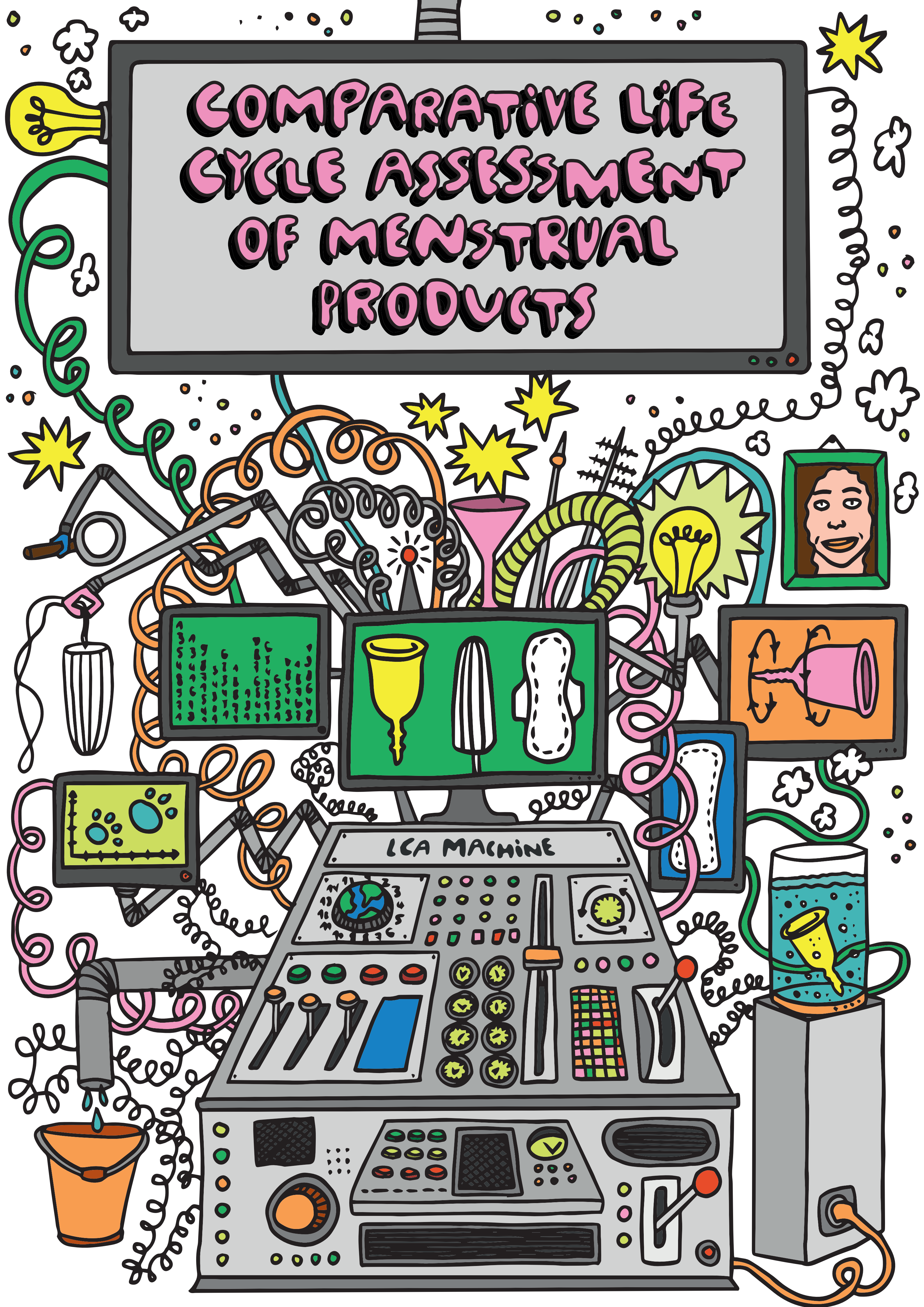
COMPARATIVE LIFE CYCLE ASSESSMENT OF MENSTRUAL PRODUCTS
LCA MACHINE

Comparative Life Cycle Assessment of Menstrual Products

Baseline Year	2019
Issue Date	16.12.2020
Publication Date	March 2022
Report version	1.0
Database version	ecoinvent 3.6
Commissioner	einhorn products GmbH
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Suggested citation:

(Vilabrille Paz et al., 2020). Vilabrille Paz, C., Ciroth, A., Mitra, A., Birnbach, M. and Wunsch, N. (2020) Comparative Life cycle assessment of menstrual products. GreenDelta GmbH, commissioned by einhorn products GmbH

GreenDelta

This study has been funded by einhorn products GmbH and its supply chain partners for reusable and disposable menstrual products.

Acknowledgement

This study could not have been possible without the participation and assistance of many people. It has been kindly reviewed by Janie Hampton (BA, MSc; International menstrual health activist and planner) who added valuable feedback and proofread this study. The project members would also like to acknowledge the detailed work of everyone who has been involved in the data collection process.

Abstract

With the current global concern about air, land and water pollution and the need to reduce carbon emissions, assessing the environmental impact of different menstrual products is increasingly important.

This study intends to overcome the gap in evidence by performing a comprehensive, peer-reviewed, comparative, life-cycle assessment of menstrual products according to the norm ISO 14040/44. The products studied were silicone menstrual cups, and tampons and pads made either of organic cotton or cellulose-based materials and plastic. All life-cycle stages were considered including the production of components; manufacturing; distribution by producer; shopping trip; use by consumer; and disposal. The use of land, water, energy and materials; pollution of air, land and water; and health effects were also considered according to the Environmental Footprint impact assessment method.

The study assumed that over 1 year, a person would use 260 tampons or pads, or one fifth of a cup (with a lifespan of 5 years), to collect their menstrual blood. Based on 16 environmental impact categories applied to all 5 products, the menstrual cup is the most environmentally friendly product, due to its reusability. This is despite the amount of energy and water required to wash hands and the cup during use. Menstrual pads made of viscose fluff-pulp and plastic show lower impacts than tampons, mainly because of lower impacts in the use phase. Organic cotton tampons are better than conventional tampons. However, for tampons and the viscose-based pad the results strongly depend on the impact category. The organic cotton pad creates the greatest environmental impact mainly because of its greater weight compared to other single-use products. 17 sensitivity analyses were conducted to check the influence of assumptions and uncertainties on the overall results of the life cycle assessment (e.g., material origin and datasets; lifetime, sterilization method and wearing time for the menstrual cup; amount of water and soap during hands washing).

These results demonstrate the importance of including the use phase of menstrual products in life-cycle assessment studies. However, more research is needed about the behaviour of menstrual product users.

From an environmental perspective, the performance of the menstrual cup is clearly better than single-use products. When promoting menstrual health, organizations, educators and governments should use these results to inform and support the reduction of the environmental impacts of menstrual products. Next to personal preferences, this environmental information is also relevant to users when selecting menstrual products.

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Executive summary

Background

Awareness of the environmental impact of menstrual products is increasing. One question is whether the reusable menstrual cup has more or less environmental impact than single-use products such as tampons and pads. Also, there is an interest in comparing single-use products and the different materials used for their production. Hence, it is important to identify which products show a better environmental performance and provide clarity to consumers, the menstrual product industry, researchers, and regulatory bodies. Available studies analysing the environmental performance of menstrual products are scarce and often deliver incomplete results.

Method

This study is a comprehensive assessment of the life-cycle impacts of the most commonly used menstrual products in Germany. The products assessed are:

- Silicone menstrual cup
- Conventional tampons made of viscose
- Organic tampons made of organic cotton
- Conventional pads made of fluff pulp and plastic materials (incl. super-absorbent polymer)
- Organic pads made of organic cotton and a biopolymer

The environmental impacts of these products throughout their life-cycle were compared according to the structure and requirements of ISO 14040/44 for life-cycle assessment. Since the results are intended to be disclosed to the public, the study was reviewed by a panel of experts as stipulated in the norm. The Environmental Footprint method, recommended by the European Commission, was selected. It includes 16 environmental impact categories covering global warming; the use of land, water, energy and materials; pollution of air, land and water; and health effects.

In this cradle-to-grave study, all life-cycle stages were considered – production of the components, manufacture, distribution, shopping trip, use, and end-of-life. In addition, the study also identified the main drivers of environmental impacts, and the potential to reduce impacts.

To ensure that all the products assessed are comparable, they must each fulfil the same function. The 'functional unit' was defined as the collection of the amount of menstrual fluid that is expelled by an average menstruating person over a period of one year, assuming thirteen menstrual cycles per year; five menstruating days per cycle, and changing the product as often as recommended by the producers. The results refer to this unit i.e.one year of menstrual protection.

The average values for the frequency of changing the products and the lifetime of the menstrual cup were selected according to the recommendations of health institutions and the menstrual products industry. Also included are hygiene routines such as handwashing to ensure the safe use of tampons and cups. Since pads are not inserted in the vagina, hand-washing before change is assumed to be unnecessary. The inputs are summarized in Table ES- 1.

The weight of each product is also displayed in Table ES- 1. This is noted because the weight is relevant for the environmental impact – the amount of raw materials needed, the manufacturing, transport, and the end-of-life treatment efforts depend on the weight. The cup and its packaging has the greatest weight, most of which is its packaging. However, since it has a lifetime of 5 years, only an estimated 1/5 of the cup is used to cover menstrual protection for one year.

Table ES- 1. Overview of the analysed products

Product		Weight (g/product)[1]	Change frequency (h)	Number of products/year	Use phase	
					Input	Frequency
Tampon	Conventional	2.88	6	260 tampons	Hand washing (water & soap)[2]	260
	Organic	3.71			Toilet paper for disposal[2]	260
Day pad	Conventional	5.00	6	260 pads	Toilet paper for disposal[3]	13
	Organic	9.11				
The menstrual cup, 5 years lifetime		54.16	10.6	1/5 of a cup	Hand washing (water & soap)[2]	148
					Cup washing (water & soap)[2]	148
					Cup sterilization (water & energy)[4]	13

[1] Including packaging
[2] Every time the menstrual product is changed
[3] After using the last pad
[4] Between periods

Most brands of cups recommend sterilising a menstrual cup in a pan of boiling water for 5 to 10 minutes. A new study revealed that it is safe to simply clean the cup with soap and water each time it is changed during menstruation (s. chapter 3.4.3). At the end of each menstrual period, the cup can be sterilised in two ways. To cover both procedures, two scenarios were analysed for the use of the cup:

- Cooker scenario: the cup is sterilized in a pan of boiling water on the cooker.
- Kettle scenario: The water is boiled in a kettle and poured over the cup in a container to sterilise it.

Primary data were available for the bill of materials and manufacture of the menstrual cup, the organic and conventional tampons, and the organic pads, and secondary data were selected for the conventional pads. Secondary data were selected for distribution, shopping trip, use, and end-of-life.

Results

The results of the assessment are shown in Table ES- 2. The colour scale shows the level of impact – green indicates the lowest impact and red the highest. The colour scale also helps the understanding of how far the values are from each other: the more similar the colour, the closer the values are.

The menstrual cup shows the best environmental performance, especially in the kettle scenario. This is because the cup is reusable– the environmental impact from production, distribution, shopping trip and end of life is much lower than for the single-use products. The use phase is the most relevant life-cycle stage for the cup, mainly due to the electricity consumed for sterilization and the production of soap to wash the cup and hands.

The organic pad shows the greatest impact in the majority of categories. The production of organic cotton and bioplastic were identified as the main drivers to the impacts. The greater weight of the organic pad – the pad itself as well as the packaging – explains the poorer results compared to the other single-use products. However, it is worth noting that the applied database plays a significant role in the results of the indicators for the "organic cotton" flow.

The conventional pads show, in general, lower impacts than the organic pad, and in many categories lower than the tampons. The impact is mainly driven by the production of the components – plastic and viscose for the distribution layer in the first place, followed by the top- and back-sheets and the wrapper. For the production of the conventional pad, only secondary data was available to calculate the impacts. Ideally primary data would be used, as for the other four products.

Between the conventional tampons and the organic tampons, the second present less impact for most of the categories. The results of both products depend on the impact of the core materials – viscose and organic cotton – and the use phase. If the use phase is not considered, the tampons cause less impact than the conventional and organic pads.

In general, the manufacturing, distribution, shopping trip, and end of life stages have less relevance to the environmental impacts, compared to the production and the use phases.

Table ES- 2. Life-cycle environmental impacts

Impact category	MC, cooker Scenario	MC, kettle Scenario	TC	TO	PC	PO	Unit
Land use	1.06E+00	7.62E-01	1.13E+01	3.87E+01	9.52E+00	4.51E+01	Pt
Water scarcity	3.60E+02	2.06E+02	9.63E+02	8.56E+02	8.63E+02	1.02E+03	m3 depriv.
Resource use, mineral and metals	3.52E-09	3.11E-09	1.30E-08	6.46E-09	1.67E-08	1.41E-08	kg Sb eq
Resource use, energy carriers	3.02E+01	1.76E+01	7.58E+01	4.31E+01	9.97E+01	9.30E+01	MJ
Climate change	2.20E+00	1.25E+00	5.87E+00	5.01E+00	5.99E+00	8.84E+00	kg CO2 eq
Eutrophication terrestrial	2.00E-02	1.33E-02	6.21E-02	1.72E-01	5.42E-02	2.20E-01	mol N eq
Eutrophication marine	7.47E-03	6.68E-03	9.96E-03	8.67E-02	5.54E-03	8.95E-02	kg N eq
Eutrophication freshwater	2.30E-03	9.66E-04	2.34E-03	1.34E-02	1.89E-03	1.39E-02	kg P eq
Acidification terrestrial and freshwater	8.22E-03	5.50E-03	3.62E-02	4.95E-02	2.44E-02	6.23E-02	mol H+ eq
Ecotoxicity freshwater	4.22E+00	3.92E+00	1.01E+01	2.55E+01	7.61E+00	3.00E+01	CTUe
Cancer human health effects	5.30E-08	4.24E-08	9.04E-08	7.07E-08	6.79E-08	9.16E-08	CTUh
Non-cancer human health effects	6.96E-07	5.98E-07	2.07E-06	1.58E-06	6.57E-07	1.26E-06	CTUh
ionizing radiation, HH	3.22E-01	1.57E-01	7.24E-01	4.61E-01	6.73E-01	6.87E-01	kBq U-235 eq
Photochemical ozone formation, HH	4.20E-03	2.93E-03	1.72E-02	1.38E-02	1.85E-02	2.37E-02	kg NMVOC eq
Respiratory inorganics	5.22E-08	4.09E-08	3.70E-07	3.09E-07	2.59E-07	4.70E-07	disease inc.
Ozone depletion	1.42E-07	1.05E-07	8.02E-07	3.23E-07	4.55E-07	9.28E-07	kg CFC11 eq

The colour scale indicates the level of impact – from green (lowest impact) to red (highest impact)
Additionally, the colour scale helps the understanding of how far the values are from each other; the more similar the colour, the closer the values are

An extensive set of sensitivity analyses was performed to explore the influence in the results of the assumptions and decisions made. The most relevant life cycle stages were tackled – the production of components for the single-use products, and especially the use phase of tampons and the menstrual cup due to the difficulty to predict the users' behaviour. Table ES- 3 presents the parameters which have the greatest influence on the results.

Table ES- 3. Most relevant parameters identified from the sensitivity analysis results

MC cooker	MC kettle	TC	TO	PC	PO
Sterilization frequency	Sterilization frequency	Hand washing – amount of water and soap	Hand washing – water temperature	Addition of hand washing	Data for organic cotton
Cup washing – amount of water & soap	Cup washing – amount of water & soap	Hand washing – water temperature	No. of toilet paper sheets		
Wearing time	Wearing time	No. of toilet paper sheets	Data for organic cotton		

Conclusions

The comparison of the environmental impacts of the menstrual products (displayed in Table ES- 2) is the same for the majority of the sensitivity analyses: the menstrual cup causes the least environmental impacts, while the organic pad shows the worst results. The conventional pads create, in general, less impacts than the tampons – closely followed by organic tampons and then by conventional tampons. The main reason for the greater impacts of the tampons compared to the conventional pads is the influence of the use phase.

In previous studies the use phase of menstrual products was excluded or incompletely considered. The comparison of the climate change impact provided in the literature to the impact calculated in this study demonstrates that it is necessary to include the use phase for complete results.

The behaviour of the menstrual products users is based on theoretical assumptions. Possible situations such as flushing the products down the toilet instead of disposing them in a rubbish bin, are excluded. Since it has a potentially harmful effect on the environment, that would be more severe for products containing a higher amount of plastic, so inclusion could affect the results.

This study represents an improvement in the life cycle assessment of menstrual products. No other study compares so many different products – not only the cup, tampons, and pads but also different materials for tampons and pads.

Recommendations and next steps

The menstrual hygiene industry should provide primary data and support to researchers to perform further studies, which would enhance data quality and comparability of results. Special attention should be given to data for the use phase.

The consumption of water, soap, and electricity needed to use menstrual products safely, affects their impact on the environment. Clear, understandable, and evidence-based scientific information about the safe handling of the products should be provided to users.

Since the menstrual cup shows the best performance, organizations, governments, and education should consider the cup as a good alternative to single-use products to reduce environmental impacts. More effort should be made by the industry and researchers to find materials and improve production processes to reduce the impact of 'disposable' single-use products. In addition to that, it was evident that the selected database was a key factor in the results formation and that different datasets caused notable fluctuations in the results. This variability was particularly apparent for the "organic cotton". Therefore, it is seen that more in-depth research is required for certain processes and flows to obtain more a more reliable outcome in the impact categories.

1 Introduction

Disposable, single-use menstrual products were first developed at the end of the 19th century. In 1896 Johnson and Johnson manufactured the first mass-produced single-use menstrual pads. A few decades later, in 1927, the first single-use tampons' patent was registered by Ives Jean Burill [1]. Today, the use of these products is widespread.

The menstrual cup was developed in the 1930s, but its use remained low until the beginning of the 21st century when medical-grade silicone was used for its production [2]. In Germany, tampons and pads are the most commonly used single-use menstrual products [3], and among reusable products, the menstrual cup is preferred [4].

While tampons and menstrual cups are placed inside the vagina to collect the menstrual fluid, pads are placed in underwear. So, the recommendations regarding the correct use of cups and tampons are important because of the risks associated with their use, mainly the bacterial toxins released by *Staphylococcus aureus* [5]. According to medical research, these bacteria may cause toxic shock syndrome (TSS), an illness with symptoms of fever, low blood pressure, and skin rashes that can lead to multiple organ failure or fatal shock [6]. While TSS has been associated with tampon use, a recent study claims that TTS may also be caused when using menstrual cups, but this has not been verified. [7]. As menstrual pads are used externally, no clear recommendations are given for their use. An estimate of the number of single-use menstrual products consumed is difficult, due to the variation in duration of menstruation and an individual's intensity of bleeding. However, it can be assumed that on average 20 pads or tampons are used per menstrual cycle (see section 3.5If a menstruating person menstruates on average 38 years [8], 13 times each year [9], the total amount of used single-use products per person is an average of 9,880. Given that the lifespan of menstrual cups varies from 1 to 10 years, it is clear that the number of menstrual cups needed is much lower than tampons and pads. Consequently, the environmental impacts related to the production, transportation, and disposal will be lower for the menstrual cup than for tampons and pads.

In order to analyse the environmental impact of menstrual products, it is necessary to assess them from a life-cycle perspective, i.e. to consider all stages from raw material production to waste treatment. The methodology used in this study to evaluate the environmental impacts of menstrual products is a well-known, established, and widely used methodology – 'Life cycle assessment' [10].

There is a lack of literature on the environmental assessment of menstrual products; and essential elements of the life cycle are not considered. This study, commissioned by *einhorn products GmbH*, intends to overcome the lack of available studies, and complete the missing parts of the existing assessments.

A challenging issue regarding the environmental assessment of menstrual products is to model the use phase – it is difficult to know how menstruating people use their chosen products. For example, although it is recommended to wash hands before and after changing a tampon, is it done every time? And how much water and soap does each person use to wash their hands? To tackle this challenge, assumptions must be made, based on existing recommendations to prevent health issues related to TSS or the presence of bacteria. In addition, scenarios and sensitivity analyses are defined to cover different behaviours, and to explore their influence on the environmental performance of each menstrual product.

The disposal of used single-use menstrual products is also relevant. After their use, in most European countries single-use products are disposed of by incineration. Landfill still exists in some countries in Eastern and Southern Europe and Great Britain, although the quantity of menstrual products going into landfills is not clear [11]. The most problematic method of disposal, which has significant negative impacts on the environment, is flushing used menstrual products down the toilet.

The average menstruating person is assumed to dispose of nearly 200 kg of menstrual products in a lifetime [12]. Of this amount, a survey conducted in Great Britain found that half of British menstruating people flush tampons away [13], while altogether 1.5- 2 billion menstrual items are flushed down the toilets each year [14].

Flushed menstrual products impact several areas and are a cause of concern. According to a study by Zero Waste Europe [15], single-use menstrual products are part of the 6.2% of single-use plastic waste collected on British beaches and 5% of floating waste on the Catalan coast of the Mediterranean Sea. When flushed down the toilet, absorbent menstrual products also clog pipes, pumps, and sewers, which further attracts organic pollutants. When they end up in a wastewater treatment plant, they are not completely separated. During the screening process, fibres from the products are released into the environment. During storms, overflow from combined sewage systems is discharged into waterways, which might still contain residual menstrual products. This causes pollution in the receiving water body, such as the sea, causing beach litter as well as marine toxicity, as they are ingested by marine organisms. Moreover, these products also release microplastics into wastewater, which is then passed on to wastewater or sewage sludge and into oceans. Furthermore, management and treatment of menstrual products flushed in toilets, leads to a higher energy use for the wastewater treatment and a higher cost for the public administration.

The reason for used menstrual products being flushed in the toilet is because of either a lack of understanding, shame, or incorrect or absent labelling [15]. For example, a survey conducted by Anglian Water in 2016 revealed that 60% of menstruating people chose to flush tampons rather than dispose of them in a bin; while 41% said they were not aware that tampons were not flushable and could cause environmental harm [13]. Thus, in order to encourage proper disposal of single-use menstrual products, an important first step is education and awareness on the topic and opening up discussions.

2 Literature review

Literature on the life-cycle assessment of menstrual products, though available, is currently sparse. This might partly be due to the lack of available information on product composition from manufacturers. The one published, well-documented study of comparative life-cycle assessment of menstrual products is by Powers and Hait [16]. The study analysed the life cycle impacts of menstrual pads, tampons, and the menstrual cup. While a useful life-cycle inventory of the menstrual products was also documented as part of the study, the single-use menstrual products chosen for the analysis were all of the mainstream conventional type. Alternative options, such as organic pads or tampons, were not considered. In the analysis of the menstrual cup, the boiling of the cup was not included, which forms a significant part of the use phase of the cup as will be seen later in this report. The results of this study show that the menstrual cup is the most environmentally friendly option. Between the pads and tampons, no clear assertion can be made; each of them shows a better performance in three out of six impact categories.

