ENVIRONMENTAL ASSESSMENT OF PRODUCTS: CARBON FOOTPRINT BASED COMPARISON OF TWO WATER COOLING SYSTEMS

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ABSTRACT

Climate change is a phenomenon caused by greenhouse gases (GHG) mostly released by human activities. Its effects have been aggravated throughout the last years; therefore there is a need of all stakeholders to join efforts in order to keep these effects at bay. By the adoption of life cycle thinking tools, such as the carbon footprint (CF), companies can contribute to offset climate change impacts and, additionally, it can help them to translate sustainability issues into quantifiable measures. The CF is a limited Life Cycle Assessment (LCA) that measures the impact, expressed in carbon dioxide equivalents (CO_2e) a product, service or organization has on climate change throughout its life cycle. Kuvatek is a Danish company which wants to demonstrate scientifically that its water cooler is more environmentally friendly (focusing only on climate change impacts) in comparison to the product from an Italian manufacturer.

This study has been done in collaboration with Kuvatek. The first objective is to develop CF skills by conducting a comparative screening CF analysis of the two water coolers. The CF methodology is based on LCA following ISO 14040 and 14044 and it is cradle-to-grave assessment; covering production, use and end of life stages of the product. The results show that the total CF of Kuvatek's water cooler is 62 $KgCO_2e$, whereas it is almost ten times higher for the competitor, i.e. 597 $KgCO_2e$. An individual analysis of each life cycle stage showed that the competitor has a greater CF in each of the stages. Among the three life cycle stages, the use stage of both companies contributes to the CF the most, but the CF of the competitor is ten times the CF of Kuvatek (i.e. 565 $KgCO_2e$ and 58 $KgCO_2e$, respectively). The electricity consumed by each product is the main process contributor to the CF of the use stage and also to the total CF of the products. Kuvatek mainly consumes electricity during the water cooling process, emitting 40,18 $KgCO_2e$, whereas the competitor does it in standby mode, thus emitting 330,56 $KgCO_2e$.

The second objective of the study is to investigate Kuvatek's motivations of conducting and communicating the CF assessment. The used methods are literature review and interviews with the director of Kuvatek. The main findings are: 1) the motivation to conduct the CF is to gain insights into the product as well as to communicate the results to the customers in order to make informed product choices 2) the main benefit of the CF assessment is the identification of the CO_2 sources within the supply chain and the drawbacks are both cost and lack of knowledge 3) the interest in documenting the CF performance of their product is because it can be included in the product' environmental profile and it will probably be part of the information of all products. Based on the study outcome, three main recommendations are suggested to Kuvatek: 1) Kuvatek can improve its total CF by focusing in the electricity consumed during the water cooling process of the use stage 2) the CF is a precursor of the LCA, so now they can take a step forward and conduct a full LCA to have the whole picture of how the water cooler affects both the environmental impacts and resources 3) if the results from this study are published, a critical review needs to be done by an expert panel prior publication

Key words: *Carbon footprint, life cycle assessment, climate change, water cooler, communication*

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LIST OF ABBREVIATIONS

BSI	British Standard Institution
CO_2	Carbon dioxide
CO_2e	Carbon dioxide equivalent
DEFRA	Department for Environment, Food and Rural Affairs
EPA	Environmental Protection Agency
EPD	Environmental Product Declaration
FU	Functional unit
GHG	Greenhouse gas
GWP	Global warming potential
IISD	International Institute for Sustainable Development
ILCD	International Reference Life Cycle Data System
IPCC	International Panel on Climate Change
ISO	International Organization of Standardization
LCIA	Life Cycle Impact Assessment
LCA	Life Cycle Assessment
NGO	Nongovernmental Organization
PAS	Publicly Available Specification
SETAC	Society of Environmental Toxicology and Chemistry
SMEs	Small and medium enterprises
UN	United Nations
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
VOC	Volatile organic compounds
WBSCD	World Business Council for Sustainable Development
WCED	World Commission on Environment and Development
WRI	World Resource Institute

CHAPTER OUTLINE

The entire study is divided in four parts.

Part one includes introduction (CHAPTER I) covering background, contextualization, objectives and scope of the study.

Part two includes CHAPTER II about literature review and CHAPTER III explains the theoretical framework. After the background knowledge on the subject has been presented, CHAPTER IV describes the research questions that will guide the overall line of the study. CHAPTER V discusses the research methodology applied to the study.

Part three of the thesis covers CHAPTER VI in where the comparison of the carbon footprints of the water coolers following the LCA methodology is explained.

Finally, part four comprises CHAPTER VII, where the results of the study are presented and discussed and CHAPTER VIII consists of conclusion and recommendations.

CHAPTER I Introduction

The effects of climate change are a worldwide problem and it is considered one of the most significant environmental problems in the history of humanity (UNEP, 2014).

Back to the times of the industrial production and to its connected development activities, the development was understood as having an industrialized society and an economic prosperity. No one would expect the future problem that the transformation of the available resources into wealth would cause. This led to a fast enhancement of the consumption level of energy and materials (Linnenluecke & Griffiths, 2013). The industrial revolution started around 1850 (Cranston & Hammond, 2012) but its related environmental problems started to be perceived just around 1950 and it was not until 1980 when the revolution on environmental management and protection started. Soon, several impacts on the environment emerged due to the industrial activities, such as a rise in the temperature, hole in the ozone layer, droughts, floods and acid rain. These impacts threat human lives, economic development and the natural world itself (European Commission, 2014a).

Today, the Intergovernmental Panel on Climate Change (IPCC) is the main institution implicated in the monitoring of the climate change issues and it considers the raise of greenhouse gases (GHGs) in the atmosphere as the main cause of the phenomenon (IPCC, 2007).

The intensification of climate-change related impacts (stronger tornados and increased tornados damage, prolonged draughts and floods, rising global temperature and sea level etc.) strongly contributed to generate global awareness about this problem and the need to offset the climate change has been progressively understood (Dias & Arroja, 2012). Furthermore, the old concept of development has been slowly replaced to the sustainable development, which finds a balance between environmental, social and economic issues. Several events have been happening since climate change is on the agenda. One of the first international efforts was the Brundtland Report, reported by the World Commission on Environment and Development in 1987 and later the Rio Earth Summit in 1992, where the United Nations Framework Convention on Climate Change (UNFCCC) was adopted.

Both the Brundtland Report and the Rio Declaration stated the need for sustainable development in the whole world and nations agreed on contributing to a better life not only for the current, but also the future generations. In 1997, a further step was taken in the climate change action and it led to the Kyoto Protocol, which was agreed by the countries participating in the UNFCCC. This is a legally compulsory treaty stating that basically six major gases are responsible for global greenhouse effect. These gases are: Carbon dioxide (CO_2), Methane (CH_4), Nitrous oxide (N_2O), Hydrofluorocarbons (HFCs), Perfluorocarbons (PFCs) and Sulphur hexafluoride (SF_6) (UN, 1998). During the Kyoto Protocol, emission reduction targets for various industrialized countries were established with the goal of decreasing, between 2008 and 2012, 5% of the total emissions from these countries against the levels in 1990. Other further United Nations climate conferences were held in Copenhagen (2009), Cancún (2010), Durban (2011) and Doha (2012), where new rules, commitments, institutions, and pledges about the international climate regime were discussed (European Commission, 2014b).

As it can be seen from the abovementioned examples, climate change has been highlighted not only at policy level, but also at industry level. An example of the latter is the creation of the GHG Protocol, which is an international tool for governments and businesses to comprehend, quantify and manage GHG emissions (GHG Protocol, 2012). In addition, consumer level (i.e. consumers, as part of the society's structure, should be aware of the climate change problem and e.g. avoid buying environmental harmful products) has to be integrated as well in order to address climate change. This is vital, because in order to decrease the GHG emission and reduce the impacts of climate change, there is a need for a commitment of all the stakeholders, such as governments, companies and individuals (IISD, 1992). Concretely, the reduction of carbon emissions by organizations is very relevant for sustainable development and it is becoming a business topic of higher importance (Schaltegger & Csutora, 2012).

Within the principles of sustainable development, firms have to strive for sustainability practices that change radically the way business is done (Linnenluecke & Griffiths, 2013). In fact, as an answer to the threat of climate change, companies around the world have adopted sustainable practices such as the implementation of life cycle thinking tools, which have gained in popularity (Dias & Arroja, 2012). These tools strive for sustainability and are being used in the present by companies in order to translate sustainability issues into quantifiable measures with the objective of helping address the main concerns of the triple-bottom line, which are finding a balance between: societal responsibility, environmental performance and economic contribution. In this sense, one of the tools is the carbon footprint (CF), which measures the impact that a product, service or organization has on climate change throughout its life cycle (Finkbeiner, 2009).

1.1 Contextualization

Within the global approach of the sustainability practices undertaken by companies, this study focuses on the CF assessment of two water coolers from two companies situated in different countries, Denmark and Italy. Thus, the study is based on a comparative analysis of two products. Since the initiative is undertaken by the Danish company, called Kuvatek, and this is also the main source of information, the Danish water cooler is referred as the first product. The second product, produced by the Italian competitor, is compared to the first one.

Kuvatek is a microenterprise because it employs fewer than 10 persons (concretely, 4 employees) and its annual turnover and/ or annual balance sheet is below 2 million € (European Commission, 2003a). It is situated in the northern Danish town of Sindal and it designs and manufactures the first product, whereas the second product is produced by a leading Italian global manufacturer of water coolers.

A water cooler, also called water dispenser, is an appliance that both cools and dispenses water. There are basically two types: bottleless water coolers and bottled water coolers. The former are connected to a water supply, whereas the latter require delivery of the water in large bottles from vendors. In addition, the water coolers can be installed differently, the main ones are: “wall mounted”, where the water cooler is linked to a building’s water supply; “bottom load water dispensers”, which have the bottle on top; “table top water coolers”, where the dispenser is placed on top of the table; and “freestanding”, where the bottles might be either bottom- or top-loaded or also be feed off a pipe. Sometimes, the pipe-fed water coolers may also include filters so as to purify the water of different contaminants (Waterworld, 2014). Depending on the type of the water coolers, they will usually provide water between 6-10 ºC. The alternative to its use is to storage bottles of water in a fridge.

To cool the drinking water with water coolers is a process that mainly occurs in developed countries. The water coolers are worldwide produced, in places such as North

America, Europe and Asia and are sold to developed countries or people with purchasing power from developing countries. The hottest countries are usually the ones that would mostly need these water coolers, since the water temperature running out of the pipes is very high. With atmospheric temperatures around 40-45 ºC, the water supply temperature can be approximately 35 ºC (Laval, 2013). The water cooling service is not a vital necessity (like it would e.g. be the supply of potable water) but it might be considered a delight factor that increases a person's quality of life.

The director, John Green, and managers of Kuvatek have strong beliefs that their products are more environmentally friendly in comparison to their main competitor, which will be called *"Competitor"* in order to protect the affected stakeholders from possible negative impacts from this study. Their beliefs are based on evidences of lower electricity consumption during the use of the product, less transportation to deliver the product to the end consumer, more environmentally friendly components, e.g. their refrigerant has a lower global warming potential (GWP) in comparison to the competitor etc. So, in order for Kuvatek to translate their beliefs into substantial statements and more importantly, to demonstrate it scientifically and also compare the performance of their product against the one of the competing products, an environmental performance of the product is conducted. This environmental performance is in the shape of a carbon footprint assessment and it is an adequate tool to make a screening process to assess how environmentally friendly Kuvatek's products are (focusing only on GHG emissions). Additionally, the CF is a good example of how to bring the company's environmental concerns into quantitative terms.

1.2 Project objectives

The project consists of two objectives:

a) Develop skills in carbon footprint assessment by conducting a CF comparison of Kuvatek's water cooler to the one of its competitor.

b) Reflect critically over the reasons Kuvatek has in order to implement a tool such as the carbon footprint and also to document the CF performance of their products.

1.3 Project scope

The main purpose of this study is to conduct the carbon footprint of the Danish and the Italian water coolers produced by Kuvatek A/S and its competitor, respectively. Both companies mark out the study's organization boundaries.

The study, which is a thesis work for the 4th semester of the Master in Environmental Management and Sustainability Science, is based on the collaboration with Kuvatek, but it is not a consultancy work and a critical perspective is applied throughout the study. There are several mutual expectations. For the researcher, it is to present carbon footprint results based on the collected data and by the use of the life cycle assessment software called Simapro. The expectations from Kuvatek are to help as much as possible in the comprehension of the water cooler's functioning and in the provision of needed data and information.

As the thesis is a research within a limited period of time with educational purposes, the scope is to calculate initial results, whereas using the results for external communication would require a critical review by an expert panel. Thus, the carbon footprint assessment should be taken as a screening process in order to have an initial idea of how Kuvatek stands (in terms of CO_2 emissions) in relation to its competitor.

In addition, the researcher assumes that errors might occur mainly due to assumptions made throughout the study and thus one should make careful use of the project results.

CHAPTER II Carbon footprint as a tool for sustainable development: the background on carbon footprint and sustainability review

In order to get a full understanding of the analysis that is worked out throughout the entire project, it is useful to start defining and describing the concepts on which the project is based, i.e. life cycle thinking and footprinting. In the next sections, a literature review is presented, where the carbon footprint tool is defined and positive and negative critics in relation to its own features are depicted. After that, the concept and origin of sustainability and how it is implemented by companies through the CF is explained. Lastly, an overview of the different existing CF initiatives is illustrated.

2.1 Carbon footprint

This section is divided in two parts. The first part introduces the definition of CF, an overview of its history and the main features it is composed of. The second part describes the positive and negative critics to the CF.

2.1.1 Definition, history and main features

The carbon footprint of a product is a limited Life Cycle Assessment (LCA) and it is a sub-set of the data covered by a full LCA. The LCA, which is an internationally standardized method, evaluates both the environmental impacts and resources throughout the entire life cycle of a product. Climate change is one of the main impact categories considered in LCA, thus it is said that the carbon footprint is an LCA with the analysis restricted to emissions that have a climate change impact (European Commission, 2009). The CF concept is useful to communicate important issues to a wide audience as it provides consumers additional information to adapt their behaviour. In this sense, it naturally connects to the expanding field of sustainable consumption (Peters, 2010) and it is closely linked to the environmental or ecological footprints. However, the main difference is that the CF is measured in mass or weight units (kilograms per functional unit) whereas the environmental or ecological footprints are measured in spatial units (e.g. global hectares) (Cranston & Hammond, 2012).

Different authors define the concept of carbon footprint very similarly:

The carbon footprint of a product, service or organization is the amount of GHG expressed in CO_2- equivalents (CO_2e) emitted by any of them throughout its entire life cycle (i.e. supply chain, use and end of life recovery and disposal), by establishing concrete system boundaries (Brito de Figueirêdo *et al*., 2012 after Pandey *et al.*, 2011; Scipioni *et al*., 2012 after Finkbeiner, 2009; Cranston & Hammond, 2012).

The concept of "Carbon Dioxide Equivalent" (CO_2e) can be defined by the Environmental Protection Agency (2013) as follows:

"It is a metric measure used to compare the emissions from various greenhouse gases based upon their global warming potential (GWP)."

CO_2e is the CO_2 concentration that would cause the identical level of radiative forcing as a specific type and concentration of greenhouse gas. CO_2e is expressed as parts per million, by volume (ppmv). According to EPA (2013), the formula for its calculation is:

CO_2e = (million metric tons of a gas) * (GWP of the gas)

The quantification of the CF is done by using indicators such as the GWP. The GWP is an indicator that illustrates the potential relative climate change effect of a greenhouse gas (per Kg) over a specific period of time. For example, a GWP calculated for a time horizon of 100 years is a GWP_{100}. This reference is taken very often by regulators (IPCC, 2007). Then, in the CF calculation, the GWPs for different emissions can be added to give a unique indicator that represents the product's overall climate change impact throughout its entire life cycle.

As already stated in CHAPTER I, there are six major gases responsible for global greenhouse effect and consequently for climate change (UN, 1998). Briefly, and in order to keep clear the connection of the different phenomena, the IPCC explains that the GHG are one of the climate change drivers, due to its potential to absorb the heat in the atmosphere and cause the greenhouse effect. This is one of the main reasons for climate change to happen, which has many impacts such as the rise of the temperature (global warming), increased frequency of extreme events and sea level rise (IPCC, 2007).

According to the *Fourth Assessment Report* of the IPCC, in Table 1, the GWP and the chemical formula of the main greenhouse gases that affect climate change, on 100-year time horizon are depicted:

Table 1 Global Warming Potentials (GWP_{100}) of main greenhouse gases

Species	Chemical formula	GWP_{100}
Carbon dioxide	CO_2	1
Methane	CH_4	25
Nitrous oxide	N_2O	298
HFCs	-	124-14800
Sulphur hexafluoride	SF_6	22800
PFCs	-	7390-12200

Source: **(Solomon, *et al*., 2007)**

As it can be seen, the PFCs have the highest GWP, meaning that it absorbs much more heat in the atmosphere in comparison to carbon dioxide. Therefore, this is one of the reasons why it is one of the gases that contribute to the climate change the most.

In relation to the history of the CF, the use of footprints to indicate the human activity impact on the environment started some decades ago, in 1979. Later on, William Rees and Matthias Wackernagel put a big effort to develop these unitary indicators that would show the environmental impacts in one number and that would allow comparisons across efforts and phenomena (Rees, 1992, after Lifset, 2014; Wackernagel & Rees, 1996). According to Weidema *et al.* (2008), one of the reasons why CF has become so popular is due to retail chains and proactive companies that provide or request information to the customers, e.g. for the purchase of carbon offsets and airplane tickets. Carbon footprint has been promoted and spread outside the research community, by companies, nongovernmental organizations (NGOs) and several private initiatives. Lifset (2014) explains that in contrast, not only the carbon footprint has risen nowadays, but also other types of footprinting, such as the water footprinting. This indicates the opposite of what happened at the beginning (the effort to include a broad range of concerns) because now the direction seems to be to narrow down the focus to one type of impact.

2.1.2 Critics to the carbon footprint due to its nature

Due to the very nature of the CF, a critical perspective both positive and negative can be attributed to its use.

2.1.2.1 Positive critics

Many advantages can be found when looking into the carbon footprint features. According to Weidema *et al.* (2008) and Lifset (2014), it has a broader appeal than LCA because it is a "catchy" concept, in which the different issues are kept simple, i.e., it is an indicator that encompasses the climate change impacts from human activities in a single number. This is in contrast to the nature of a pure LCA, which considers human activities' all aspects of natural environment, resources and human health and then it identifies and assesses potential trade-offs (Finkbeiner, 2009).

In line with Weidema *et al.* (2008), it is possible to calculate the CF on-line and the results are easily understandable and placed in context. The CF quantifies complicated phenomena, attempts at comprehensiveness in analysis and it eagers to communicate technical information to the public in an accessible way (Lifset, 2014). The CF also allows getting the life cycle focus into organizations and different decision making contexts, unlike the pure LCA has yet succeeded (Finkbeiner, 2009). Thus, it can be said that the CF is a precursor of the LCA, i.e. a company might go first for a CF and then for a complete LCA.

2.1.2.2 Negative critics

In relation to the negative critics, one should be aware of oversimplification when relying completely on one indicator, because it might give a deceitful picture of the impacts in particular cases and thus it might not always lead to a good decision (Finkbeiner, 2009; Lifset, 2014; Weidema *et al.*, 2008). For example, one could think that a low carbon footprint of biofuels means that it is an eco-friendly product, but, as the CF just covers the global warming, it does not show the negative impacts the biofuels have on land use. The CF could be a valid indicator if the several types of biofuels are compared to each other (Weidema *et al.*, 2008).

This view is also shaped by Finkbeiner (2009), who states that if carbon footprint is taken as the unique yardstick, then life-threatening trade-offs have to be faced. This means that for example, the waste-treatment plants would need to be shut down or the diesel particulate filter from cars would need to be removed due to their contribution to a higher carbon footprint. In addition, in order to achieve sustainable production and consumption, a CF might not be enough and a complete LCA should be conducted, i.e. all relevant environmental impacts such as eutrophication, land use, acid rain, smog etc.

should be taken into consideration (European Commission, 2009; Schmidt, 2009). As the CF has a very limited environmental focus, its purpose might only be to increase the overall knowledge of GHG emissions emerged from each stage of the life cycle of a product system (Schmidt, 2009).

In line with Cohen & Vandenbergh (2012), there are methodological challenges when implementing a reliable CF of a product, such as the need to make many assumptions in order to measure and verify the carbon emissions of a product within its life cycle.

Next section goes deeper into the traditional sustainability concept and how the CF can help companies to get closer to sustainability understood from a company's perspective.

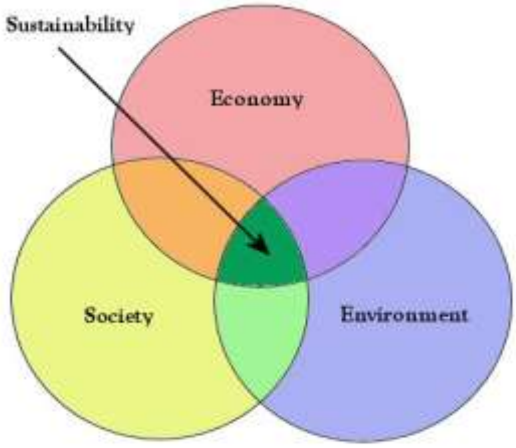
2.2 Sustainability in companies in the context of climate change

The concept of sustainable development has been defined in the Brundtland report, called *Our Common Future* in 1987 as follows:

"[…] *development is sustainable where it meets the needs of the present without compromising the ability of future generations to meet their own needs."* (WCED, 1987).

Since then, several definitions of sustainability are based on the concept of the "triple bottom line", which is about finding a balance between societal responsibility, environmental performance and economic contribution.

Figure 1 Triple bottom line of sustainability



Source: **(Powers, 2014)**

From a firm's point of view, sustainability might be defined differently than the wider concept explained above. It is about meeting the necessities of both the direct and indirect stakeholders of a firm without compromising its capacity to meet the necessities of future stakeholders (Dyllick &Hockerts, 2002, after Friedli *et al*., 2014).

One more definition is given by the International Institute of Sustainable Development (IISD):

"For the business enterprise, sustainable development means adopting business strategies and activities that meet the needs of the enterprise and its stakeholders today while protecting, sustaining and enhancing the human and natural resources that will be needed in the future"(IISD, 1992).

This definition grasps the initial concept of sustainable development, and it also assumes that economic development has to meet the needs of an enterprise and its related stakeholders (lenders, shareholders, employees, customers, communities affected by the company's activities and suppliers). In addition, the sustainable development concept highlights that businesses are a primary globalization driver that depend on both human and natural resources, as well as on financial and physical capital. However, the economic activity should neither destroy nor degrade the human or natural resources (IISD, 1992).

Climate change is viewed as one of the six dominant sustainability problems, together with loss of biodiversity, population growth, scarcity of drinking water, poverty and deforestation. And very probably it is the most important one. The social and economic activities are both causing and being affected by the impacts of climate change (IPCC, 2007; Stern, 2007; Banuri, 2009). For example, uses of coal, oil and gas generated respectively 44%, 35% and 20% of the worldwide CO_2 emissions (IEA, 2013).

