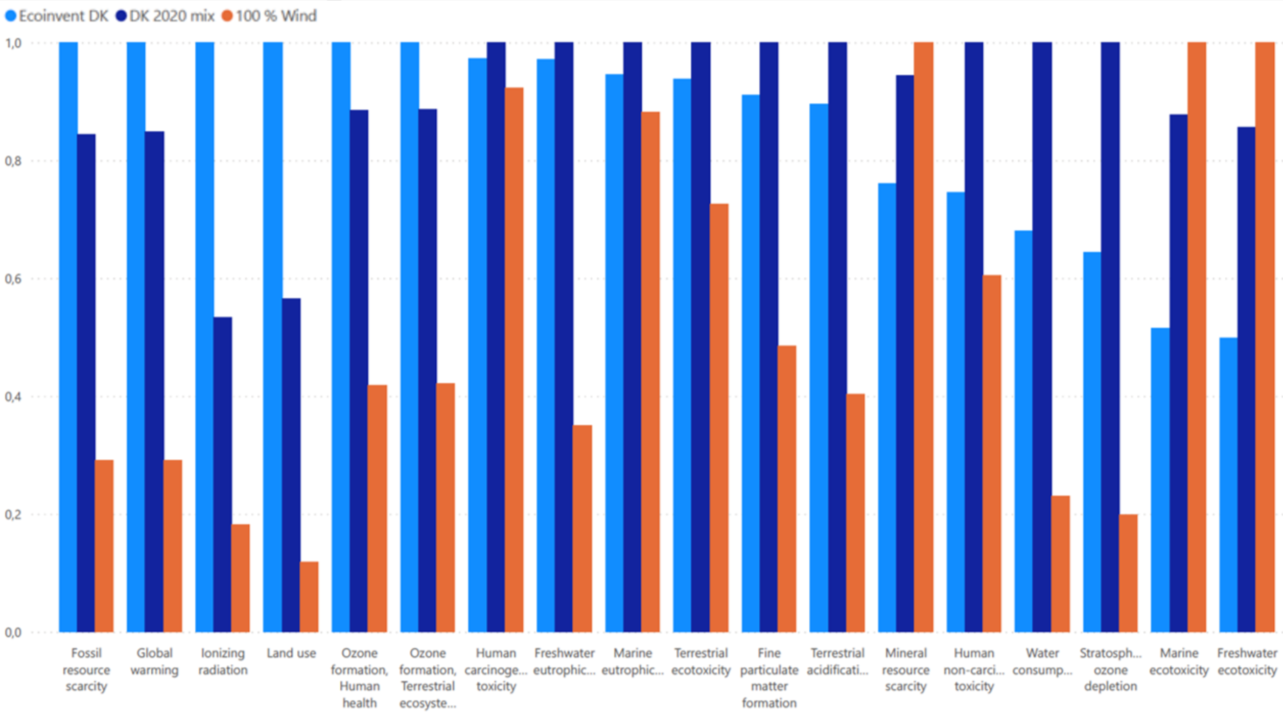

Figure 7: Sensitivity scenario of DK current mix, DK Ecoinvent and DK 100 % wind electricity

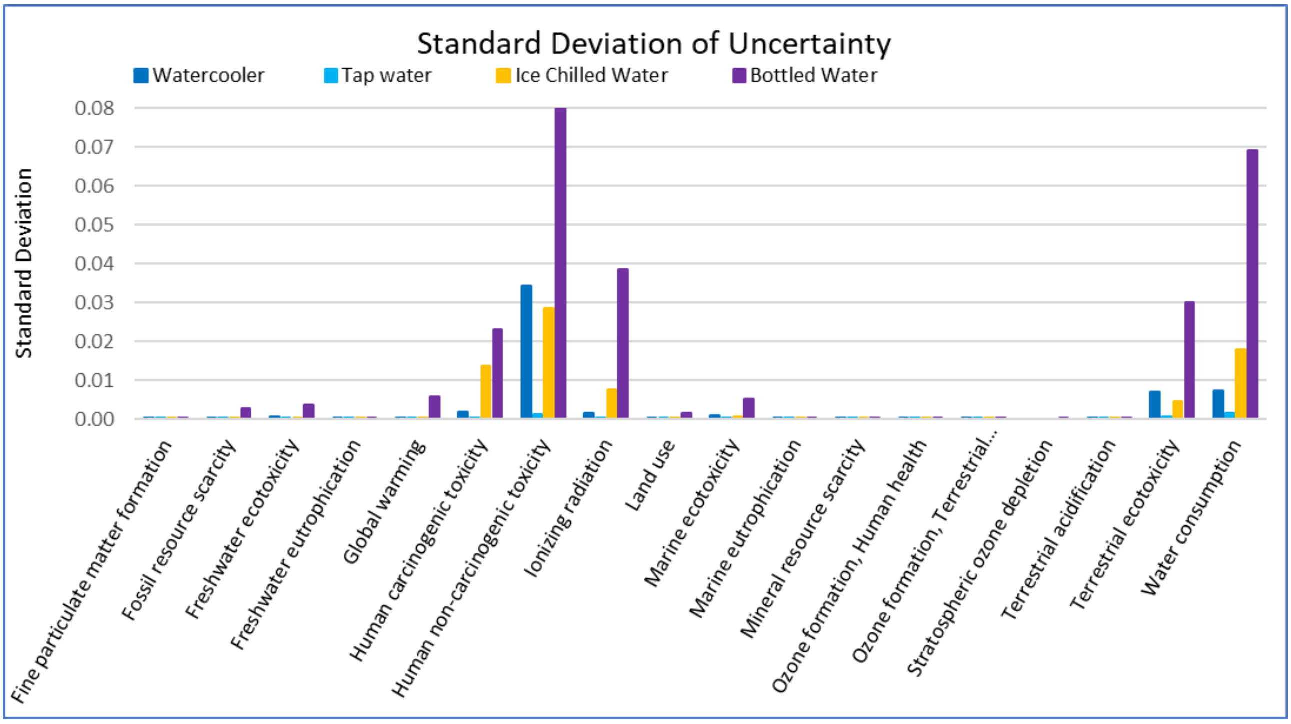

Figure 8: Standard Deviation of Uncertainty

water in glass and plastic bottles. 2016. Journal of Cleaner Production.

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