Earlier studies on the LCA of menstrual products provide some useful insights into possible hotspots (processes in the life cycle of products with a relevant contribution to the environmental impacts) along the product life-cycle. A post-graduates thesis by the Royal Institute of Technology Stockholm is a good attempt to capture the life-cycle impacts of a tampon and pad but is limited to a preliminary level, due to the lack of sufficient data needed to cover all phases of the menstrual product life cycle [17]. For example, for tampons, only the impacts of assembly and waste utilization processes were included, and information on transport and production processes was lacking. The study concludes that pads create higher impacts. However, no clear conclusion can be made, because the processes included were not the same for both products.

A study by Weir [18] assessed a variety of menstrual products such as tampons, menstrual cups and sea-sponges, comparing their private costs and assessing their environmental impacts via a life-cycle assessment. In this study, menstrual cups had the best environmental performance. However, it only assessed raw materials and did not consider land use, transportation, assembly at plant, use phase or method of disposal. So it cannot be considered as a true life-cycle assessment study.

Other reports published by independent organizations and companies on the composition, consumption, and waste information of menstrual products also exist. For example, ZeroWaste Europe [15] published a report that attempted to analyse the environmental and economic impacts of single-use menstrual products alongside baby nappies and wet wipes. It covered extensive data on the consumption and waste generation of menstrual products in the European Union.

However, the environmental impacts of the menstrual products were adapted from other studies and scaled up to calculate CO_2 equivalents on a macro level. The report did not make distinctions between different types of menstrual products or consider their environmental implications from a life cycle perspective.

Natracare, an organic menstrual product company, is transparent about the composition and impact of their organic regular pad, and published an environmental product declaration on their website [19].

A common conclusion from the literature reviewed is that the raw materials used in the production of tampons (mainly viscose and cotton) and pads (plastic and wood pulp)are the main contributors to life-cycle impacts. Power and Hait [16] demonstrate that for cups, the use-phase is the most relevant, although other inputs were neglected. In UNEP 's draft report on 'recommendations from life-cycle assessment of menstrual products' (open for review in 2020) [20], the production of materials is recognized as relevant, as well as the behaviour of consumers. This study also identifies that previous studies exclude relevant elements of the life-cycle, mainly the use phase.

3 Goal and Scope

3.1 Purpose

Several menstrual products are currently available in the market. Some, such as tampons and pads are 'disposable' and only used once and some such as menstrual cups are reusable. The question of which of these products present environmental advantages is frequently asked. However, the scarce availability of evidence-based scientific analyses of the environmental effects caused by using these products, complicates a robust answer. To overcome such difficulties and provide clarity to the environmental performance of menstrual products, this study aims to provide the environmental life-cycle impacts of the silicone menstrual cup, and tampons and pads made either of organic cotton or materials like cellulose fibres.

3.2 Project goal and intended application

The goal of the study is to identify which menstrual products, from the selected ones - namely conventional pads, organic pads, conventional tampons, organic tampons, and menstrual cups, are more beneficial from an environmental perspective. This is done by calculating the environmental impacts of these products throughout their life-cycle, according to the structure and requirements of ISO 14040/44 [21].

The results will be disclosed to the public to enable transparency, keeping in line with the fulfilment of the study's motivation. To support a public comparative claim, the norm stipulates a mandatory critical review by independent experts (see section 3.11 critical review).

The intended applications of the results are:

- Enhance evidence-based insight into the environmental performance of menstrual products.
- Communication of the results for education purposes and to enhance transparency.
- Help decision-making in general, beyond consumer purchase decisions.
- Identification of the potential to improve, based on the identification of hotspots along the lifecycle of the assessed products.

3.3 Intended audience

Internally, the *einhorn* team is the intended audience of the study. External audience groups are the users of menstrual products, supply chain partners, competitors, and the general public.

3.4 General description of the studied product systems

The selected menstrual products fulfil the service of retaining menstrual fluid. Different options are available in the market: single-use products like tampons and pads, and reusable ones like the menstrual cup. They are made of different materials and manufactured and used in different ways.

To narrow the analysis in terms of product and packaging composition and materials, specific menstrual products were selected for the assessment, with the intention of being significant for the German market. The characteristics of the selected products need to be similar to ensure comparability of results. The *einhorn* products were selected for the menstrual cup, and organic cotton tampons and pads because of data availability and the intention of the commissioner to know the environmental performance of their products. Additionally, in 2019 *einhorn* was the best- known brand offering organic cotton products in Germany [4]. Tampons and pads made of raw materials other than organic cotton are widely available in the market and are also considered in the study. In this assessment, they are named as 'conventional products'.

An overview of the selected products is presented in Table 1. Detailed material compositions can be found in the life cycle inventory (see section 4.1).

Table 1. Description of the selected products

Product		Specifications	Main materials	Packaging size
Tampon	Conventional (TC)	Regular size: 3 droplets / 9-12 grams	Viscose core, non-woven core cover	56 pc
	Organic (TO)		Organic cotton	16 pc
Pad	Conventional (PC)	• Ultra • Day • Size for standard periods	Cellulose core with a super-absorber	24 pc
	Organic (PO)		Organic cotton	10pc
Menstrual cup (MC)		Average of small and medium sizes – 21.5 mL capacity	Medical grade silicone	1 cup

3.4.1 Tampons

As demonstrated in recent surveys, for more than 50% [3] and up to 76% [4] of menstruating people in Germany, the tampon is the most commonly used menstrual product. This study includes two types of tampons, differentiated by the materials used for their manufacture – conventional tampons and organic cotton tampons.

According to EDANA[1] (Figure 1), tampons are made of an absorbent core enclosed by a plastic nonwoven fabric, that facilitates insertion and removal, and keeps the tampons fibres intact. To allow the removal of the tampon, a withdrawal string is attached to it. The tampon is wrapped in a film made of synthetic polymers to keep it clean before it is used.

EDANA published the Syngina method to measure the absorbency capacity of tampons, which determines the quantity of menstrual fluid absorbed [22]. A scale exists to classify the tampons according to the quantity absorbed, as displayed in Figure 2. The tampons included in this study have an absorption capacity between 9 and 12 grams, shown as 3 droplets. These tampons are generally referred to as 'normal' size tampons. Some tampons are contained in a plastic applicator to facilitate insertion. In this assessment, tampons without applicators are considered, as these are more common in Germany.

All the materials needed to produce tampons arrive at the factory where they are manufactured. First, the string is looped around a rectangular fibre pad (the core). Then the characteristic cylindrical shape of tampons is created by compressing an asymmetrically folded and rolled fibre pad. The compression creates helical grooves and the tampon expands [23]. The tampons are then wrapped in plastic film and packed in cardboard boxes, with a leaflet made of paper containing a product description and instructions for use.

The National Centre for Health Research [24] explains that the presence of dioxins in tampons which originate during the bleaching of fibres used in their production, may be harmful to the human body. Two methods are available for bleaching: elementary chlorine-free (ECF) and totally chlorine-free (TCF). In the first method, chlorine compounds are used, typically chlorine dioxide, while in the second no elemental (molecular) chlorine is used [25]. The number of dioxins present in menstrual products, nor the potential consequences to human health, are not included in the

[1] EDANA: non-woven and related industries association https://www.edana.org/

scope of this study. There is also no discussion of which of the bleaching approaches available to the user is better.

The U.S.A. Food and Drugs Administration (FAD)[2], The United Kingdom National Health Service (NHS)[3], recommend some preventive measures for TSS, that are followed for the modelling in this study, such as:

- Use a tampon with the lowest absorbency suitable for an individual's menstrual flow
- Alternate between tampons and menstrual pads or liners during a period
- Wash hands before and after insertion of a tampon
- Change tampons regularly, usually at least every 4 to 8 hours
- Never have more than one tampon inserted in the vagina at a time
- When using a tampon at night, insert a fresh tampon before sleeping and remove it after waking up
- Remove the tampon at the end of the period

After the tampon is removed, it must be disposed of in the municipal solid waste fraction, and the packaging materials in the corresponding rubbish bin. To avoid dripping menstrual fluid when the tampon is carried to the rubbish bin, and any leakage inside the bin, a used tampon is usually wrapped in toilet paper.

[2] The U.S.A. Food and Drugs Administration (FAD) https://www.fda.gov/

[3] United Kingdom National Health Service https://www.nhs.uk/

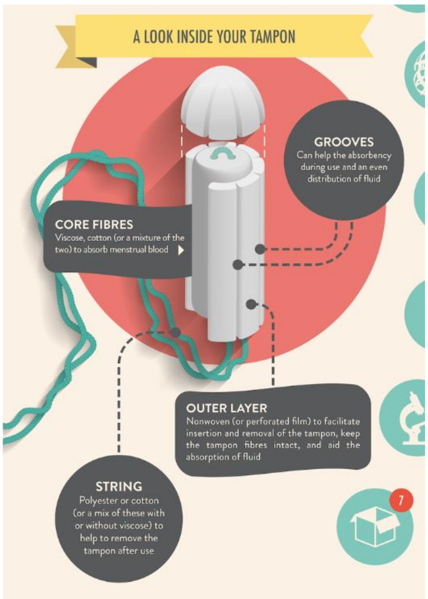

Figure 1. Components of tampons. Source EDANA

DROPLETS	GRAMS
1 DROPLET	< 6
2 DROPLETS	6 – 9
3 DROPLETS	9 – 12
4 DROPLETS	12 – 15
5 DROPLETS	15 – 18
6 DROPLETS	18 – 21

Figure 2. Absorbency scale for tampons. Source EDANA Tampon Code of Practice

Conventional tampons (TC)

Recent surveys found that *o.b.* is the preferred conventional tampon brand in the German market. [3,26]. The normal size tampons, *o.b. ProComfort Normal* tampons, with three drops absorption capacity, sold in a 56 tampons package, were selected for the Öko-Test magazine[4] to carry out several tests to determine whether harmful substances are present in tampons and pads. They consist of a viscose core, a polyethylene/polypropylene nonwoven cover, and a

[4] Öko-Test Magazine publishes he analysis of the performance of end user products and services available in the German market.

polyester string [27]. The outer tampon box is made of at least 79% recycled paperboard and includes an information leaflet. The ink used for printing is 40% vegetable-based [28]. This composition and packaging size is assumed to be the reference for the assessment of conventional tampons.

The starting point for the conventional tampon raw materials is viscose. Viscose, also known as rayon, represents 91% of the tampon's weight. It is a man-made textile derived from the wood pulp of trees such as eucalyptus, beech, pine, bamboo, soy, or sugarcane [29]. The production of viscose fibres usually follows an elaborate chemical process, beginning with bleaching of the wood pulp to turn it into dissolving pulp and to clean any impurities present. This is then treated with a chemical mixture after which it is spun into fibres [30]. These fibres can further be made into threads for weaving or knitting as per their end-use in the textile industry, or in the case of the tampons, to make the absorbent tampon core.

While viscose production is segmented globally, most of the final viscose fibre production in the world takes place in China, accounting for 66% of total viscose production in 2015 followed by Indonesia and India [31].

According to *o.b.* [27], their tampons are elemental chlorine-free bleached (ECF), i.e. no elemental (molecular) chlorine is used in the bleaching sequences [25]; however, chlorine compounds are still used, typically chlorine dioxide.

Organic cotton tampons (TO)

The organic cotton tampons sold by *einhorn* are selected as representative for this category, specifically the *TamTampon normalo*, with three drops absorption capacity. One package of *TamTampon* contains 16 units and is produced in Europe (the exact location is confidential). The tampon's structure is similar to the conventional tampon (see Figure 1). However, the absorbent core of organic tampons is not covered by a protective layer as it is not needed due to the characteristics of cotton fibre.

The absorbent core is made of GOTS[5] certified organic cotton, as well as the tampon string used for removal. *einhorn* tampons are wrapped with a plastic film made of polypropylene. They are sold in a Blue Ange certified[6] cardboard box, made of 100% recycled fibres. A leaflet with the product description and instructions for use is contained in the box. The ink for the box and leaflet is Cradle-to-Cradle certified. The main component of the organic tampon is organically-sourced cotton, which represents almost 97% of the tampon's weight. Farming of organic cotton is carried out in accordance with organic standards and is usually a certified process. This type of farming does not allow the use of chemical pesticides or genetically-modified organisms. Soil fertility is made up of crop rotation, intercropping and compost use [32]. Nearly 51% of the world's organic cotton production is from India, followed by China, Kyrgyzstan, Turkey and Tajikistan [33].

Cotton manufacture starts from the planting of cotton crops, their growth, and harvest which takes approximately 5-6 months. Once the cotton boll is harvested, it is sent to a ginning factory, where the seed of the cotton is separated from the lint. A portion of the seeds is saved for the next cycle of cotton planting [34]. The lint is pressed into bales which is then sent to appropriate processing plants, such as yarn production in the case of the textile industry, as represented in Figure 3. When it comes to *einhorn's* organic cotton tampons, these bales are used to produce the organic tampon cores. Cotton yarn is used for the tampon string.

Additionally, the organic cotton fibres go through a bleaching process to separate potentially hazardous moulds, fungi, bacteria, and other contaminants. A total chlorine-free (TCF) process is used, i.e. completely free of chlorine.

[5] Global Organic Textile Standard https://www.global-standard.org/de/

[6] Blue Angel certification (100% of recycled paper) https://www.blauer-engel.de/en

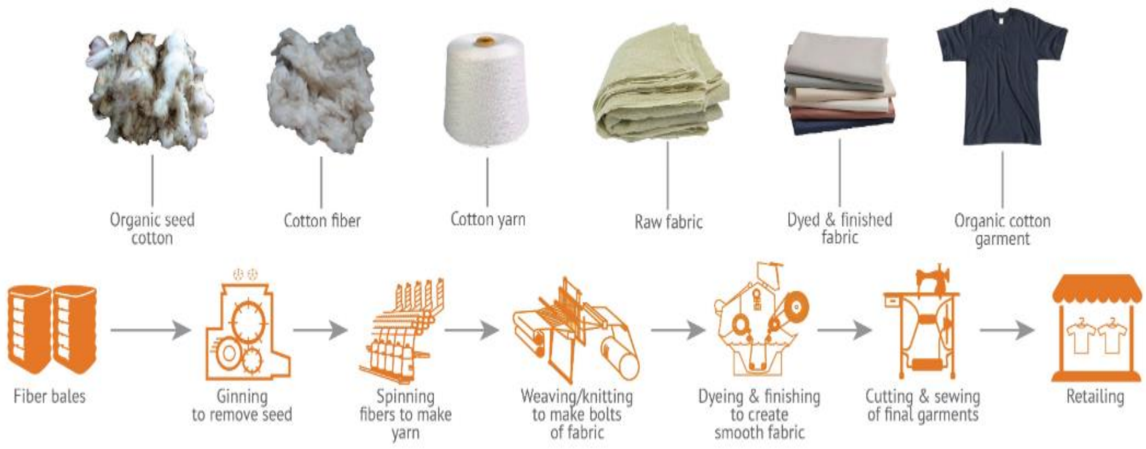

Figure 3. Diagram illustrating the organic cotton production process. For organic cotton tampons, the production process is limited to yarn production. Source: www.aboutorganiccotton.org

3.4.2 Menstrual pads

More than 30% [3] and up to 66% [4] of menstruating people in Germany state that they use menstrual pads. As with tampons, two kinds of pads are studied – conventional pads made of mainly cellulosic materials, synthetic fibres and plastic, and organic cotton pads.

According to EDANA[1] (see Figure 4), pads consist of a top layer that is in contact with the skin and keeps the top side of the pad dry. Underneath there is a distribution layer that draws and directs the fluid to the next layer, the absorbent core, where the menstrual fluid is collected. The core may contain a super-absorbent polymer (SAP) that, as its name says, can absorb a high amount of menstrual fluid. Hence, the amount of material needed for the core is reduced. As a consequence, pads with an SAP are lighter and thinner. To protect underwear from leakage, a back-sheet is located under the absorbent core. The back-sheet surface is covered with glue to stick the pad to the underwear. Before the pad is worn, release paper is attached to the back-sheet to protect the glue from drying. Normally, each pad is folded and packaged in a wrapper to keep it clean.

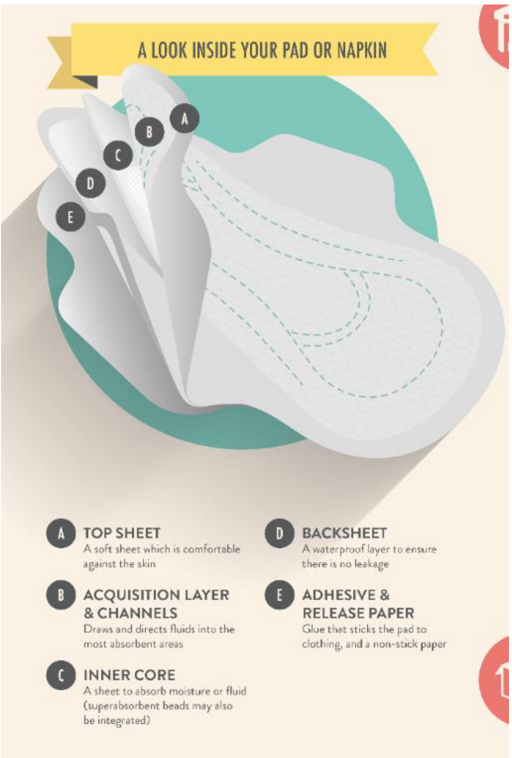

Figure 4. Components of menstrual pads. Source EDANA

A large variety of pad sizes and types is available in the market, e.g. maxi or ultra, day or night, or with or without wings. The difference between a maxi and ultra-pad is that the second is thinner, usually because of the presence of SAP. For example, the maxi pads from the brand *Always* are 10-12 mm thick and the ultra-pads 2-3 mm [35]. The terms *maxi* and *ultra* are widely used in the market by producers and retailers, as well in the Öko-Test[4] article about pads.

A standardized absorbency scale for pads has not been developed to date. However, middle-sized pads are frequently referred to as *normal* and indicated for moderate period flows. Thus, normal-sized pads are considered in the study to enhance comparability with the normal-sized tampons. Additionally, the *einhorn* organic cotton pad is classified as *normal* size, *day*, and *ultra-pad* (although they do not use SAP) with wings. Consequently, the selected conventional pad should have the same characteristics.

The manufacturing of pads is similar to the production of baby nappies with the addition of the last step to attach the silicon paper to the back-sheet [23]. First, the core material is fibreized. After the super-absorbent polymer is added, if necessary, then the pads are formed. Later, they are laminated with film and nonwoven substrates. In the last step, the pads are shaped, cut, folded, and packed for distribution. The top-sheet and core are produced before they arrive at the factory.

Unlike tampons and menstrual cups, which are placed in the vagina, pads are worn outside, on underwear. Hence, there is not an official recommendation about how often a pad must be changed. Based on a previous life-cycle assessment study [16], the selected wearing time is 4 to 8 hours, i.e. the same time as for tampons. Also, it is reasonable to consider that it is not necessary to wash hands before changing a menstrual pad, as they are worn externally. Additionally, it not necessary to touch the top-sheet in contact with the skin.

After the pad is changed, it must be disposed of with the municipal solid waste fraction, covered in the wrapper to avoid leakage. Instead of the wrapper, toilet paper may be used to wrap the pad, at least after removing the last one, when no wrapper is available. The packaging materials can be disposed of in specific fractions, depending on the product.

Conventional pads (PC)

Among the conventional pads' brands available in the German market, *Always* is the preferred [3] and most well-known [4]. The *normal* size *ultra-pads with wings* are selected for this category from a large range of *Always* pads, and their material and packaging composition is used here. The reason is to ensure comparability with the organic cotton pads (also day ultra-pads, normal size, with wings).

The top-sheet of the *Always* pads is made of polyethylene, and the distribution layer of rayon, polyethylene, polypropylene, and polyester [36]. Absorbent cellulose with SAP is the material of the core. The term *absorbent cellulose* is quite general; however, it is assumed that it refers to fluff pulp as it is the most common material for the production of pads [17,23,37]. The materials of the back-sheet are polyethylene and polypropylene. As the type of glue and release paper used in the pad are not specified, they are assumed to be the same as those for the organic pad. The selected pads are generally sold in packages containing 24 units.

The production of fluff pulp is similar to viscose and is a commonly-used raw material in absorbent personal hygiene products (baby nappies, menstrual and incontinence pads) due to its absorbent nature. It is made by a chemical process using long fibre softwoods like pine. To produce fluff pulp, the wood chips undergo a process called 'Kraft process' where they are soaked in a chemical solution and cooked to release the cellulose fibres from the wood. After this, it is mechanically separated from the partially cooked pulp and dirt, also known as screening. Next, the pulp undergoes a washing process to separate the cellulose fibres from the wood chips. The pulp is then bleached and screened once again. Finally, it is dried and then packaged [38].

The bleaching process can be either elementary chlorine-free (ECF, like the conventional tampons) or totally chlorine-free (TCF, like the organic cotton tampons). However, according to *Always*, the pads included in this study are ECF bleached [39]. The dissolving pulp is then treated with a chemical mixture after which it is spun into fibres to produce conventional pads.

To produce sodium polyacrylate for the SAP, initially acrylic acid undergoes neutralization with sodium hydroxide. This is followed by a polymerization process initiated by a small amount of ammonium peroxydisulphate, which finally yields sodium polyacrylate polymer.

Organic cotton pads (PO)

Organic cotton alternatives present a similar layer structure as conventional pads but are partly or mainly made of organic cotton. The *einhorn* organic cotton day ultra-pads, named *Padsy Bonjo*, were selected to represent this category. The *Padsy Bonjo* pads, which are manufactured in Europe (the exact location is not included in the report due to confidentiality), consist of a top-sheet, with direct skin contact and placed over the absorbent core, both made of GOTS[5] certified organic cotton. The back-sheet, with adhesive on it, is located under the core. On the bottom, there is the release paper, made of FSC paper[7] with a silicone coating. The organic pads are sold in 10 unit packages consisting of a bag and a Blue Angel[6] cardboard box. The back-sheet, the wrapper, and the packaging bag are made of biopolymers (based on corn). There are also pads in the market where only the top-sheet is made of organic cotton, while the remaining structure is similar to conventional pads (they are not assessed here).

The supply chain of organic cotton is explained in section 3.4.1 for organic tampons (see Figure 3). However, the fibres used for producing the organic pads are not the same as the ones used for the tampons. The cotton fibre bales resulting from the ginning process are sent to a combing process to improve the quality of the fibres prior to spinning them into yarn. In the combing process the shorter fibres, named noils, are separated from the higher quality longer ones. Thus, the noils are a by-product that is used to produce the top-sheet and core of the organic cotton

[7] Forest Stewardship Council https://www.fsc.org/en

pads. The bleaching process of the organic cotton fibres is the same as for organic cotton tampons and is described in section 3.4.1.