Due to the fact that product designs, energy systems and production processes of all types are main sources of carbon emissions, companies are principally responsible for decreasing the emissions related to the life cycle of their products and services. Thus, climate change efforts might fail if companies are not completely engaged in decreasing carbon emissions from their entire systems (Schaltegger & Csutora, 2012).

There are several voluntary initiatives that have been carried out by and for corporations in order to reduce their GHG emissions, such as the adoption of environmental standards, approaches and tools, which might indicate the corporations' interest in sustainability (Ny *et al.*, 2006, after Lozano, 2012). Its implementation allows companies to account for several benefits. The main initiatives and its differences are explained in section 2.3.

Since the 1970s until late 1990s, these initiatives developed from purely end-of-pipe measures, which tend to be inefficient and costly, toward the approach of the whole system, in which processes, products and systems are modified in order to lessen waste and to use resources more effectively and efficiently, in nearly closed-loops (Sarkis Cordeiro, 2001, after Lozano, 2012).

If businesses integrate the sustainability concept and adopt environmental initiatives, it can help to control the effects companies have on climate change. Not only the environment, but also societies and economies might benefit from this approach in the long run (IISD, 1992).

2.2.1 Implementation of carbon footprint by companies

Wu and Pagell (2011) state that the higher demands for natural resources and the need to protect the environment are forcing companies to rethink their business models and reorganize their supply chain operations.

The CF is being applied more frequently by organizations because they find several benefits from it (Dias & Arroja, 2012).

2.2.1.1 Advantages for the company

The advantages for the company can be divided in two parts: first, those derived just from implementing the CF in the company, and second, those originated from implementing plus communicating the CF to the public.

Advantages by implementing the CF in the company:

- It determines potential opportunities for GHG mitigation and cost- savings opportunities throughout the supply chain (due to the identification of the efficiencies that help decrease waste and/or energy use) (Dias & Arroja, 2012; Carbon Trust, 2008).
- It helps in the implementation and development of GHG management strategies throughout the life cycles of products and to improve the product's environmental performance.

Advantages by implementing and communicating the CF to the public:

- By communicating the CF, it might allow consumers to make more informed choices about the products with the least climate change impact and assuming that they value the additional information provided in the products within the market, then the company might increase their sales due to a boost of consumer demand (Cohen & Vandenbergh, 2012; Tan *et al.*, 2012). Furthermore, this might reinforce the brand reputation of the company (Carbon Trust, 2008). The explanation is that consumers may demand products that go for environmental protection or awareness because of altruism or the *"warm glow"* (i.e. the positive emotional feeling people get for being socially responsible) linked to spending money in such an issue as the environmental awareness (Andreoni, 1990, after Cohen & Vandenbergh, 2012).
- Inclusion of the environmental considerations as part of the companies' marketing and operations strategies can benefit in attracting investors and in assessing their own or their suppliers' green credentials (European Commission, 2003b).
- Proactive engagement (by the willing to work together) between the different stakeholders and regulators might lead to enhanced connections across the supply chain. For example, green consumers might create opportunities for suppliers to innovate and offer companies products with reduced carbon content inputs (Cohen & Vandenbergh, 2012; Carbon Trust, 2008).

2.2.1.2 Disadvantages for the company

A fast growth of different footprint methods has happened along with an increase of private and national initiatives. This has led to disadvantages such as:

- Organizations might have to face significant costs, especially if they have to use several methods or if they have to comply with verification and labelling requirements for several retailers and countries. The costs and related burdens probably are much higher for SMEs (European Commission, 2013). It should be noted, though, that the cost of conducting the CF might vary depending on the product complexity and its supply chain. For example, smaller companies can reduce costs if they do not hire external consultants and the right product for the CF analysis is chosen (Carbon Trust, 2008).

- Companies and nongovernmental organizations, among others, have conducted the CF assessment. This has led to different methodological approaches (e.g. ISO 14040/14044 and PAS 2050) for its calculation. Therefore, this methodological difference may lead to ambiguous results because results may be pushed in one or another direction by the selection of the methodology. This happens especially when the CF is implemented for marketing intentions (Finkbeiner, 2009).

  A further explanation of the burdens that this unharmonized methodology can cause on product comparisons can be read in the following section.

2.3 Carbon footprint initiatives – A wide range of possibilities

In line with Finkbeiner (2009), the national and international carbon policies are being combined with international standards focusing on different types of corporate carbon accounting. The developed standards are answers to the need of industries for commonly acceptable methods of physical carbon accounting and they try to serve a growing market demand for information related to climate change along the supply chains of products and towards consumers.

Several international, national and sectoral initiatives related to the carbon footprinting can be found (Finkbeiner, 2009; Schaltegger & Csutore, 2012; Garcia & Freire, 2014). The main ones are:

At the organizational level:

1. The international standard ISO 14064-1: 2006 specifies principles and requirements for quantification and reporting of GHG emissions and removals at the organizational level. It includes requirements for the design, development, management, reporting and verification of an organization's GHG inventory (ISO, 2006 a, b).

At the product level:

2. ISO/TS 14067 provides concrete requirements and guidelines for quantifying and communicating the CF of products (ISO/TS, 2013).
3. ISO 14040 and ISO 14044 are generally used to assess the GHG emissions of a product throughout its life cycle (ISO, 2006 c, d).
4. British Standard PAS 2050 developed by the Carbon Trust and the British Department for Environment, Food and Rural Affairs (DEFRA) is a publicly available specification that provides a method for assessing the life cycle GHG emissions of products (BSI, 2011). It is built on the existing ISO 14040 and ISO 14044 standards (ISO, 2006 c, d).
5. The Product Life Cycle Accounting and Reporting Standard is developed by the World Resource Institute and the World Business Council for Sustainable Development (WRI/ WBSCD). It provides the needed requirements both in order to quantify the products' GHG inventories and for the public reporting (WRI & WBSCD, 2011).
6. Climate Declaration is a single issue of an Environmental Product Declaration (EPD) and it describes the GHG emissions of a product, whereas the EPDs are public statements of the product's entire set of environmental impacts. The Climate Declaration is based on the same standards than the EPD, i.e. ISO 14040, 14044 and 14025 for environmental declaration (IEC, 2014).

As it can be seen, there is a great choice of guidance for CF accounting and communication based on different standards and LCA methodologies (SETAC, 2008). However, and due to a lack of global agreements, the main problem of having the vast array of standards is that each of them has its own methodological approach that can lead to different results and compromise the comparisons between products (Dias & Arroja, 2012; SETAC, 2008; European Commission, 2009).

Despite these facts, common issues can be found among these standards. They consider GHG emissions from processes that are related to a product's life cycle, they allow the use of the IPCC emission factors to estimate GHG emissions and they apply global warming potentials from 100 years in order to show the results in terms of CO_2-equivalents (Brito de Figueirêdo, *et al.*, 2012).

Dias & Arroja (2012) conclude that in order to avoid biased product comparisons, more precise rules that limit the freedom extent in the choice of, among others, the system boundary, functional unit, data quality and allocation rules should be elaborated.

The Society of Environmental Toxicology and Chemistry (SETAC) goes one step further and suggests the need to create a new unified standard that would encompass the former ISO standards in order to address the GHG emissions of products and services on a global scale (SETAC, 2008).

CHAPTER III Theoretical Framework

The main theory connected to the study is system theory. Below, a description of this theory and its link to the study is depicted. Afterwards, system analysis, which is the practical method of system theory, is explained.

3.1 System theory/thinking

Different terms are attributed to system theory. Richmond (1991) remarks that system theory can be described as system thinking, system approach and system dynamic.

According to Tschan (2010) and Kohler *et al.*, (2010), system theories explain the relationships among elements within systems.
Kohler *et al. (2010)* describe system theories in their book as follows:

"System theory is an interdisciplinary cognitive model in which the system can be made to describe and explain many different, complex phenomena" (Kohler *et al.*, 2010, p.38)

One of the founders of the so called General System Theory was the biologist Ludwig von Bertalanffy and he explained it as an interdisciplinary framework where the fundamental principles of all kind of systems where described, i.e. from cells and different organisms to the societies and from ecological and biological to social systems. Bertalanffy explained in 1979 that a galaxy, a cat and a cell are real systems, i.e. they are beings that exist separately from an observer but they are perceived in or inferred from observation (Mulej, 2007). The complexity of the organized systems is the interplay of individual phenomena that are connected together in a nonlinear way (Kohler *et al., 2010).*

In line with Tschan (2010), one main supposition within system theories is that the system itself (e.g. the environment) develops or has properties that cannot be completely described or predicted by watching the behaviour of the system' elements (e.g. water, soil etc.). In addition, the elements' properties within a system, e.g. the interaction of water in the atmosphere, might only be understood once people comprehend the system as a whole.

With the former understanding, it can be said that social and biological systems are open systems that interact between each other, i.e., they exchange material, energy and information (Tschan, 2010). Systems tend to get self-organized, i.e., they develop functions or structures by themselves without having external influence or pressure. Additionally, systems change over time abruptly and unpredictably (Tschan, 2010).

Applied to this study, one could see three different open systems that interact between each other: the set of companies within the industrial system, the society and the environmental system. The companies' processes have influence on the surrounding, i.e. the society and environment because of the interconnection of the systems. This is the reason of the importance of looking into the problems caused by the companies' impacts as a whole. If any of these three systems might be impacted by any event, the others will suffer the consequences as well. For example, sudden floods or draughts events (which mostly happen in a nonlinear way) caused by the climate change phenomenon will have an impact on the environment (causing alterations on living and nonliving elements), on the society (e.g. people who have to move out to other regions or economic losses) and on the industrial systems as they will need to apply measures in order to reduce their impacts on the other two systems. This will cause the systems to change overtime.

With an environmental focus, Ecimovic (2008) explains as follows:

"The climate change system is a macro system of Planet Earth's nature or biosphere made up of interdependencies, interactions, co-operations of superior, inferior natural systems. The climate change system responds not only to our civilization's activities, but also to rules, practices, interdependencies, interactions and co-operations of other systems in nature" (Ecimovic, 2008, p.321).

Ecimovic (2008) establishes the main attention on the human beings and how it has taken advantage of natural resources over time. He adds that both science and people should understand the interactions, interdependencies, co-operations and all the transformations that happen within the environment in order to have a sustainable future of the civilization.

As in last centuries, industrial life has prevailed above environment and climate change, now humans can be helped by the systems theory in order to look at the system as a whole. There is no system that humans might know everything about, thus the understanding of its functioning and its connections with other systems is a learning process (Ecimovic, 2008).

From an industrial point of view, a slightly different perspective of system theory or system thinking is given by Richmond, Managing Director of High Performance Systems, Inc.:

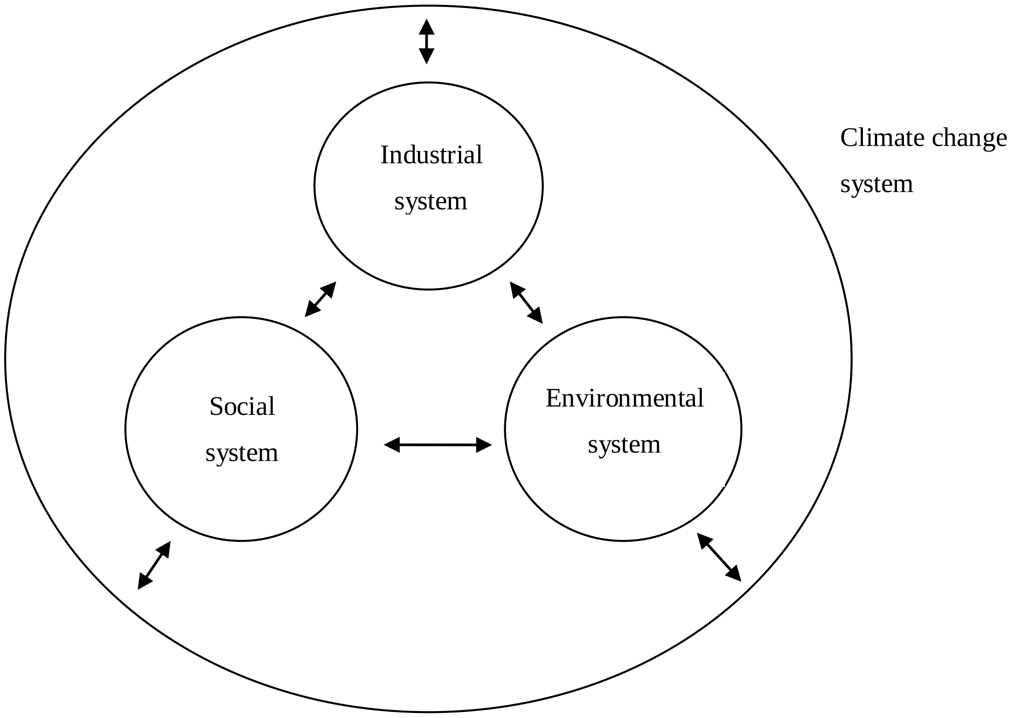
"You are adopting a systems viewpoint when you are standing back far enough—in both space and time—to be able to see the underlying web of ongoing, reciprocal relationships[...]" (Richmond, 1991).

In this line, Werhane (2007) explains that the operation and features of an industrial system influence the social and environmental factors that get in contact with the system. Thus, from the system thinking point of view, nature and society are connected to the industrial system and companies can use system thinking as a tool to be able to contribute to sustainable development.

The overall perspective of the system theory/ thinking reminds to the sustainability concept, see section 2.2. For example, the societal responsibility is linked to both, the environmental performance and the economic contribution and vice versa. Looking into an even broader perspective, these three systems, i.e. industry, society and environment are embedded in a bigger one, the climate change system. All of them are interlinked and should be taken into account when looking at the systems as a whole.

Figure 2 depicts the researcher's interpretation of the system theory.

Figure 2 Interconnection of systems



Source: **Own figure**

3.2 System analysis

System analysis is described as a practical method of system theory and it is the scientific basis of the life cycle analysis. In system analysis, a system model is designed, firstly more simple and then by increasing complexity as much as needed in order to accomplish the desired quality of results. The model is based on elements and relationships which can be graphically depicted as a flow diagram of processes linked by flows, which are the relationships. A model is always an abstract and a reduced image of reality. However, it is then possible to make a mathematical description and to use computerized techniques to process the model and obtain results from it (Kohler *et al.*, 2010).

Applied to this study, an example of the system analysis can be seen in Figure 8, CHAPTER VI, showing the product system that is analysed in the carbon footprint assessment. Within the system boundary, the different features of a system model can be depicted: a flow diagram of processes (which are the life cycle stages) are linked by both, the product and the environmental flows. The product flows show the relationship within the stages whereas the environmental flows show the relationships between the environment and the technosphere. Afterwards, the model is processed by the use of the computerized technique called Simapro, which is explained in section 5.1.

In CHAPTER I, CHAPTER II and CHAPTER III, the topic has been introduced, the problem has been defined and the context of the study has been explained. In the next chapter, and based on the background information, the formulation of the research questions is depicted.

CHAPTER IV Formulation of the Research Questions

The study gives an answer to the research questions, which guide the general line of the study.

There are two main research questions, and each of them includes two sub questions as follows:

1. **How can Kuvatek demonstrate that the life cycle of the water cooler model DF12 has a lower carbon footprint (CF) than the water cooler from its *"Competitor"*?**

   a. *What is the CF of the two products?*
   b. *Are the results of the CF in accordance to Kuvatek's beliefs about their environmentally friendly water coolers?*

2. **Why is Kuvatek interested in conducting concretely a carbon footprint assessment and also in communicating the results of the CF comparison?**

   a. *What are the advantages and disadvantages for the company when carrying out the CF?*
   b. *What are Kuvatek's ideas of documenting and communicating the CF performance of their products?*

CHAPTER V Research Methodology

In this chapter, the research design, the type of methodology applied to the study and the methodology used to answer both research questions are presented.

5.1 Mixed research design

The research started with data collection based on desk study, i.e. literature review on carbon footprint cases, reports, several ISO guidelines, articles etc. in order to gather background information and to get a deep understanding of it. Several of these files were obtained online, but others, such as the "Measurement report on water coolers" (Termovel, 2013) which was conducted by a third party and other documents containing water coolers information were obtained from Kuvatek. Afterwards, on-site data collection activities were conducted. Here, three visits to Kuvatek were done. For the first visit, the interview was conducted with the director and employees for an initial approach regarding the expectations the director had of the study and the gathering of general information from the company. Observations were done in order to understand how the product under study worked. The second visit was mainly to collect quantitative data about both water coolers (because Kuvatek keeps the competitor's water cooler), so as to then introduce the data in Simapro. Observations on Kuvatek's storage room for end of life materials were done as well. Third visit was based on an interview in order to gather more qualitative data to answer the second research question and for clarifications. All interviews were semi-structured, recorded and transcribed; they are attached to Appendix C.

Throughout the entire data gathering process, several e-mails were exchanged with Kuvatek to receive all undetermined and missing information. All data was collected and then validated by the comparison with official reports and the company's websites. Where validation was not possible, assumptions were made and reported. After this, analysis and interpretations of data were done. On the one hand, both water coolers' systems (Kuvatek and its competitor) were modelled by introducing the data in Simapro and obtaining carbon footprint results, which would give an answer to the first research question. Simapro is a computer software tool with a variety of LCA applications. Basically, it models and analyses the life cycle stages of products or services in order to measure their environmental impacts. On the other hand, the qualitative data served to answer the second research question about Kuvatek's motivations on CF assessment.

Table 2 encompasses the research framework, which gives an overview of the research activities related to each phase of the project and its corresponding timeline.

Table 2 Research framework

Phases of the research project (timeline)	Research activities
1.Desk study- Data collection *(Month 1)*	(1) Literature review on CF cases, reports, ISO guidelines, relevant theories etc. (2) Understand context and relation between sustainability, climate change, CF tool
2. On site- Data collection *(Months 2 and 3)*	(3) Quantitative data collection:weight and measure water coolers' components (4) Qualitative data collection: interviews, observation
3. Data analysis *(Month 4)*	Analyse data that has been collected by: (5) Quantitative assessment by the use of Simapro (6) Qualitative assessment by the transcription of interviews
4. Interpretation and reporting *(Month 4)*	(7) Check and interpret results for consistency and coherence (8) Final written report (9) Present the final results and submit report to Kuvatek

Source: **Own table**

5.2 Mixed study methodology

This study applies mixed research methods, and the main purpose for selecting this approach is "Expansion", which *"seeks to extend the breadth and range of inquiry by using different methods for different inquiry components"* (Greene, Caracelli and Graham, 1989, after Johnson & Christensen, 2014, chapter 16). In other words, it is not possible to address the research questions with only one specific type of research (Creswell, 2012). Another reason to use this type of research is related to the philosophy of pragmatism, i.e., the researcher should use the methods that are the best for any real world situation. According to Professors Johnson & Christensen (2007), there are two main types of mixed research:

1. The mixed model research: *"quantitative and qualitative approaches are mixed within or across the stages of the research process"*.

   The model has two subtypes, which depends if the quantitative and qualitative methods happen within-stage or across-stage of the research process.
2. The mixed method research: *"a qualitative phase and a quantitative phase are included in the overall research study"* (Johnson & Christensen, 2007).

Applied to this study, it is an across-stage mixed model research because both qualitative and quantitative methods are mixed across at least two of the research phases: during phases of on-site data collection and data analysis; details are shown in Table 2.

The methods shown in the next table allow getting the necessary data to be able to answer the research questions and are divided in qualitative and quantitative methods and also into primary and secondary data.

Table 3 Relationship between the type of methods and type of data

Type of data	Type of methods	
	Quantitative methods	*Qualitative methods*
Primary data (obtained from first-hand experience)	On-site measurements of the components	Semi-structured interviews Observation E-mails
Secondary data (obtained from the past or from a different party)	CF assessment by the use of Simapro	Desk study/literature review

Source: **Own table**

5.3 Methodology used to address the first research question

In order to get the needed data to be able to answer the first research question, mixed methods were used, as explained in section 5.1. However, the methodology that prevails is the LCA methodology by following the ISO guidelines in which all the requirements in order to be able to conduct the CF assessment are stated.

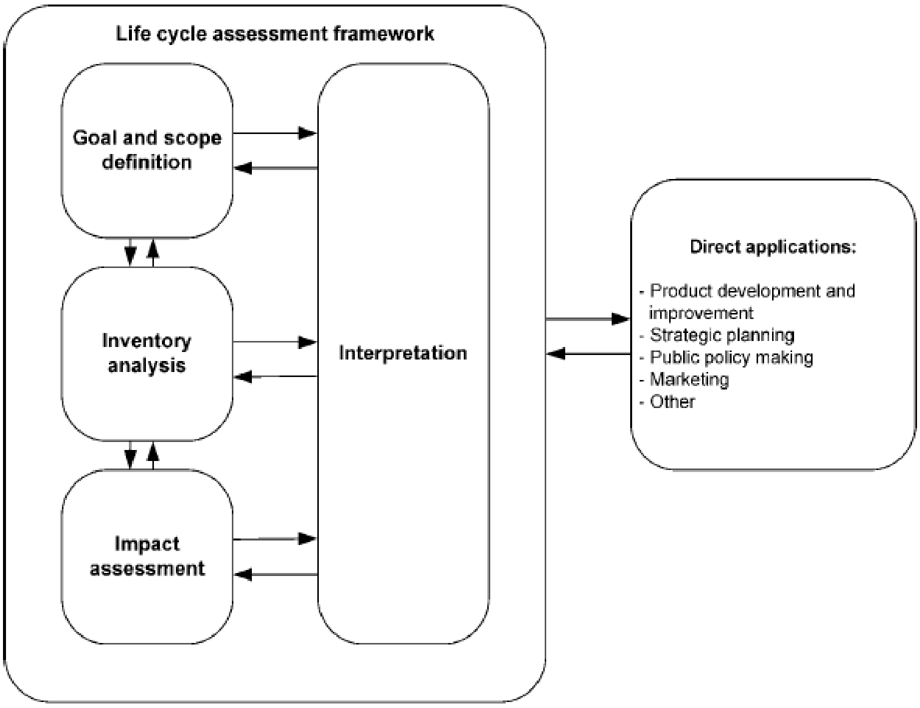
Therefore, the carbon footprint methodology of this study is based on LCA following ISO 14040 and 14044 (ISO, 2006c, d). For details, ISO 14067 has been followed as well (ISO/TS, 2013). The latter ISO is based on the principles provided in ISO 14040 and ISO 14044.

ISO 14067 recommends the LCA methodology to account the CF of a product because:

"The development of CF quantification and CF communication takes into consideration all stages of the life cycle of a product, including raw material acquisition, production, use and end-of-life stage" (ISO/TS 2013, p.12).

According to ISO 14040, the LCA methodology is an iterative process that consists of four phases: goal and scope definition, inventory analysis, impact assessment and interpretation as shown in Figure 3. Therefore, these phases are also the basis for the carbon footprint analysis in CHAPTER VI.

Figure 2 Phases of an LCA



Source: **(ISO, 2006c)**

5.4 Methodology used to address the second research question

The qualitative methods used to answer the second research question include interviews held with Kuvatek and literature review.

Once the research question was formulated, literature review was done, which is based on information from sources such as articles and reports provided by different authors on the research question topic (mainly focusing on CF implementation by companies and communication of the environmental performance of products).

Afterwards, this data collection based on desk study is validated (i.e. the data the researcher comes across is verified by the use of different methods) by conducting interviews with Kuvatek. By making the critical comparison between the literature review findings and the outcome of the interviews allowed to make an analysis of the differences and similarities between the two sources of information and to draw conclusions from it. This process is a narrowing down from a more ‘general knowledge’ to the specific study.

The semi-structured interviews are based on key questions that supports to define the fields to be investigated, but also allows both interviewer and interviewee to diverge so as to follow up an idea or answer in more detail (Gill *et al.*, 2008). The interviewees from Kuvatek were:

a. John Green, director of Kuvatek
b. Mia Andersson, communications employee
c. Rasmus Høgh, export sales employee

These are some examples of the key questions discussed during the interviews:

1. Which is the purpose and motivation of the company when having interest in conducting a CF of their product?
2. Why did you (the director of Kuvatek) think about the CO_2 emissions more than for example, the water emissions? Is it your own concern?
3. In your opinion, which are the advantages and disadvantages of carrying out a CF?
4. So, after the CF screening (and after having a review on the results by an expert panel), would you like to communicate the results to the public at some point? By which means?

CHAPTER VI Comparative carbon footprints of water cooling systems

This chapter encompasses the different LCA phases following the ISO 14040 and 14044 guidelines.

6.1 Description of the systems

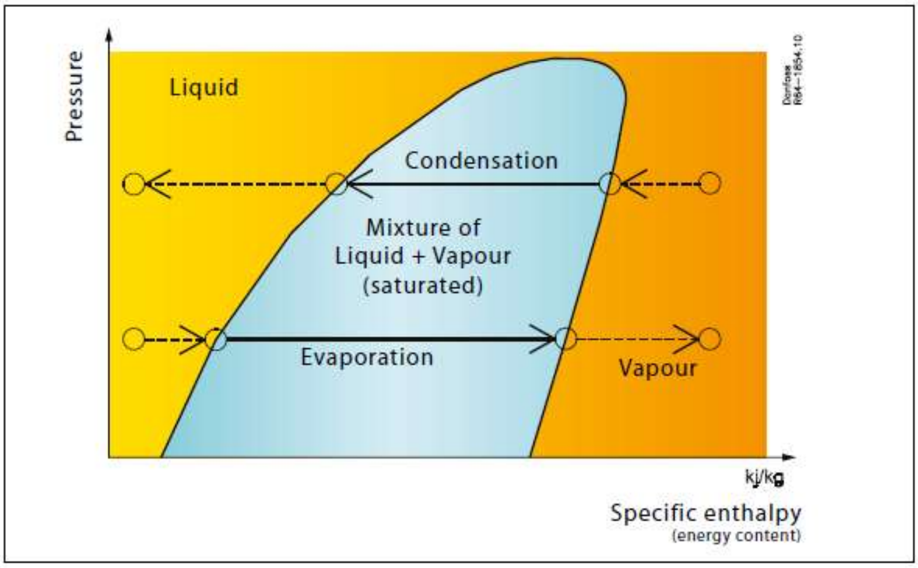
This section is not part of the ISO 14040/14044 requirements; however, the researcher finds it important to describe the system differences.

In overall, the water coolers systems operate in the same way. Usually, the water coolers have a reservoir inside in order to keep a certain amount of water so the water can be cooled down before being tapped. In the reservoir, the water gets cooled down by a refrigerant, which has the property to absorb heat and thus will cool the water inside the reservoir. When the refrigerant goes through the water cooler system, it is compressed by a compressor and it evaporates into gas. This gas can then absorb the heat surrounding the reservoir, which will cause the cooling of the water. As people tap the water, the water cooler will refill the reservoir and the process starts working again (Danfoss, 2007).

According to the director of Kuvatek, when the water comes from the pipes, it first gets hot, and then cold again due to the heat exchange between the water and the refrigerant. Both of them are in different pipes and they never get in contact.

Energy content and pressure are the common properties for refrigeration systems. The diagram in Figure 4 shows the liquid, vapour and mixture regions for a given refrigerant. Liquid is on the left side of the diagram whereas vapour is on the right side. In between both phases, there is the mixture region. The regions are bounded by the saturation curve, which separates the two phase-state (Danfoss, 2007).

Figure 3 Refrigerant diagram



Source: **(Danfoss, 2007)**

The refrigerant suffers different change of phases within the compressor: from gaseous to liquid, and then back to gas. The refrigerant, while it is cold, it is liquid (i.e. with a low energy content), and when heat is applied to it, it turns into gas (i.e. with a high energy content), and it is this phase change from gaseous to liquid and back to gas “the whole secret of the water cooler”. The evaporator helps to remove the heat, so the refrigerant can get cold but when the refrigerant gets sucked into the compressor it is in gaseous phase. This is a circular system.

The above description of the refrigeration system is very similar for any water cooler. In addition, both water coolers under study are bottleless, fed off the pipes and can be “wall mounted” or “table topped”, see section 1.1 for further explanation of the concepts. However, several important differences between the two selected water coolers can be found, see Figure 7.

The water cooler selected by Kuvatek for the study is the model DF12, used, among others, in municipalities, schools and hospitals; and it can serve around 100 people/ hour. This model is the most recommended by the director of Kuvatek because both it is the most sold model by now and because it is the most flexible and appropriate for this kind of users (due to its design, quantity of water delivered per time etc.). This model is shown in Figure 5.

This model is a flow-through system, i.e., the machine cools the drinking water while being tapped and therefore, neither water container nor ice bank is needed. The system does not require pre-filter from the water supply or statutory inspections. Due to the lack of several components (tank, filter, UV lights etc.), there is no need of service in order to maintain or replace these items. The water cooler is suitable for energy control program. There is also a sensor to measure the water temperature and indicates when it needs to be cooled down (Termovel, 2013).

Figure 4 Kuvatek's water cooler

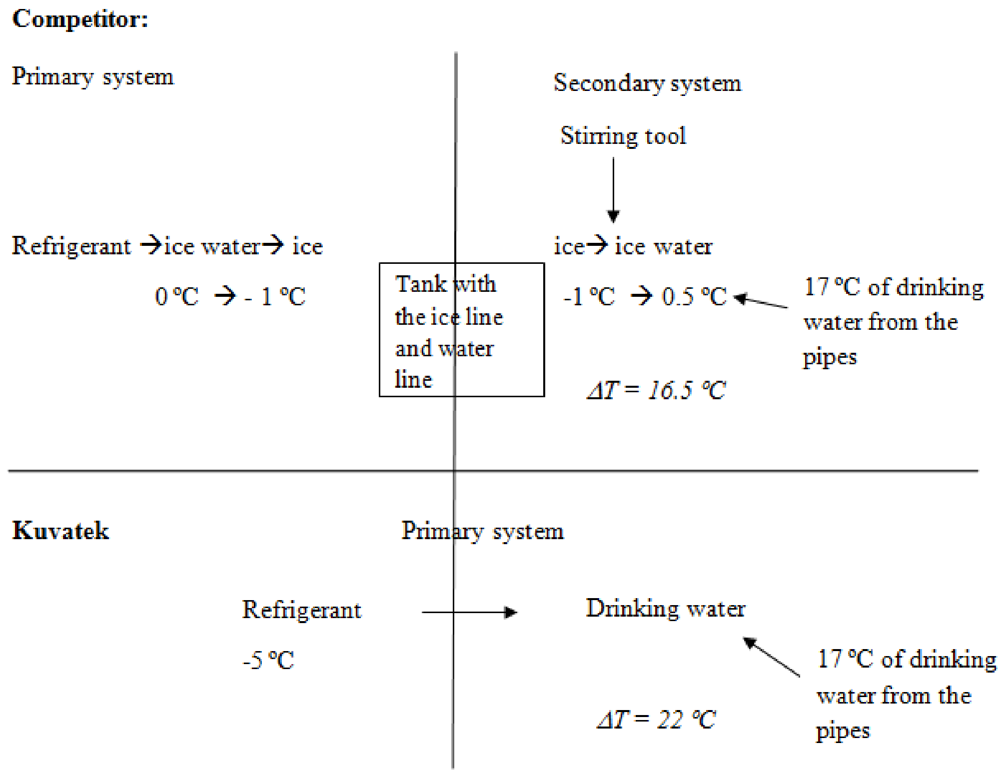
Source: **(Kuvatek, 2014)**

Figure 5 Competitor's water cooler

Source: **(www.miw.co.uk)**

The competitor's water cooler shown in Figure 6 is also used for schools and canteens and can serve approximately to 100 persons/ hour. The machine has a tank with a water line and an ice line and the drinking water is cooled down by the ice line. There is also a stirring wheel in order to ensure that the water does not get completely frozen. In order to avoid bacterial growth in the tank, it is constantly illuminated with UV light and a pre-filter is recommended. The water cooler is not suitable for energy control program due to risk of bacterial growth (Termovel, 2013). Due to the several extra items this water cooler has, service in order to maintain or replace them is needed.

Figure 6 Comparison of the basic functioning of both water coolers



Source: **Own figure**

It should be noted that the values given in the figure are just examples in order to understand the difference in the functioning of the water coolers.

ΔT (Delta T) is the change in temperature over a specific time period and it makes the difference when delivering the water at a certain temperature between both systems. Kuvatek delivers at 5.3 °C, whereas the competitor at 9.7 °C. It shows how fast the water is converted from hot to cold and also the efficiency.

The competitor has a primary system (from water to ice) and a secondary system (ice to water). There are basically two changes in phase and a low transformation temperature (ΔT = 17-0.5 = 16.5 °C). The transformation between the drinking water and the cold water costs a lot in terms of energy because there is a high energy loss in the change of the phases, which are mainly 3: from water to ice, then from ice to water and finally, the constant use of power from the stirring wheel. In addition, there is a loss of energy from the electronic machines, like the UV light, the T° measurement etc.

Kuvatek has only the primary system, by the use of the refrigerant directly to cool down the drinking water. There is a $\Delta T = 17- (-5) = 22$ ºC, which means there is a fast heating transfer and the water gets cooled down faster than for the competitor.

6.2 Goal definition

The goal of the study is the comparison of the CO_2e of a water cooler model DF12 from Kuvatek to the water cooler from its competitor for use in schools, hospitals or offices in Denmark.

Thus, the intended application of the study is to provide carbon footprint at company level by the comparison of the two products with a future documentation purpose, i.e. this study can serve as an initial step to show customers how environmentally friendly Kuvatek is (in terms of climate change) in comparison to their competitor.

The intended audience of the CF results is, on the one hand, for Kuvatek itself (for its internal use) in order for the director of Kuvatek to see how right he is in his beliefs that they are producing an environmentally friendly product and also to comprehend how they stand in relation to their competitor.
On the other hand, the idea of the director is to disclose the study to the public (with the customers as the main target) by including the CF results in the sales/ marketing material. In line with ISO 14040 (2006), this would only be possible with a previous critical review conducted by a panel of experts.

6.3 Scope and limitations

The comparative carbon footprint is a screening process. The scope includes several sections:

6.3.1 Function and functional unit

Both products that are being compared to each other have the same function, which is to cool down the tap water.
The reference of the study is the functional unit, which is "the use of the water cooler for a period of 1 year".
The reference flow is the amount of tap water cooled during this period, which is estimated to be 10.00 m^3/ year.

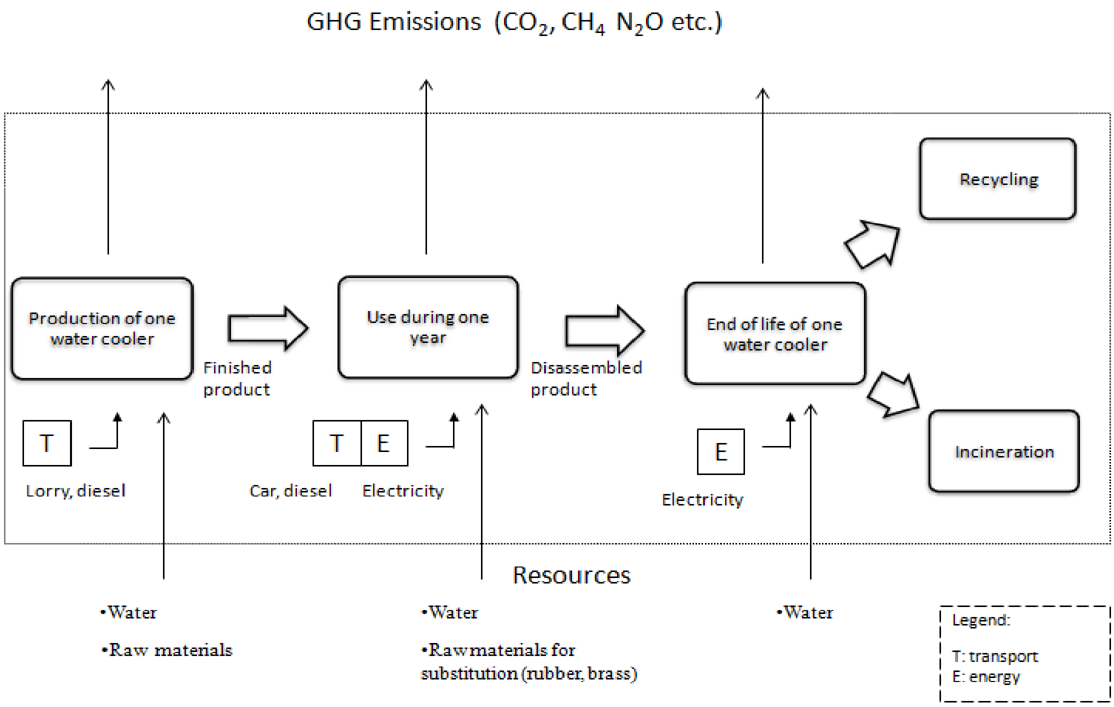
6.3.2 System boundary

The CF assessment covers the entire water cooler supply chain. Therefore, the system is modelled based on the concept of "cradle-to-grave", which includes the entire LCA stages: production, use and end-of life of the water cooler. The raw materials production/ extraction stage is accounted indirectly in the production stage, see section 6.3.4.

The approach to the system delimitation is the consequential modelling, which, according to Thrane & Schmidt (2007), *"[...] uses a market oriented approach to identify the affected processes [...]"*.

Figure 8 depicts the system boundary for any of the two product systems. Here, a process flow diagram depicts the unit processes, i.e. the LCA stages, and its relationships connected by product flows (the horizontal arrows) and the environmental flows (the vertical arrows). The system boundary is shown by the dashed line, which separates the environment from the technosphere (in which the unit processes are included).

Figure 7: System boundary for the water cooler system



Source: **Own figure**

Several inputs and outputs have to be deleted due to the difficulty to get the data from the competitor (as this information does not appear in a public source of information such as website or public report). Thus, inputs, outputs or processes for which data were not available for one of the two systems are omitted in the other system as well as to make a fair comparison.

- For the production stage, inputs such as the water consumption, energy inputs and emissions and waste outputs were omitted. In addition to the abovementioned reason, the director of Kuvatek states that the water consumed in Kuvatek's production site accounts for less than the amount used in average in a household and that the water and energy consumption together won't account a big difference if it is produced or not, because the place needs to be kept functional, anyway. The appliances needed during production don't consume much electricity, as many tools are powered by battery.

  Probably not many impacts derive from Kuvatek's production stage because it is a small production site where the water cooler pieces are assembled. The main difference between the production stages of both water coolers are probably given by the materials used to produce them.
- For the use stage, the emissions were omitted because there is no available data and the actual emissions could come from the refrigerant within the water cooler, but it is a closed system, so it won't affect the environment during the use of the product.
- For the end of life stage, emissions are implicitly accounted by the selection of a specific material treatment (recycling, incineration etc.). Regarding the transport from Kuvatek to a recycling or incineration plant is implicitly accounted in the selection of the waste materials.

6.3.3 Allocation procedure

Allocation is about dealing with multifunctional processes. No co-products are derived from the main supply chain, but allocation can be seen in the recycling process and in the selection of the suppliers.

As already mentioned, there are three stages under study (production, use and end of life) that include several processes. The products/ services for each stage are, respectively: water cooler, cooled water and disposal of the water cooler. However, out of these, only the end of life stage includes multifunctional processes, i.e. the recycling activities.

By the use of consequential LCA methodology, allocation is avoided through system expansion.

In the studied system, system expansion can be observed in these examples:

- When a material such as plastic is recycled, the process provides two services (co-products): the treatment of waste (input flow) and the generation of recycled plastic material (output flow) that can be used for a new purpose. Allocation of the recycling- dependent emissions between these two flows is avoided by expanding the system boundary: the generation of recycling material substitutes for the production of the virgin material somewhere else. This will result in the avoidance of the emission of a certain amount of CO_2 because there won't be a need to produce an amount of this material due to the recycling process.
- There is a selection of marginal suppliers for the components of the water coolers.

Thrane & Schmidt (2007) explain as follows: *"For small-scale changes, which often occur at company level LCAs, the method suggests that the most competitive producers [...] are affected on expanding markets, because they are most able to respond to a change in demand. The opposite happens if the market is in regress, because the company then affects the capacity that is being taken out of the market"* (Thrane & Schmidt, 2007, p.219). By method, it is meant the consequential methodology. Thus, the marginal suppliers are able to increment or reduce their supply when demand for their product increments or lessens (Grant, 2011). Applied to the study, the marginal suppliers are affected by the expanding market because, when producing the water coolers, it will lead to a rise in demand of several components and these suppliers, which are the most competitive ones, will be able to react to these market changes.

6.3.4 Types and sources of data

The sources of data for the CF assessment of both companies are primary and secondary, see Table 3 for further details, and it includes a mixture of measured, calculated, estimated and assumed data.

However, there is a limitation on available data for the competitor because there is no direct communication with them, so Kuvatek is the main source of information.

The data used to be able to model the systems in Simapro is called the foreground data, and it includes, among others, resource quantity or electricity inputs. It is obtained from both, primary and secondary information.

On the contrary, the background data, which is directly obtained from Simapro databases, cannot be influenced by the researcher and it includes information for the production of generic materials, transport and energy. The extraction of raw materials stage is implicitly accounted in the production stage of the studied system.

6.3.5 Data quality requirements

According to Weidema (1998), after Thrane & Schmidt (2007), the data quality requirements are based on five key parameters:

a) Temporal scope: the data is based on 2013 and on current year, 2014. The data has been collected throughout three months.
b) Geographical scope: the data is based in EU context.
c) Technological scope: the level of technology used is average (i.e. not old, neither cutting edge).
d) Reliability: material data for the production stage and inputs such as electricity and water for the use stage are reliable because they are measured on-site and based on third-party reports, respectively. Data for all the transportation distances and treatment of the materials for the end of life stage are based on both estimations and assumptions.
e) Completeness: data is missing in relation to the inputs and outputs that have been omitted from the system boundary, see section 6.3.2 for further details.

6.4 Inventory analysis

As mentioned in section 6.3.2, consequential modelling approach is applied; therefore, the dataset of consequential, system processes is used, as it is the most appropriate for LCA screenings.

The inventory analysis includes the use of resources (e.g. water and materials), energy (electricity/ heat), and the travel distances, which are mainly measured on volume or mass (m^3 or Kg/ g), energy units (Kwh) and length (Km or KgKm), respectively.

The life cycle processes used to model both systems (Kuvatek and competitor) in Simapro are depicted in Appendix B.

Several assumptions are needed when only partial information is available. These assumptions are based on internet searches, reports from both companies and discussion with Kuvatek's director. In next section, the inventory tables and the related assumptions for each stage are presented.

6.4.1 Data collection

This section refers concretely to the data collection conducted for the comparative carbon footprint assessment but not for the overall study.

Data collection is divided into the three stages of the water cooler supply chain: production, use and end of life. So, for each stage, the inventory tables of both water coolers are presented and underneath, the assumptions made. For the inventory data were calculation is needed, it is referred to its corresponding table in Appendix A (i.e. Tables A1, A2, A3 and A4).

Table 4 Inventory of production stage in Kuvatek

Water cooler DF 12 -Kuvatek (1 piece)	Quantity	Units	Type of material	LCI data sources
Materials *(used to produce 1 water cooler)*				
• Iron	-	-	-	
•Aluminium	1738,80	g	Material no. 5754, plate, virgin	
•Stainless steel	8401,80	g	SS 303,virgin (304)	
• Steel	13736,00	g	ST 37(common steel), DIN 17100, virgin	
•Copper	4124,44	g	99,9%Cu, deoxidized copper, virgin	On-site measured in Kuvatek
•Brass	58,00	g	Common brass, IO:CuZn37; As No.272, virgin	
•Silver	0,56	g	56%silver, 44%copper, virgin	
•Plastic	144,00	g	EPS (Polystyrene), virgin	
• Plastic	10,00	g	PEHD, high density polyethylene, virgin	
• Plastic	102,00	g	ABS (Acrylonitrile butadiene styrene), virgin	
• Plastic cable	373,20	g	PVC [Poly(vinyl chloride)], virgin	
• Nylon	95,00	g	PA6 (polycaprolactam) or Nylon 6,6 , virgin	
• Synthetic Rubber	1,00	g	NBR 70 (Nitrile butadiene rubber), virgin	
•Synthetic Rubber tube	27,00	g	EPDM(ethylene-propylene-diene-monomer)	
• Natural rubber	28,00	g	Natural, virgin	
•Refrigerant	260,00	g	Propane/R290;CAS nr. 74-98-6; GWP:3	Calculated-see Table A1
• Oil (in compressor)	539,00	g	Polyolester	
Uncategorized (mix of materials)	*634,00*	g		
• Component with motor starters for compressor:				
Steel	*0,5*			
PVC plastic	*0,3*			
Aluminium	*0,2*			
• Condensator:	1937	g		
Copper	*0,6*			
Stainless steel	*0,4*			
Total materials weight	***29638,80***	g		Sum of all materials
Weight of the water cooler	**29800,00**	g		Based on Kuvatek's website
Error	161,20	g		29800 g -29638 g
% of error compared to the total water cooler weight	0,54	%		(29800/161,2)*100
Transport (from production site to the consumer and which kind of transport vehicle)	**5960,00**	kgkm		Calculated-see Table A1

The below on-site pictures show some examples of how the components were firstly separated by materials in order to weight them afterwards.