3.4.3 Menstrual cup

A menstrual cup is a reusable product retaining menstrual fluid by collecting it inside the cup. As many menstrual cup brands are available in the market, and the recommendations on how to use them are diverse, the cups' producers analysed in the Öko-Test Magazin[4] are used as a reference in the study. The information given by the selected menstrual cups' producers in their websites or information leaflets was studied and summarized in annex A.

einhorn's menstrual cup (also included in Öko-Test[4]), *Papperlacup*, is selected for this product group (see Figure 5). It is made of medical-grade silicone, as are 13 out of 15 of the cups analysed in the Öko-Test. The *Papperlacup* is manufactured in Germany, as well as the liquid silicone rubber (LSR) it is made of. Alternative materials are natural rubber or thermoplastic elastomer (TPE); however, silicone is mainly used. A weighted average of both existing cups' sizes (small and medium) is considered for the study. This means the average capacity of one menstrual cup is 21.5 ml. *Papperlacup* is available in pink and yellow colour.

The packaging of the *einhorn* cup consists of an organic cotton bag inside a Blue Angel certified[6] cardboard box. The box has a transparent window made of cellulose fibre. A leaflet containing a product description and use instructions, and stickers are also included in the box.

Figure 5. Papperlacup. Source einhorn

Menstrual cups made of liquid LSR are manufactured by means of injection moulding, which enables the moulding of the silicone into a distinctive cup shape. The use of LSR in medical applications is justified by the fact that it is highly biocompatible and durable, enabling it to withstand long-term contact with human body parts [40]. In technical terms, LSR refers to a two-component compound that is cured with a platinum-catalysed reaction. LSRs are usually processed by an injection moulding process where a pump mixes component A, the platinum catalyst, and component B, containing a cross-linker and inhibitor, into a multi-cavity heated mould to form the final part [41] (see Figure 6).

The cross-linker contains silicone-hydrogen groups, that react with the vinyl groups of the polymer to form the silicone rubber. The advantages of liquid silicone rubber are that the production cycles are short as well as the fact that the curing of the rubber occurs in the mould, with no post-curing required [42].

In the menstrual cup production process, the two components, A and B, are transported in separate drums to the injection moulding site, where following the optimum process conditions, LSR is injected into the menstrual cup shape. Metered equipment is used to add pigment to the LSR during the moulding process, which imparts colour to the menstrual cup.

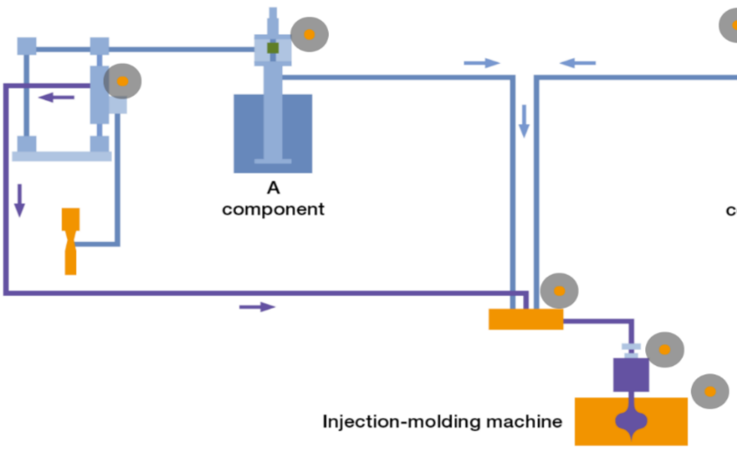

Figure 6. Schematic diagram representing the liquid silicone rubber injection moulding process. Source: Wacker Chemie AG

The distribution of menstrual cups differs from the other products. The finished cup is sent by courier to Berlin, where it is packed and then distributed to the retailers.

Before using the menstrual cup for the first time, it must be boiled to sterilize it and remove any volatile silicones that might be present. The boiling time recommended by different brands varies greatly, from 3 to 20 minutes. It is then inserted in the vagina, where it collects menstrual fluid. After a few hours, or when necessary, it is removed by squeezing the base of the cup to release the seal and gently pulling, and the retained fluid is poured into the toilet. The wearing time prescribed by producers varies from 6 to 12 hours, although most of them indicate that it is safe to wear it for up to 12 hours. After, the cup is cleaned, usually with water and soap. Menstrual cup brands often recommend suitable soaps on their websites. Alternatives for cleaning the cup in public toilets exist, such as using wet wipes, or carrying a bottle with water to rinse the cup, or to carry a second cup until it is possible to wash the first one with soap. Producers recommend washing hands with water and soap before and after changing the cup.

When a menstrual period is finished, and before the cup is stored, it must be sterilized to kill the bacteria that may be present on the surface. It is usually recommended to place it in a pan of boiling water for 5 to 10 minutes. Some brands also recommend doing it in a microwave; however, this is not contemplated in this study since it is not common.

einhorn supported a study to determine the adequate cleaning and sterilizing procedures during the use of the cup, based on the presence of bacteria. The results demonstrated that cleaning the cup with soap and water every time it is changed during the period, is enough to use it safely [65]. This supports what most brands already communicate in their leaflets (see Appendix A – Analysis of the recommendation of menstrual cup producers). Additionally, an alternative sterilization procedure was tested – the cup was placed in a container and boiling water was poured over it and the container was left covered with a plate for 5 minutes, instead of using a cooker. The results of the laboratory test show that this method ensures adequate sterilization of the menstrual cup. This method needs less energy and water compared to boiling on the cooker.

One of the menstrual cup producers analysed in Annex A is Dr. Wolff/Safe Cup[8], which recommends sterilizing the cup every time it is changed, either in the microwave (using a special container) or in a pan on the cooker. Hence, the frequency of sterilization of the cup would be much higher.

The lifetime of a menstrual cup is not clearly defined. Many producers claim that a cup can be used for up to 10 years. Other brands recommend changing it every 1 or 2 years, and some of them do not specify the life span.

[8] Dr. Wolff/Safe Cup https://www.vagisan.com/de-de/safecup

3.5 Functional unit and reference flow

3.5.1 Functional unit

The functional unit is defined as the collection of the amount of menstrual fluid that is expelled by an average menstruating person over a period of one year, following the frequency of change recommended by producers.

The results of this study refer to the functional unit, i.e. to the use of menstrual products for one year. This definition of the functional unit is based on the theoretical behaviour of menstrual products' users, which is based on recommendations. The basis of such recommendations is the safe use of the products regarding the health of menstruating people. As introduced in section 3.4.2, no recommendation exists for the wearing time of the menstrual pad; however, a wearing time of 6 hours is considered normal.

A technical parameter that could be used to define the frequency of change of the products is their absorption capacity – 3 droplets for the tampons and 21.5 ml for the cup. In the case of the menstrual pad, it is not defined (see section 3.4.2). Nevertheless, it is difficult to determine the amount of expelled menstrual fluid as it varies for each person's menstrual cycle. Additionally, the cycles over a year vary, and therefore the amount of bleeding in one month cannot be extrapolated to the whole year. Moreover, the user's decision to change a product is influenced by many factors, e.g. the feeling that they might be saturated with blood, or that access to a toilet or more menstrual products is not possible in the following time. All these factors make prediction a challenge.

Furthermore, according to the blood retention capacity defined for cups and tampons, and taking into consideration the average volume of expelled menstrual fluid, the wearing time would be higher than the recommended time. An example of the menstrual cup is explained here.

A study of menstruation flow assessment [43] found that the quantity of bleeding ranges from 36.5 to 72.5 ml – with an average of 54.5 ml. The participants also reported heavier bleeding during the first two days and lower the last two days of their periods; however, the quantity during those times was not mentioned. Assuming that 80% of the menstrual flow is expelled during the first three days (43.6 ml), a maximum of 14.53 ml would need to be collected each of the first three days, and 5.45 ml each of the last two days. The cup can collect up to 21.5 ml, which means that it would be possible to wear it for 24 hours. According to the recommendations of producers, a cup should not be worn longer than 12 hours because of possible risk for TSS.

Hence, it is reasonable to include the recommended time for use in the definition of the functional unit.

3.5.2 Reference flow

The number of products needed to fulfil the functional unit is called the 'reference flow'. Two aspects must be considered to define it – the frequency and duration of the menstrual period, and

how often the product is changed. Both can vary depending on the menstruating person. Average values are taken for this analysis. The average number of menstrual periods per year is 13, each lasting 3 to 7 days [9]. Thus, the average is 5 days. In this analysis 65 days of menstruation per year are considered, which can be translated into 260 units of tampons or pads that are needed to fulfil the functional unit.

To define the number of menstrual cups needed to complete the functional unit, the lifetime of the cup also needs to be considered. Although there is a clear difficulty to define the life span (as explained in section 3.4.3), 5 years is considered a good compromise based on the available information. Thus, 1/5 of the cup is needed to fulfil the functional unit. The wearing time of the menstrual cup is calculated as a weighted average based on the producers' recommendations (see Appendix A- 1).

Table 2 gives an overview of the reference flows and the inputs during the use phase. Hand washing is only included before changing the menstrual products because it is considered that hands must be washed anyway after using the toilet and it would be the same for all product systems. Thus, no inputs are needed during the use phase of the pad.

Table 2. Reference flows and use phase inputs' overview

Product		Change frequency (h)	Reference flow	Use phase	
				Input	Frequency
Tampon	TC) conventional	6	260 tampons	Hand washing (water & soap)[1]	260
	TO) organic			Toilet paper for disposal[1]	260
Day pad	PC) conventional	6	260 pads	Toilet paper for disposal[2]	13
	PO) organic				
The menstrual cup, 5 years lifetime		10.6	1/5 of a cup	Hand washing (water & soap)[1]	148
				Cup washing (water & soap)[1]	148
				Cup sterilization (water & energy)[3]	13

[1] Every time the menstrual product is changed
[2] After using the last pad
[3] Between periods

Two main procedures were defined in section 3.4.3 for the sterilization of the cup – boiling the cup on the cooker or placing it in a container with boiling water. To cover both possibilities two scenarios are defined:

- Cooker scenario: the cup is sterilized on the cooker.
- Kettle scenario: the cup is sterilized in a container with boiling water. The water is boiled in a kettle, based on study findings [65].

Table 3 shows the characteristics of the defined scenarios for the menstrual cup. The boiling time for the cooker scenario is calculated as a weighted average based on the producers' recommendations (Appendix A- 2).

Table 3. Overview of the scenarios for the menstrual cup use

Parameter		Description	
		Cooker scenario	Kettle scenario
Sterilization	Frequency	Between periods	Between periods
	Method	On the cooker, boiling the cup without a lid on the pan	Pouring boiling water, boiled in a kettle
	Boiling time	5.25 minutes	N/A

The amount of inputs needed during the use phase, e.g. the amount of water and soap for washing hands, is given in the life cycle inventory (see sections 4.6.3 and 4.6.4).

Therefore, with the inclusion of these two different scenarios for the menstrual cup, six different cases in total will be evaluated in this report as a baseline: conventional tampon, organic tampon, conventional pad, organic pad, menstrual cup with cooker scenario, and menstrual cup with kettle scenario.

3.6 System boundaries

The system boundaries define the life-cycle stages, processes, and flows considered in the product system providing the system function. All life cycle stages, from "cradle to grave" are included and represented in

Figure 7 – raw materials production, product manufacture, distribution, use, and end of life.

The components needed to manufacture the menstrual products (semi-finished products) are included in the product systems by means of materials production, i.e. all processes from raw materials extraction, through processing until the produced materials are transported to the manufacturing site of menstrual products. This includes not only the materials for the menstrual product itself but also for the primary packaging – primary packaging comprises the products' packaging as it is presented in the shop.

The manufacturing of cups, tampons, and pads considers the production at the plant, including energy and water consumption, auxiliary materials, and waste.

The transport from the production site to retailers, including secondary packaging (used to pack several pieces of primary packaging during transport and storage) is counted in distribution. The transport needed for purchasing a menstrual product is included in the shopping trip.

The use phase of menstrual products is representative of Germany. The water and soap needed to wash hands before the menstrual product use, as well as to clean the menstrual cup are also included. Additionally, the water and energy to sterilize the cup are taken into consideration. For the disposal of tampons and pads, toilet paper is included.

The waste to be disposed of comprises the menstrual products and the primary packaging after their lifetime, including the collection and transport to the treatment facilities as well as waste treatment.

Infrastructure (e.g. the supermarket where products are sold, or machines used during production) is only considered when it is included in the background data from the Ecoinvent 3.6 database. The foreground data, presented in the life cycle inventory, excludes the infrastructure.

3.6.1 Cut-off criteria

Processes may be excluded from the system boundaries if they are the same for all products or according to the following cut-off criteria defined in ISO 14044:2006 [44]

- Mass. Mass inputs contributing less than 1% to the inputs of a product system are negligible.
- Energy. Energy inputs contributing less than 1% to the inputs of a product system are negligible.
- Environmental significance. Inputs contributing less than 1% to the results (to all impact categories) are negligible.

Accordingly, the following processes are excluded from the system boundaries:

- Toilet paper use, flushing the toilet, and washing hands after the menstrual product is exchanged. These are equivalent to all products.
- Cellulose fibre window in the menstrual cup packaging, and the stickers delivered with the menstrual cup. Their contribution to the weight of the packed menstrual cup is under 1%.

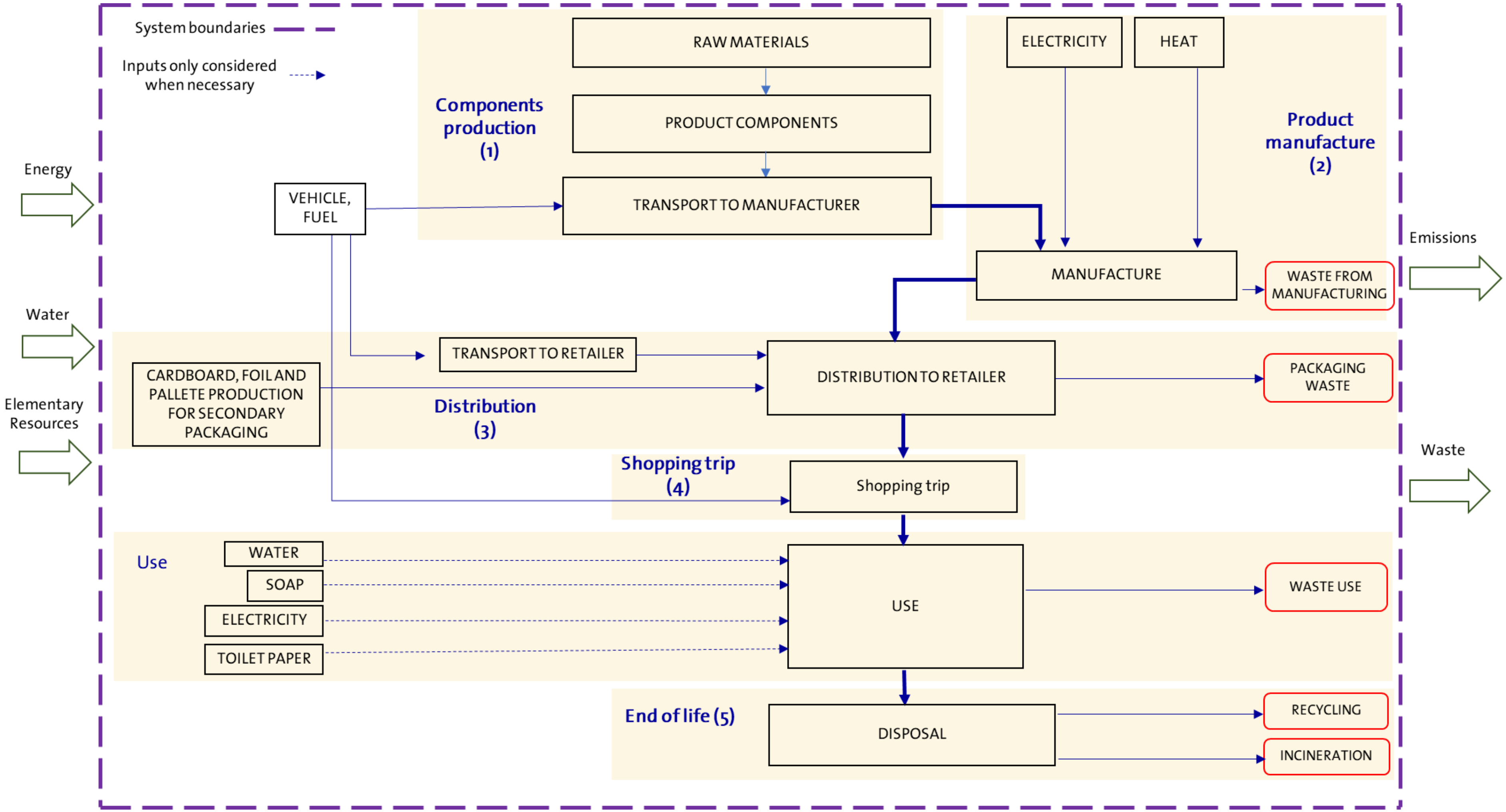

Figure 7. System boundaries

- The ink used for printed packaging and leaflets. The weight of ink compared to the weight of packaging and leaflets and the product system, is lower than 1%.
- Semi-finished products' packaging. The components of the menstrual products are delivered with packaging; however, the amount of packaging corresponding to a menstrual product is very low. This means the contribution to the impacts (for each impact category) is < 1%.
- Water for manufacturing. The data provided for water consumed during manufacturing includes both the amount needed for the products, and also for other purposes like the kitchen or the toilet. Its influence on the results was tested and identified as very low for all impact categories (<1%). Considering that the amount of water needed only for the menstrual products is even lower, it has been excluded.
- Auxiliaries for manufacturing: lubricants and solvents. Data are not available for all products. Further, the amounts are very low, and their contribution to the results lower than 1%. Since it is expected that the amount used is similar for all products, they have not been considered.

3.7 Data quality requirements

The quality requirements of the data are specified and address all aspects established in ISO 14044:2016 [44].

- Time-related coverage. The reference year for the study is 2019. Accordingly, the data used would ideally refer to that year. Primary data refers to 2019, while literature data may be from the previous year but not older than 10 years. Data from 2007-08 for determining the amount of some of the components of the conventional pad (detailed explanation in section4.1.1), were applied.
- Geographical coverage. Data used around the production of raw materials represents the market supply. This either uses global market processes provided by Ecoinvent 3.6, or by selecting a geographical area that best represents the global market. Data for the manufacturing processes represent the European market for the conventional products; the German market for the menstrual cup; and the corresponding markets to the manufacturing sites of the organic products. Since the use of the menstrual products is assessed for Germany, use-phase, and end of life data represent the German market.
- Technology coverage. Data used in the foreground system represents the status quo of menstrual processes' manufacture, distribution to retailers, mobility for the shopping trip,

the technologies available for using menstrual products (cooker and kettle for sterilization, or soap and tap water for washing hands), and end-of-life treatment options. In the background system, the Ecoinvent 3.6 database refers to the status quo.

- Precision. Regarding the precision of the used data, the variability of the modelled values with a relevant influence on the results is analysed performing numerous sensitivity analyses.
- Completeness. The collected data and its application in the model are thoroughly explained in the life-cycle inventory, which is a result of an iterative process to ensure completeness. All relevant processes are considered in the product system, and input and output data are available.
- Representativeness. The selected products are representative of the German market of menstrual products.
- Consistency. The methodology to assess the menstrual products is uniformly applied to them all, which is a crucial aspect to ensure the comparability of the products. For the assumptions made and uncertainties which occurred, sensitivity analyses were performed.
- Reproducibility. The methodology and data used are documented thoroughly in this report, to allow the reproduction of the results by any independent researcher.
- Sources of the data. Table 4 provides an overview of the data sources for modelling of the foreground system, while for the background system Ecoinvent 3.6 cut-off system model is used. This system model is suitable for the study because there is no complex recycling activity in the product system that requires being tackled.

Table 4. Overview of the used data

Life cycle stage	Menstrual product				
	MC	TC	TO	PC	PO
Bill of materials	Primary data	Specific data from own measurements	Primary data	Specific data from own measurements	Primary data
Manufacture	Primary data	Primary data	Primary data	Secondary data	Primary data
Distribution and shopping trip	Secondary data	Secondary data	Secondary data	Secondary data	Secondary data
Use	Secondary data	Secondary data	Secondary data	Secondary data	Secondary data
End of life	Secondary data	Secondary data	Secondary data	Secondary data	Secondary data

- Uncertainty. The occurred uncertainties may be originated by (i) methodological and modelling decisions such as allocation (see section 4.2.2) or background datasets, or (ii) applied data. All these aspects are examined in the sensitivity analysis.

3.8 Allocation procedure

The method adopted with multifunctional processes in this study is to avoid allocation, whenever possible, as recommended in the ISO 14044:2006 [44], by applying system expansion or subdividing the multifunctional unit processes under study.

If the allocation procedure cannot be avoided, the criteria recommended in the ISO standard applies for this assessment: physical allocation in the first place followed by economic allocation.

In the foreground system, the production of organic cotton fibres for the organic pad manufacture requires allocation of the combing process, which is not included in Ecoinvent 3.6. Economic allocation is selected for the modelling of the combing process, as it represents better the value of the by-product noils than the mass allocation. A detailed explanation of the allocation procedure is described in section 4.2.2. Further, a sensitivity analysis of the allocation procedure is included in section 6.2.

In the background system, the allocation procedures carried out by Ecoinvent 3.6 apply, i.e. economic allocation is always applied.

3.9 Calculation

Calculations are conducted in the life-cycle assessment software openLCA version 1.10.3.

3.9.1 Life-cycle impact assessment

The impact assessment method 2.0 from the European Commission[9] is used in this study, which includes the impact categories (named also categories interchangeably) presented in Table 5.

The climate change categories – biogenic, fossil, land-use and transformation are condensed for the assessment in the category of climate change. This is done to avoid the use of too many impact categories. A detailed description of the impact categories is provided in Appendix B – Definition of the impact categories included in the EF method.

[9] https://eplca.jrc.ec.europa.eu//EnvironmentalFootprint.html

The impact categories *'cancer and non-cancer human health effects'* are only environmental indicators. They measure the impact on human health from flows released into the environment (air, water, soil) e.g. from an agricultural process. The results of these categories are not related to the consequences of using different menstrual products for the human body.

Table 5. Impact categories included in the EF 2.0 impact assessment method

Impact category	Unit
Land use	Pt
Water scarcity	m3 depriv.
Resource use, mineral and metals	kg Sb eq
Resource use, energy carriers	MJ
Climate change	kg CO2 eq
Climate change - biogenic	kg CO2 eq
Climate change - fossil	kg CO2 eq
Climate change - land use and transformation	kg CO2 eq
Eutrophication terrestrial	mol N eq
Eutrophication marine	kg N eq
Eutrophication freshwater	kg P eq
Acidification terrestrial and freshwater	mol H+ eq
Ecotoxicity freshwater	CTUe
Cancer human health effects	CTUh
Non-cancer human health effects	CTUh
Ionizing radiation, HH	kBq U-235 eq
Photochemical ozone formation, HH	kg NMVOC eq
Respiratory inorganics	disease inc.
Ozone depletion	kg CFC11 eq

3.9.2 Data quality assessment

The data quality is analysed for the foreground as well as background systems. This assessment is based on the Ecoinvent pedigree matrix and using the Ciroth_Muller_Weidema_Lesage data quality system [45], available in openLCA. The quality is assessed over five indicators namely reliability of the data, completeness of the data, its temporal correlation, geographical correlation, and further technological correlation. The scale used for the measurement is numerical, with 1 denoting the best quality and 5 denoting the worst quality. A detailed description of the scale for each category is explained in Appendix C – Definition of the indicators to assess data quality.