Figure 8 Aluminium components

Figure 9 Components with several materials

Figure 10 Stainless steel components

Figure 11 Copper components

Table 5 Inventory of production stage for the competitor

Water cooler - Competitor (1 piece)	Quantity	Units	Type of material	LCI data sources
Materials				
• Iron	7923,00	g	virgin	
•Aluminium	226,00	g	Material no. 5754, plate, virgin	
•Stainless steel	4684,00	g	SS 303,virgin	
• Steel	13233,60	g	ST 37(common steel), virgin	
•Copper	1513,44	g	99,9%Cu, deoxidized copper, virgin	On-site measured
•Brass	-	-	-	in Kuvatek
•Silver	-	-	-	
•Plastic	-	-	EPS (Polystyrene), virgin	
• Plastic foam	4596,13	g	PE (Polyethylene) foam, virgin	
• Plastic	465,00	g	ABS (Acrylonitrile butadiene styrene), virgin	
• Plastic	1112,30	g	PVC [Poly(vinyl chloride)], virgin	
• Nylon	498,00	g	PA6 (polycaprolactam), virgin	
• Synthetic rubber tube	15,00	g	EPDM (ethylene-propylene-diene-monomer)	
• Synthetic Rubber	33,00	g	NBR 70 (Nitrile butadiene rubber), virgin	
• Natural rubber	-	-	Natural, virgin	
•Refrigerant	370,00	g	R134a;CAS No. 811-97-2 ;Freon GWP:1300	Calculated-see Table A2
• Oil (in compressor)	323,40	g	VG22 Ester	
Uncategorized (mix of materials)	194,00	g		
• Motor starter and temperature relay:				
Iron	93,00	g		
PVC Plastic	101,00	g		
Total materials weight	***34992,87***	g		Sum of all materials
Weight of the water cooler	**32620,00**	g		Based on competitor's website
Error	2372,87	g		34992,87 g -32620g
% of error compared to the total water cooler weight	7,27	%		(32620/2372,87)*100
Transport (from production site to the consumer and which kind of transport vehicle)	**68045,32**	kgkm		Calculated-see Table A2

Table 4 and Table 5 present the collected data for the production stage. The first column shows the materials of the water coolers with its corresponding weight and the fourth column presents the type of the material. The last column depicts the sources of the inventory data, in where some minor calculations are included as well.

Additionally, the total weight of the materials is compared to the official weight of the water coolers and showed a low level of error (0, 54% for Kuvatek and 7, 27 % for the competitor). Errors might occur due to the needed calculations in order to get mass units of some materials. In addition, several water cooler components are difficult to be separated into the different materials as it can be seen in Figure 9. The error is bigger for the competitor because more estimation for the calculations is needed. At the end of the table, the transportation distance from production site to the consumer is depicted.

Several assumptions are made:

The materials for both water coolers are virgin. For some materials, it is needed to search on internet for the composition and chemical formula in order to find them later on in Simapro databases. The types of materials for the competitor are the same than for Kuvatek.

The below on-site pictures show some examples of the materials from the competitor's water cooler.

Figure 12 Iron components

Figure 13 Components with several materials

Figure 14 Plastics component

Figure 15 Stainless steel components

Next two tables present the inventory for the use stage.

Table 6 Inventory of use stage for Kuvatek

Water cooler DF12 -Kuvatek (1 year)	Total used by 1 piece	Units	LCI data sources
Electricity *(use+ standby)* ***Electricity*** *(use)*	70,39 53,24	kWh/ year kWh/ year	Based on Project Ark-TCO
Standby electricity	17,15	kWh/ year	Based on Målerapport på drikkevandskølere A1
Water use *(during the use of 1 water cooler in a year)*	10,00	m3/ year	Based on Project Ark-TCO
Maintenance *(km or fuel used to* get to the customers)	99,33 3,33	KgKm/ year km/year/piece	Calculated- see Table A3
Other materials (needed substitution materials during its use)	0,36 0,0018	KgKm kg of produced rubber	Calculated- see Table A3

Table 7 Inventory of use stage for the competitor

Water cooler - Competitor (1 year)	Total used by 1 piece	Units	LCI data sources
Electricity *(use+ standby)* ***Electricity*** *(use)*	696,10 258,10	kWh/year kWh/year	Based on Project Ark-TCO
Standby electricity	438,00	kWh/year	Based on Målerapport på drikkevandskølere A1
Water use *(during the use of 1 water cooler in a year)*	10,00	m3/ year	Based on Project Ark-TCO
Maintenance *(km or fuel used to* get to the customers)	4077,50 125	KgKm km/year/piece	Calculated- see Table A4
Other materials (needed substitution materials during its use)	417,20 0,05	KgKm Kg of produced brass	Calculated- see Table A4

The tables present the energy inputs (electricity), the water consumed and the maintenance in terms of transportation for one water cooler during 1 year use. In addition, “other materials” refers to the substituted materials needed during the use of the product and the transportation distance required to deliver the materials to the customers. This is further explained in CHAPTER VII. The transportation distance is not analysed with Simapro because the software requires introducing a specific transportation vehicle, but Kuvatek sends the substituted materials by post and the competitor does it partially as well.

Several assumptions are made. For details on the assumed values, see Table A3 and Table A4.

a) The maintenance distances on which the final maintenance calculations are based on.
b) The weight of the substituted materials.

Table 8 and Table 9 illustrate the inventory analysis for the end of life stage.

Table 8 Inventory of end of life stage for Kuvatek

Water cooler -Kuvatek (1 piece)	Quantity	Units	End-of-life (%)		
			Recycling	Re-use	Incineration
Materials					
•Aluminium	1738,80	g	100		
•Stainless steel	8401,80	g	100		
• Steel	13736,00	g	100		
•Copper	4124,44	g	100		
•Brass	58,00	g	100		
•Silver	0,56	g	100		
•Plastic EPS	144,00	g	100		
•Plastic tube EPDM	27,00	g	100		
• Plastic PEDH	10,00	g	100		
• Plastic ABS	102,00	g	100		
• Plastic cable PVC	373,20	g	100		
• Nylon PA6	95,00	g	100		
• Synthetic Rubber	1,00	g	100		
• Natural rubber	28,00	g	100		
•Refrigerant	260,00	g			100
• Oil (in compressor)	539,00	g			100
Hazardous waste	No				
Lifetime (estimate)	Around 10 years				

When Kuvatek's water cooler reaches its end of lifetime, it can be handled in two different ways. On the one hand, as the customers of the water cooler are offices, hospitals, schools etc. which have its own garbage sorting, they have the choice to dismantle the water cooler by themselves and place the main components into the corresponding recycling container.

On the other hand, the customers can send the product back to Kuvatek, where it is sorted by the main materials (such as aluminium and stainless steel) and collected on site in different containers. When the containers get completely filled, Kuvatek plans to sell it to a recycling treatment plant. With regards to the refrigerant, as it is propane and it is environmentally harmless, Kuvatek opens the system so it can evaporate into the air. The oil and the compressor containing it probably get incinerated as a whole.

The pictures below are taken on-site, where Kuvatek keeps containers sorted by materials of the dismantled water coolers.

Figure 16 Different sorted materials

Figure 17 Copper pipes

Figure 18 Stainless steel pipes

Figure 19 Steel compressors

Table 9 Inventory of end of life stage for the competitor

Water cooler -Competitor (1 piece)	Amount	Units	End-of-life (%)		
			Recycling	Re-use	Incineration
Materials					
• Iron	7923,00	g	100		
•Aluminium	226,00	g	100		
•Stainless steel	4684,00	g	100		
• Steel	13233,60	g	100		
•Copper	1513,44	g	100		
•Plastic insulation tube EPDM	15,00	g	100		
• Plastic foam PE	4596,13	g	100		
• Plastic ABS	465,00	g	100		
• Plastic PVC	1112,30	g	100		
• Nylon PA6	498,00	g	100		
• Synthetic Rubber	33,00	g	100		
•Refrigerant	370,00	g			100
• Oil (in compressor)	323,40	g			100
Hazardous waste	Yes-refrigerant				
Lifetime (estimate)	Around 6 years				

The two tables show the end of life treatment and the % every material from production stage would receive. In addition, the existence of hazardous waste and the lifetime of the product are depicted.

The assumptions made are applied to both water coolers:

a) The lifetime of the product.

b) When modelling this stage in Simapro, the treatment of the majority of the materials is recycling, but the alternative treatment is assumed to be incineration. Refrigerant and oil in compressor are just incinerated.

c) Other specific assumptions in relation to the modelled processes of this stage are described in Appendix B.

6.4.2 Data calculation

In the inventory tables of section 6.4.1, the calculations' results are presented. These calculations of the production and use stage are fully detailed in Appendix A. They are mainly related to the conversion of the materials and travel distances' units so as to put them in relation to the functional unit and then according to the specific Simapro requirements.

6.5 Impact assessment

As the study is a comparative carbon footprint assessment, this will automatically lead to a limited impact-coverage because only GHG related to climate change are analyzed. For the carbon footprint, all GHG are related to global warming potential.

For this phase, the mandatory steps are included in the assessment, which are the classification and the characterization. The valuation step, which is optional, is not carried out because the results from characterization should not imply difficulties, as they are solely based on one category indicator. This is explained below.

For classification, the different substances are assigned to the impact category they contribute to. For CF, all GHG are sorted but they will just have one impact category, which is climate change.

For characterization, each life cycle inventory result (which are the different emissions) is multiplied by a characterization factor, which is determined by the impact assessment method (Thrane & Schmidt, 2007). The characterization model required by ISO 14067 is the "Baseline model of 100 years of the IPCC" and therefore, the used method is the single issue- *IPCC 2007 GWP 100a*, which contains the climate change factors i.e. the characterization factors of IPCC with a time frame of 100 years.

The six main GHG and its related global warming potentials on which the characterization factors are based on are presented in Table 1. CO_2 is usually the category indicator of climate change, and it is also used for this study. Therefore, the results of characterization are expressed in kg CO_2 equivalents (kgCO_2e) per emission and it shows the impact potential of climate change.

Simapro automatically gives the total kgCO_2e for the available processes within its database.

6.6 Interpretation

According to ISO 14044, CF interpretation and results should be presented in this chapter. However, due to practicalities, the results of the comparison of the CF assessment are included in CHAPTER VII, along with the discussion of the results.

CHAPTER VII Results and Discussion

Sections 6.1 and 6.2 of this chapter present the main findings that allow answering the two research questions. Afterwards, section 6.3 briefly presents the limitations of the analysis.

6.1 Carbon footprint analysis

This section gives an answer to the first research question, which is:

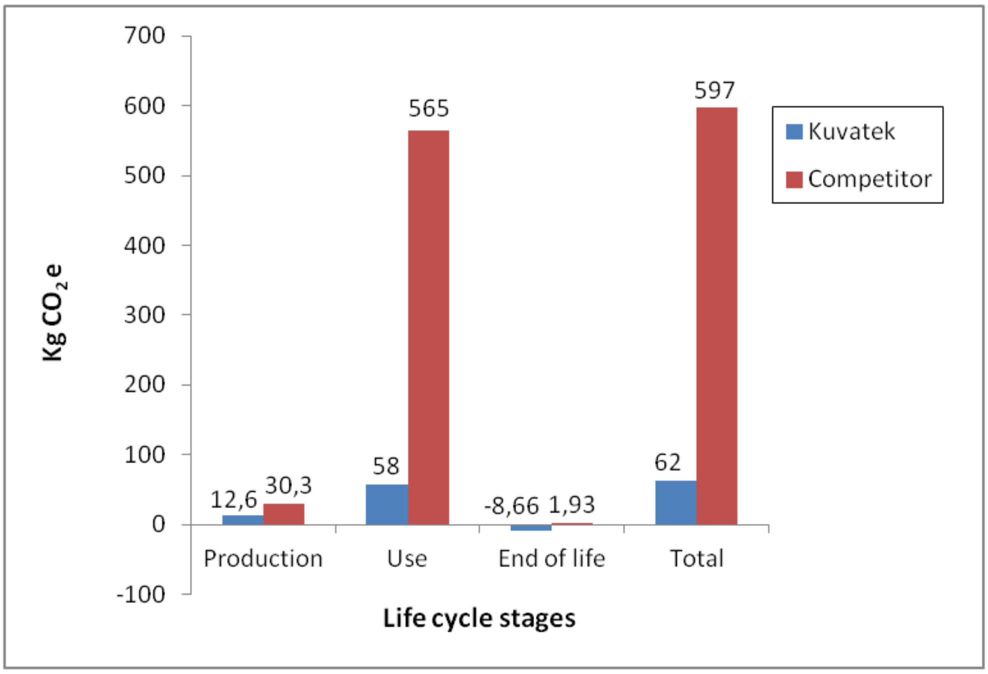
How can Kuvatek demonstrate that the life cycle of the water cooler model DF12 has a lower carbon footprint (CF) than the water cooler from its *"Competitor"*?

Kuvatek can demonstrate it by conducting a screening carbon footprint assessment of both their product and the competitor's product and then by comparing the results.

There are also two sub-questions that are answered throughout the section.

6.1.1 Analysis on entire life cycle

Figure 20 Carbon footprint comparison of the life cycle stages on both companies



These are the results of the foreground system, i.e. the processes the researcher created. Here, the first sub-question of the first research question finds its answer:

What is the CF of the two products?

The total carbon footprint of Kuvatek's water cooler is 62 KgCO_2e, whereas it is almost 10 times higher for the competitor, i.e. 597 KgCO_2e.

Among the three life cycle stages, and considering 100 % as the total CF for each product, the use stage contributes to the carbon footprint the most, to 93.5 % and 94.6% for Kuvatek and the competitor, respectively. In addition, Figure 21 shows that the CF of the use stage of the competitor is ten times the CF of Kuvatek. The reasoning behind this is further analysed in section 6.3.1.

For the production stage, Kuvatek's product contributes to 20% of its total CF, whereas the competitor contributes to 5 %. In addition, the above figure shows that the CF of the competitor is more than double Kuvatek.

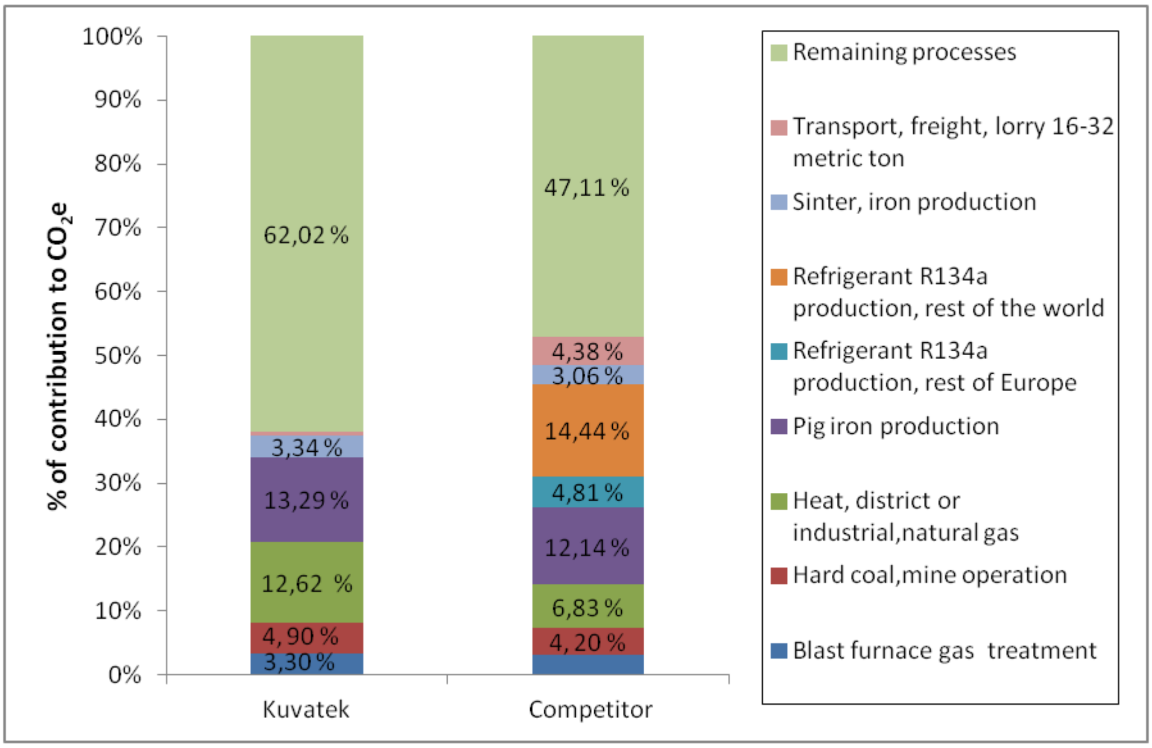
Last, for the end of life stage, Kuvatek's CF is negative, which means that the amount of 8, 66 KgCO_2e is saved somewhere else due to the recycling treatment of the materials. The mentioned amount of CO_2 is translated into a saving of 14% of CO_2e of the total product's CF. On the contrary, the competitor has a positive contribution to the total CF of 0, 32%. As it can be seen, the end of life stage has a trifling contribution to the overall CF of both companies.

Next sections go deeper in detail by analysing the main contribution processes to the carbon footprint of each life cycle stage of the products and they are based on the background system of Simapro. The results of the analysis are presented as the % each process contributes to the CF of the specific stage (shown in the vertical axis of the graph). The "remaining processes" are obtained by the selection of a specific cut-off percentage, which excludes some processes because they contribute to the CF less than the selected %.
In the horizontal axis, both companies are depicted, so when referring to the specific company it is meant the water cooler of that company.

6.1.2 Analysis on production stage

The first life cycle stage of the water cooler is its production.

Figure 21 Main processes contributing to the carbon footprint in production stage



The selected cut-off criterion for this stage is 3%. Based on this, the above figure shows the eight main contributing processes to the total CF in the production stage and it can be seen that the processes mainly derive from the extraction/production of raw materials. The contribution of each process to the total CF stage is fairly similar for both companies. Main differences are explained in terms of absolute units, i.e. Kg of CO_2e:

For Kuvatek, the main sources of carbon footprint come from the production of pig iron (1, 67 KgCO_2e), which is an intermediate product from smelting iron ore that can be worked into wrought iron and steel; the generation of heat from natural gas (1, 59 KgCO_2e) and the hard coal mine operation (0, 61 KgCO_2e).

For the competitor, the main sources come from the production of the refrigerant (4, 36 KgCO_2e), the production of pig iron (3, 66 KgCO_2e) and the generation of heat from natural gas (2, 06 KgCO_2e).

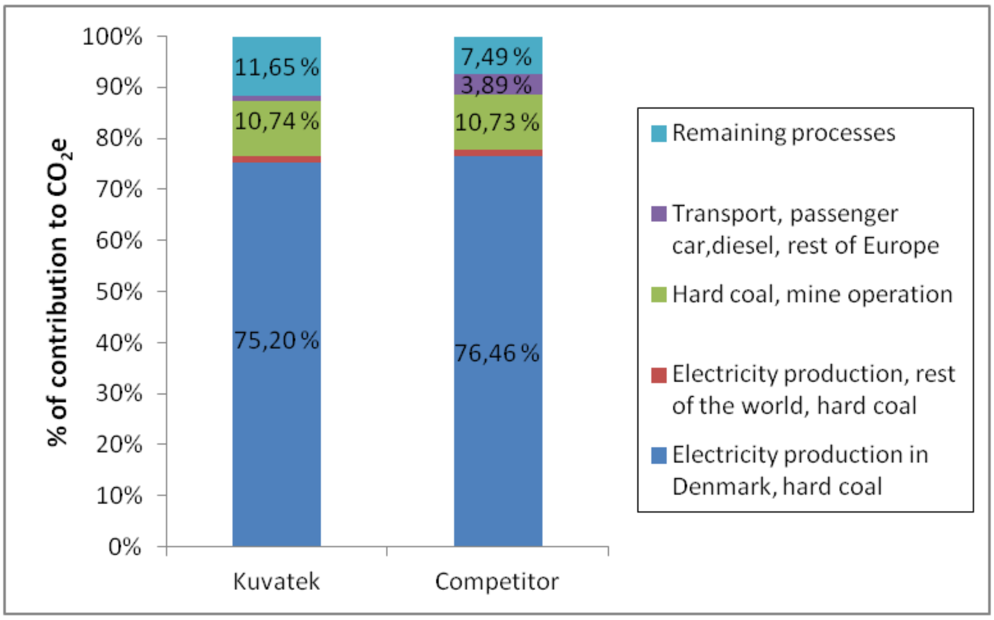
Based on the explained absolute values, the major CF difference between both products in this stage is attributed to four processes:

a) The production of the refrigerant R134a (tetrafluoroethane) is only accounted for the competitor because Kuvatek uses the refrigerant R290 (propane), which has a GWP of 3, whereas the refrigerant used by the first company has a GWP of 1300. As the GWP is an indicator that illustrates the potential relative climate change effect of a greenhouse gas, see section 2.1.1, the production of tetrafluoroethane emits a larger amount of CO_2e than the propane.
b) The production of pig iron generates the double amount of CF for the competitor than for Kuvatek. Both water coolers contain similar amount of steel, but the competitor's product has in addition iron as part of its materials, whereas Kuvatek does not. As the pig iron can be used to produce any of the two materials, it has sense that more CO_2e is emitted from the production of pig iron process in the product that uses in total more of these materials.
c) The transport by lorry generates 0, 07 $KgCO_2e$ and 1, 32 $KgCO_2e$ for Kuvatek and the competitor, respectively. This transport covers from production site to the end consumer (considering one way trip). For Kuvatek this distance is 200 Km, because the product travels within Denmark from Sindal to Kolding whereas it is ten times (2086 Km) for the competitor, whose product travels from Italy to Kolding. Thus, as the transportation calculation is directly proportional to the distance, and it is higher for the competitor, it makes sense that the CF for the latter is greater than for Kuvatek.

6.1.3 Analysis on use stage

The second life cycle stage of the water cooler is its use.

Figure 22 Main processes contributing to the carbon footprint in use stage



The selected cut-off criterion for this stage is 1%. The figure shows the four main contributing processes to the carbon footprint during the use stage. The CF contribution of each process to the total CF of the stage is very similar for both companies. However, the absolute amount of CF of every process is significantly bigger for the competitor than for Kuvatek. The three main processes are:

a) The electricity production in Denmark, which is 43, 64 KgCO_2e and 431, 25 KgCO_2e for Kuvatek and the competitor, respectively.

b) The mine operation for the hard coal extraction, which is 6, 23 KgCO_2e and 60, 52 KgCO_2e for Kuvatek and the competitor, respectively.

c) The transport by passenger car is the third most contributing process for the competitor, with 21, 25 KgCO_2e and the electricity production in the rest of the world for Kuvatek, with a CF of 0, 82 KgCO_2e.

These values have sense because, as it will be explained further on in the sensitivity analysis, the competitor's water cooler requires larger amounts of electricity during its use, thus more production of hard coal for the electricity will be needed as well.