The data quality of the foreground system (see

Figure 7) is calculated for processes the most relevant in the product system, i.e. the quality of the most relevant data presented in the inventory is assessed.

Also, the data quality of the background data from ecoinvent 3.6 is assessed with the quality entry provided in the database, except for the temporal correlation score. The value for this indicator is adapted to the scope of the study, i.e. to the year 2019. The results are calculated with a weighted average, i.e. the data quality is influenced by the relevance of a process.

3.10 Interpretation

In the interpretation phase, the environmental performance of the products selected is compared, and hotspots are identified. Also, significant issues are analysed by performing a contribution analysis. As recommended in the ISO 14044:2006 [44], the following techniques are included in the study to establish and enhance confidence and reliability of the results of the LCA:

- Completeness check: Ensuring that all relevant information and data needed for the interpretation are available and complete.
- Consistency check: Ensuring that the assumptions, methods, and data are consistent with the goal and scope.
- Sensitivity check: Assessing how changes in data and methodological choices affect the reliability of the final results and conclusion.

3.11 Critical review

As introduced in section 3.23.2, the critical review, performed by a panel of independent experts, is required when publishing a comparative LCA. The review is conducted in parallel with the study. The members of the panel are introduced here and presented in detail in the critical review report in section 10.

- Dr. -Ing. Alexandra Pehlken leads the *Steinbeis Transferzentrum Ressource* (Germany) in the field of Resource Efficiency.
- Ran Liu, from *Öko-Institut e.V* (Germany), is a Senior Researcher for sustainable products and material flows.
- Annemarie Harant is a founder and CEO of the *erdbeerwoche GmbH* (Austria) and an expert in menstrual products and menstrual topics.

These three members cover the key topics of this study – life cycle assessment, research, and menstruation and menstrual products.

4 Life-cycle inventory

This study attempts to use the most current and relevant life-cycle inventory (LCI) data for the modelling of the product systems. The background system, shown in

Figure 7 is modelled almost completely using Ecoinvent 3.6. Selected datasets as well as modified background processes are explained in this section. Primary data is preferred for the foreground system, though is not available for all processes. These cases are identified and explained in the LCI.

The inventory is organized according to the life-cycle stages of components production, manufacturing, distribution, shopping trip, use, and end of life. The processes included in each stage are displayed in

Figure 7.

Geographical codes are used to explain the datasets selected for modelling the product systems, as explained in Table 6.

Table 6. Geographical codes used in the inventory

Code	GLO	CN	IN	EUR	DE	CH
Region	Global	China	India	Europe	Germany	Switzerland

4.1 Breakdown of materials in menstrual products

The breakdown of materials in each product is presented in the following tables. Weight values are referred to as one item.

4.1.1 Conventional products

Data for the conventional products were obtained by dismantling and weighting the components of the *o·b· ProComfort Normal* tampons, with three drops absorption capacity, and the *Always normal size ultra-pads with wings*.

The material input needed to produce the tampons' components is displayed in Figure 8, and the amount per item in Table 7.

Figure 9 shows the inputs needed to produce the components of conventional pads, and Table 8 the amounts contained in each item. By using the weighing procedure, it is not possible to determine the amount of SAP and adhesive in the conventional pad. According to [46], 5.65% and 6.94% are the ratios of SAP and adhesive in conventional pads and are used in this study. The materials of the release paper and the adhesive are unknown for the conventional pads and assumed to be the same as the organic pads.

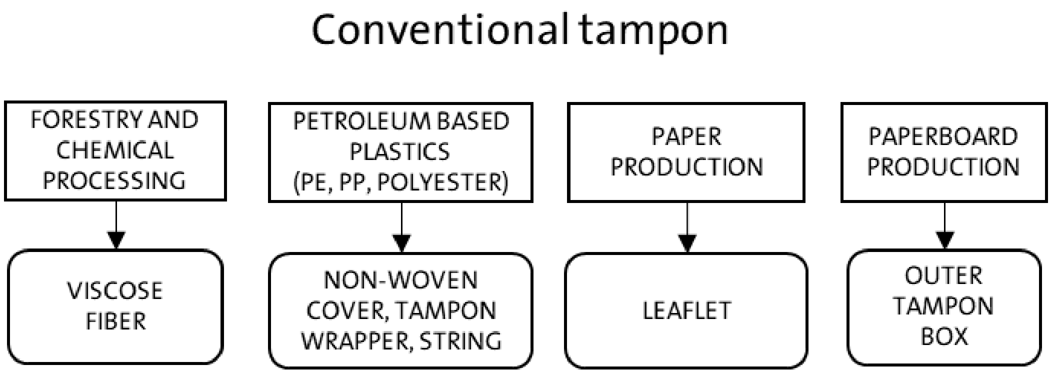

Figure 8. Material input to produce the components of the conventional tampon

Table 7. Composition of conventional tampon

Conventional tampon – weight values referred to 1 item			
Component	Material	Weight [g]	Composition [%]
Core	Viscose	2.34	81.10
Core cover	Nonwoven, PE and PP	0.10	3.47
String	Polyester	0.08	2.77
	TOTAL	2.52	-
Wrapper	PE	0.06	2.08
	TOTAL	2.58	-
Leaflet	Paper	0.03	1.11
Box	Cardboard at least 79% recycled	0.27	9.47
	TOTAL	2.88	-

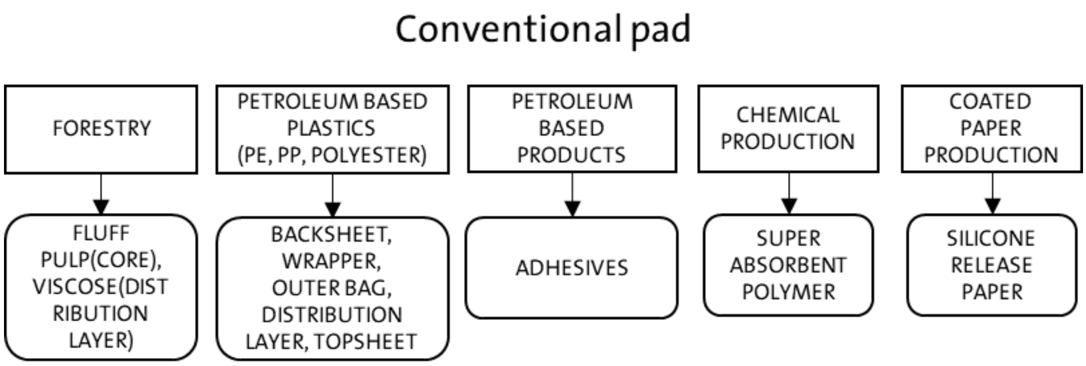

Figure 9. Material input to produce the components of the conventional pad

Table 8. Composition of the conventional pad

Conventional pad – weight values referred to 1 item			
Component	Material	Weight [g]	Composition [%]
Top-sheet	PE	0.8	15.97
Distribution layer	Rayon, PE, PP, and polyester	0.9	17.97
Core	Sulfate pulp	1.55	30.98
SAP	Sodium polyacrylate	0.25	4.96
Back-sheet	PE and PP	0.39	7.88
Adhesive	Epoxy structural adhesive	0.31	6.09
Release paper	Silicone paper	0.2	3.99
	TOTAL	4.4	-
Wrapper	LDPE	0.5	10.0
	TOTAL	4.9	-
Plastic bag	LDPE	0.10	2.16
	TOTAL	5	-

4.1.2 Organic products

Data for the composition of the organic cotton tampons and pads was calculated by subtracting manufacturing waste from the materials input, both provided by the producers (primary data). The weight of packaging was measured. The weight of the adhesive in the organic pad is omitted due to confidentiality to the manufacturer so included in the back-sheet weight.

The materials used for the production of the components of the organic tampons is displayed in Figure 10, and the quantity of the materials per item in Table 9. For the organic pad, the materials used and the corresponding amounts per unit are presented in Figure 11 and Table 10, respectively.

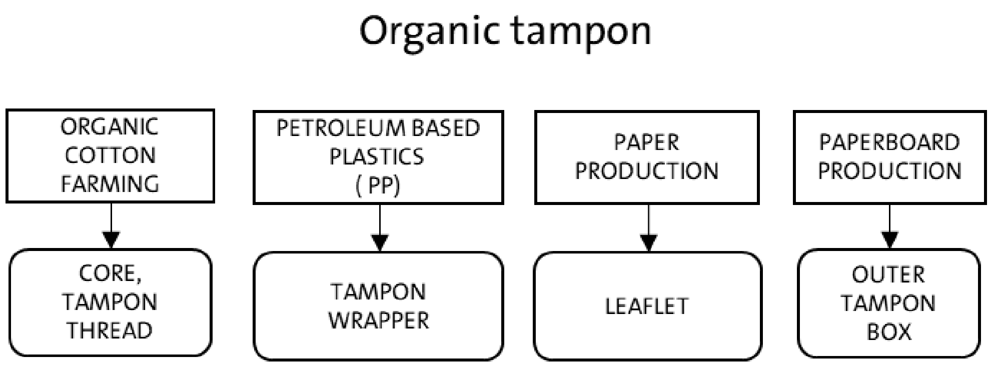

Figure 10. Material input to produce the components of the organic tampon

Table 9. Composition of organic tampons

Organic tampon – weight values referred to 1 item			
Component	Material	Weight [g]	Composition [%]
Core	Organic cotton	2.79	75.55
String	Organic cotton	0.09	2.35
	TOTAL	2.89	-
Wrapper	PP	0.09	2.54
	TOTAL	2.98	-
Leaflet	Paper	0.09	2.43
Box	Cardboard 100 % recycled	0.63	17.12
	TOTAL	3.71	-

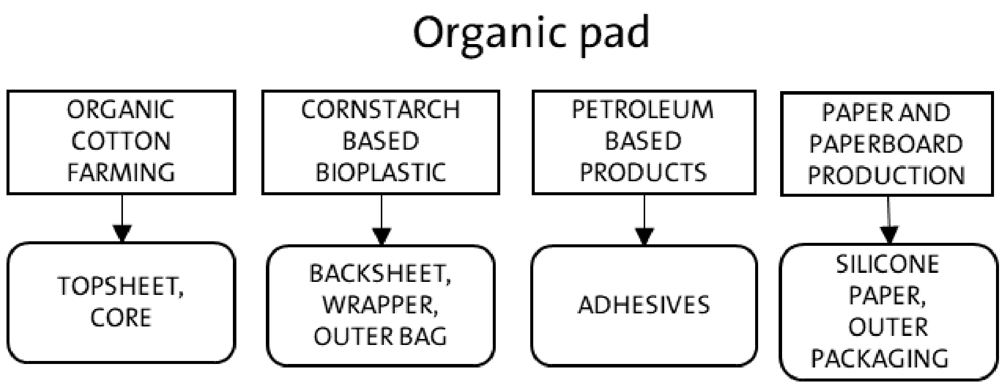

Figure 11. Material input to produce the components of the organic pad

Table 10. Composition of the organic pads

Organic pad – weight values referred to 1 item			
Component	Material	Weight [g]	Composition [%]
Top-sheet	Organic cotton	1.21	13.28
Core	Organic cotton	3.22	35.34
Back-sheet with adhesive	Materbì bioplastic	1.55	16.97
Release paper	Silicone paper	0.47	5.20
	TOTAL	6.45	-
Wrapper	Materbì bioplastic	1.35	14.83
	TOTAL	7.80	-
Bag	Materbì bioplastic	0.3	3.29
Box	Blue Angel cardboard	1.01	11.09
	TOTAL	9.11	-

4.1.3 Menstrual cup

Figure 12 shows the materials used to produce menstrual cups, and

Table 11 gives an overview of the menstrual cup composition and the packaging, based on primary data.

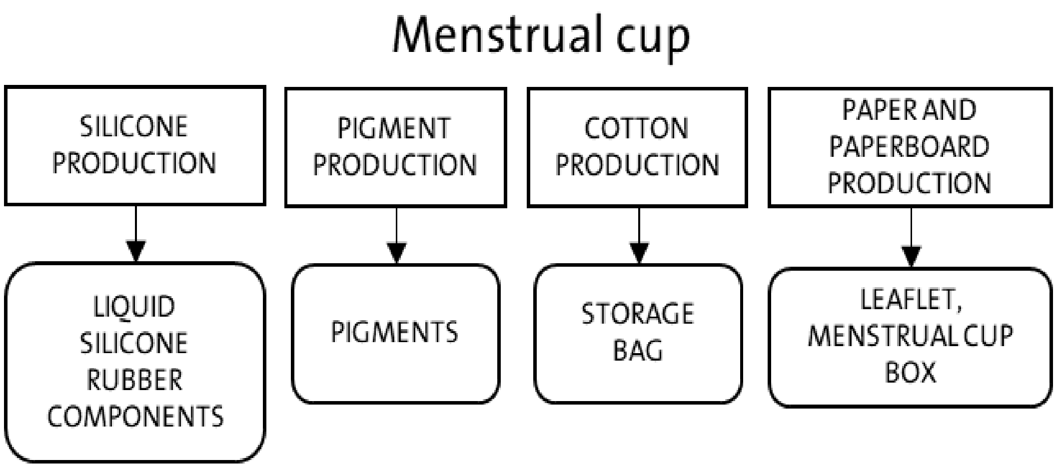

Figure 12. Material input to produce the components of the menstrual cup

Table 11. Composition of the menstrual cup

Menstrual cup – weight values referred to 1 item			
Component	Material	Weight [g]	Composition [%]
Cup	Silicone	11.16	20.61%
Pigment	Pigment dispersion, unspecified	0.210	0.39%
	TOTAL	11.37	-
Box	Blue Angel cardboard	32.88	60.71%
Label	PE	0.13	0.24%
Leaflet	Paper	2.33	4.30%
Bag	Organic cotton	7.45	13.76%
	TOTAL	54.16	-

4.2 Production of components

The materials needed to produce the components of menstrual products are described in this section. Due to confidentiality, the weight of organic cotton noils is not disclosed; however, the selected datasets are indicated, and the transport to the manufacturing site.

Unless otherwise indicated, the datasets are from Ecoinvent 3.6. The modelled quantity of materials includes the waste generated during the posterior manufacturing stage (waste percentages are collected in Appendix D- 6).

Table 12 shows the amount of material per functional unit and the selected datasets for modeming the core materials, and the transport. The same information for the remaining components, including packaging, is described in Appendix D – Life cycle inventory. In the following sections, the main aspects of the components' production modeming are explained.

Table 12. Inventory of the core materials per FU with losses

Product	Core material	Amount/FU(kg)	Dataset	Transport
TC	Viscose	6.47E-01	Production of viscose fibre, GLO	Assumed the same as fluff pulp
PC	Fluff pulp	4.19E-01	Bleached sulfate pulp, GLO	Included in the dataset
	SAP	8.41E-02	See Table 13	1,000 km (within Europe)
TO	Organic cotton fibre	7.85E-01	Organic cotton fibre production from ginning, IN	Assumed to be the same as in the Ecoinvent process "market for fibre, cotton, organic"
PO	Organic cotton noils	Confidential	See Table 14	
MC	Liquid silicone rubber, medical-grade	2.43E-03	silicone product production, EUR	Primary data

4.2.1 Conventional products

The modeming of the components for the conventional products is based on the compositions presented in Table 7 and Table 8 and displayed in Appendix D- 1 for the conventional tampons and in Appendix D-3 for the conventional pads. As the region where they are produced is unknown, global processes are selected in the first place; otherwise, Europe is chosen. The transport distances are modelled in the background dataset. If they are not included, a transportation distance of 1,000 km within Europe is considered [47]. The influence of choosing other locations for the production of the core materials is discussed in the sensitivity analysis in section 6.2.3.

If the available datasets do not fully match the components' materials, a similar one is selected. This is the case of the core cover of the conventional tampons; the nonwoven polyethylene is modelled as polyethylene film. The recycling content of the printed box in the dataset is similar to the minimum content given by *o·b·* Hence, the dataset is considered valid and not modified. Further, the dataset used for the adhesive production *(market for adhesives, for metal,* *EUR*) refers to the adhesive used for metals which has an epoxy resin base, similar to the adhesive used in the pads. The results will confirm that epoxy is the most important element of the adhesive. Hence, the database selection is justified.

For the modelling of the conventional pad core, the process for bleached sulphate pulp is selected for fluff pulp production. This was chosen because the production process is similar. The major difference between chemical pulp and fluff pulp is at the final stage of drying. Most of the chemical pulp is known as 'market pulp' which is dried to around 10% of moisture content and delivered in sheeted bales. They are commonly used in paper and tissue paper production. On the other hand, fluff is dried to only about 6-10% moisture content and is shipped on rolls. In either case, the production processes involved in the manufacture of fluff pulp and market pulp is almost identical, with the difference occurring in the last part of the drying process [38]. The description of the process in the Ecoinvent 3.6 database named 'sulfate pulp production, from softwood, bleached' is similar to the one stated above and is therefore used in this study to model the absorbent core of the conventional pad.

Regarding SAP production for the conventional pad, the process inventory for polymerization of acrylic acid was obtained from the literature [48] and shown in Table 13.

Table 13. Inventory for the production of 1kg SAP

Production of 1kg of SAP, based on literature data [23]			
Input	Amount	Unit	Dataset
Acrylic acid	0.782	kg	market for acrylic acid production, EUR
Sodium hydroxide	0.468	kg	market for sodium hydroxide production, GLO
Electricity	7.83	MJ	market group for electricity production, GLO
Water	1.753	kg	market for tap water, GLO

4.2.2 Organic products

In the case of the *einhorn* products, the quantity of raw materials needed is provided by the manufacturers, as well as transportation distances. The detailed LCI of the TO is shown in Appendix D- 2 and of the PO in Appendix D- 4.

The organic cotton needed for the pads and the tampons is assumed to be produced in India, the origin of more than half of the world 's organic cotton production [1]. The available data in Ecoinvent 3.6 for organic cotton harvesting is from an organic farm in Orissa state in India.

Organic cotton modelling: emissions of heavy metals

The emissions that are modelled in the dataset for the harvesting of organic cotton include the uptake of heavy metals by the organic cotton plant during harvesting. This absorption is in some cases higher than the heavy metals emissions in the soil, which results in a positive impact on the environment of cotton harvesting. It could also mean that organic cotton and therefore the organic menstrual product contain heavy metals. However, this can be discarded because the organic products are GOTS certified[5], which ensures that they are free of heavy metals.

As is specified in the Ecoinvent LCI calculation tool for crop production [49], the LCA practitioner can decide if those heavy metal flows are included or excluded from the assessment, depending on the product system. Additionally, according to C. Li et al. [50], it was found that the presence of heavy metals in the cotton fibres was negligible. Thus, it was decided to exclude any heavy metal flows which were identified. This is to avoid any confusion with the interpretation of the results in the final stage of the analysis. Furthermore, it does not reflect the true composition of the product under this study.

In the sensitivity analysis, the influence of using a different dataset from the GaBi database SP40[10] representing the global market of organic cotton is explored (see section 6.2.4).

Organic cotton modelling: fibres (TO) and noils (PO)

The output of harvesting is seed-cotton that goes through a ginning process to separate the cotton fibre from the seeds (a detailed description of the supply chain of organic cotton is given in section 3.4.1). The cotton fibres used in the production of organic tampons are those obtained from the ginning process. The by-product of ginning is cottonseed, which has different uses. Ecoinvent 3.6 applies economic allocation to distribute the impacts from the ginning process. Hence, it is not necessary to modify the process. In the case of the organic cotton pads, the organic cotton input is the by-product of the combing process which comes after ginning. This by-product is named noils, which are shorter fibres separated from the longer ones to improve the

[10] http://www.gabi-software.com/deutsch/my-gabi/neuestes-gabi-upgrade/

fibre quality for further processing (e.g. for cotton yarn for textiles). Thus, it is necessary to apply allocation. The supply chain of both products is displayed in Figure 13.

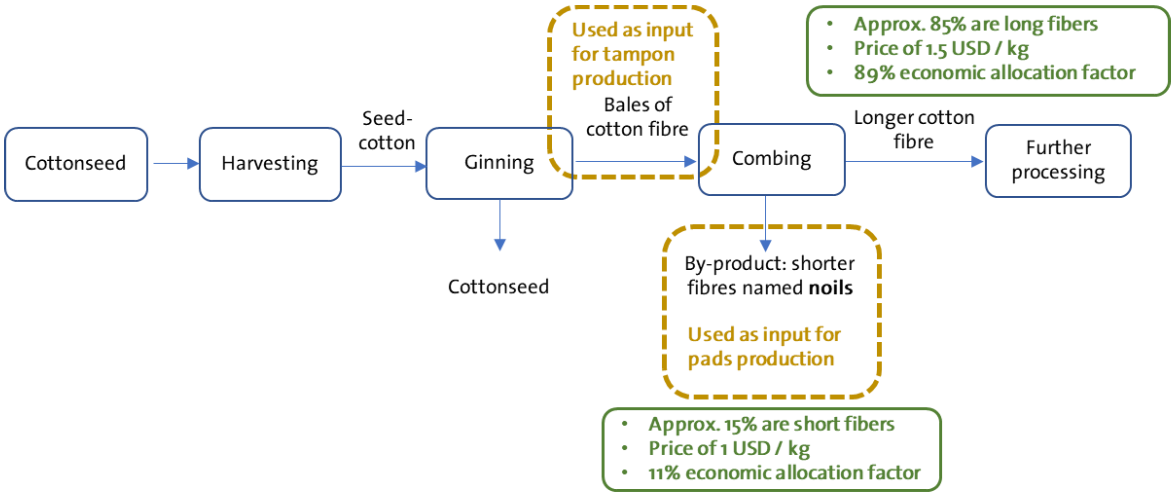

Figure 13. Supply chain of organic cotton fibre for organic tampons and pads

Firstly, the combing process presented in Table 14 is modelled according to an LCA study on cotton fibre [51], which includes energy consumption and waste treatment. In the same study, economic allocation is applied to the combing process. The monetary values are 1 USD for the noils and 1.5 USD for the longer fibres. The mass percentage of noils related to the longer fibres is 15% for standard quality cotton. Based on these data, the calculated allocation factor for the noils is 0.11 and for the longer fibres 0.89. By applying these factors, the lower value of the by-product is well represented in the LCI. Additionally, one of the organic cotton suppliers for the *einhorn* products performed a life cycle assessment with an economic allocation factor for the noils of 11%, which supports the allocation approach for this study. Although the market prices may vary, the ratio is the relevant value for allocation, which is expected to be stable. The influence of selecting economic instead of physical allocation is explored in the sensitivity analysis in section 6.2.5.

Table 14. Inventory to produce 1kg of organic cotton fibres in a coming process

Combing process for organic cotton noils production (PO) – inputs and outputs for producing 1kg of long fibres			
Input	Amount	Unit	Dataset
Electricity	0.322	kWh	market group for electricity, low voltage, GLO
Organic cotton fibres	1.176	kg	organic cotton fibre production from ginning, IN
Output	Amount	Unit	Comment
Organic cotton long fibres for spinning	1.00	Kg	Used for textile production
	1.5	USD	Price
Organic cotton noils (by-product)	0.176	kg	Used for the organic pads
	0.176	USD	Price

Bioplastic: heavy metal emissions

The selected dataset for the production of bioplastic represents the same material used for the back-sheet, wrapper, and packaging bag of the organic pads – Materbì based on maize. In the dataset, heavy metal emissions from maize harvesting are negative, which means that the intake is higher than the output. Since for the organic cotton dataset such flows were not considered, the same procedure is followed for bioplastic. The influence of maize starch is low, and therefore the performance of a sensitivity analysis to check this assumption is not needed.

4.2.3 Menstrual cup

Silicone is the main component of the menstrual cup. The used dataset covers the European production of silicone products, i.e. a mix of production technologies is considered. According to the Ecoinvent documentation for plastics [52], the production of liquid silicone rubber is included in the dataset.

The *einhorn* menstrual cup is available in pink and yellow colours. Since the pigments are classified as food safe, inorganic pigments are modelled for the cup. The Evah pigments[11] fatavase from the Evah Institute provides fatasets for yellow pigment, but not for pink. Therefore, a 50% mixture of white and red pigments is assumed. As two white pigments are available, a mix of both is considered. The region of production is selected according to the available datasets. A detailed explanation of the modelling of the menstrual cup components and packaging is included in Appendix D-5.

4.2.4 Bleaching of conventional and organic products

In ecoinvent 3.6 the bleaching of the sulphate pulp, which is used for the conventional products (fluff pulp and viscose), is already included in the dataset. It is a combination of total chlorine-free (TCF) and an elementary chlorine-free (ECF) process.

[11] http://www.evah.com.au/our-services.html

The bleaching of organic cotton is added as a service process to organic cotton fibre production. The dataset global market for bleaching textile from Ecoinvent is used, where a TCF procedure is modelled, as it is the case of the assessed products. The organic cotton tampon core and string, as well as the pad core and top-sheet, are bleached. Waste flows are included for the tampon core and the pad core and top-sheet, but not for the tampon string as it is considered negligible. Data are provided by an expert on the organic cotton supply chain and show that the waste rate of the organic cotton fibres is higher than the noils. This is because the noils used for the pads originate from the combing process that produces cleaner fibres, while the cotton fibres from ginning (as used for tampons) contain a higher amount of impurities. Table 15 shows the bleaching process.

Table 15. Waste inventory of bleaching 1kg of organic cotton

Input	Amount (TO, kg)	Amount (PO, kg)
Organic cotton (fibre or noils)	1.225	1.125
Bleaching, textile, global market	1	1
Output	Amount	Unit
Waste textile, soiled	0.225	0.125

4.3 Manufacture

This section describes the most relevant aspects of the manufacturing data and a detailed explanation is provided in Appendix D – Life cycle inventory. The manufacturing location is known for *einhorn* products; the menstrual cup is produced in Germany, while the location of the organic tampons and pads manufacture is not disclosed due to confidentiality. The datasets used in the model are selected for the countries known if available, otherwise for Europe, and as a last option global dataset are taken. To enhance comparability, it is assumed that conventional products are manufactured in Europe. The priority is to choose European datasets, otherwise, global processes are taken. In the sensitivity analysis, the influence in the results of using different electricity sources is performed.

Water inputs are excluded from the assessment because available data refer both to the production of the menstrual products and also for other purposes like the kitchen or the toilet. Furthermore, no water is needed for the production of the menstrual cup. Calculations were made to estimate the relevance of water use and treatment and showed a very low contribution. The use of lubricants and cleaning agents is not available for all products and therefore not considered; it was identified that their contribution to the results is irrelevant.

Primary data are available for the *einhorn* products and conventional tampons, including electricity and energy consumption as inputs and rejected products, and materials waste (also for packaging) as outputs. However, data on menstrual cup packaging waste are not available. Packaging waste rates are assumed from the production of organic cotton tampons, as specified in Appendix D-5, although the influence of manufacturing waste in the results of the menstrual cup is negligible.

Manufacturing data for the conventional pads are based on published LCA studies on baby nappies [47,53]. According to Cordella et. al [23], the manufacture of menstrual pads is similar to nappies. In the same report, manufacturing data for nappies is used for menstrual pads. Ideally, data from nappies would be converted to pads based on the volume of the unit to determine the consumption of energy. However, due to data availability, the conversion is made according to the weight of the studied pad. It is a simplified but a reasonable assumption considering that the weight is related to the volume (the higher the weight, the higher the volume).

An overview of energy consumption is provided in Table 16. Overall, the energy consumption for the pads' production is higher than for the tampons due to the size and shape. The energy inputs are slightly higher for conventional than organic tampons because of the higher material losses. Furthermore, the energy calculated to produce conventional pads is lower than for organic ones, because the conventional pads are smaller than organic cotton ones. The energy consumption for the menstrual cup manufacture has been reduced compared to the past due to the type of silicone used; it does not require the energy-consuming process of post-curing (see section 3.4.3). In fact, the cup requires the lowest energy consumption per product.

Table 16. Electricity input for manufacture per FU

Electricity consumption	MC	TC	TO	PC	PO
Manufacturing (MJ/FU)	4.47E-04	3.83	3.56	5.41	Confidential (higher than PC)

The datasets for the treatment of the waste flows are market processes representing the region where the manufacturing takes place. Transport to the treatment facilities is included in the selected dataset. More details about the end-of-life modelling are given in section 4.7.

4.4 Distribution

Primary data for secondary packaging for the distribution of the *einhorn* products are available.

The organic tampons and pads are transported from the manufacturing site to the shop packed in carton boxes on EUR pallets and wrapped in a polyethylene plastic film. It is assumed that the conventional products are distributed in the same way. However, the number of conventional products transported in one box is higher – the number of conventional units in each package sold is also higher.

The distribution of the menstrual cup is done in two steps. Firstly, it is sent by courier to Berlin (cardboard and plastic are necessary), where it is packed and then distributed in the same way as the other products. The cups are transported to Berlin packed in LDPE film and in a corrugated box.

The production of secondary packaging and waste treatment are assumed to take place in Europe. Table 17 displays the amount of packaging and the selected datasets for its production. The amount of generated waste is the same as the inputs. Regarding the waste treatment, 70% of the paperboard is recycled and 30% goes to the ecoinvent process *paper waste market group for waste paperboard*, while the packaging film is treated in the *market group for waste polyethylene*. As the EUR pallet input is very low, its disposal is not considered.

The reason for the low number of modelled pallets is that they are reused (instead of disposed of like the boxes and plastic film); though the number of times is not known. To overcome this lack of data, a distribution process for tea bags from the ESU food database [12] (*distribution and selling, tea* in tea bag, *in supermarket*) was used. According to this process, 4.26E-04 pallets are needed to distribute 1 kg of tea bags (considering that the pallet is reused). It is assumed that a box of tea-bags is similar for transportation purposes to a box of menstrual products – they are light, delivered in similar packaging, and require no special transport conditions. Moreover, the materials, as well as the amounts needed to produce a pallet, are also taken from the ESU food database (*EUR-flat pallet/p/RER U*) and modelled with ecoinvent 3.6 for the background processes (Appendix D- 12).

[12] http://esu-services.ch/data/data-on-demand/

Table 17. Inventory of secondary packaging per FU

Input per FU	TC	TO	PC	PO	MC to Berlin	MC to retailer
Box/FU (kg) (corrugated board box production, EUR)	5.73E-02	1.23E-01	3.29E-01	3.66E-01	1.62E-04	2.90E-03
Film/FU (kg) (packaging film production, low density polyethylene, EUR)	6.93E-04	1.49E-03	3.21E-03	3.58E-03	2.65E-05	3.38E-05
EUR pallet/FU (items)	3.44E-04	4.63E-04	6.96E-04	1.17-03	-	5.86E-06

The transport weight per functional unit including primary and secondary packaging is displayed in Table 18.

Table 18. Transport weight including primary packaging (per product) and including primary and secondary packaging (per functional unit)

Input	Transport weight with primary and secondary packaging (kg/FU)
TC	8.09E-01
TO	1.09E+00
PC	1.63E+00
PO	2.74E+00
MC to Berlin	1.16E-02
MC to retailers	1.38E-02

The transport distances are based on an LCA study on the distribution of beverage packaging [54] since in Germany these products are transported to almost every supermarket and corner-shops where menstrual products are also sold. Only lorry transport is considered in Europe. The modelled transport is presented in Table 19.

Table 19. Transport modelled for distribution

Means of transport	All products: distance to retailer	MC: distance to Berlin
transport, freight, lorry 16-32 metric ton, EURO5	625 km	-
transport, freight, lorry 3.5-7.5 metric ton, EURO5	7 km	675 km

4.5 Shopping trip

The shopping trip is modelled in the same way for all products and presented in Table 20. First, the number of packages of each product needed to fulfil the functional unit is calculated. For example, 260 tampons, which are sold in a 56-item package, are needed per functional unit, i.e. 4.64 packages are needed per functional unit (per year). Assuming that one package is purchased per shopping trip, the number of trips per functional unit equals the number of packages. It is assumed that two packages of organic products are purchased per shopping trip; otherwise, the number of organic products per package would not be enough for one menstrual cycle. For the organic pad, a maximum of 13 trips is needed, since 13 menstrual cycles per functional unit are considered in this study. The distance per shopping trip and the transport used are based on literature data for Germany [55].

A distance of 11.75 km per trip is considered – the journey to the supermarket and back home. The options included in the literature are to go by foot, bike, car or public transport. The car (62%), and public transport (15%) are modelled, the others have not been considered as their impacts are negligible. The dataset for car transport is '*transport, passenger car*' in Europe and for public transport is assumed to be '*transport, regular bus*' in Switzerland. Data for other means of transport and region are not available in ecoinvent 3.6.

According to Hottenroth, in 2013 the average shopping bag in Germany weighs 10 kg [56]. The weight ratio of one package of menstrual products related to the shopping bag, is the escalating factor applied to calculate the contribution of the purchased menstrual products to the 10 kg shopping bag.

Using conventional tampons as an example, 4.64 packages weigh 0.75 kg, and the shopping bag for all trips weighs 46.64 kg. Hence, 0.016 is the ratio of tampons in the shopping bag. This factor is used to calculate the proportion of distance in kilometres, that corresponds to the tampons from the shopping trip. Accordingly, the required shopping distance for each product is calculated and applied to transport by car or bus, as shown in Table 20.

Table 20. Modelling of the shopping trip

Product	Number of shopping trips/FU	Weight shopping bag	Weight of the product	Ratio product/shopping bag	km/FU by car	km/FU by bus
TC	4.64	46.40	0.750	0.0162	0.132	0.547
TO	8.13	81.25	0.965	0.0119	0.169	0.700
PC	10.8	100	1.274	0.0127	0.230	0.949
PO	13.0	130	2.369	0.0182	0.418	1.726
MC	0.2	2	0.011	0.0057	0.002	0.008

4.6 Use

4.6.1 Hand-washing

The process of washing hands is common to both tampons and menstrual cups. The number of times that hands are washed per functional unit is displayed in Table 2 – 260 times/FU for the use of tampons, and 148 times/FU for the use of the cup. It depends on the number of menstrual days and on the wearing time of the menstrual products.

The amount of water and soap needed for washing hands is not established, as it is very variable depending on the person. Henkel AG & Co. KGaA carried out a consumer study to define those amounts. The results were used in a study on the environmental impacts of personal hygiene products [57] and applied in the ESU food database for the process of hand washing (*hand washing, liquid soap*). Assuming that hands are washed with liquid soap, 2.3 g of soap and 0.64 l of water are needed for each hand-wash. To avoid uncertainties related to the use of warm water with different choices of temperature and heating method- it is assumed that cold water is used. This assumption is also tested during sensitivity analysis. The amount of soap and water, and the water temperature, are analysed in the sensitivity analysis in sections 6.2.8 and 6.2.9, respectively. The liquid soap is modelled according to the literature [58] and described in Appendix D – Life cycle inventory. The packaging size is taken from the *Balea Med ph 5.5 Hautneutral* [13] soap from the German shop *dm* (same packaging size is assumed for washing of the menstrual cup). Packaging production is also included.

The waste treatment of the soap packaging and the wastewater treatment from hand-washing are included and modelled for Germany and Switzerland respectively.

Table 21 collects the inventory of the hand washing process, for hand wash and functional unit. In the sensitivity analysis, in section 6.2.8 the amount of water and soap is modified.

Table 21. Inventory of hand wash, per hand wash and per FU

Flow	Amount/ hand wash (kg)	Amount/FU		Dataset
		MC	Tampons	
Input				
Liquid soap	0.0023	0.34	0.60	From [1] (see Appendix D- 13)
Container	2.74E-4	0.04	0.07	injection molded HDPE, EUR
Water	0.64	94.7	166.4	market for tap water, EUR
Output				
Wastewater	0.64	95.1	167	treatment of wastewater, from residence, capacity 1.1E10l/year, CH (applicable to Europe)
Waste plastic	2.74E-4	0.04	0.07	market for waste polyethylene, DE

[13] https://www.dm.de/balea-med-balea-med-ph-5-5-seifenfreie-waschlotion-p4058172336898.html

4.6.2 Toilet paper for disposal

It is assumed that tampons are wrapped in toilet paper after use and before disposal to avoid the tampon leaking on the way to the rubbish bin and inside it. For the disposal of the last menstrual pad used in a menstruating period, toilet paper is also used as a wrapper for disposal. It is assumed that the number of toilet paper sheets per disposed of a tampon or a pad (approximately the same length as one pad wrapper) is three. The amount of toilet paper is also tested during sensitivity analysis in section 6.2.17. An Ecoinvent process for the European production of tissues is selected for toilet paper production, as presented in Table 22.

Toilet paper from the brand *tip*[14] was chosen for its weight and packaging, including the cardboard roll and the plastic bag. A package contains 16 rolls of toilet paper.

The packaging waste is included in the use phase, and the toilet paper waste is included at the end-of-life phase of tampons. Different amounts of toilet paper per disposal are analysed in the sensitivity analysis in section 6.2.17.

Table 22. Inventory of the use of toilet paper, per disposal, and per FU

Flow	Amount/ Disposal (kg)	Amount(kg/FU)		Dataset
		Tampons	Pads	
Input				
Toilet paper	1.05E-3	2.72E-01	1.36E-02	tissue paper production, EUR
Cardboard	6.15E-05	1.60E-02	8.00E-04	injection molded HDPE, EUR
LDPE packaging	2.18E-05	5.68E-03	2.83E-04	market for tap water, EUR
Output				
Waste cardboard	6.15E-05	1.60E-02	8.00E-04	30% waste paper market for waste paperboard, DE 70% waste paperboard to recycle
Waste plastic	2.18E-05	5.68E-03	2.83E-04	market for waste polyethylene, DE

4.6.3 Cup washing

The number of times that a cup is washed per functional unit is presented in Table 2. It depends on the number of menstruating days per year and on the wearing time of the menstrual cup.

Similar to hand- washing, it is difficult to define how much water and soap are needed to wash a menstrual cup. Experiments were carried out to determine such values by measuring the amount

[14] https://www.supermarktcheck.de/product/61858-tip-toilettenpapier-

of soap and water (tap open to approximately medium flow) needed to properly clean the cup. The amounts calculated are 1.88 g of liquid soap, and 1 l of water as presented in Table 23. These amounts are tested during sensitivity analysis in section 6.2.14. The liquid soap modelling is performed in the same way as for the hand washing. Also, the wastewater and plastic waste from soap packaging are considered.

Table 23. Modelling of the cup washing

Flow	Amount/cup wash (kg)	Amount/FU	Dataset
Input			
Liquid soap	1.882E-03	2.79E-01	From [23] (see Appendix D- 13)
Container	2.24E-4	3.32E-02	injection molded HDPE, EUR
Water	1	148	market for tap water, EUR
Output			
Wastewater	1	148	treatment of wastewater, from residence, capacity 1.1E10l/year, CH (applicable to Europe)
Waste plastic	2.24E-4	3.32E-02	market for waste polyethylene, DE

4.6.4 Cup sterilization

The menstrual cup is sterilized between periods, i.e. 13 times per functional unit (see Table 2). The LCI of this process is performed for cooker and kettle scenarios. Additionally, the cup is sterilized for 8 to 9 minutes before the first use in both scenarios (see annex A). Table 24 collects the inputs (electricity and water) and outputs (wastewater treatment) of the sterilization.

Cooker Scenario

In this scenario, the cup is sterilized by boiling it with water in a pan heated on the cooker. To calculate the amount of water needed, a standard 14 cm diameter pan was selected and filled with enough water to cover the cup during the sterilization process. The measured amount for the assessment was 650 ml of water. A study about the energy consumption of different cooking methods to boil eggs was the basis of the energy consumption calculations [59]. Data for ceramic and cast-iron electric cookers are available. According to the Federal Statistical Office of Germany (Statistisches Bundesamt) [60], 94% of German households are equipped with electrical cookers, and 6% with gas cookers.

A weighted average of the energy consumption of both cookers analysed in the study was selected. Energy is required to bring the water to the boil and the cooker remains on during the time required to boil the menstrual cup. For the base case, the cup was boiled for 5.25 minutes. The calculated energy needed per sterilization is 0.555 MJ. It is assumed that the pan is not covered with a lid during sterilization. Boiling time variations, the sterilization frequency, the use of renewable energy, and boiling with a lid were tested during sensitivity analysis.

Kettle Scenario

The results of the laboratory tests commissioned by *einhorn* represent the base for kettle scenario, as introduced in section 3.4.3. It found that pouring boiled water over a cup in a container (e.g. a mug) is sufficient for sterilization. The water can be boiled in a kettle. The amount of water needed was measured and amounts to 250 ml. According to [61], the energy needed to boil 250 ml of water in a standard kettle is 0.1098 MJ. Thus, the energy consumption in the kettle scenario is significantly lower than in the cooker scenario.

In the sensitivity analysis the parameters of the sterilization process are modified in both scenarios, specifically is sections 6.2.10 (sterilization time), 6.2.11 (use of a lid to cover the pan), 6.2.12 (use of renewable energy sources), and 6.2.13 (sterilization frequency).

Table 24. Inventory of the cup sterilization, in both scenarios, per FU

Flow	First use/FU	Between periods/FU		Dataset
		Cooker scenario	Kettle scenario	
Input				
Electricity (MJ)	0.596	7.21	1.43	market for electricity, low voltage, DE
Water (kg)	0.65	8.45	3.25	market for tap water, EUR
Output				
Wastewater (kg)	0.65	8.45	3.25	Treatment of wastewater, from residence, capacity 1.1E10l/year, CH (applicable to Europe)

4.7 End of life

The end-of-life phase is modelled similarly for all products, as shown in Table 25. Single-use menstrual products are transported with the municipal solid waste fraction to incineration. Tampons are wrapped in toilet paper; and pads in the wrapper or toilet paper. A dataset for Germany was selected.

The paper and the cardboard are 70% recycled [62] and 30% treated in the German market, i.e. mainly incineration. Two incineration processes are modelled for paper waste – one for graphical paper, and one for cardboard – both in Germany.

Plastic as well as bioplastic packaging materials go to incineration with the packaging waste fraction.

The process selected for incineration of the menstrual products is the same for all of them, without considering the absorbed blood and the water content, or the different materials of the products. The process selected represents waste composition in Germany well, considering the presence of different materials and water content.

Table 25. End of life modelling

		market for municipal solid waste, DE	market for waste plastic, DE	market for waste graphical paper, DE 30%	market for waste paperboard, DE 30%	Paper and cardboard recycling, 70%
TC	Component	Tampon and toilet paper	Wrapper	Leaflet	Box	Leaflet and box
	Weight (kg/FU)	9.28E-01	1.56E-02	2.51E-03	2.13E-02	5.56E-02
TO	Component	Tampon and toilet paper	Wrapper	Leaflet	Box	Leaflet and box
	Weight (kg/FU)	1.02E+00	2.44E-02	7.02E-03	4.94E-02	1.32E-01
PC	Component	Pad, wrapper, release paper, toilet paper	Packaging bag	N/A	N/A	N/A
	Weight (kg/FU)	1.12E+00	2.82E-02			
PO	Component	Pad, wrapper, release paper, toilet paper	Packaging bag	N/A	Box	Box
	Weight (kg/FU)	1.57E+00	7.80E-02		7.88E-02	1.84E-01
MC	Component	Organic cotton bag	Menstrual cup	Leaflet waste	Box	Leaflet and box
	Weight (kg/FU)	1.52E-03	2.27E-03	1.40E-04	1.97E-03	4.93E-03

5 LCIA results

In this section, the LCIA results are presented and analysed. First, the results are analysed for each menstrual product in section 5.1. In section 5.2 the overall results are presented to compare the environmental impact of the products (lowest to highest). The reasons for the results of the comparison are explained in section 5.2.4. All results that are mentioned in this section but not displayed as absolute results, are included in Appendix F – Absolut results.

5.1 Results per product

The results obtained were analysed for each product – the relevance of the life cycle stages is determined, and the processes with a higher contribution within each stage are identified. The aspects most relevant to understand the results are included in the next sections.

Conclusions of the life cycle stages and contribution to processes – baseline results

Menstrual cup – The **use phase** is the most relevant stage (>95% - almost all categories). Electricity for sterilization is the process which contributes most in the cooker scenario, and soap production (for cup and hand-washing) in the kettle scenario. Impacts from the kettle scenario are significantly lower than from the cooker.

Conventional & organic tampons – The **production** of **components** is the stage most relevant for most of the impact categories, followed by the **use phase** (wastewater treatment, toilet paper and soap production) for others. The tampon core (viscose for TC and organic cotton for TO) is the component which is most relevant.

Conventional & organic pads – The stage which contributes most is the **production of components**. The production of plastic and fluff-pulp are the most relevant for the PC, and the organic cotton and bioplastic for the PO. For some categories, manufacturing is the phase most relevant, due to the electricity consumed.

All products – The impacts from manufacturing are mainly due to electricity consumption. Distribution, shopping trip, and end of life have a lower contribution.

Box 1. Life cycle stages analysis: main findings

Appendix E – Processes' contribution includes more information regarding contributions to processes. Box 1 summarizes the main findings, and Table 26 presents the main contributors to the impacts.