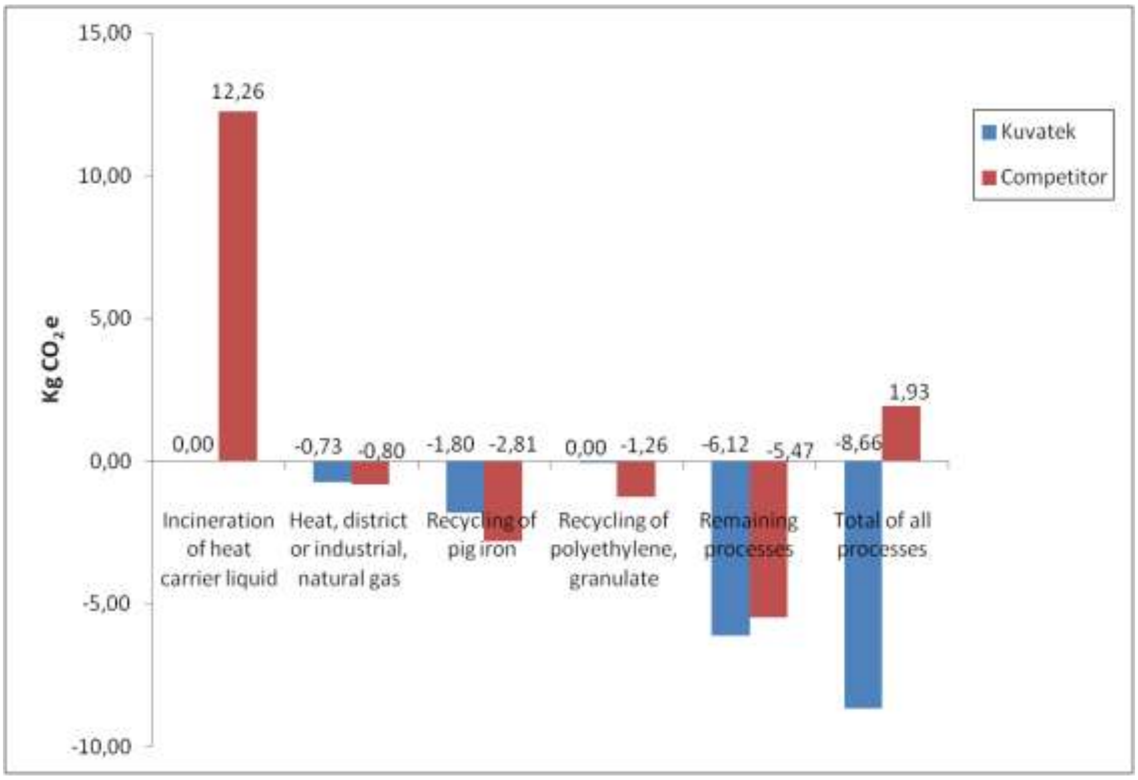
The CF related to the transportation by car is also higher for the competitor (it's 37 times the amount of Kuvatek) because, as explained in the production stage, the transport depends on the distance. During the use of the product, this transport is related to its maintenance (i.e. for reparations or other needed services). Kuvatek has to travel around 3, 33 Km per year per product, whereas the competitor does it around 125 Km. The reason for this difference is that the latter requires more trips to the customers for the maintenance services of the product, which are both, included in the guarantee of the product and extra services for unexpected reparations.

During the use of the product, as some materials do not resist the entire lifetime, Kuvatek needs to send to its customers 1 piece of natural rubber for the faucet of the water cooler per 5 years and the competitor needs to send 4 pieces of faucets per 6 years. Thus, another parameter that could be considered is the transport needed to deliver the substituted materials from production site to the customers. This is not part of the results due to uncertainties in vehicle transportation that complicated its analysis with Simapro but it was calculated to add information. The transport calculation is 0, 36 KgKm for Kuvatek (0.009 kg of substituted material covering 200 Km distance) and 417, 20 KgKm for the competitor (0.05 kg of substituted material covering 2086 Km distance). The transport is significantly greater for the competitor than for Kuvatek, thus, if it had been added as inputs for Simapro analysis; the CF for the competitor would be even greater than in current results.

6.1.4 Analysis on end of life stage

The third life cycle stage of the water cooler is its end of life.

Figure 23 Main processes contributing to the carbon footprint in end of life stage



The selected cut-off criterion for this stage is 18% and the CF is presented in absolute values, because it facilitates the end of life interpretation.

It is assumed that for both companies, all plastics and metals are recycled at 100%. The oil in the compressor and the refrigerant are assumed to be 100 % incinerated. In section 6.1.5.3, a sensitivity analysis is carried out in order to see how the results vary depending on the % of recycling.

Four processes are depicted from the above figure. Only the treatment of heat carrier liquid, which is the refrigerant, has a positive value. Kuvatek's water cooler does not contribute to CF, whereas the competitor does probably because the treatment of the refrigerant R134a, used by the latter, has a higher GWP in comparison to R290 used by Kuvatek. In order to model the treatment of the refrigerants in Simapro, the process "treatment of heat carrier liquid" is the best approximation for the competitor and for Kuvatek's refrigerant it is assumed that the propane (which is a by-product of natural gas) is used as biogas. It should be noted that although these assumptions were wrong, the total CF of the product would hardly change.

The negative values for the rest of the processes mean that, due to the generation of recycling material, it substitutes the production of the virgin material somewhere else, avoiding the emission of a certain amount of CO_2. As it can be seen, allocation is avoided through system expansion, see section 6.3.3 for the whole explanation.

For Kuvatek, the three processes that avoid the most amount of CO_2e are the recycling of pig iron and the electricity/heat production. For the competitor, it is the latter processes plus the recycling of polyethylene plastic. The difference in the amount of saved CO_2e between both companies is due to the amount of material used to produce the water coolers (which work as the inputs for the end of life stage). For example, more polyethylene is saved for the competitor because it uses 4, 6 Kg, whereas the competitor only uses 0, 01 Kg to produce the product.

It should be noted that although the production of electricity is needed to be able to recycle the materials, it is still less than the required electricity to produce virgin materials. This is the reason why energy is saved.

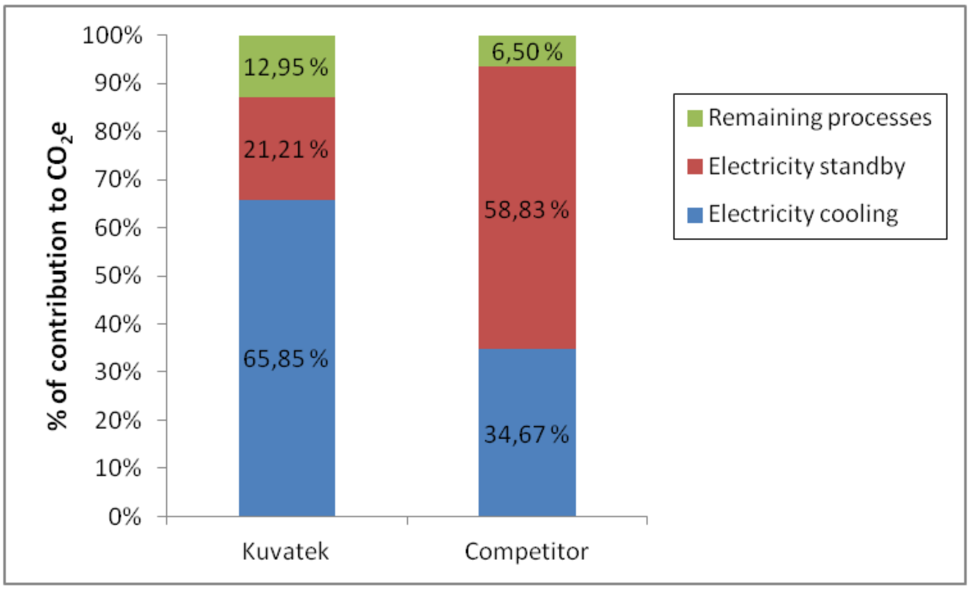
6.1.5 Sensitivity analysis

Sensitivity analysis is done in order to assess the influence that the most important uncertainties (assumptions) have on the results.

6.1.5.1 Disaggregation of electricity consumption

In the first analysis, the results of the impact assessment from the use stage of both products revealed that the main contributor of the CO_2e emissions came from the electricity used by the water coolers, which is translated into higher demand of Denmark's electricity production. This process makes the difference both in the overall CF of the water cooler and also between both products under study. Therefore, this section is a narrowing down in order to analyse which is the source of the electricity of each product and the reasons of this difference. For this intention, the electricity was disaggregated into the two main purposes the water coolers use the electricity for: to cool down the water (which has been called "electricity cooling") and the used electricity while the product is in standby mode, the "electricity standby".

Figure 24 Contribution of disaggregated electricity to the total CF in use stage



The above figure reveals that from the total electricity consumption, Kuvatek's product mainly requires electricity during its cooling, and thus it contributes to the CF the most. On the contrary, for the competitor, the highest electricity consumption is required during the standby mode of the product, and here is where the major contribution to the CF takes place.

In absolute values, during the water cooling process, Kuvatek emits 40, 18 KgCO_2e whereas the competitor emits five times more, i.e. 194, 77 KgCO_2e.

During the standby mode, there is an emission of 12, 84 KgCO_2e and 330, 56 KgCO_2e (twenty five times the former value) for Kuvatek and competitor, respectively.

These results are in line with the functioning of the water coolers:

On the one hand, Kuvatek's water cooler is designed in a way that it cools the drinking water while being tapped by the direct use of the refrigerant, which is called a flow-through system, thus, although most of the total electricity is used for this purpose, it has a lower consumption than Kuvatek. Apart from this, any water cooler mostly is in standby mode, but Kuvatek's product does not require much electricity in this phase because it lacks of several components such as water tank or UV lights that do require it.

On the other hand, the competitor's water cooler includes a tank with a water line and an ice line in order to keep a certain amount of water. In this way, the water can be cooled down by the ice line before being tapped. High losses of energy happen in the system due to several heat exchange phases between the refrigerant, the ice line and the water line. This is the main reason of the higher electricity consumption for the competitor during the cooling process. Additional components that require greater electricity consumption during the standby mode of the product in comparison to Kuvatek are a stirring wheel to ensure the water does not get frozen and UV lights to avoid bacterial growth in the tank.

6.1.5.2 Change in the lifetime

This section analyses how the CF of the competitor varies depending on an increase of its lifetime.

Table 10 Lifetime variation of the competitor

	Kuvatek	Competitor				Units
	10	6	7	8	10	years
Production	12,6	30,3	25,96	22,71	18,17	Kg CO2e
Use	58	565	564,8	564,8	564,8	Kg CO2e
End of life	-8,66	1,93	1,66	1,45	1,16	Kg CO2e
Total	62	597	592,42	588,97	584,13	Kg CO2e

The results show that by increasing the lifetime of the water cooler from 6 years (which is the current lifetime) up to 10 years, the CF of the production stage decreases by 61% and the end of life by 4%. This is because the production of new materials is avoided. The use stage remains the same because the lifetime does not affect the main contributing factor, which is the electricity consumption. Thus, although both water coolers had the same lifetime, Kuvatek's total CF would still be ten times less than the competitor.

6.1.5.3 Change in the recycling rates

Last sensitivity analysis involves evaluating how the total CF and the end of life CF of both companies vary depending on different recycling rates. The 'remaining rate' is assumed to be incineration. It is depicted in the next table in several situations.

Table 11 Variation of recycling and incineration rates

	Recycling rates			Kuvatek			Competitor		
Situation	*Plastics*	*Metals*	*Unit*	*Total*	*End of life*	*Unit*	*Total*	*End of life*	*Unit*
0	100	100	%	62	-8,66	Kg CO2e	597,0	1,93	Kg CO2e
1	30	70	%	64,9	-5,69	Kg CO2e	604,6	10,3	Kg CO2e
2	100	0	%	70,6	0,024	Kg CO2e	605,5	11,2	Kg CO2e
3	0	100	%	62,4	-8,14	Kg CO2e	604	9,86	Kg CO2e
4	0	0	%	71,1	0,539	Kg CO2e	614	19,1	Kg CO2e

For the first CF analysis, it is assumed 100 % of recycling for all the materials of both water coolers (with the exception of oil in compressor and refrigerant). This is situation 0 of the table.

When looking into the end of life stage, situation 2 when all the plastics are recycled and metals are incinerated, it has a worse climate change impact due to the higher CO_2e emission than in the opposite situation, where only the metals are completely recycled (situation 3). This is probably due to the fact that the metals used to produce the products weight more than the plastics, thus more CO_2e can be saved from its recycling.

The total CF of the end of life stage varies in a range of more or less 10 KgCO_2e and 17 KgCO_2e for Kuvatek and competitor, respectively. However, the life cycle CF of both companies has a minimum variation from its current value. Even when all the materials are incinerated, i.e. situation 4, the total CF of both companies just increases by 1%.

After the CF analysis of the entire life cycle of both water coolers is done, there is enough information to answer the second sub-question, which says:

Are the results of the CF in accordance to Kuvatek's beliefs about their environmentally friendly water coolers?

Yes, they are. Kuvatek's beliefs were based, among others, on evidences of lower electricity consumption during the use stage, less transportation distances and lower GWP value of their refrigerant compared to its main competitor.

The CF results prove that Kuvatek's water cooler emit less CO_2e in their entire life cycle and also in each stage. So, it can be stated that by focusing only on the climate change impact, the water cooler model DF12 produced by Kuvatek is more environmentally friendly than the water cooler from its competitor.

6.2 Analysis on Kuvatek's CF motivations

This section is based on the methods described in section 5.4 (which are mainly literature review and interviews) and it gives an answer to the second research question and its sub-questions.

Why is Kuvatek interested in conducting concretely a carbon footprint assessment and also in communicating the results of the CF comparison?

The director of Kuvatek has a sustainability approach, i.e. he has concerns on leaving as far as possible, a clean environment to his children. He is interested in conducting a CF assessment for his own product's knowledge and he believes it is a good business point to be at the environmental upfront. This is in line with Dias & Arroja (2012), who state that companies are implementing the CF more frequently due to the several benefits they obtain from it.

In addition of carrying out the CF, and with the condition of having the results reviewed by an expert panel, the director would like to communicate the results to the customers, so they can make an informed choice when willing to buy a water cooler within the market. The director's beliefs are in line with Cohen & Vandenbergh (2012), who also address this topic in section 2.2.1.1.

The director further says that an additional benefit is that by communicating the CF results, it may also help to put pressure on the competitors to start carrying out environmental assessments such as the CF.

What are the advantages and disadvantages for the company when carrying out the CF?

The main advantages for Kuvatek when carrying out the CF is that it allows both identifying the main sources of CO_2 and determining potential opportunities for GHG mitigation within the life cycle stages (Dias & Arroja, 2012; Carbon Trust, 2008). In the long run, the performance improvements may also lead to cost savings, productivity gains for the company and environmental amelioration due to a reduction in the GHG emissions.

The researcher believes that apart from benefitting from the CF results, the CF analysis itself is also a good learning process for Kuvatek. For example, product inventory helps the company to gather large amount of information about materials and other parameters that perhaps had not been thoroughly collected before.

Regarding the drawbacks, the director states that they are mainly the cost and more importantly, the knowledge of how to do it.

His believes are in line with the European Commission (2013), who state that SMEs have to face higher costs than bigger organizations and the costs might increase if they have to comply with verification and labelling requirements for several retailers and countries. According to Carbon Trust (2008), smaller companies can reduce costs if they do not hire external consultants and the right product for the CF analysis is chosen. Kuvatek has saved costs from the CF assessment due to the collaboration with the University.

In addition, the director of Kuvatek is concerned about the fact that more standardization could be provided by the European Union so that all businesses could start using the same figures when calculating the CF in order for the results to be more comparable.
This is in line with the problematic of the different methodological issues that can lead to ambiguous results and that has been addressed by several authors such as Finkbeiner (2009) and (Scipioni *et al.*, 2012).

What are Kuvatek's ideas of documenting and communicating the CF performance of their products?

Before the current study was conducted in collaboration with Kuvatek, the water cooler had been subjected to evaluation and compared to the same competitor than this study. The evaluation was conducted by an external company and the report out of this assessment showed Kuvatek was more efficient in several parameters such as the energy used by the product.

Based on these results, Kuvatek used to communicate the environmental benefits of their products face to face to their customers. The communication is a quite new topic for the company, so now, they are willing to take a step forward and hire an employee experienced in social media who can help them to figure out the best communication means.

The director of Kuvatek would like to document the CF performance of the water coolers because he affirms that the CF will be part of future's product information and that every company should disclose transparent CF information. The company's website or the product' catalogues might be good places to display the CF performance of the products and the latter might be included in the larger environmental performance of a product.

By documenting the environmental performance of a product, it is possible to create its environmental profile. The latter measures the impacts that a product or service has throughout its life cycle (BRE, 2014). It should be noted that if willing to document either the CF performance or the total environmental performance of their products, the results on which the performance are based on, have to go through a verification process.

The director finds especially relevant to have a stakeholder discussion among others, about product's environmental performance and its external communication with the objective of learning and improving from each other. As he states: *"we all need to be part of the discussion in order to prevent future environmental problems"*.

6.3 Limitations of the analysis

The analysis of this study is bounded by several limitations:

a) Available limited database in Simapro.
b) Model uncertainties: several processes had to be modelled in Simapro according to the best available approximations, e.g. the treatment of the refrigerant.
c) Data uncertainties and assumptions with regards to the competitor's product that led to omit several inputs and outputs from both product systems, e.g. energy and water inputs during production stage and emissions, respectively.
d) Subjectivity of various data inputs provided by Kuvatek (e.g. transportation distances and type of vehicle and end of life material treatment), as they are sometimes based on estimations and/ or assumptions.
e) The results of the CF analysis are valid under the assumptions made, which have been explained throughout the study.

CHAPTER VIII Conclusions and Recommendations

One of the most significant environmental problems in the history of humanity is the climate change effects (UNEP, 2014). They are mainly caused by the released greenhouse gases (GHG) from human activities, among which the carbon dioxide (CO_2) can be found. The climate change effects have been intensifying since the industrial revolution, when the human being greatly enhanced the consumption of energy and resources (Linnenluecke & Griffiths, 2013). The aggravation of these effects strongly contributed to generate a global awareness about the need to offset the climate change problem (Dias & Arroja, 2012). This has led to a rise of new concepts such as sustainable development, which seeks to find a balance between environmental, social and economic issues, and to integrate it in the international climate change discussions.

It is vital that all stakeholders, i.e. government (political level), companies (industrial level) and individuals (consumer level) are committed in order to address climate change within the sustainable development principles. As an answer to the threat of climate change, companies have adopted sustainable practices such as life cycle thinking tools, which help them to translate sustainability issues into quantifiable measures (Dias & Arroja, 2012). Among these tools, the carbon footprint (CF) is a limited Life Cycle Assessment (LCA) that measures the impact, expressed in CO_2 equivalents, (CO_2e) that a product, service or organization has on climate change throughout its life cycle (Finkbeiner, 2009).

One example of how to bring the company's environmental concerns into quantitative terms by the use of the CF tool is applied to Kuvatek. Based on former assessments, the company has strong beliefs that they are more environmentally friendly in comparison to their main competitor. Both companies manufacture water coolers, Kuvatek in Denmark and the competitor in Italy.

Thus, based on the former explanation, the study focuses on a comparative CF screening analysis of two products with the same function, which is to cool the tap water. The CF methodology of this study is based on LCA following the ISO 14040 and 14044 guidelines and it is a cradle-to-grave assessment covering production, use and end of life stages. This allows fulfilling the first project objective, which is to develop skills on CF assessment.

The main conclusions of this assessment are as below:

1. The total carbon footprint of Kuvatek's water cooler is 62 KgCO_2e, whereas it is almost 10 times higher for the competitor, i.e. 597 KgCO_2e.
2. For the production stage, Kuvatek's product contributes to 20% of its total CF, whereas the competitor contributes to 5 %. However, the CF of the competitor is more than double that of Kuvatek, i.e. 30, 3 and 12, 6 KgCO_2e, respectively.

   The choice of the materials to produce the product and the travel distances used to deliver the product from production site to the customers affect the CF the most.
3. Among the three life cycle stages, the use stage contributes to the CF the most: 93, 5 % for Kuvatek and 94, 6% for the competitor. However, the CF of the use stage of the competitor (565 KgCO_2e) is ten times the CF of Kuvatek (58 KgCO_2e).
4. For the end of life stage, Kuvatek's CF is negative, which means that the amount of 8, 66 KgCO_2e is saved somewhere else due to the recycling treatment of the materials and it is translated into a saving of 14% of CO_2e of the total product's CF. On the contrary, the competitor has a positive contribution to the total CF by 0, 32%.

   This stage is also affected by the choice of materials. For a product such as the water cooler, the selection of an environmentally friendly refrigerant, such as propane plays a vital role in the CF contribution of this stage.
5. The electricity consumed by each product is the main process contributor to the CF of the use stage and also for the total CF of the product.

The sensitivity analysis revealed the following:

6. Kuvatek's product mainly requires electricity during the water cooling process, contributing to 65, 85 % of the total CF of the use stage. During the standby mode of the product, it contributes to 21, 21 %.

   On the contrary, for the competitor, the highest electricity consumption is required during the standby mode of the product, contributing to 58, 83 % of the total CF of the use stage and 34, 67 % during the cooling process.

7. By increasing the current lifetime of the water cooler from 6 years up to 10 years, the CF of the production stage decreases 61% because the production of new materials is avoided. However, as the use stage remains the same, the change of the total CF of the competitor is trifling.
8. Although the most preferable climate change option is when all plastics and metals are recycled; the overall CF of the water coolers do not suffer significant changes by the variation of the recycling rates.

In addition, and in order to fulfil the second project objective, Kuvatek's motivations of conducting and communicating the CF assessment are investigated.

These are the main conclusions:

1. The director of Kuvatek is interested in conducting a carbon footprint assessment for his own product's knowledge and additionally would like to communicate the results to the customers so they can make informed choices of the products and to put pressure on competitors to do the same.
2. The main benefits for the company from the CF assessment are the identification of the main sources of CO_2 within the supply chain of their product and the possibility of improvement. On the contrary, the drawbacks are the cost and the lack of knowledge to conduct it.
3. The director of Kuvatek would like to document the CF performance of the water coolers because he thinks it will be part of the future's product information and every company should disclose it. The documentation of either the CF performance or the environmental performance requires a previous verification process.

Based on the study outcome, three main recommendations can be suggested to Kuvatek:

- ***Recommendation No. 1***: "Although the CF of Kuvatek is lower than its competitor, Kuvatek might want to improve it even more. In this case, they could lessen the total CF by focusing in the electricity consumed to cool the water during the use stage. In addition, the choice of materials to produce the products is important; materials such as iron and steel contribute to the CF of its production stage the most".

- ***Recommendation No. 2***: "As the CF is a precursor of the LCA, Kuvatek can now take a step forward within the environmental assessment tools and conduct a full life cycle assessment of the water cooler in order to have the whole picture of how the product affects both the environmental impacts and resources. The LCA assessment could be used for several applications: a) improvements on environmental performance of the product based on complete environmental information; b) creation of an environmental profile of Kuvatek's product; c) general statements of 'how *green* the products from Kuvatek are in comparison to the competing ones' ".
- ***Recommendation No. 3:*** "If the LCA results are published or used to support marketing claims or comparative assertions, ISO 14040 (2006) requires a critical review conducted by a third party to verify that the LCA requirements have been met. So, if the comparative CF assessment of this study is published, the review needs to be done by an expert panel. Prior to the publication, data quality of this study needs to be improved, by reducing the secondary data, the uncertainties and assumptions".

So, if the study results are reviewed, published and enclosed as part of the product's environmental profile, the customers would be able to make an informed choice between Kuvatek's water cooler and the one from the competing product. As Kuvatek has a lower CF than its competitor, the customers could now contribute to offset the climate change impacts by purchasing the product that contributes the least to the climate change.

In a nutshell, the carbon footprint is just one out of many available tools for companies willing to address the sustainability concerns. Although the CF just focuses on climate change impacts, it already gives an idea of the environmental friendliness of a product compared to another. Kuvatek is just one out of thousands of companies around the world that can apply the CF results to improve their products and also to decrease the environmental damage in terms of CO_2 emissions. If more companies put effort on this, at some point, climate change effects might be kept at bay. The human being is the main reason of the current environmental situation, thus it should be the initiator of changes at political, industrial and consumer level.

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APPENDICES

APPENDIX A Calculations for the inventory analysis

The calculations are separated by each life cycle stage and by both companies.

PRODUCTION STAGE

For both companies, materials such as the oil for the compressor and the refrigerant are converted from volume to mass units according to the formula: Density = mass / volume. The densities are assumed from online reports and the volumes are taken from the official brochures of the water cooler.

Table A1 Production stage - Calculations for Kuvatek

Inventory data	Calculations	Explanation
Oil (polyolester) in compressor: 550 cm3	Density of polyolester : 0.98 g/ ml (National Refrigerants, 2014) 0.98 g/ ml * 550 cm3* 1 ml/ 1cm3 = ***539 g of polyolester*** 1cm3 = 0.001L = 1 ml	
Refrigerant (propane)	Density of propane: 1.6 Kg/ m3 (National Refrigerants, 2008) Volume: 0.1625 m3 Weight in mass: 1.6 Kg/ m3* 0.1625 m3 = 0.26 Kg = ***260 g of propane***	
Transport (from production site to the consumer)	29.8*200 = ***5960 KgKm***	The average place where the water cooler is delivered is Kolding, situated approximately 200 km away from Sindal, where Kuvatek is situated. A 20 t diesel truck (assumed) comes and picks the water cooler (s) up, along with other email in the area. Simapro always assumes one way, in this case, 200 Km. The water cooler weights: 29.8 kg/ cooler.

Table A2 Production stage- Calculations for the competitor

Inventory data	Calculations	Explanation
<u>Water tank</u> *Plastic PVC*	Density of PVC (regarding flexible PVC products): is 1.1-1.3 g/ cm3 (PVC, 2014) By taking the midpoint, D= 1.2 g / cm3 or 1.2 g / ml: D= mass / volume; Mass= density*volume Mass= 1.2 g / ml* 721.9 ml (it's 1L of PVC) = ***866.4 g of PVC***	Additional calculations are needed in order to get the mass units of materials from components such as the water tank. These materials are the plastics polyethylene foam and the PVC, which are based on the on- site measured volumes (which also required calculations) of the components and the assumed densities.
<u>Water tank</u> *PE(Polyethylene) foam:*	Its density is unknown, so it is assumed a density of 0.93 g/ ml, because it stands in between the high and the low density (PVC, 2014). 0.93 g/ ml * 4942 ml (1ml = 1cm3) = **4596 g of *Polyethylene foam***	
Oil (VG 22 ester) in compressor: 350 cm3	Density of VG 22 ester: 924 kg/ m3 = 924000 g/ m3 (Bel-Ray, 2012) 924000 g/ m3* 350 cm3* 1 m3/ 1.000.000 cm3 = ***323.4 g of VG 22 ester oil*** 1m3= 1.000.000 cm3	
Transport *(from production site to the consumer)*	32.62 kg*2086 km/year (1936 km+ 150 km) = ***68045, 32 Kg Km***	The water cooler is produced in Italy, near the village Recanati and then it follows several steps until it gets to the customer. Once the product is finished, it is firstly sent to Ebeltoft in Denmark; this distance is approximately 1936 Km. Then, it is sent from Ebeltoft to Kolding, covering a distance of 150 Km. Once in Kolding, there is a plumber that will distribute the product to the different customers (offices, factories, hospitals etc.) covering an area of 25 km. Although the competitor might have more plumbers surrounding Ebeltoft, they are not included in the calculation and neither the 25 km to reach the customers. This is done in order to be able to compare both systems. The water cooler weights 32.62 Kg. The transportation vehicle is assumed to be the same as for Kuvatek: a 20 t truck.

USE STAGE

For the energy and water consumption of the product of both companies, minor calculations are needed in order to relate the values obtained from the "Measurement report on water coolers" to the functional unit.

Table A3 Use stage - Calculations for Kuvatek

Inventory data	Calculations	Explanations
Standby electricity	0.047 kWh/ day. In 1 year: 365 days*0.047 = ***17.15 kWh / year of standby electricity***	
Electricity (use+ standby)	2.7 kWh / 14 days. In 1 year: 365 days* 2.7/ 14= ***70.39 kWh / year of used and standby electricity***	
Electricity (use)	Electricity (use+ standby) - Standby = 70.39-17.15 = ***53.24 kWh / year of used electricity***	
Maintenance	From February 2007 until February 2014 (i.e. 7 years), Kuvatek drove 3500 Km in total. 3500 Km./7 years = 500 km/ year (from Sindal to the customers to maintain 150 water coolers) In Kuvatek, it is produced 150 water coolers/ year, then 500 / 150= ***3.33 km/ year/ machine.*** The maintenance can be expressed as follows: 29.8 kg*500 km/year = 14900 Kg Km 14900/ 150 water coolers = 99.33 Kg Km for 1 water cooler	Maintenance is quantified in terms of transportation distance. The maintenance vehicle is assumed to be a medium diesel car.
Other materials	On the one hand, the amount of material is calculated: Its substituted 1 piece of natural rubber for the water cooler faucet per 5 years. It's sent by post to the customer. So, the 6 pieces of natural rubber from Kuvatek's water cooler weight 28g. Thus, 28/ 6 = 4.6g / piece. As the replaced piece is bigger than the rest, it is estimated a weight of 9g = 0.009 kg	"Other materials" means the needed substituted materials during the use of the product. Due to uncertainties on

	0.009 kg/ 5 years = ***0.0018 kg of produced rubber*** 0.009 kg * 200 km = ***0.36 kgKm of transport*** 5 years	vehicle transportation when sent by post throughout the travel distance, this transportation calculation is omitted from Simapro analysis.
Water consumption	1 m3 = 1000L = 1000 Kg Thus, 10 m3 = 10.000 Kg	

Table A4 Use stage - Calculations for the competitor

Inventory data	Calculations	Explanations
Standby electricity	1.2 kWh/ day. In 1 year: 365 days*1.2 = ***438 kWh / year of standby electricity***	
Electricity (use+ standby)	26.7 kWh / 14 days. In 1 year: 365 days* 26.7/ 14= ***696.1 kWh / year of used and standby electricity***	
Electricity (use)	Electricity (use+ standby) - Standby = 696.1-438 = ***258.1 kWh / year of used electricity***	
Maintenance	For 1 water cooler, it is estimated that it is needed around 5 trips for service, i.e.: • 2 times for the service contracted/ year • 1 time for unexpected service From the customers to Kolding: 50 km per time (back and forth) 50*3 = 150 km • 2 times during its lifetime (6 years) from Kolding to Ebeltoft → 600 km (300 km back and forth*2 times); thus 600/6 = 100 Km Total: 150+100 km = 250 km / year / machine	Maintenance is quantified in terms of transportation distance. The maintenance vehicle is assumed to be a medium diesel car. It is estimated that if the water cooler needs to be repaired, then, a plumber from Kolding goes to the customers to pick it up and comes back to Kolding for reparation with a frequency of three

	For Simapro requirements, the distance for the maintenance is considered as only one way, thus ***125 Km / year / machine*** in total. The maintenance can also be expressed as follows: 32.62 kg/water cooler*125 km/year = 4077, 5 Kg Km	times per year. Sometimes, the product needs to go to Ebeltoft for full reparation. This is considered twice per year for a 6 year lifetime.
Other materials	For the competitor, it is estimated that a 300 g brass faucet is substituted 4 pieces every 6 years, thus (4/6 = 0.67 pieces /year). 0.300 Kg /6 years = ***0.05 kg of produced stainless steel*** On the other hand, the transportation distance in order to send the substituted piece to the customer is calculated: It is firstly sent by a 20t truck from Italy to Ebeltoft and then, from Ebeltoft to Kolding by post. Thus: 0.300 Kg * 2086 Km (total distance)*0.67 faucets/ year = ***417.20 KgKm of transport***	However, due to uncertainties on vehicle transportation when sent by post throughout the travel distance, this transportation calculation is omitted from Simapro analysis.
Water consumption	1 m3 = 1000L = 1000 Kg Thus, 10 m3 = 10.000 Kg	

APPENDIX B Processes screenshots from Simapro

The processes used to model both systems (Kuvatek and competitor) in Simapro are depicted as screenshots of each life cycle stage. This allows the reproduction of the study.

Figure B1 Life cycle process for Kuvatek

Known outputs to technosphere. Products and co-products

Name	Amount	Unit	Quantity	Allocation %	Was
life cycle kuvatek	1	p	Amount	100 %	
(Insert line here)					

Known outputs to technosphere. Avoided products

Name	Amount	Unit	Distribution	SD^2 or 2*SD	Min
(Insert line here)					

Inputs

Known inputs from nature (resources)

Name	Sub-compartment	Amount	Unit	Distri
(Insert line here)				

Known inputs from technosphere (materials/fuels)

Name	Amount	Unit	I
Production (kuvatek)	1/10 = 0,1	p	
Use (Kuvatek)	1	year	
End of life (Kuvatek)	1/10 = 0,1	p	
(Insert line here)			

Figure B2 Life cycle process for the competitor

Known outputs to technosphere. Products and co-products

Name	Amount	Unit	Quantity	Allocation %	Was
life cycle competitor	1	p	Amount	100 %	
(Insert line here)					

Known outputs to technosphere. Avoided products

Name	Amount	Unit	Distribution	SD^2 or 2*SD	Min
(Insert line here)					

Inputs

Known inputs from nature (resources)

Name	Sub-compartment	Amount	Unit	Distr
(Insert line here)				

Known inputs from technosphere (materials/fuels)

Name	Amount	Unit	I
Production (Competitor)	1/6 = 0,167	p	
Use (Competitor)	1	year	
End of life (Competitor)	1/6 = 0,167	p	
(Insert line here)			

PRODUCTION STAGE

Figure B3 Production stage processes for Kuvatek

Known outputs to technosphere. Products and co-products

Name	Amount	Unit	Quantity	Allocation %	Was
Production (kuvatek)	1	p	Amount	100 %	
(Insert line here)					

Known outputs to technosphere. Avoided products

Name	Amount	Unit	Distribution	SD^2 or 2*SD	Min
(Insert line here)					

Inputs

Known inputs from nature (resources)

Name	Sub-compartment	Amount	Unit	Distr
(Insert line here)				

Known inputs from technosphere (materials/fuels)

Name	Amount	Unit
Aluminium, wrought alloy {GLO}| market for | Conseq, U	1738,80	g
Steel, chromium steel 18/8 {GLO}| market for | Conseq, U	8401,8	g
Steel, low-alloyed {GLO}| market for | Conseq, U	13736	g
Copper {GLO}| market for | Conseq, U	4124,44	g
Brass {GLO}| market for | Conseq, U	58	g
Silver {GLO}| market for | Conseq, U	0,56	g
Polystyrene, general purpose {GLO}| market for | Conseq, U	144	g
Fleece, polyethylene {GLO}| market for | Conseq, U	10	g
Acrylonitrile-butadiene-styrene copolymer {GLO}| market for | Conseq, U	102	g
Polyvinylchloride, bulk polymerised {GLO}| market for | Conseq, U	373,2	g
Nylon 6-6 {GLO}| market for | Conseq, U	95	g
Synthetic rubber {GLO}| market for | Conseq, U	28	g
Seal, natural rubber based {GLO}| market for | Conseq, U	28	g
Propane {GLO}| market for | Conseq, U	260	g
Lubricating oil {GLO}| market for | Conseq, U	539	g
Transport, freight, lorry 16-32 metric ton, EURO5 {RER}| transport, freight, lorry 16-32 metric ton,	29,8*200 = 5,96E3	kgkm

Figure B4 Production stage processes for the competitor

Known outputs to technosphere. Products and co-products

Name	Amount	Unit	Quantity	Allocation %	Was
Production (Competitor)	1	p	Amount	100 %	
(Insert line here)					

Known outputs to technosphere. Avoided products

Name	Amount	Unit	Distribution	SD^2 or 2*SD	Min
(Insert line here)					

Inputs

Known inputs from nature (resources)

Name	Sub-compartment	Amount	Unit	Distr
(Insert line here)				

Known inputs from technosphere (materials/fuels)

Name	Amount	Unit
Cast iron {GLO}| market for | Conseq, U	7923	g
Aluminium, wrought alloy {GLO}| market for | Conseq, U	226	g
Steel, chromium steel 18/8 {GLO}| market for | Conseq, U	4684	g
Steel, low-alloyed {GLO}| market for | Conseq, U	13233,6	g
Copper {GLO}| market for | Conseq, U	4596,13	g
Fleece, polyethylene {GLO}| market for | Conseq, U	4596,1	g
Acrylonitrile-butadiene-styrene copolymer {GLO}| market for | Conseq, U	465	g
Polyvinylchloride, bulk polymerised {GLO}| market for | Conseq, U	1112,3	g
Nylon 6-6 {GLO}| market for | Conseq, U	498	g
Synthetic rubber {GLO}| market for | Conseq, U	48	g
Refrigerant R134a {GLO}| market for | Conseq, U	370	g
Lubricating oil {GLO}| market for | Conseq, U	323,40	g
Transport, freight, lorry 16-32 metric ton, EURO5 {RER}| transport, freight, lorry 16-32 metric ton,	32,62*2086 = 6,8E4	kgkm

USE STAGE

Figure B5 Use stage processes for Kuvatek

Known outputs to technosphere. Products and co-products

Name	Amount	Unit	Quantity	Allocation %	Wa
Use (Kuvatek)	1	year	Time	100 %	
(Insert line here)					

Known outputs to technosphere. Avoided products

Name	Amount	Unit	Distribution	SD^2 or 2*SD	Min
(Insert line here)					

Inputs

Known inputs from nature (resources)

Name	Sub-compartment	Amount	Unit	Dist
(Insert line here)				

Known inputs from technosphere (materials/fuels)

Name	Amount	Unit
Transport, passenger car, medium size, diesel, EURO 5 {RER}| transport, passenger car, medium siz	3,33	km
Seal, natural rubber based {GLO}| market for | Conseq, U	0,0018	kg
Tap water, at user {Europe without Switzerland}| market for | Conseq, U	10000	kg
(Insert line here)		

Known inputs from technosphere (electricity/heat)

Name	Amount	Unit	Distribution	SD^2 or 2*SD	Min
Electricity, low voltage {DK}| market for | Conseq, U	70,39	kWh	Undefined		
(Insert line here)					

Figure B6 Use stage processes for the competitor

Known outputs to technosphere. Products and co-products

Name	Amount	Unit	Quantity	Allocation %
Use (Competitor)	1	year	Time	100 %
(Insert line here)				

Known outputs to technosphere. Avoided products

Name	Amount	Unit	Distribution	SD^2 or 2*SD
(Insert line here)				

Inputs

Known inputs from nature (resources)

Name	Sub-compartment	Amount	Unit
(Insert line here)			

Known inputs from technosphere (materials/fuels)

Name	Amount	Unit
Transport, passenger car, medium size, diesel, EURO 5 {RER}| transport, passenger car, medium siz	125	km
Brass {GLO}| market for | Conseq, U	0,05	kg
Tap water, at user {Europe without Switzerland}| market for | Conseq, U	10000	kg
(Insert line here)		

Known inputs from technosphere (electricity/heat)

Name	Amount	Unit	Distribution	SD^2 or 2*SD
Electricity, low voltage {DK}| market for | Conseq, U	696,1	kWh	Undefined	

Figure B7 Use stage processes for Kuvatek with disaggregated electricity

Known outputs to technosphere. Products and co-products

Name	Amount	Unit	Quantity	Allocation %	Wa
Use (Kuvatek)_separated electricity	1	year	Time	100 %	
(Insert line here)					

Known outputs to technosphere. Avoided products

Name	Amount	Unit	Distribution	SD^2 or 2*SD	Min
(Insert line here)					

Inputs

Known inputs from nature (resources)

Name	Sub-compartment	Amount	Unit	Dist
(Insert line here)				

Known inputs from technosphere (materials/fuels)

Name	Amount	Unit
Transport, passenger car, medium size, diesel, EURO 5 {RER}| transport, passenger car, medium siz	3,33	km
Production (kuvatek)	1/10 = 0,1	p
End of life (Kuvatek)	1/10 = 0,1	p
Seal, natural rubber based {GLO}| market for | Conseq, U	0,0018	kg
Tap water, at user {Europe without Switzerland}| market for | Conseq, U	10000	kg
(Insert line here)		

Known inputs from technosphere (electricity/heat)

Name	Amount	Unit	Distribution	SD^2 or 2*SD	Min
Electricity cooling	53,24	kWh	Undefined		
Electricity standby	17,15	kWh	Undefined		
(Insert line here)					

Figure B8 Use stage processes for the competitor with separated electricity

Known outputs to technosphere. Products and co-products

Name	Amount	Unit	Quantity	Allocation %	Was
Use (Competitor)_separated electricity	1	year	Time	100 %	
(Insert line here)					

Known outputs to technosphere. Avoided products

Name	Amount	Unit	Distribution	SD^2 or 2*SD	Min
(Insert line here)					

Inputs

Known inputs from nature (resources)

Name	Sub-compartment	Amount	Unit	Distr
(Insert line here)				

Known inputs from technosphere (materials/fuels)

Name	Amount	Unit
Production (Competitor)	1/6 = 0,167	p
End of life (Competitor)	1/6 = 0,167	p
Transport, passenger car, medium size, diesel, EURO 5 {RER}| transport, passenger car, medium siz	125	km
Brass {GLO}| market for | Conseq, U	0,05	kg
Tap water, at user {Europe without Switzerland}| market for | Conseq, U	10000	kg
(Insert line here)		

Known inputs from technosphere (electricity/heat)

Name	Amount	Unit	Distribution	SD^2 or 2*SD	Min
Electricity cooling	258,1	kWh	Undefined		
Electricity standby	438	kWh	Undefined		
(Insert line here)					

Figures B7 and B8 depict the use stages by disaggregating the electricity consumed by the water coolers (i.e. electricity cooling and electricity standby). Therefore, a process for each electricity type was created; see Figure B9 and Figure B10.

Figure B9 Electricity used for cooling

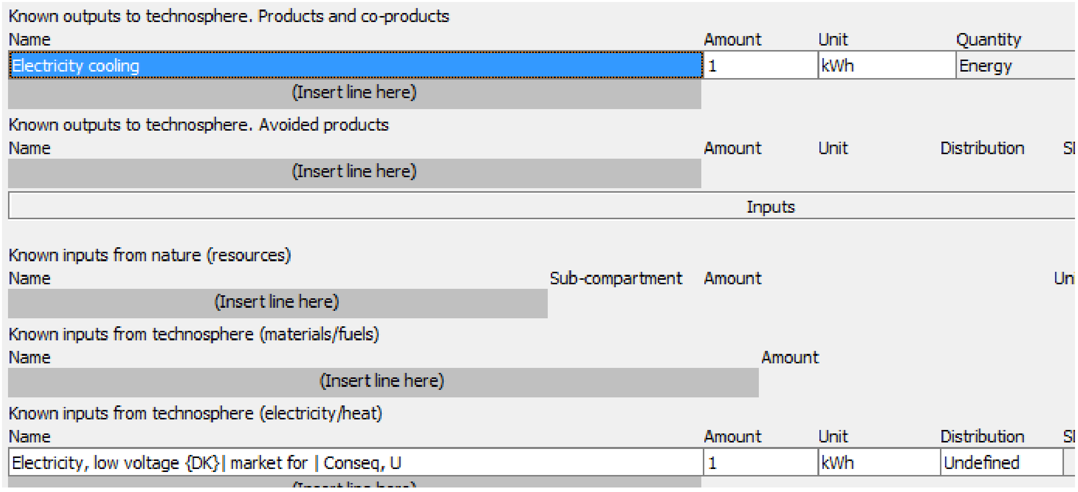
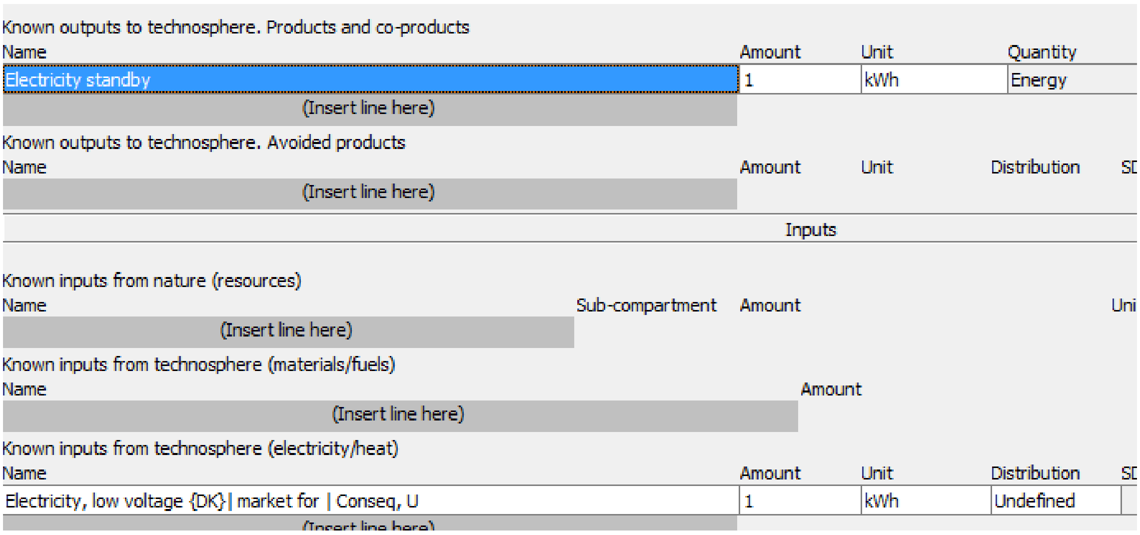


Figure B10 Electricity used for standby



END OF LIFE STAGE

Several assumptions are made:

a) The energy inputs used for the created processes for rubber and nylon are assumed to be the same than for the plastics.

b) Some materials do not have the corresponding incineration process in Simapro databases, so they are assumed from similar materials (as they share alike composition, there should not be significant differences in emissions):
For nylon, the assumed incineration process is taken from plastic polystyrene and for silver it is copper.