Table 26. Main contributors to the life cycle impacts: most contributing process within the most contributing life cycle stage

Impact category	MC, Scenario cooker	MC, Scenario kettle	TC	TO	PC	PO	Unit
Land use	Sterilization	Soap	Toilet paper	Org. cotton	Distribution	Org. cotton	Pt
Water scarcity	Sterilization	Wastewater	Viscose	Manufacture	Manufacture	Manufacture	m3 depriv.
Resource use, mineral and metals	Soap	Soap	Viscose	Soap	Top-sheet	Adhesive	kg Sb eq
Resource use, energy carriers	Sterilization	Soap	Viscose	Soap	Dist. layer	Wrapper	MJ
Climate change	Sterilization	Soap	Viscose	Org. cotton	Dist. layer	Org. cotton	kg CO2 eq
Eutrophication terrestrial	Sterilization	Soap	Viscose	Org. cotton	Dist. layer	Org. cotton	mol N eq
Eutrophication marine	Wastewater	Wastewater	Wastewater	Org. cotton	Dist. layer	Org. cotton	kg N eq
Eutrophication freshwater	Sterilization	Sterilization	Viscose	Org. cotton	Dist. layer	Org. cotton	kg P eq
Acidification terrestrial and freshwater	Sterilization	Soap	Viscose	Org. cotton	Dist. layer	Org. cotton	mol H+ eq
Ecotoxicity freshwater	Soap	Soap	Soap	Org. cotton	Incineration	Org. cotton	CTUe
Cancer human health effects	Wastewater	Wastewater	Viscose	Wastewater	Dist. layer	Incineration	CTUh
Non-cancer human health effects	Wastewater	Wastewater	Viscose	Toilet paper	Dist. layer	Org. cotton	CTUh
ionizing radiation, HH	Sterilization	Sterilization	Manufacture	Manufacture	Manufacture	Wrapper	kBq U-235 eq
Photochemical ozone formation, HH	Sterilization	Soap	Viscose	Org. cotton	Dist. layer	Org. cotton	kg NMVOC eq
Respiratory inorganics	Soap	Soap	Viscose	Org. cotton	Core	Org. cotton	disease inc.
Ozone depletion	Sterilization	Soap	Toilet paper	Org. cotton	Distribution	Org. cotton	kg CFC11 eq

Org. cotton = organic cotton; Dist. Layer = distribution layer
Sterilization = electricity consumption; Wastewater = wastewater treatment; Manufacture = energy consumption
Soap, toilet paper, viscose, org. cotton, fluff pulp, dist. layer, wrapper = refers to the manufacture of the material
Wastewater = from the use phase

5.1.1 Menstrual cup (MC)

For menstrual cups, the use phase dominates the environmental impacts as represented in Figure 14 for the cooker scenario. The contribution is higher than 95% for almost all categories. Hence, the impact of the remaining life cycle stages has a very low influence on the results. Silicone production for the menstrual cup contributes 8.5% to *resource use, minerals and metals*, while the contribution to *land use* of producing the organic cotton bag amounts to 11%. The distribution of impacts in the kettle scenario is similar to the cooker scenario; however, the contribution of the use phase is lower due sterilization consuming less energy.

In the cooker scenario, the electricity consumption for sterilization is the most relevant process followed by soap production and wastewater treatment (see Figure 15). A different situation is observed in the kettle scenario: soap production is the process which contributes most, followed by wastewater treatment and electricity consumption (see Figure 16). The influence of tap-water use and the plastic waste from the soap packaging is low compared to the other processes.

The water and soap inputs are summarized in Table 27. The impact categories strongly affected by soap production are dominated by hand washing (higher soap input), while cup washing is the main contributor to the categories affected by water use and wastewater treatment (higher water input).

Table 27. Water and soap input during the use phase of the menstrual cup (amount/FU)

Input	Hands washing	Cup washing	Sterilization	
			Cooker	Kettle
Soap (kg)	0.34	0.28	-	-
Water (l)	94.7	148	8.45	3.25

A relevant reduction of the impacts is observed in the kettle scenario due to the lower electricity consumption (see Table 24) – from 6.6% for *freshwater ecotoxicity* to 53% for *freshwater eutrophication*. The *climate change* impact is reduced by 40%. This is displayed in Figure 17.

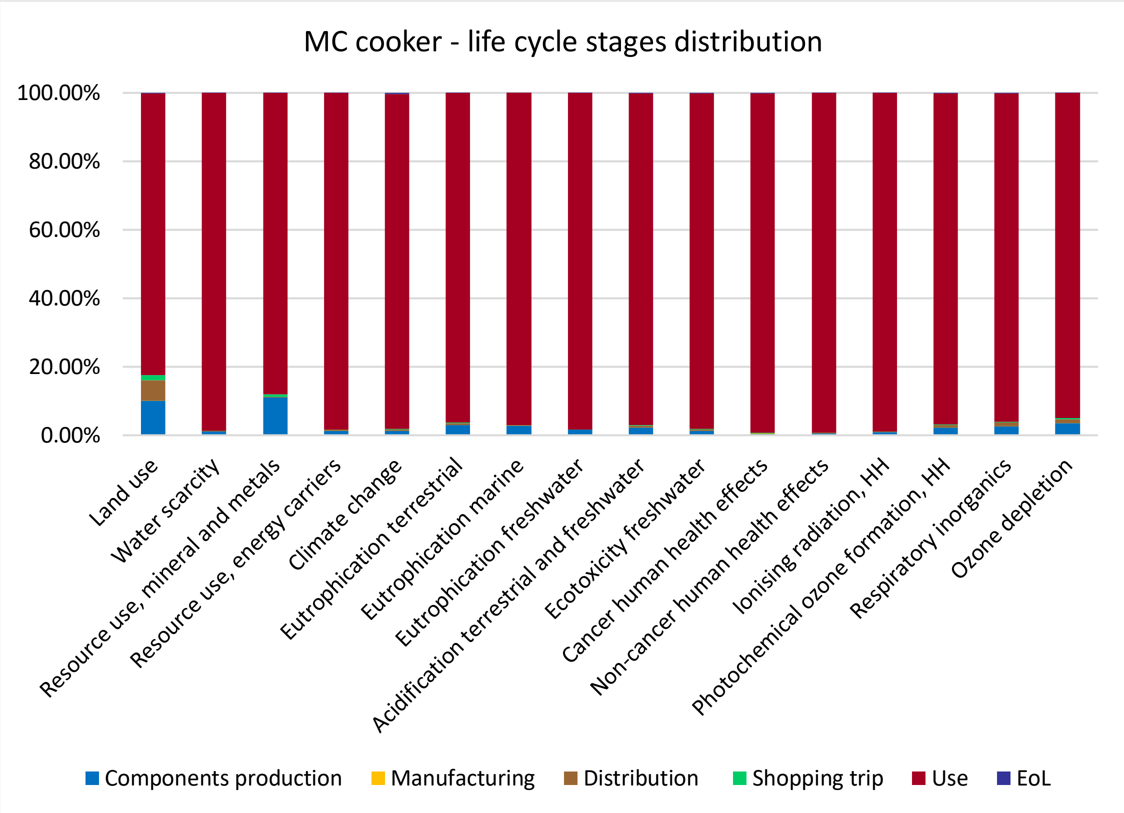

Figure 14. Life cycle stages contribution to the MC overall results in the cooker scenario

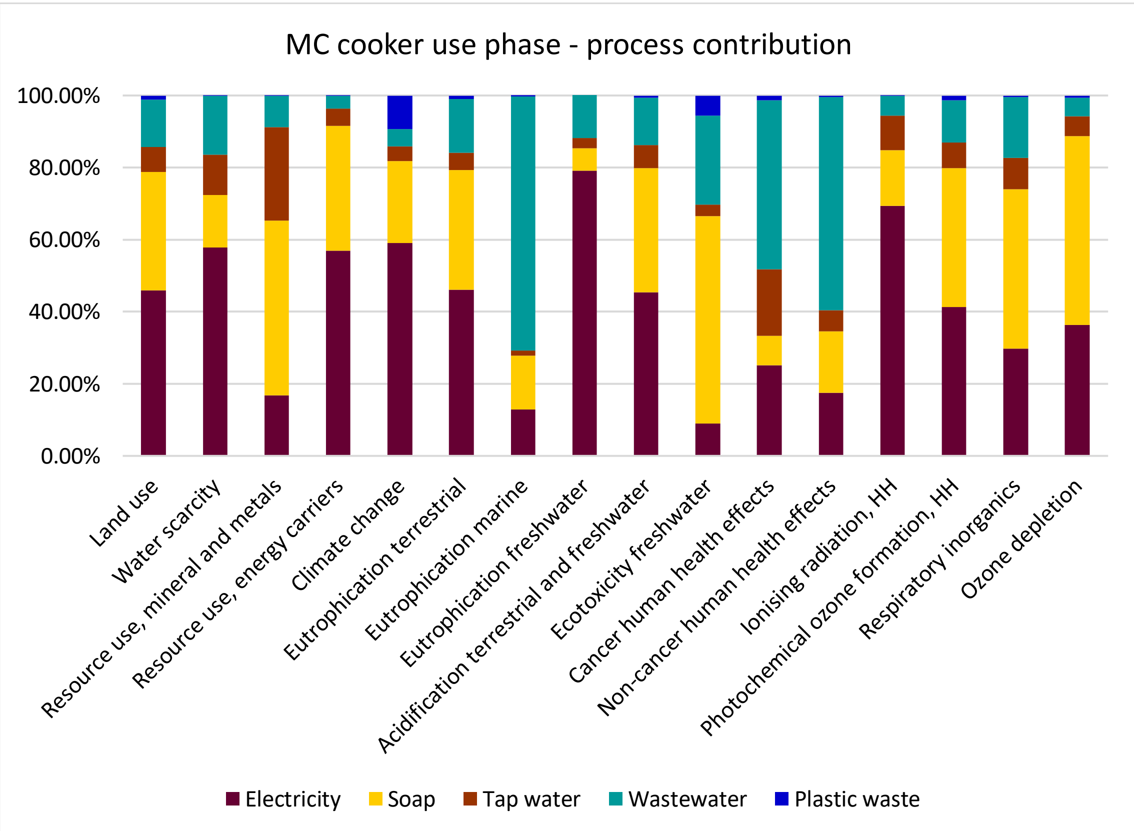

Figure 15. Processes' contribution to the use phase impact of the MC – scenario cooker

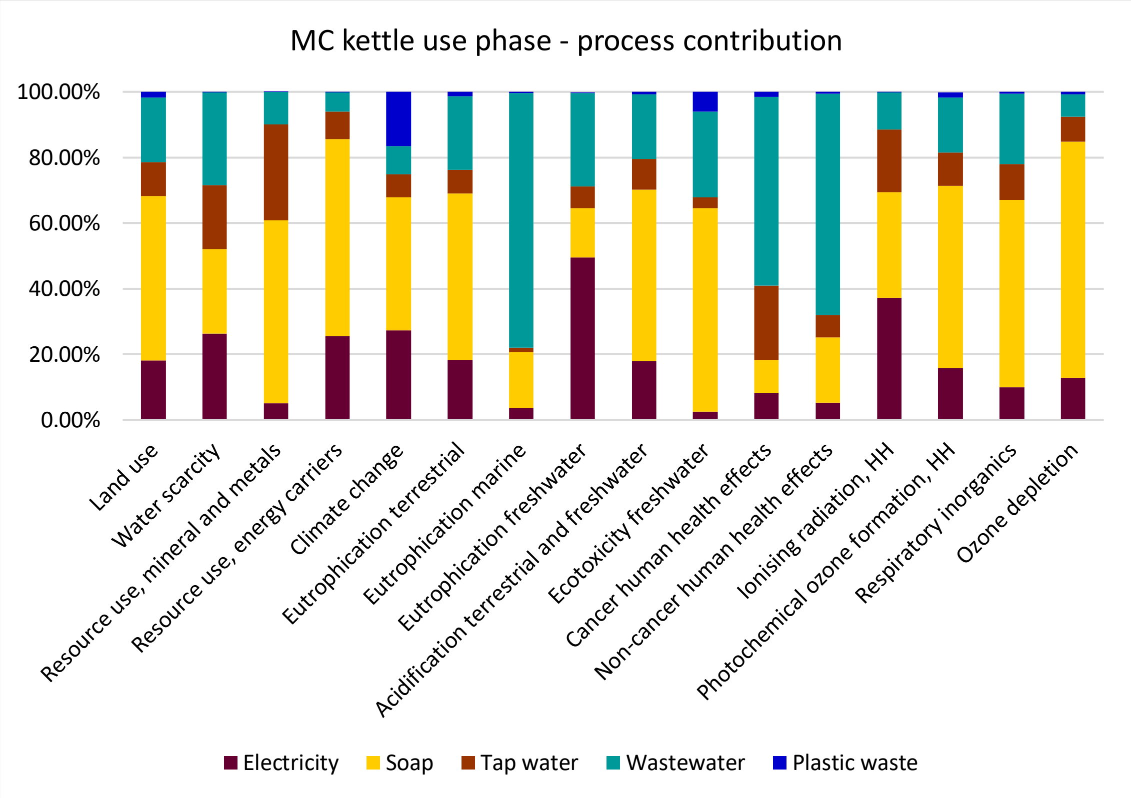

Figure 16. Processes' contribution to the use phase impact of the MC – kettle scenario

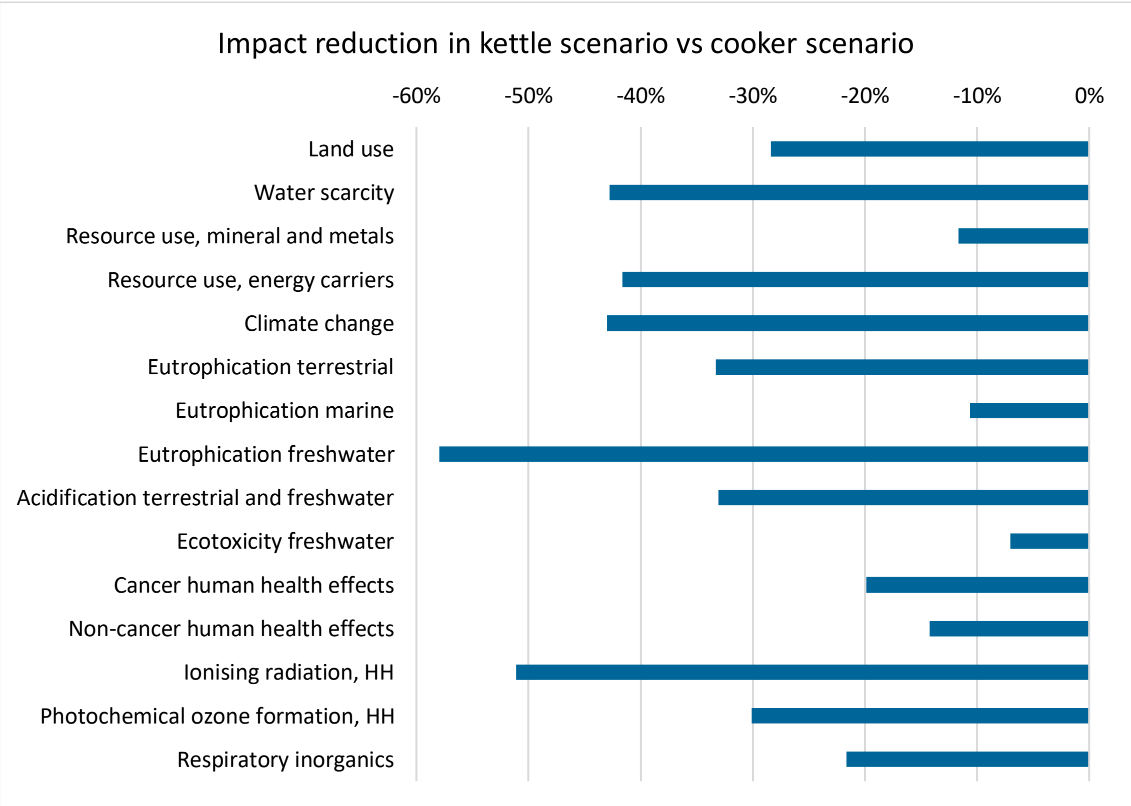

Figure 17. Impacts reduction in scenario kettle vs scenario cooker

5.1.2 Conventional tampons (T)

As observed in Figure 18, the production of components for tampons contributes the most to the life-cycle of conventional tampons, followed by the use phase, manufacturing, shopping trip, end-of-life, and distribution.

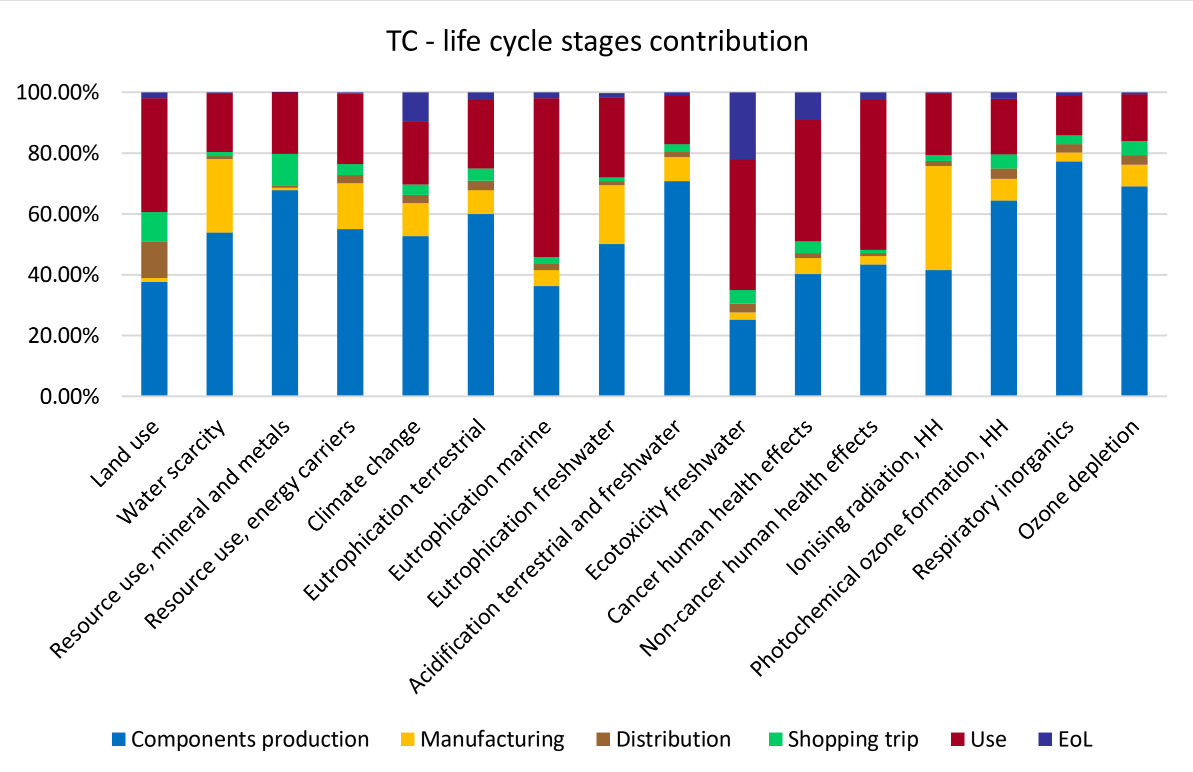

Figure 18. Life cycle stages contribution of the conventional tampons overall impact

Within the production of components, the viscose tampon core strongly influences the results in all impact categories, positioning the other components as almost irrelevant (see Appendix E- 2). The energy needed to produce viscose is responsible for most of its impacts. The production of the packaging box plays a relevant role in the impact categories *land use* (because of paper production) and *resource use, minerals and metals* (because of latex production).

During the use phase, the contribution from hand-washing dominates the impacts as displayed in Figure 19. Since the use phase is identical for both tampons, the diagram applies to TC and TO.

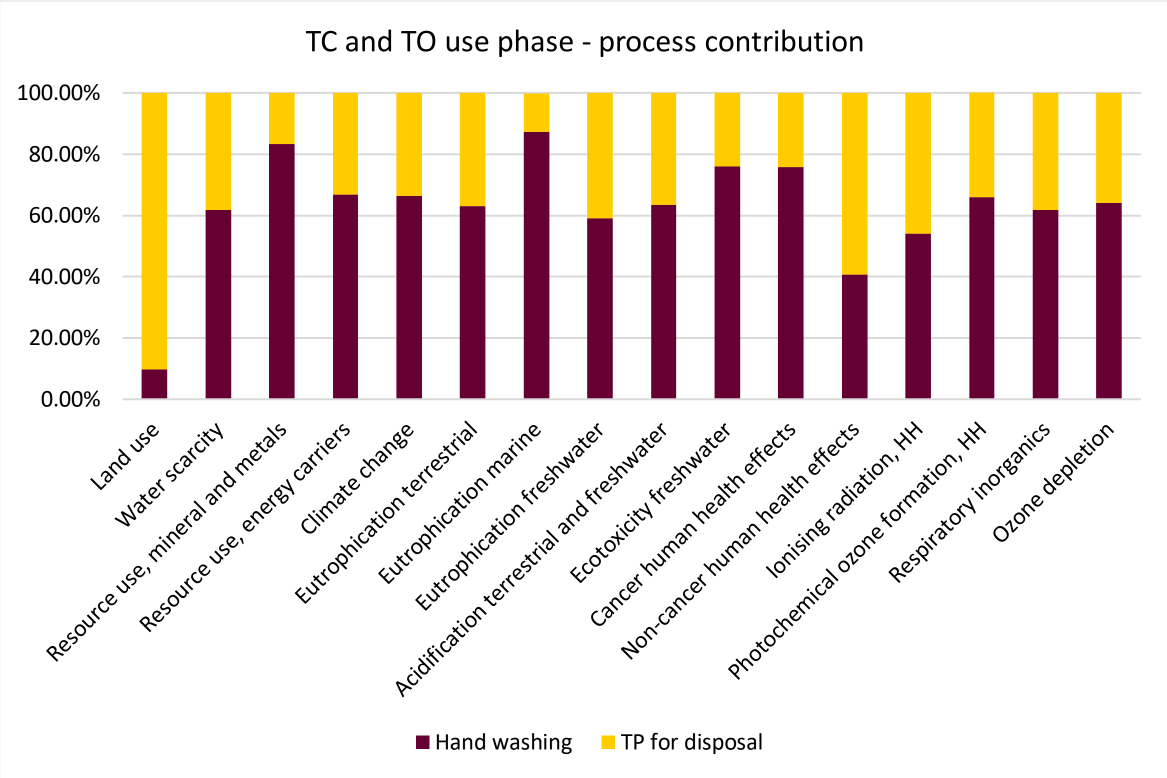

Figure 19. Contribution of hand washing and toilet paper to the use phase impact of tampons

5.1.3 Organic tampons (TO)

The production of the organic tampons' components and the use phase are the life cycle stages which contribute most, followed by manufacturing, distribution, shopping trip, and end-of-life (see Figure 20). The production of components is very relevant, mainly due to the production of organic cotton fibre (see Appendix E- 3). This strongly influences the impact categories *land use, terrestrial, marine and freshwater eutrophication, acidification, ecotoxicity freshwater*, and *respiratory inorganics*. Regarding the packaging, the printed box influences the category *resource use, minerals and metals* due to the production of latex needed for chipboard production.

The impact categories that are not strongly influenced by cotton production are mainly affected by use and manufacturing. The use phase distribution is the same as the one for conventional tampons presented in Figure 19.

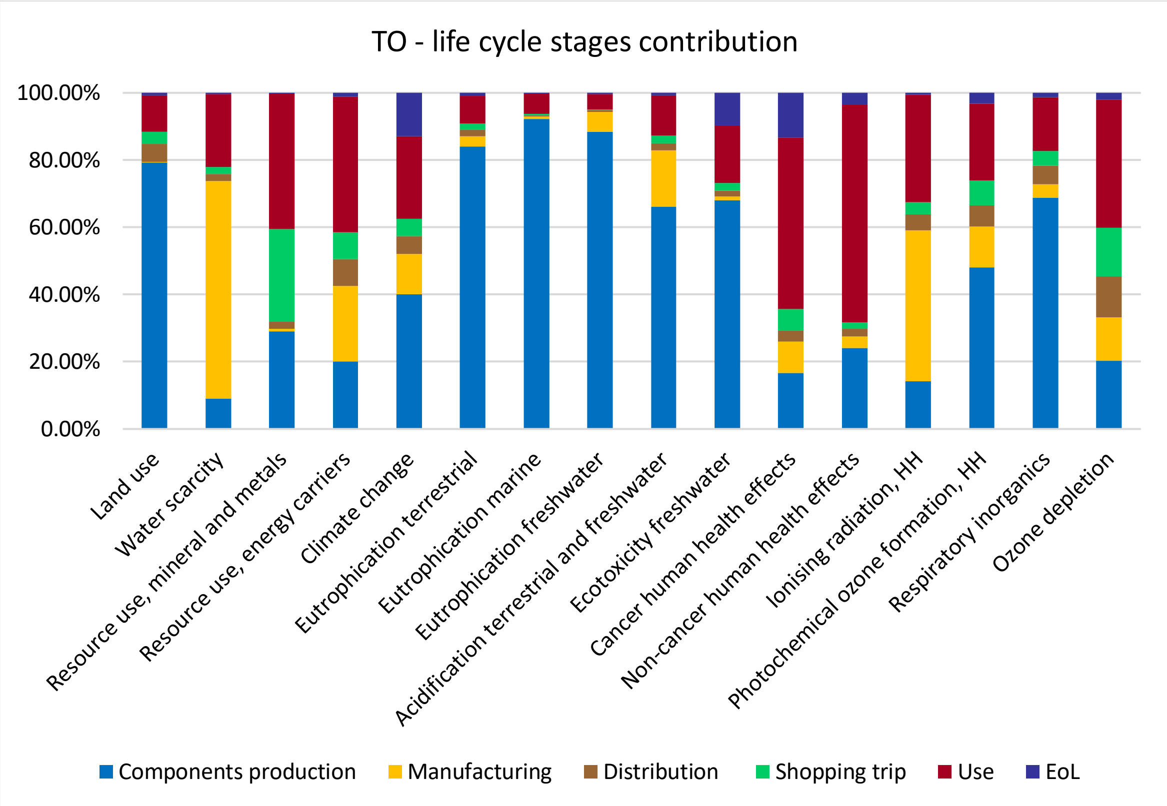

Figure 20. Life cycle stages contribution of the organic tampons overall impact

5.1.4 Conventional pads (PC)

The environmental impacts created by conventional pads are heavily influenced by the production of their components, followed by manufacturing, distribution, and end-of-life, as displayed in Figure 21. The impacts related to manufacturing are mainly caused by energy consumption. Road transport during distribution has a high contribution to *land use*. The incineration of municipal waste influences *freshwater ecotoxicity* due to heavy metals emissions to water.

Taking a deeper look into the production of raw materials in Figure 22, it is clear that the production of plastic has a large influence on the results – plastic is present in the top-sheet, distribution layer, back-sheet, wrapper, packaging bag, and SAP. Within the distribution layer, polyethylene and rayon contribute the most to the overall impacts followed by polypropylene, and polyester. The composition of the distribution layer is assumed to be equal between the four materials (see Table 8). From the non-plastic components, the sulphate pulp present in the absorbent core is the most relevant material, especially for the impact category *respiratory inorganics*.

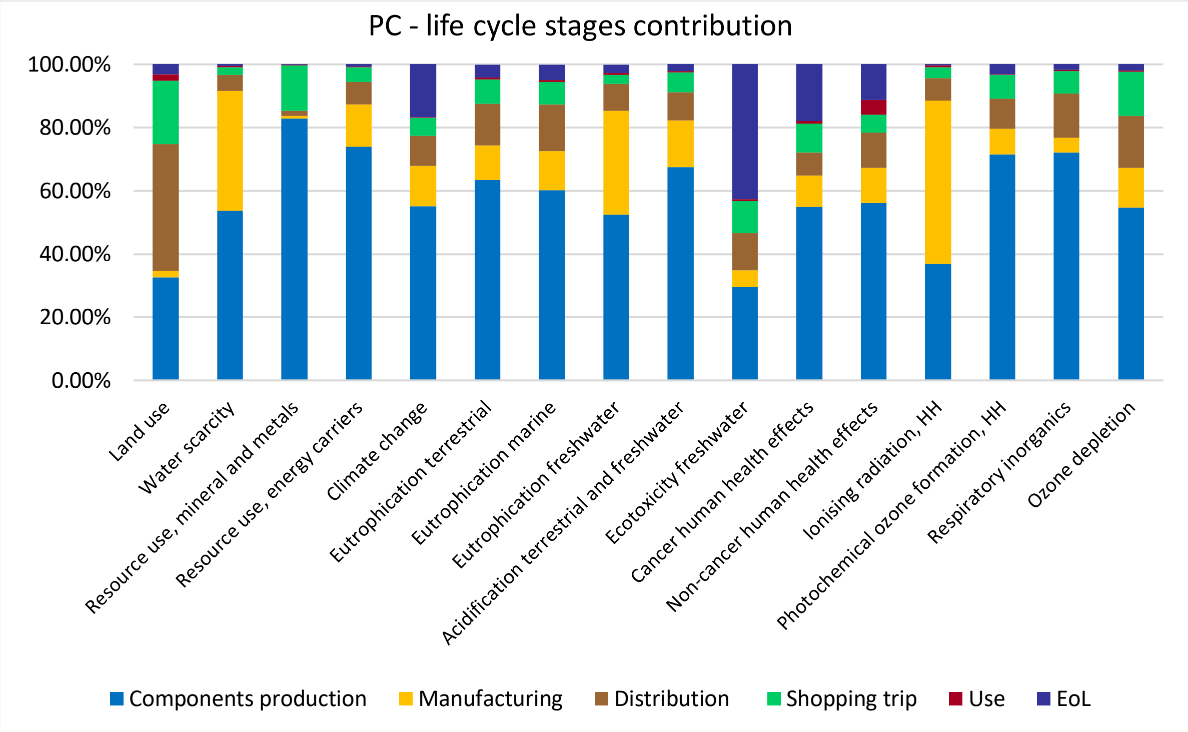

Figure 21. Life-cycle stages contribution of the conventional pads overall impact

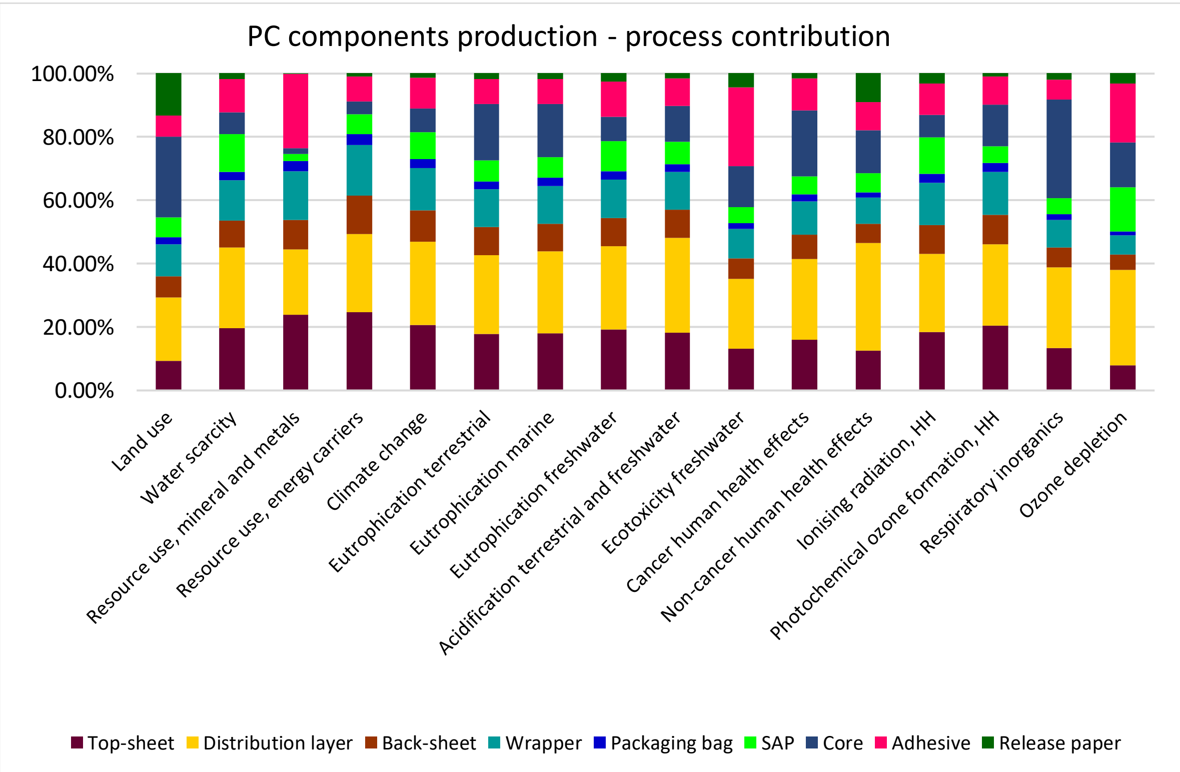

Figure 22. Conventional pad components contribution to the components production impact

5.1.5 Organic cotton pads (PO)

Figure 23 shows that the production of raw materials has the strongest influence on the results of the organic pad life cycle. This influence is created by the production of organic cotton noils, especially in the categories *land use*, *terrestrial*, *marine and freshwater eutrophication*, *acidification*, *ecotoxicity freshwater*, and *respiratory inorganics*. The contribution of manufacturing comes from electricity consumption and affects *water scarcity*. Distribution, shopping trip, and end-of-life have a similar effect on the results, depending on the impact category.

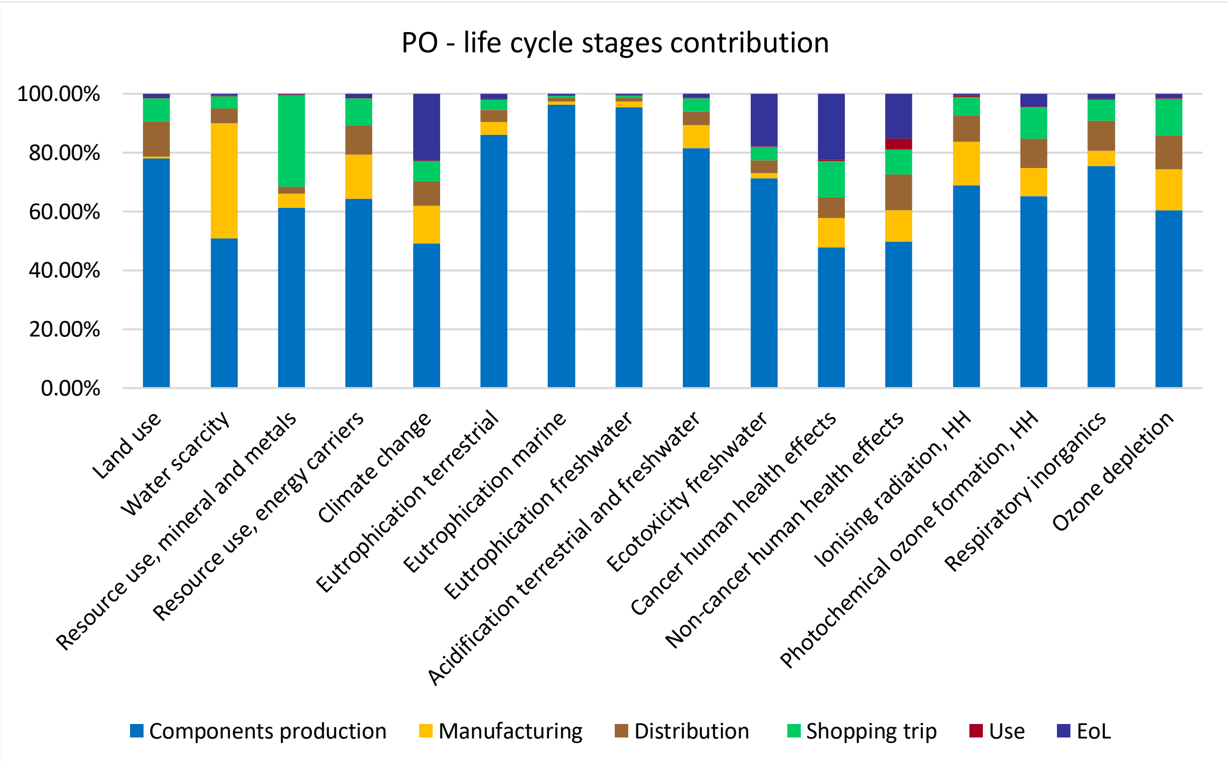

Figure 23. Life cycle stages contribution of the overall impact of organic pads

Figure 24 shows the processes contributing to the components' production. Although the core of the pad is the component which contributes most, the bioplastic also has a relevant contribution, especially to the categories of *water scarcity*, *resource use energy carriers*, *ionizing radiation*, and *ozone depletion*. The reason for this is the energy consumed for the production of bioplastic. The relevant contribution of the adhesive to *resource use, minerals and metals* is due to the production of epoxy resin.

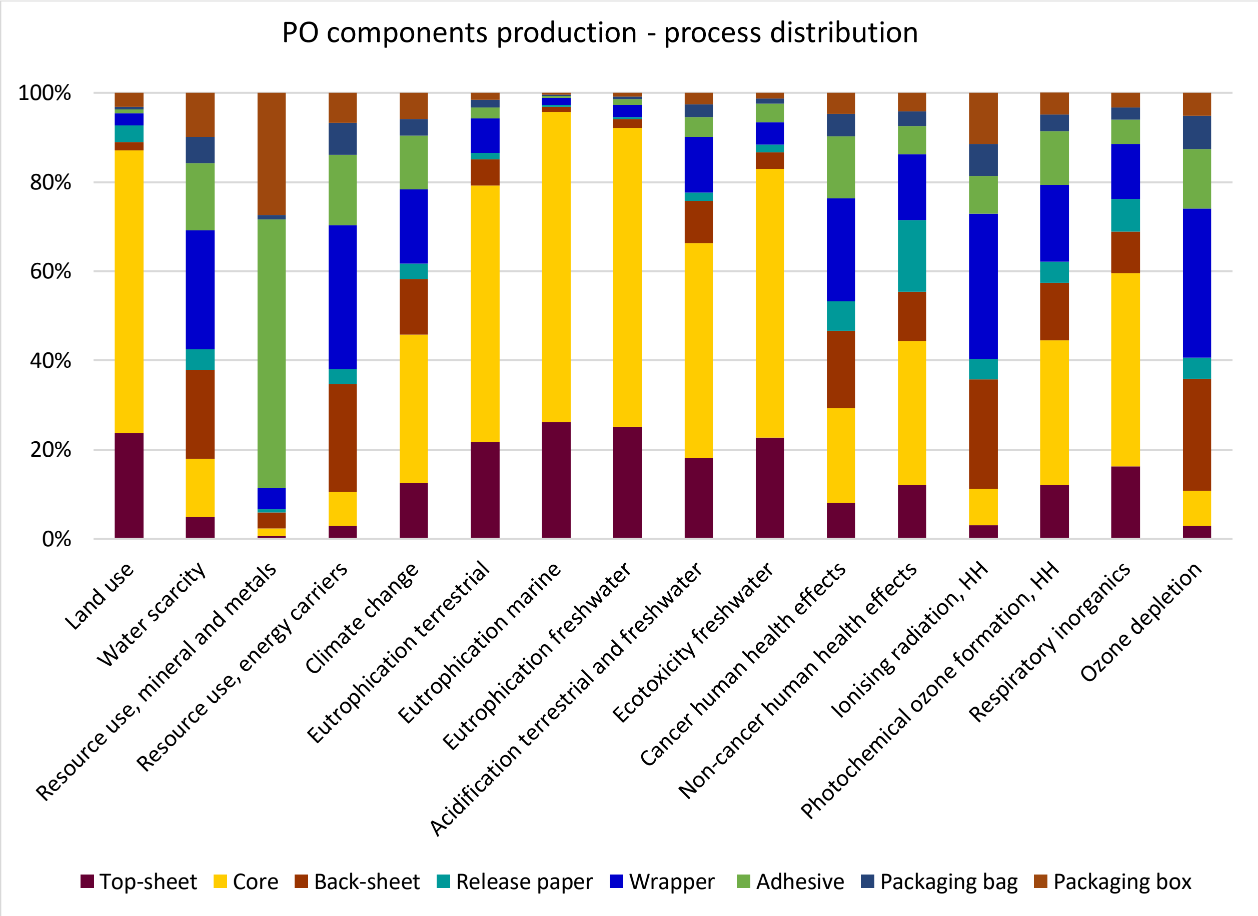

Figure 24. Organic pad components contribution to the impacts of components production

5.1.6 All products: manufacturing, distribution, shopping trip, and end-of-life

The understanding of the impacts from the life-cycle stages of manufacturing, distribution, shopping trip, and end of life is very similar for all products.

- During manufacture, the consumption of electricity is the most relevant process as displayed in Table 28. It is especially relevant for the impact categories of *water scarcity*, *ionizing radiation*, and *eutrophication freshwater*. Within the remaining contribution (up to 100%), the waste treatment, mainly incineration, is responsible for almost all of the remaining impacts. These processes are more relevant for the menstrual cup due to the low energy needed for its manufacture; however, their contribution to the overall results is very low.

Table 28. Contribution of electricity consumption to the manufacturing impacts

Impact category	MC	TC	TO	PC	PO
Land use	30.56%	86.07%	90.46%	80.97%	71.88%
Water scarcity	93.55%	99.38%	99.76%	99.85%	99.58%
Resource use, mineral and metals	82.99%	97.48%	94.50%	98.80%	99.35%
Resource use, energy carriers	89.57%	80.17%	78.39%	96.32%	85.68%
Climate change	15.48%	69.17%	72.01%	83.30%	74.79%
Eutrophication terrestrial	50.05%	82.33%	85.14%	94.75%	90.18%
Eutrophication marine	40.85%	79.25%	85.94%	85.51%	70.79%
Eutrophication freshwater	98.01%	97.78%	98.72%	100.00%	95.56%
Acidification terrestrial and freshwater	63.88%	84.59%	95.07%	96.68%	91.22%
Ecotoxicity freshwater	2.58%	50.89%	63.69%	44.04%	47.65%
Cancer human health effects	16.85%	76.56%	87.41%	76.49%	77.78%
Non-cancer human health effects	30.29%	85.44%	87.39%	91.10%	86.45%
Ionizing radiation, HH	96.82%	99.17%	99.08%	99.83%	97.92%
Photochemical ozone formation, HH	40.85%	79.37%	85.71%	93.38%	87.83%
Respiratory inorganics	41.73%	62.46%	72.29%	79.24%	80.39%
Ozone depletion	65.48%	65.54%	56.23%	92.20%	86.24%

- The most relevant processes of the distribution phase are the transport to retailers, and the cardboard production used for transportation (the plastic film and the EUR-pallet create a very low contribution, under 1%). The impacts of transport are influenced by the transported weight, which includes both the menstrual products and the secondary packaging (mainly cardboard). Specifically, the influence of the menstrual products' weight amounts to 79% for menstrual cups, 86% for organic pads; 80% for conventional pads; 93% for conventional tampons; and 88% for organic tampons. The weight of the secondary packaging plays a minor role.
- Within the shopping trip, the use of a car to drive to the shop clearly dominates the impacts of this stage. Its strongest influence is on *resource use, minerals and metals*, due to the use of nylon for the production of the car glider.
- All products are incinerated at the end-of-life stage, and the packaging partially recycled, as explained in Table 25. The process of municipal solid waste (MSW) incineration contributes most to the end-of-life of single-use products, while plastic incineration is the most relevant end-of-life process for the menstrual cup. The categories most affected by MSW incineration are *climate change*, *ecotoxicity freshwater*, and *cancer human health* effects.

5.2 Comparison of the menstrual products

This section presents and compares the overall results (section 5.2.1), the stages of the life cycle (5.2.2), and the comparison of the core materials of the single-use products (5.2.3). Based on the information obtained, it is possible to provide a detail explanation of the results' comparison for every impact category (5.2.4).

5.2.1 Overall results

The overall environmental impacts (named baseline results) of the menstrual products, including the cooker and kettle scenarios, are presented in Table 29 and classified from the lowest to highest. A colour scale, from green (lowest impact) to red (highest impact) is applied to indicate the level of impact. For example, for the impact category of *land use* it is observed that the cup in both scenarios shows a similar result, as well as the conventional tampons and pads, and the organic tampons and pads.

The menstrual cup (MC) creates the lowest impact in 15 out of 16 categories in the kettle scenario, and in 13 out of 16 in the cooker scenario. In contrast, the organic pad (PO) shows the highest impact in 12 out of 16 impact categories. Among the conventional tampons (TC), the organic tampons (TO), and the conventional pads (PC), the best environmental performance varies depending on the impact category. It is difficult to assert which product of the three is the best from an environmental point of view. Additionally, depending on the context, some impact categories may be more relevant than others, and therefore the level of impact may be different depending on the categories considered. In the next sections, the results are studied in detail to understand the impact level.

Figure 25 and Figure 26 provide a relative comparison of the products' impacts for the cooker and kettle scenarios, respectively. The product creating the highest impact is presented as 100% contribution.