Propane is the used refrigerant by Kuvatek, which is a by-product of natural gas. So the waste treatment of the gas is assumed to be burning it in a biogas-engine to produce energy.

Figure B11 shows the recycling and incineration parameters, separated by plastics and metals, used for the end of life stage.

Figure B11 Recycling and incineration parameters

Input parameters

Name	Value	Distribution	SI
Recyclingratemetals	1	Undefined	
Recyclingrateplastics	1	Undefined	
(Insert line here)			

Calculated parameters

Name	Expression
remainingmetals	1-recyclingratemetals = 0
remainingplastics	1-recyclingrateplastics = 0
(Insert line here)	

Figure B12 End of life processes for Kuvatek (1 piece)

(Insert line here)

Known inputs from technosphere (materials/fuels)

Name	Amount	Unit
Aluminium scrap, post-consumer {GLO}| market for | Conseq, U	-1738,80*Recyclingratemetals = -1,74	g
Waste aluminium {GLO}| market for | Conseq, U	-1738,80*remainingmetals = 0	g
Iron scrap, unsorted {GLO}| market for | Conseq, U	-8401,8*Recyclingratemetals = -8,4E3	g
Scrap steel {GLO}| market for | Conseq, U	-8401,8*remainingmetals = 0	g
Iron scrap, unsorted {GLO}| market for | Conseq, U	-58*Recyclingratemetals = -58	g
Scrap steel {GLO}| market for | Conseq, U	-58*remainingmetals = 0	g
Iron scrap, unsorted {GLO}| market for | Conseq, U	-13736,0*Recyclingratemetals = -1,37	g
Scrap steel {GLO}| market for | Conseq, U	-13736,0*remainingmetals = 0	g
Copper scrap, sorted, pressed {GLO}| market for | Conseq, U	-4124,44*Recyclingratemetals = -4,12	g
Scrap copper {GLO}| market for | Conseq, U	-4124,44*remainingmetals = 0	g
_Waste polystyrene, recycling {GLO}| market for | Conseq, U	-144*Recyclingrateplastics = -144	g
Waste polystyrene {GLO}| market for | Conseq, U	-144*remainingplastics = 0	g
_Waste polystyrene, recycling {GLO}| market for | Conseq, U	-102*Recyclingrateplastics = -102	g
Waste polystyrene {GLO}| market for | Conseq, U	-102*remainingplastics = 0	g
_Waste polyethylene, recycling {GLO}| market for | Conseq, U	-10*Recyclingrateplastics = -10	g
Waste polyethylene {GLO}| market for | Conseq, U	-10*remainingplastics = 0	g
_Waste pvc, recycling {GLO}| market for | Conseq, U	-373,20*Recyclingrateplastics = -373	g
Waste polyvinylchloride {GLO}| market for | Conseq, U	-373,20*remainingplastics = 0	g
_Waste rubber, recycling {GLO}| market for | Conseq, U	-56*Recyclingrateplastics = -56	g
Waste rubber, unspecified {GLO}| market for | Conseq, U	-56*remainingplastics = 0	g
_Waste nylon, recycling {GLO}| market for | Conseq, U	-95*Recyclingrateplastics = -95	g
Waste polystyrene {GLO}| market for | Conseq, U	-95*remainingplastics = 0	g
Scrap copper {GLO}| market for | Conseq, U	-0,56	g
Waste mineral oil {GLO}| market for | Conseq, U	-539	g
Biogas {DK}| heat and power co-generation, gas engine | Conseq, U	-0,162	m3
(Insert line here)		

For many materials such as plastics, rubber and nylon, there was a need to create new processes for the recycling treatment, because in the used database of Simapro, these recycling processes cannot be found.

Therefore, first, a specific recycling process is created in Simapro and then the waste of this material has as one of the technosphere inputs the created recycling process. Now, the new process, which is e.g. "waste nylon, recycling" includes the waste material (nylon) that has a final recycling treatment. The latter process was previously created ("recycling of nylon 6-6").

Figures B13 and B14 show the example of how the processes for the nylon are created.

Figure B13 Created process for the recycling of nylon (1)

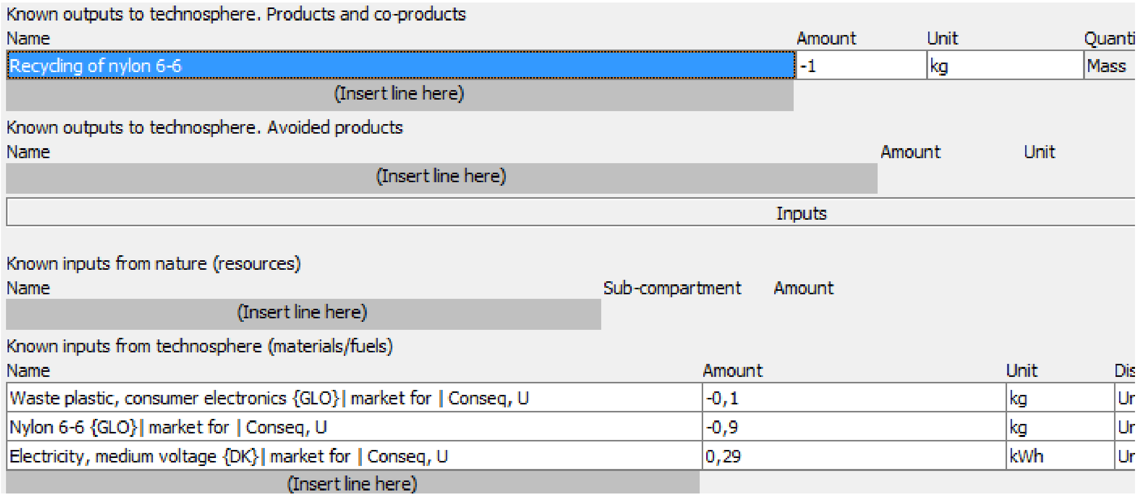
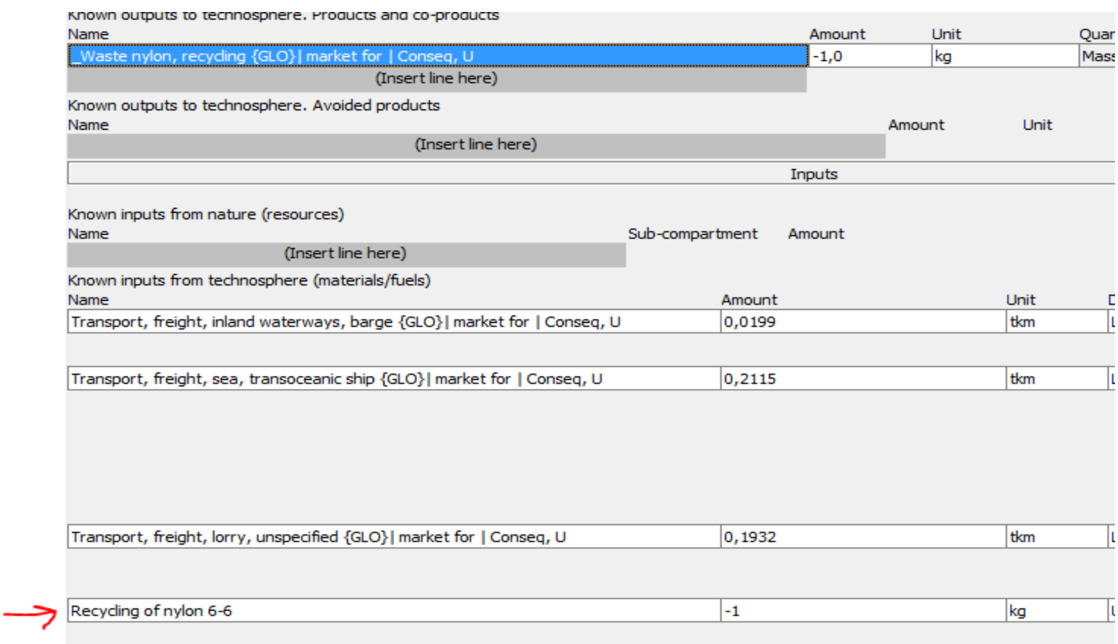


Figure B14 Created process for the recycling of nylon (2)



The polystyrene and Poly (vinyl chloride) are plastics like the polyethylene and they have been created in the same way. Thus, just the latter plastic is shown in Figure B15 and Figure B16.

Figure B15 Created process for the recycling of polyethylene (1)

Name	Amount	Unit	Qua
Recycling of polyethylene	-1	kg	Mas
(Insert line here)			

Known outputs to technosphere. Avoided products

Name	Amount	Unit
(Insert line here)		

Inputs

Known inputs from nature (resources)

Name	Sub-compartment	Amount
(Insert line here)		

Known inputs from technosphere (materials/fuels)

Name	Amount	Unit
Waste polyethylene {GLO}| market for | Conseq, U	-0,1	kg
Fleece, polyethylene {GLO}| market for | Conseq, U	-0,9	kg
Electricity, medium voltage {DK}| market for | Conseq, U	0,29	kWh

Figure B16 Created process for the recycling of polyethylene (2)

Name	Amount	Unit	Qua
Waste polyethylene, recycling {GLO}| market for | Conseq, U	-1,0	kg	Mass
(Insert line here)			

Known outputs to technosphere. Avoided products

Name	Amount	Unit
(Insert line here)		

Inputs

Known inputs from nature (resources)

Name	Sub-compartment	Amount
(Insert line here)		

Known inputs from technosphere (materials/fuels)

Name	Amount	Unit
Transport, freight, inland waterways, barge {GLO}| market for | Conseq, U	0,0199	tkm
Transport, freight, sea, transoceanic ship {GLO}| market for | Conseq, U	0,2115	tkm
Transport, freight, lorry, unspecified {GLO}| market for | Conseq, U	0,1932	tkm
Recycling of polyethylene	-1	kg

Figure B17 Created process for the recycling of polystyrene (1)

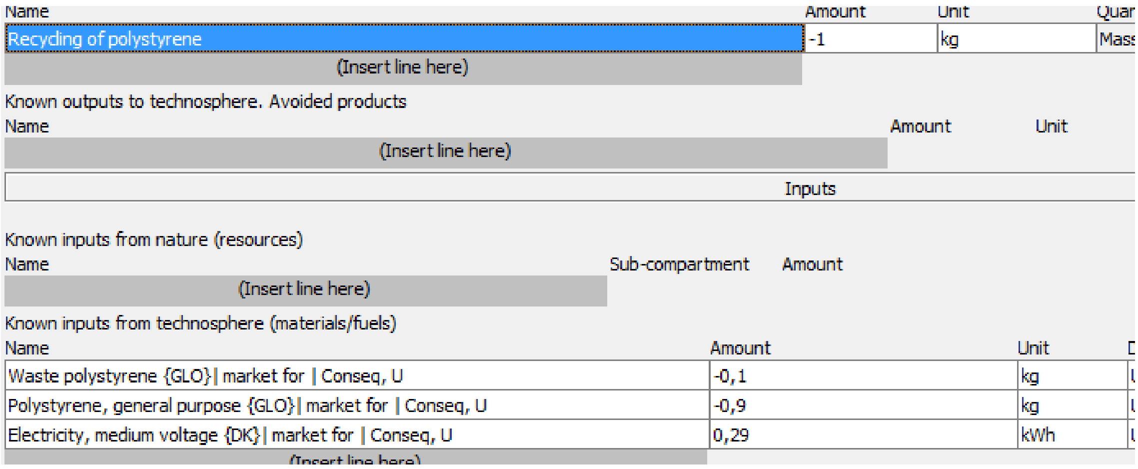


Figure B18 Created process for the recycling of polystyrene (2)

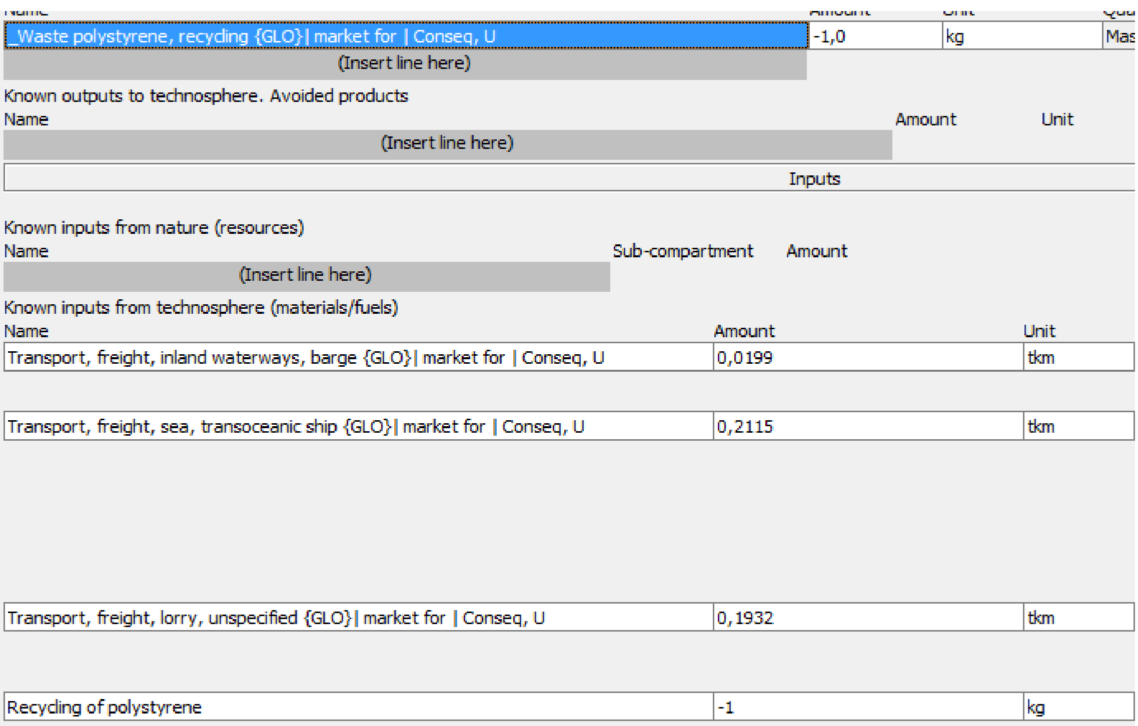


Figure B19 Created process for the recycling of PVC (Poly (vinyl chloride)) (1)

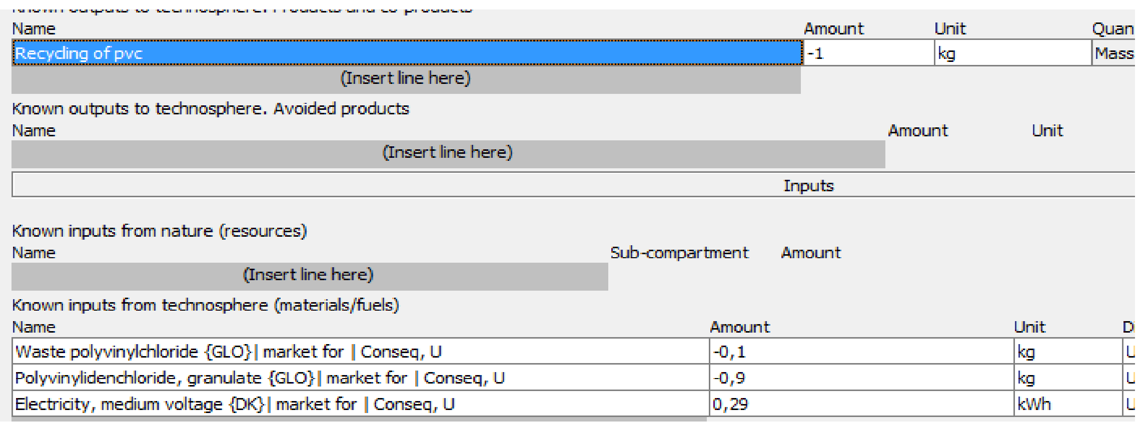


Figure B20 Created process for the recycling of Poly (vinyl chloride) (2)

Name	Amount	Unit	Quai
_Waste pvc, recycling {GLO}| market for | Conseq, U	-1,0	kg	Mas
(Insert line here)			

Known outputs to technosphere. Avoided products

Name	Amount	Unit
(Insert line here)		

Inputs

Known inputs from nature (resources)

Name	Sub-compartment	Amount
(Insert line here)		

Known inputs from technosphere (materials/fuels)

Name	Amount	Unit	[
Transport, freight, inland waterways, barge {GLO}| market for | Conseq, U	0,0199	tkm	
Transport, freight, sea, transoceanic ship {GLO}| market for | Conseq, U	0,2115	tkm	
Transport, freight, lorry, unspecified {GLO}| market for | Conseq, U	0,1932	tkm	
Recycling of pvc	-1	kg	

Figure B21 Created process for the recycling of rubber (1)

Known outputs to technosphere. Products and co-products

Name	Amount	Unit	Quanti
Recycling of rubber	-1	kg	Mass
(Insert line here)			

Known outputs to technosphere. Avoided products

Name	Amount	Unit
(Insert line here)		

Inputs

Known inputs from nature (resources)

Name	Sub-compartment	Amount
(Insert line here)		

Known inputs from technosphere (materials/fuels)

Name	Amount	Unit	Dis
Waste rubber, unspecified {GLO}| market for | Conseq, U	-0,1	kg	Un
Synthetic rubber {RER}| production | Conseq, U	-0,9	kg	Un
Electricity, medium voltage {DK}| market for | Conseq, U	0,29	kWh	Un
(Insert line here)			

Figure B22 Created process for the recycling of rubber (2)

Known outputs to technosphere. Products and co-products

Name	Amount	Unit	Quantity	Allocatio
_Waste rubber, recycling {GLO}| market for | Conseq, U	-1,0	kg	Mass	100 %
(Insert line here)				

Known outputs to technosphere. Avoided products

Name	Amount	Unit	Distribution
(Insert line here)			

Inputs

Known inputs from nature (resources)

Name	Sub-compartment	Amount	Unit
(Insert line here)			

Known inputs from technosphere (materials/fuels)

Name	Amount	Unit	Distributic	SD^2	Min	Ma
Transport, freight, inland waterways, barge {GLO}| market for | Conseq, U	0,0199	tkm	Lognorm:	2,28		
Transport, freight, sea, transoceanic ship {GLO}| market for | Conseq, U	0,2115	tkm	Lognorm:	2,28		
Transport, freight, lorry, unspecified {GLO}| market for | Conseq, U	0,1932	tkm	Lognorm:	2,28		
Recycling of rubber	-1	kg	Undefine			

APPENDIX C Transcripts from the interviews

Interview 1 25.2.2014

Part 1: Interview with Mia and Rasmus

Which is the purpose of the company when having interest in conducting a CF of their product? #00:00:12-4#

It is in order to have the environmental profile. For John it is not important that it has to be used for selling but it is important for him to know that he and the product is sustainable. The results can be used in the sales/ marketing way and he is not doing that, so far but it can be changed. John is and wants to be sustainable but it is not taking the full advantage of it. They did an investment with the Danish military. They did some testing on their cooler and the competitor in order to see the electricity, how fast the water gets cold after the weekend, etc. The report can be found on the website. In the data sheet comparing both companies it can be seen how much water it can be taken out of the water coolers over 14 days, which is almost the same; but the total amount of electricity for Kuvatek and the other one, there is a huge difference. It's more or less a factor 10. This is our newest thing in the sustainable development but we need more, that is where you come in. #00:02:18-6#

So this was done to have an idea in order to see where you stand in comparison to the other company? #00:02:26-6#

Yes, but actually, it was the military that paid for this. So, it's something we just provided our machinery and the other company provided theirs and they put them in the military base in Norresundby and checked facts. There is going to be an official report about this in 14 days, in the military's homepage. An external company would do all the measurements. #00:03:15-0#

So this is somehow like the starting point, right? #00:03:15-0#

Yes, this is real facts. We don't know where John took the GWP from, so this is something we did and we have all the facts in the report. #00:03:50-5#

So I guess that the data that appears in there can be used for the CF? #00:03:50-5#

Yes, but I don't know if this data will be used in the sales opportunity, we hope so. The report will be public so it might be pretty easy to use it. #00:04:16-1#

I will need qualitative and quantitative data. #00:04:36-7#

Do you might have some impression of what kind of quantitative data will be? (asking me) #00:04:38-9#

It’s about energy, materials etc. #00:05:02-2#

But you mean our own materials? (to me) #00:05:02-2#

Yes #00:05:02-2#

Ok, it's just to know, because it could be marketing materials, where we just put in some numbers of our own but they are not % valid because nobody have tested them, it's actually our own testing. Another company could do their own testing and get completely different results. It depends on the spin you put on it and how you read these numbers. #00:05:26-4#

I know that some data will not be as objective as others and that's why in some parts of the calculations, there are assumptions. This is something always happens in these kind of studies. #00:05:42-9#

Regarding the report with the military, which was made by the State, there is nothing tricky as the company has nothing to do with it. #00:06:17-9#

Part of the qualitative data will be to figure out, the main reasons why Kuvatek wants to take the CF, what is it expecting from it, the motivations? This is more the second objective. The data and figuring out the system is the first objective. #00:07:52-5#

It is better to ask John about this. #00:08:05-1#

John believes that no one else makes a cooler in this way and that anyone can copy it, that's why taking pictures might be possible. #00:08:45-3#

Could you tell me a bit about the history of the company? #00:08:54-8#

John bought the company 7 years ago, in 2007. He bought it from a guy, only had it for a very short time. By then, it was located in Odense. They were making water coolers and had a small amount of failure that they had to fix because they were not made well enough, and that's why he is now offering a 4 year free service, because the products don't break. You can see a big difference between the price of the competitors and Kuvatek. John believes that they are made of quality materials and they are made in-house. And also because of results like this, CF and the natural cooler propane= refrigerant (R-290) that it does not lead out any CO2 or anything into the air, so it is the most clean propane they can use for the tanks. And other companies use other types which are dangerous for the environment. That is another reason why there is a big difference in the price. #00:11:26-2#

So, let's say that in the long term it is worth it, it's an investment. #00:11:31-3#

Yes, it is the so-called total cost of ownership. During the total period we have a product Kuvatek's would be cheaper than many of the competitor's but here and now, when people have to buy it, it costs 2 or 3 times the amount. But, thinking over a 5 year period of time, if you buy a product that costs, e.g. 7500dkk from the competitor, whereas from Kuvatek it is around 16000 dkk. The product might be same but the service agreements for the other company might be around 2000-2500 dkk/ year. So, when thinking over 5 years than it is around 12000 dkk +7500 of the price of the product, you have a total of 20000, whereas in Kuvatek the price is 16000 without any service cost, because it is included in the price. In conclusion, over time it is cheaper but now, it is more expensive. This is the CF taken into consideration. That is one of our challenges. We have to convince that over the long run it is cheaper, but not right now. There is a department in the municipality which takes care of the reparations. There are 2 different budgets. The one over the production, what can I pay for this product? But the customers don't take into considerations how much they might spent over year for services. This is one of the challenges of this product. John can't do anything about this. Their product costs 20000 and when a competitor can deliver it for 7500, this one often wins. It's hard to convince the customers to buy the product from Kuvatek, when there are fairly similar ones of half of the price. #00:14:03-8#

Yes, I guess this is something the customers will realize throughout the years.. #00:14:03-8#

Yes, and here is where we would like to build in the CF. If there can be a proof to the customers that they are emitting less CO_2 compared to the competitors, it can help them by including the results in the marketing material and showing that they are a green company. #00:15:10-1#

Coming back to the history, another thing is that after John took over, and fixed the products, there has been just one reclamation throughout the 7 years. This one was from Frederiksia. When you take the water in from the ground, they put it both to a coffee maker and to this machinery, and all the water going into the coffee maker, it pumps back, and there is a lot of bacteria and calcium, so when it pumps back going into the machinery, it builds up the bacteria. So, this happened at one product at a hospital. Since then, they figured out that they just need one tube of water led from the ground into the machinery, and it can't be split into the coffee maker because it pushes up. It has to be settled like this because there is no water tank, you don't have any filtration. Others they use UV filters and other components. There is no tank inside, the water goes through. John doesn't use the extra things the others do. The water coolers don't have tanks, the water just goes through the system. The product delivers clean water from the ground, which is already pretty clean and has a high quality in DK, that's why it doesn't need the extra components, like the UV lights to clean the water or the water tank to store the water. So, then you avoid the bacteria growth inside any tank, energy is saved etc.

The water cooler is for good quality water, like here in DK, which does not need any special treatment, right? So the purpose it is just to cool the water... #00:18:39-9#

Yes, there is no cleaning parts in it, because the Danish and in general the Scandinavian water has a good quality. Some other companies, like Philips created a product where the water can be filtered (thus it can be used in other countries) but John thinks that its product can be improved but for DK and Scandinavia there is no need for extra components.

The function of the water cooler is basically to cool the water. Filters might be added in special cases, if the water quality is worse or maybe the water taste is worse, like it happened in Copenhagen. Filters are added when it is required, e.g. in a specific hospital.

Which LCA approach do you think Kuvatek is interested in?

They are interested in the cradle to grave, because one of the benefits for the customers is the low energy consumption of the product.

When thinking of the materials contained inside, the rubber used inside the cooler might not be the best material, but John can't find another material that can last so long. There are some small parts in the product which can't be recycled. But the outer materials can be basically entirely recycled and at low prices. And actually, a very low amount of CO2 is lead out from burning and recycling. So, it is actually some small parts in the engine which can't be recycled.

Which are the competitors? #00:30:45-5#

There are two types of competitors: the other water cooler producers and also the coffee producers. The latter makes water inside the coffee machines. They have both functions. Also the people who produce water in bottles, but the competitors making the water coolers, than there are 2 or 3 main ones. *Different opinions on who are the competitors: the biggest right now or the biggest within the years. ??*#00:32:27-7#

Which would be the other option if we would not use the water cooler? #00:32:27-7#

Store the water in the fridge. Some hospitals use ice cubes and put it inside the glass with the tap water.

Which is the model you would like to on focus on? #00:37:06-6#

There are two basic models, one can deliver 65l water/h and the other one, 120 l /h. These two have different taps. The water cooler can be built on the tap or have the handle on it (like a beer tap). The model DF12 is the one that are in municipalities, schools, hospitals, almost everywhere with more than 100 people.

So is this model the most popular, the most sold one?

By now, it is the one that has been sold the most. It is the one John recommends the most.

Part 2:

The DF12 water cooler is used per 100 people in a company. John beliefs it can deliver to this people. The product delivers 120 l / h within the tolerance of getting either too hot or too cold. When the water cooler delivers water, at some point, turns on the compressor, so it cools down and then the total amount in the glass has a certain temperature and it has to be within the tolerance, but it is not necessarily the same temperature coming out all the way through. Half a liter is delivered at the same temperature. As it can be seen from the data sheet of the comparison with the competitor from the military, the compressor starts very often (52 for Kuvatek) in order to keep the same temperature all the time but there is a need to be sure that it does not use much electricity(0.9 Wh). #00:04:24-2#

Does the company comply to the VA? Is that a standard, a certification? #00:05:45-2#

It is a standard but it is not important or required in DK anymore, since this year. It is a certificate that states that it is possible and allowed for people to use it without harming them. #00:06:25-3#

Is it an external certifying that the product is appropriate? #00:06:27-7#

Yes, that it is approved in terms of chemical, toxicological issues etc. #00:07:18-5#

So now you don't need it anymore? #00:07:18-5#

No, and that is what makes John to be concerned of, as everyone can make water coolers without any certification or quality service checking the product. The certification allows connecting the water supply from the ground into the water cooler, but as these requirements are no more necessary, now anyone can do it and it is a problem. Now what it is being considered is to create a new certificate for all water coolers in order to be able to sell them in DK, where the water coolers could be nearby food without compromising the food quality. #00:10:13-0#

Is there any other standard? #00:10:13-0#

John is not ISO certified, or Energy Star. For example, for the last one, it does not mean you are doing "good" but just better than the competitors. There are a lot of standards throughout the market. #00:17:08-8#

When looking into the CF, and the CO2 emissions from Kuvatek, there are only 2 driving sales person. But if you take one of the competitors, called Waterlogic, they have 17 sales person in DK driving around. So, at some point, they can say they are sustainable but they arent actually, as they drive around without knowing if they will even sell the product. Maybe the production is sustainable, but not the overall company. Right now how it works in Kuvatek is that people are working from home and then arranging meetings, so they drive directly to a meeting. #00:18:21-1#

Once the product is done, how is it sold? #00:18:21-1#

A logistics company comes and picks up the product and delivers it with all the other mail from the area, and delivers it to the company or private person or whoever wants it. It’s from the production to the end user. There is no other distribution level to take care of it. All material is delivered in the company, produced in house and then sold. The advantage is the saving of energy and money. The next step might be the cooperation with kitchen can’teens and architects, so when they build something, to design it thinking of the space of the water cooler. Kuvatek also cools beer for their main customer, which is a brewery. #00:22:26-5#

<u>John comes into the interview.</u> Coming back to the history:

The company started in 1998 with a heating purpose. In 1995 it started for cooling purposes. In 1985 it was for cooling the beer and then in 1987 it started for water cooling. In 2003 the company started to have some problems and in 2007John bought the company. The hard of the machine hasn’t changed much since then but the quality improved. At the beginning, for the beer cooling there were 15 employees and now there are 5. #00:27:27-5#

When looking into the CF, they would like to compare or make an evaluation to a competitor, at least roughly. The water cooler business is very small, so to find studies might be difficult. #00:37:09-5#

In which LCA approach are you interested in? #00:37:09-5#

Maybe the cradle to grave, but it may also be too much. Thinking in the LCA phases, an idea is taking back the product in future. For example, changing the compressor and then selling it out again. #00:40:28-5#

Which model would you like to focus on, the DF12? #00:40:40-3#

Yes, as it is a simple machine to use. #00:41:34-7#

Which is the motivation when conducting the CF? #00:41:55-2#

We have used the natural cooler since 1999. Then, the first test and production happened in 2000. All the material can be recycled directly. SO, it has been the purpose since the beginning to make the machine to protect the environment. There is no need to throw away the product every two years. They have an idea of a better product, but as electronics need to be inserted in it, it won’t be good for the environment, that's why they haven’t started yet. Whatever different or new material would be introduced, if they can’t recycle it or treat it correctly afterwards, they won’t use it, although they could still make better products and gain more profits. John has some sustainability thoughts: not to leave garbage to their kids from the products he produces. #00:48:16-5#

Who need the products and why? #00:48:18-6#

Regarding these questions, there are a lot of official statements from the Danish government that young people need water. So, actually, the water cooler is not a need, just nice to have. It's the delight factor. #00:49:38-2#

Which is the temperature of the water? #00:49:43-9#

Between 3-8ºC. #00:50:33-8#

How does the water cooler work? #00:50:36-3#

You use the compressor to make a high pressure in the cooler, than it gets very hot and then you blow away the heat. #00:52:46-8#

Which are the main materials? #00:52:46-8#

Stainless steel, aluminium, copper, brass, PBC (a bit, inside the tube), PA6 (nylon) on the top of the handle, #00:56:05-1#

Is there a scheme of the supply chain? #00:56:15-8#

We know where it starts, but not the things that happen in between, like where the metal plates start from. We know the process in general. #01:01:16-1#

What about the VA certification? #01:01:27-1#

In DK, there is no need anymore. Different certifications might appear. However, there is no similarity of Energy Star for water coolers. Kuvatek has passed the CEE evaluation and they still have the VA standards, so it is fine for them by now, in the sense that there is no need for other certification.

The interest in CF is also to make the new development based on sustainability. #01:15:27-9#

<u>Down in the production of the company</u>: #01:15:27-9#

The copper pipes have stainless steel inside and bend it. The refrigerant comes inside, surrounds the stainless steel and the hot water gets cold because of the refrigerant. The latter will then go to the compressor. And it is running in circles. There is also a sensor to measure the water T and "says" that it need to be cooled down. Every time you open the tap, the water gets cooled. The hot water gets cool very fast. The cooling and the taping system is separated. The design and colours change depending on the place of instalment. After installing everything, they do some testing, then a vacuum test to remove all the air. Then, they add the refrigerant and do another test to be sure everything works. Afterwards, they cover the system and then send it. #01:27:39-9#

Looking into the competitor's product: they cool the water constantly and the is product always on, including the UV lights. You put the filters to stop the bacteria so they don't go into the tank and then you put the UV light to kill the bacteria in the tank. But it actually doesn't kill the bacteria, it just sterilizes it. It has two lights, then the tank has a volume of 1 gallon (3.785 l) and cools it down to 5C. The water is constantly cooled down but it has a very small compressor and little power. For the small parts, you will always need a third person driving around to change the parts, which has additional costs. This product is a standard one, the way the other do very similarly. It has many electronic parts, whereas the water cooler from Kuvatek does not. The GWP of this refrigerant is 1300, whereas theirs is just 3. The standby time is usually 99% for any water cooler.

28.4.2014

<u>Interview 3 with John Green, Director of Kuvatek</u>

Why is Kuvatek interested in conducting concretely a carbon footprint (CF) assessment? #00:01:05-0#

It's because it will be important. We already started to take back our products and up-grade them to today's standard and sell it 30% off or 25% with full warranty because it is important we deliver a nice world to our kids and I think it will be more and more important in the business and we can use it to put on pressure on our competitors. #00:01:43-9#

Thinking of the take back system, we also hope it will rise the company's reputation, although we are aware that still many people will go for new water coolers. In addition, the director is thinking of a kind of exchange system between customers according to their own needs, instead of trading. So they could purchase between them instead of buying a new one from the company.

So you thought more about the CO2 emissions maybe more than the water emissions? #00:01:49-7#

Yes, the CO2 #00:01:51-4#

But is it your own concern? #00:01:51-4#

It is an own concern but also I also think it is a good business point to be at the upfront. #00:01:59-5#

In relation to documenting the environmental performance of the products, it's also related to the environmental communication, one thing it to conduct the CF and another to communicate it. **So, you would also like to communicate it at some point, right? #00:03:57-8#**

Of course, our customers should have a choice with what to buy, whereas to buy an environmental friendly product or another one from the competitor where you cant recycle many parts. So, the customers should have a choice.

So, after the screening CF, will you communicate it to the public whatever the results will be..? #00:04:17-0#

We are taking up two products to compare in order to see, on the one hand, if we are "good" and on the other hand to see if we have to modify our way of production and behavior and to put pressure on our competitor to do the same than we do. So, the purpose is to get an idea and to put pressure on everyone to do better. #00:04:51-4#

Because Rasmus said at the beginning it would be used for marketing purposes? #00:05:01-3#

Of course, it is for that. We already started using the military report results for marketing purposes, such as the energy consumption and the cooling temperature. The results are much better compared to the competitor. So, of course it is for marketing and we also hope the CF can be started to be included. #00:05:30-4#

Yes, but the CF should be treated carefully because of the errors, but at least it is a screening so it gives an idea of how you stand... #00:05:35-2#

It looks like we are doing good and we are on our way doing better or the screening might indicate that we are not as good as we want to be, that's why we started the recycling program, to take back our machines. If the customer does not want to use it anymore, I (the director of Kuvatek) will buy it. We already have one customer, a school. They have three machines but they actually just need two of them. I also visited another school, and they would like to have fresh water, but they would like to have a second hand water cooler. #00:06:50-8#

So, then from the first school you bought it from, you will then renew it and then sell it to the second school? #00:06:50-8#

Yes, we will renew it and sell it second hand, maybe with the same 4 year warranty. #00:07:03-3#

I think the machine we will buy it is 8 years old, we take it in, renew the compressor and fan and then it runs for another 10 years. #00:07:29-5#

It will be interesting to see how the program works and it will put pressure on the competitors, because they can’t do that because they will have to change too many things and when they sell out the cheap machines, it will be cheaper for them to sell new ones instead of renewing every individual part of it. So, every time one water cooler from the competitor might get reach its end of life, it will be thrown out. #00:09:20-3#

But we changed our behaviour and want to be on the upfront. #00:09:23-0#

When you will communicate the results from the CF to the customers, how is your intention to do it? Because you already do it face to face to the customers when you sell the product, but now how is your idea to do it? #00:09:53-3#

I think we get a new employee now who is experiences in social media. I think we will start some discussions in relation to this and try to find an answer to questions like: shall be take a standard competitor and see what are they doing with a product that doesn't work anymore? What happened to it and ask them to join a discussion. The CF can be shown in the website, maybe the catalogues or at least to ask people to join a discussion about this. #00:10:27-9#

And will you go in the future to a CF label? #00:10:39-0#

If it is any standard were we can compare with someone, then yes. But if we are the only ones in the world doing it for our products, then I don't know what the purpose should be. #00:10:54-5#

You usually get the logo and it means that the product already complies with the requirements to get this label and it means that it is environmentally friendly. #00:11:36-8#

If we can get a figure that means something against the standard, yes but if we get a value, like CF of 2.6, people don't know what is that, and use it what for? #00:11:53-3#

It's also for marketing purposes and communication to customers. #00:12:09-8#

We would like our customers to invite them into a discussion and think about this. We try to do, but can you help me in this? #00:13:01-5#

Yes, you mean a stakeholder discussion, right? #00:13:01-5#

Yes #00:13:02-6#

We are very interested in all this theme of the communication to the customers of the CF, but we still don't know much about it but we would like to discuss it and we all need part of it in order to prevent future problem. #00:13:52-1#

Which will it be the next step after the CF (apart from your new employee that will guide you in the communication issue), you will also work with a PhD student, right? #00:14:24-6#

Yes, we will have a "GO-NO-GO" on our next development. We don't want to make it if we can't make it correctly. #00:14:46-7#

So, it's like" this is how we have been doing by now and let's see if we can make it better" #00:14:46-7#

Yes, it needs to be better. We got the inspiration from Grundfoss ambitious plan to improve. #00:15:17-6#

This idea of improvement has always been important for me #00:16:10-4#

In your opinion, which are the advantages and disadvantages of carrying out a CF? the advantages are more obvious, but do you think there are disadvantages? #00:16:15-7#

No, it should be a standard similar to make a cost project. It should be much easier to do, a program where you introduce the figures and get your results. It will be a natural thing in any development. #00:16:50-5#

Because for small companies one main drawback if the cost. #00:16:51-8#

Yes, but not only but also the knowledge of how to do. I think it is a bigger problem. #00:17:07-2#

Everyone should have easy access to their own data and provide it to the rest, in order to be possible to make comparisons. More information is available nowadays, but still not enough. I believe in EU and they should set a standard for CO2/ Km for any transportation so everyone has the same figures to start from, there is still a lot to do. EU could provide some tools and in this way, for example, the competitor can calculate the CF the same way than I do. #00:19:14-5#

Yes, in this way you would get comparable measures #00:19:20-1#

Not because we can beat each other, but in order to get better all of us. #00:20:02-1#

More standards for everyone should be provided and they should big enough to set it for the whole world. #00:20:33-4#

<u>Part 2 of the meeting: doubts about calculations and systems</u>

In relation to Kuvatek's transport measurement (from production to consumer), could you tell me in average how many times does the truck go from Sindal to Kolding per year? Does it depend on the customers demand or is it a fixed frequency per year (to deliver the 150 water coolers)? #00:21:49-2#

We produce for warehouse and when we get an order, we pick -pack one unit on one small pellet and often the truck comes and picks up one small pellet (one water cooler). In average, the truck comes 50-75 times / year, picks up 1 or 2 units each time. #00:23:46-0#

So it actually depends on the demand of the customers, right? #00:23:50-8#

Yes, we try to keep water coolers in stock but we still keep producing them with the same speed. And then, we try to find customers, but this goes always up and down. #00:24:31-4#

Up to 150 water coolers per year, right? #00:24:31-4#

Yes, last year (2013) that was the figure. #00:24:50-3#

So, then you contact the transportation company and ask them to come and pick up the water cooler? #00:26:15-7#

Yes, we tell them the amount they will have to pick. It is organized from Hjorring, where the truck goes out from. Then, each truck has their own route (one of these routes will pass by Kuvatek, in Sindal) and comes back to Hjorring. Here, they sort out the goods, depending on the next destination of the goods. Then, they will bring the goods to a bigger place, like Aalborg. In Aalborg, goods from different places like Frederikshaven are gathered together. Then, many trucks will go out and go to Copenhagen, Kolding, Frederiksia etc. So, as the truck gets full loaded from different goods, Kuvatek occupies a small place of the whole truck. However, the trucks might need to be reload in several places, so sometimes it will have to wait (maybe 1-2 days) until it gets full loaded before it heads to its destination. Kuvateks delivery is "door-to door", directly from production to the consumer. With this system, it is ensured that the trucks move as loaded as possible. #00:29:40-3#

In relation to the transportation of the competitor, do we know the type of transport that is used to send to the customers from Italy? #00:30:11-8#

The type of transportation is by truck. This is from Italy to Ebeltoft and then, from Ebeltoft to Kolding, it is by van (the same as Kuvatek). #00:30:51-3#

Continuing with the competitor, for the maintenance, do we know from which point is the substituted material (the water faucets) sent from? Is it from Italy? #00:30:26-8#

Yes, inside the truck, they also include the spare parts. Everytime they have to send the water faucets, they send it from Italy to Ebeltoft and the spare parts from Ebeltoft are maybe sent by post to the plumber (in kolding) and then the plumber goes to the customer by van, because they use the plumbers as dealers. However, for Kuvatek's spare parts, it is directly sent from the production site to the customer by post. However, the competitor has to do most of the distance by truck. Usually these water faucets are made by brass (chrome plated) #00:32:43-1#

So, we can say that for the substituted materials, they do the same trip than for the transportation? #00:32:43-1#

Yes. #00:34:10-5#

In relation to the weight of the competitor, I'd like to know was it done by putting all the pieces together again? because I found in their official website that it is 37 kg (please see attached pdf, page 47) and not 32 kg, but is it maybe because the water cooler you have in production is older and might be thus different #00:38:58-1 #00:39:02-5#

No, we took the weight from a brochure, so 32 kg should be correct. #00:39:10-5#

For the production site, how big is that amount for the inputs such as electricity and water? Can it be assumed it is comparable to a household? #00:39:31-5#

We use much less water than a household. We use a bit for the testing and I think we use 4 or 5 times more for private use. The most might come for heating the production site and the used electric light. This accounts for more than the electricity for production. We mostly use the battery hand tools, so to re-charge the battery is not much. We use one machine for welding maybe 10 times per year and it is half horse power. Welding uses much less power than computers, for example. We can put it this way, the consumption of water, electricity and heating will not be that different if we produce or not, because in order to keep the place functional, you need to keep the heating on. So, if you produce or not, it won’t make much difference. The competitors, for example, will usually use much more power whenever they use plastic, because they melt it before injection, and then they use power to cool it down afterwards. It’s a high power consumption. #00:43:55-9#

In relation to the end of life stage, is the oil for the compressor treated or lost? #00:44:39-5#

I don’t know, because we accumulate in the storage room the different materials, but still don’t have enough to send to the treatment plant. The former owners had a poor production so before him and after him, we don’t get any, so we actually don’t know. I think they will just melt it with the full compressor. I don’t think they can separate it, so when they melt it they will just make new components with it. #00:45:32-8#

So, once you get your containers full, the system treatments will take care of it, right? #00:45:32-8#

Yes, we will sell it to a recycling company and the compressor, as it has so much iron, I don’t think they will separate it. #00:46:31-0#

Is there any hazardous waste for the competitor?

Yes, the refrigerant (R134a) should be collected and treated.

Could you explain me where the oil and the refrigerant are in the system? #00:49:32-3#

The oil is just in the compressor and the refrigerant is in the system. In the compressor the refrigerant changes phase from air to liquid, then to air and into the compressor and not as air and in the evaporator it becomes liquid, and sucks into the compressor as air and this continues. Thinking of the pipe, we have the inside, containing the water, and surrounding it, it is the refrigerant. While it is liquid it is cold, and when you apply heat to it, it becomes air, and it is this phase change from air to liquid and back to air where the secret lies in. #00:52:15-4#

Could you explain a bit further the functioning of the system of both water coolers?

When looking into the functioning of the product, looking into picture 16, it can be seen that the black components are the cold part of the system and the other one is the hot side. The copper pipe above the compressor is very hot and then it gets cooled down by the fan and then it becomes hot as liquid and goes into the system. When the water comes from the pipes, it first gets hot, and then cold again (helped by the fan).

And this circular system (the flow system) starts every time the water is tapped, which will make the difference from the other system, from the competitor?

Yes, the competitors have the “ice line” which keeps the water cooled all the time and also a stirring wheel in order to ensure that the water does not get completely frozen.

They have a primary system (from water to ice) and a secondary system (ice to water).

Basically, the competitor has 2 changes in phase and a low transformation temperature (ΔT).

In the tank they have the ice and water. And then they have the drinking water, which goes down to the ice water.

The transformation between the cold water and the drinking water costs a lot because the difference in Tº is very high. $\Delta T = 16.5C$

Kuvatek has only one step, by the use of the refrigerant directly to the drinking water. There is a $\Delta T = 22C$, which means there is a fast transfer.

Is the ΔT difference of both systems what makes the difference by delivering the water cooler or hotter? #01:03:41-7#

Yes, how fast it is transformed and also the efficiency, because you lose a lot of energy in the change of the phases. The competitor has 3 losses of energy: from water to ice, then from ice to water and finally is the constant use of power from the stirring wheel. Plus, the electronic machines, like the UV light, the Tº measurement etc.

In kuvatek, there is no such a loss of energy between the transformations of the phases, they go directly to cool the water with the refrigerant to the drinking water. And there are no extra losses of energy from any electronic devices, as the competitor has.

They need the stirring wheel in order not to get ice all over, because then, if the water starts getting pieces of ice in it, the water won't be able to be tapped. In the case of Kuvatek, if we don't stop in time, then we will also get ice in our pipes. That's why we need to wait until the water starts flowing, and then you can go from -5 or -10 C (this is the Tº of the refrigerant), because the water is moving and then it can go full power. #01:07:09-0#