Table 29. LCIA baseline results and impact level

Impact category	MC, cooker Scenario	MC, kettle Scenario	TC	TO	PC	PO	Unit
Land use	1.06E+00	7.62E-01	1.13E+01	3.87E+01	9.52E+00	4.51E+01	Pt
Water scarcity	3.60E+02	2.06E+02	9.63E+02	8.56E+02	8.63E+02	1.02E+03	m3 depriv.
Resource use, mineral and metals	3.52E-09	3.11E-09	1.30E-08	6.46E-09	1.67E-08	1.41E-08	kg Sb eq
Resource use, energy carriers	3.02E+01	1.76E+01	7.58E+01	4.31E+01	9.97E+01	9.30E+01	MJ
Climate change	2.20E+00	1.25E+00	5.87E+00	5.01E+00	5.99E+00	8.84E+00	kg CO2 eq
Eutrophication terrestrial	2.00E-02	1.33E-02	6.21E-02	1.72E-01	5.42E-02	2.20E-01	mol N eq
Eutrophication marine	7.47E-03	6.68E-03	9.96E-03	8.67E-02	5.54E-03	8.95E-02	kg N eq
Eutrophication freshwater	2.30E-03	9.66E-04	2.34E-03	1.34E-02	1.89E-03	1.39E-02	kg P eq
Acidification terrestrial and freshwater	8.22E-03	5.50E-03	3.62E-02	4.95E-02	2.44E-02	6.23E-02	mol H+ eq
Ecotoxicity freshwater	4.22E+00	3.92E+00	1.01E+01	2.55E+01	7.61E+00	3.00E+01	CTUe
Cancer human health effects	5.30E-08	4.24E-08	9.04E-08	7.07E-08	6.79E-08	9.16E-08	CTUh
Non-cancer human health effects	6.96E-07	5.98E-07	2.07E-06	1.58E-06	6.57E-07	1.26E-06	CTUh
ionizing radiation, HH	3.22E-01	1.57E-01	7.24E-01	4.61E-01	6.73E-01	6.87E-01	kBq U-235 eq
Photochemical ozone formation, HH	4.20E-03	2.93E-03	1.72E-02	1.38E-02	1.85E-02	2.37E-02	kg NMVOC eq
Respiratory inorganics	5.22E-08	4.09E-08	3.70E-07	3.09E-07	2.59E-07	4.70E-07	disease inc.
Ozone depletion	1.42E-07	1.05E-07	8.02E-07	3.23E-07	4.55E-07	9.28E-07	kg CFC11 eq
The colour scale indicates the level of impact – from green (lowest impact) to red (highest impact) Additionally, the colour scale helps the understanding of how far the values are from each other; the more similar the colour, the closer the values are							

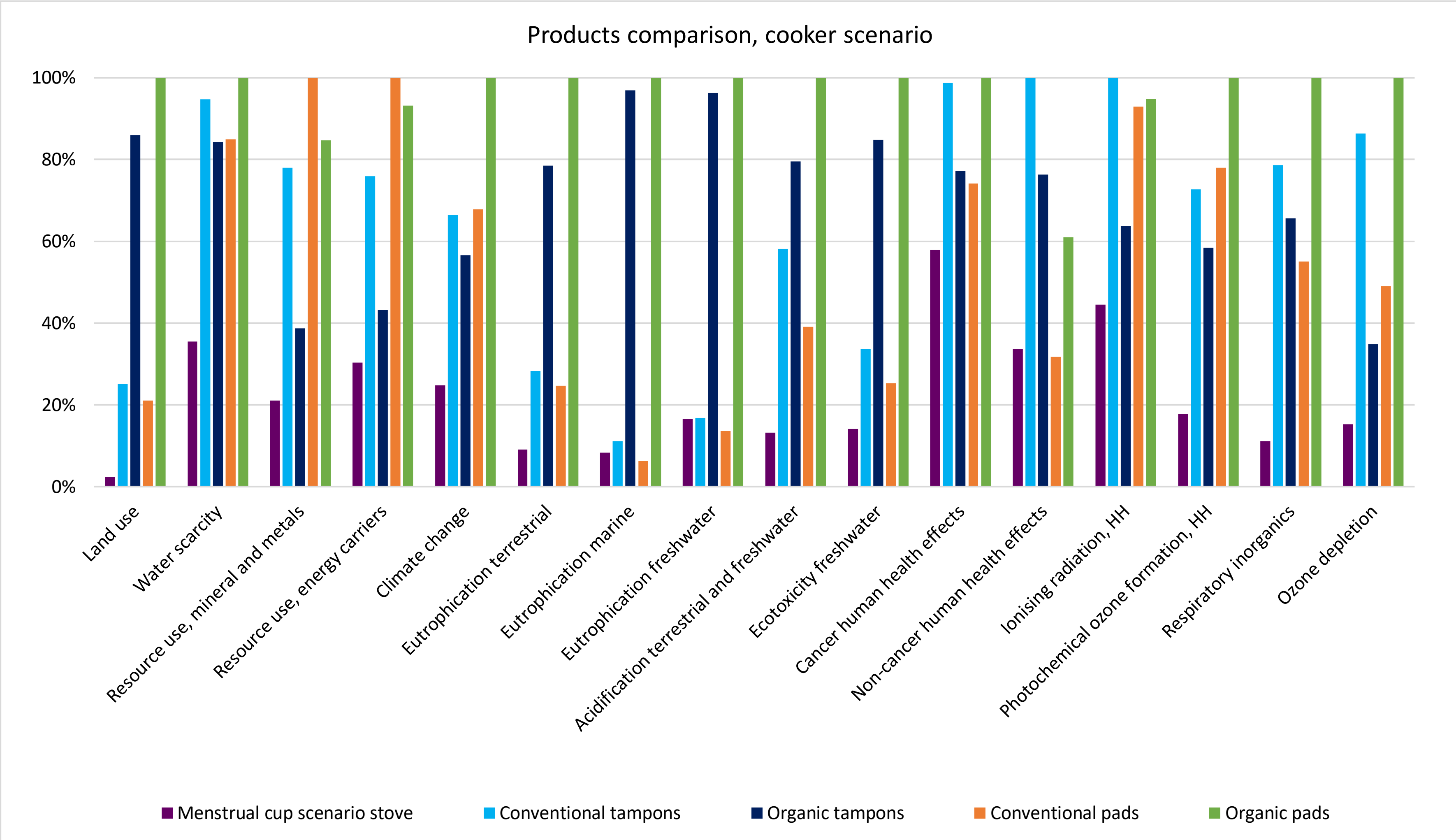

Figure 25. Relative comparison of menstrual products overall impacts – cooker scenario

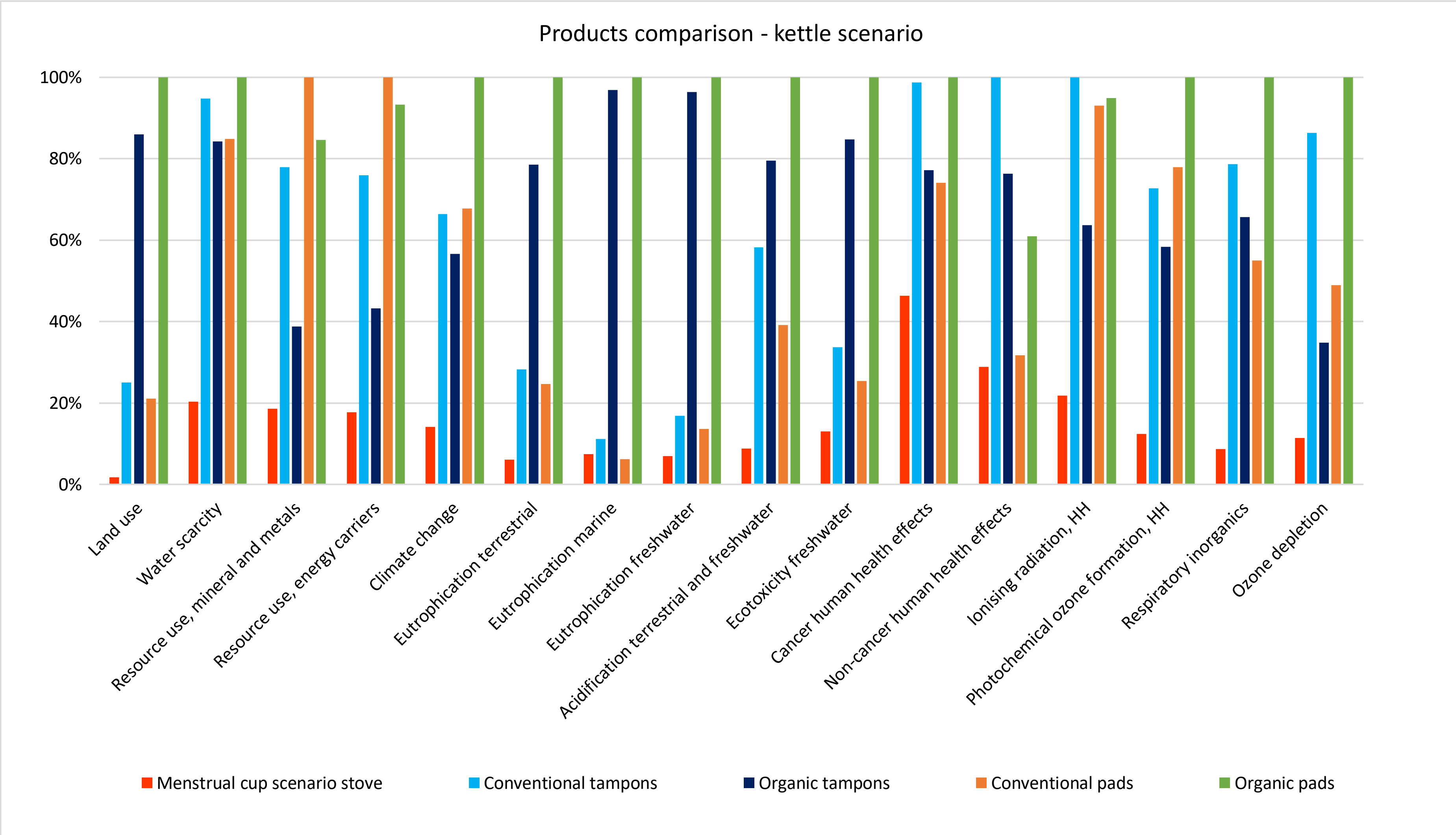

Figure 26. Relative comparison of menstrual products overall impacts – kettle scenario

5.2.2 Life cycle stages comparison

In this section, the results are compared for each life-cycle stage to support understanding of the comparison of the overall results.

- Figure 27 shows the relative comparison of the impacts of the production of the components. The cup creates the lowest impact because of its reusability – only 1/5 of the cup is needed to fulfil the functional unit (5 years lifetime). The organic pad, on the other hand, presents, in general, the highest impacts due to the production of organic cotton, and bioplastic for packaging. For the impact categories of *land use*, *terrestrial*, *marine*, *freshwater eutrophication*, *acidification and freshwater ecotoxicity*, the impact of organic cotton explains the results for the organic pad and the organic tampon. For the remaining categories, the impact of the organic pad is also strongly influenced by the production of bioplastic. This can be easily identified by comparing the impacts of the organic tampon and the organic pad – if the components production of the organic tampon shows a significantly lower impact than the organic pad, it means that bioplastic production has a strong influence on the organic pad (e.g. *ozone depletion*).

  For the impact categories which are less affected by the production of organic cotton, the organic tampon presents, in general, lower impacts than PC. In contrast, the conventional tampon components production creates a higher impact compared to conventional pad on 11 categories.
- Although the PO consumes the amount of highest energy for manufacturing, followed by PC, TC, and TO (see Table 16), it does not always show the highest impact as displayed in Figure 28. The reason is that both the amount of electricity and the composition of the mix is relevant. It is observed that the impact of TC is always higher than PC since the selected EU electricity mix is the same for both products. Nevertheless, this comparison is not possible for TO and PO. Despite the differences observed in the figure, the impact of manufacturing is not decisive for the overall result since other stages are more relevant.
- As expected, the use phase of the MC presents the highest impact on most of the categories (Figure 29) followed by tampons. Since the input for the use phase of pads only requires a small amount of toilet paper, the impacts are negligible for the comparison. For the impact categories that are more influenced by electricity consumption, the difference between the MC and the tampons' impact is higher. If hand-washing is the most relevant

process, the difference is smaller. The impact of tampons is higher for 3 categories due to the influence of toilet paper production.

- For the life-cycle stages distribution, shopping trip, and end of life, the cup always shows the lowest impact, followed by the conventional tampons, organic tampons, conventional pad, and organic pad (PO>PC>TO>TC>MC). This level of impact corresponds to the weight of the products per functional unit, from the lowest to the highest. The distribution distance is the same for single-use products, only the weight is different (see section 4.4). The shopping trip impact is not only influenced by weight, but also by the number of shopping trips. This number is lower for conventional products because more items are sold per package, and therefore fewer shopping trips are needed to purchase the same number of items (see section 0). Regarding EoL, the greater the weight, the stronger are the incineration impacts (see Table 25). Since the end-of-life modelling is simplified (as explained in section 4.7), the results from incineration depend on the amount of waste without considering the water content of the different products, which would influence the results.

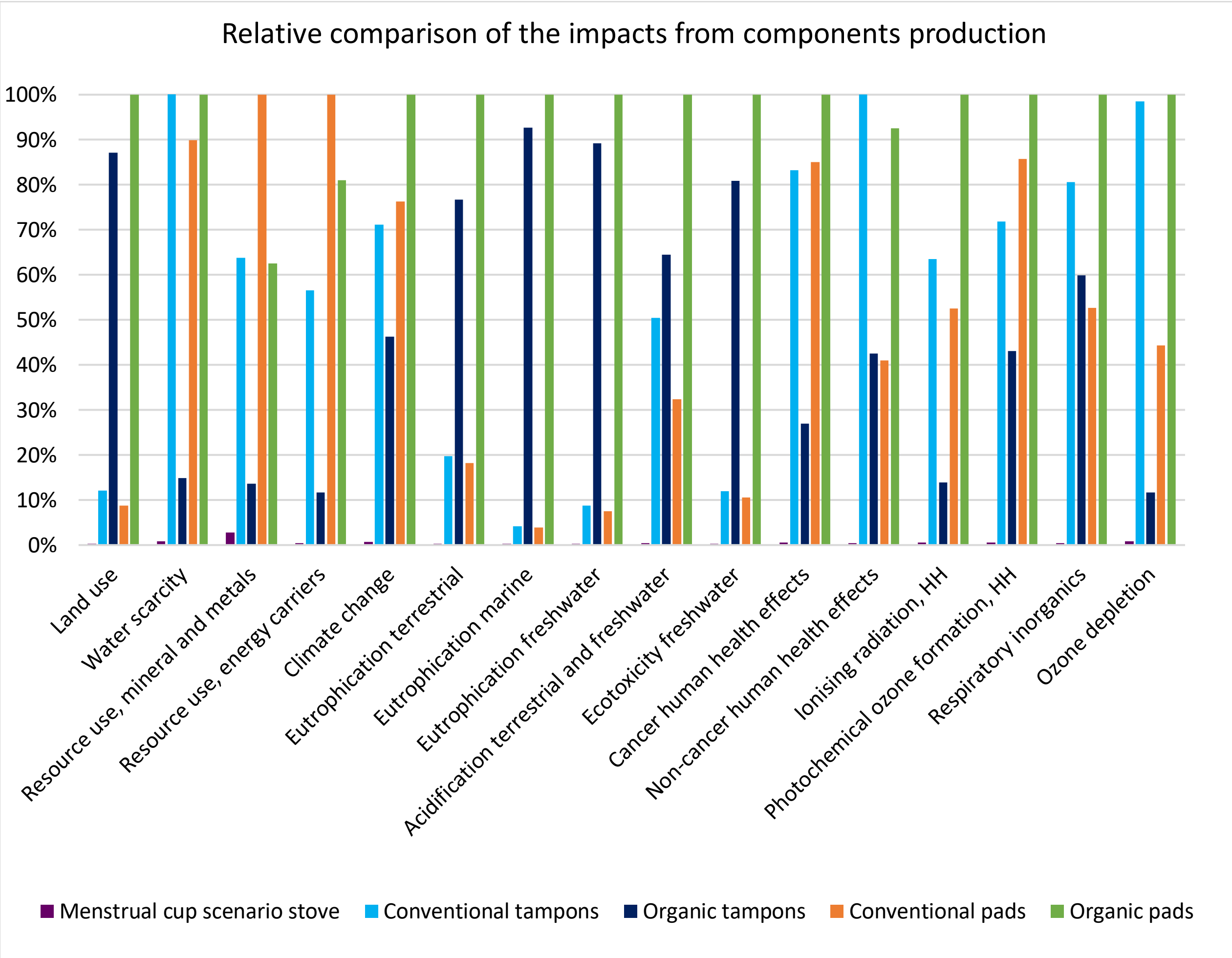

Figure 27. Relative comparison of the life-cycle stage components production

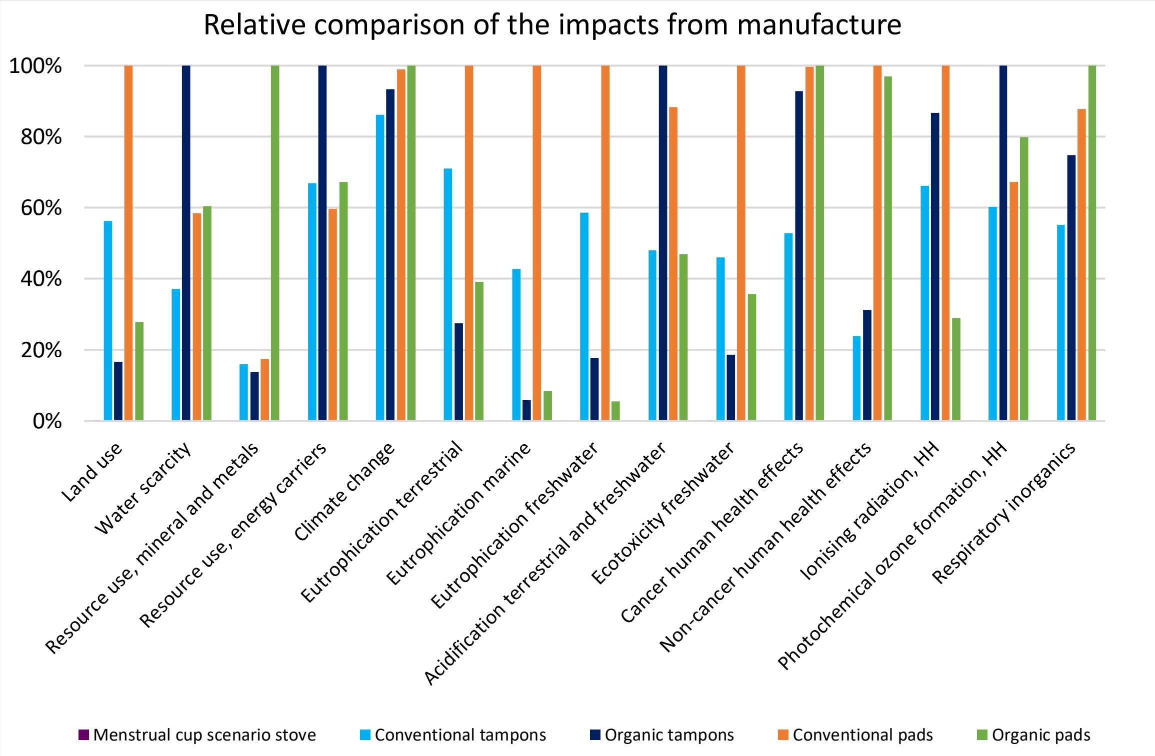

Figure 28. Relative comparison of the life-cycle stage manufacturing

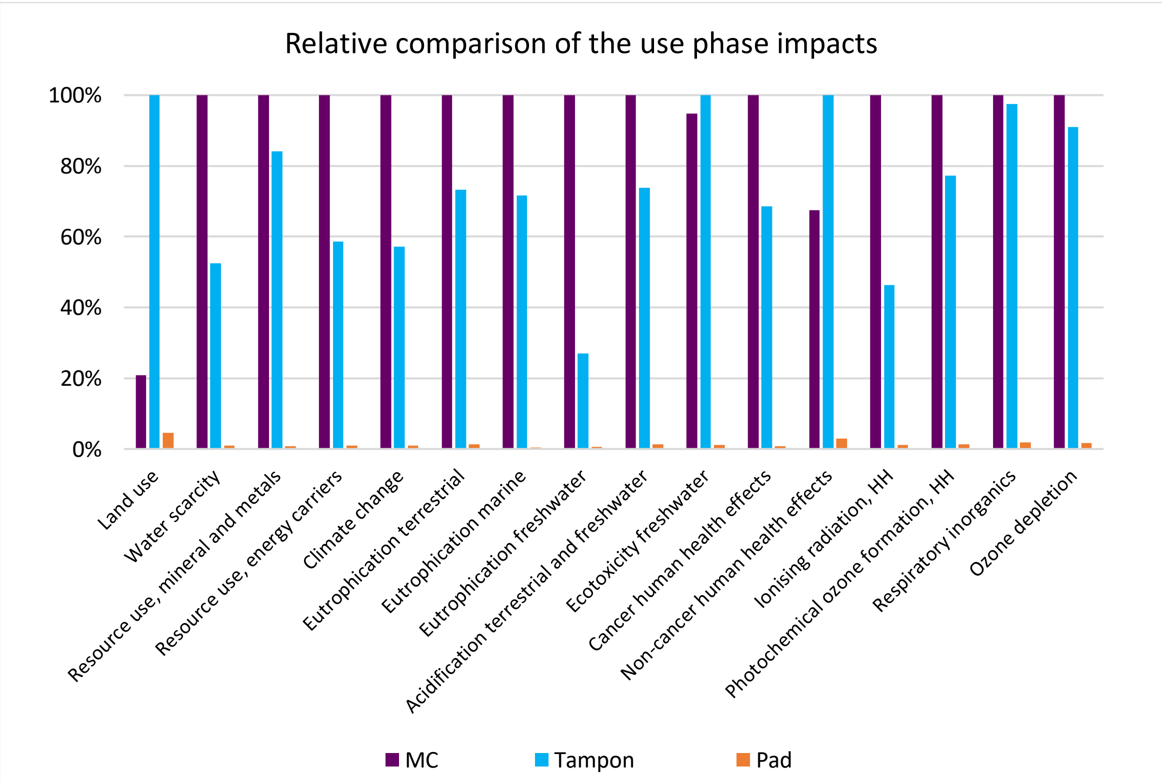

Figure 29. Relative comparison of the life cycle stage use

5.2.3 Influence of the core materials

Because of the relevance of the production of components, and especially of the core production, to the overall impacts, the materials used are compared. This provides clarity on whether the impacts are mainly influenced by the intrinsic environmental impacts of the core materials, or by other factors. Since the production of components for menstrual cups is not relevant as it is a reusable product, it was not included in this analysis. The impacts of producing 1kg of the following materials are calculated:

- Viscose (TC)
- Organic cotton fibre (TO)
- Organic cotton noils (PO).
- Fluff pulp, SAP, and distribution layer (PC)

Figure 30 shows the relative results – the material creating the highest impact is represented as 100%.

The materials for tampons, viscose for TC (worst impact on 8 categories), and organic cotton fibre for TO (worst impact on 6 categories) create the greatest impacts. The materials for PC (worst impact on 2 categories) and the organic cotton pad show, in general, lower impacts than the core materials used for the conventional and organic tampons, respectively.

When comparing organic cotton noils (PO) with fibres (TO), the former show lower impacts in 9 out of 16 categories. The reason is that the noils are a by-product, so the allocated impacts are lower than for the main product (see Figure 13). Compared to fibre production, to obtain the noils an additional process is needed: combing of the fibres. Hence, the impacts from noils are higher for some categories. These categories are those affected by electricity consumption (used for combing) rather than by cotton production.

If the conventional products are compared to the organic ones, the first show greater impacts on 10 categories. This means that organic cotton itself creates, in general, fewer impacts.

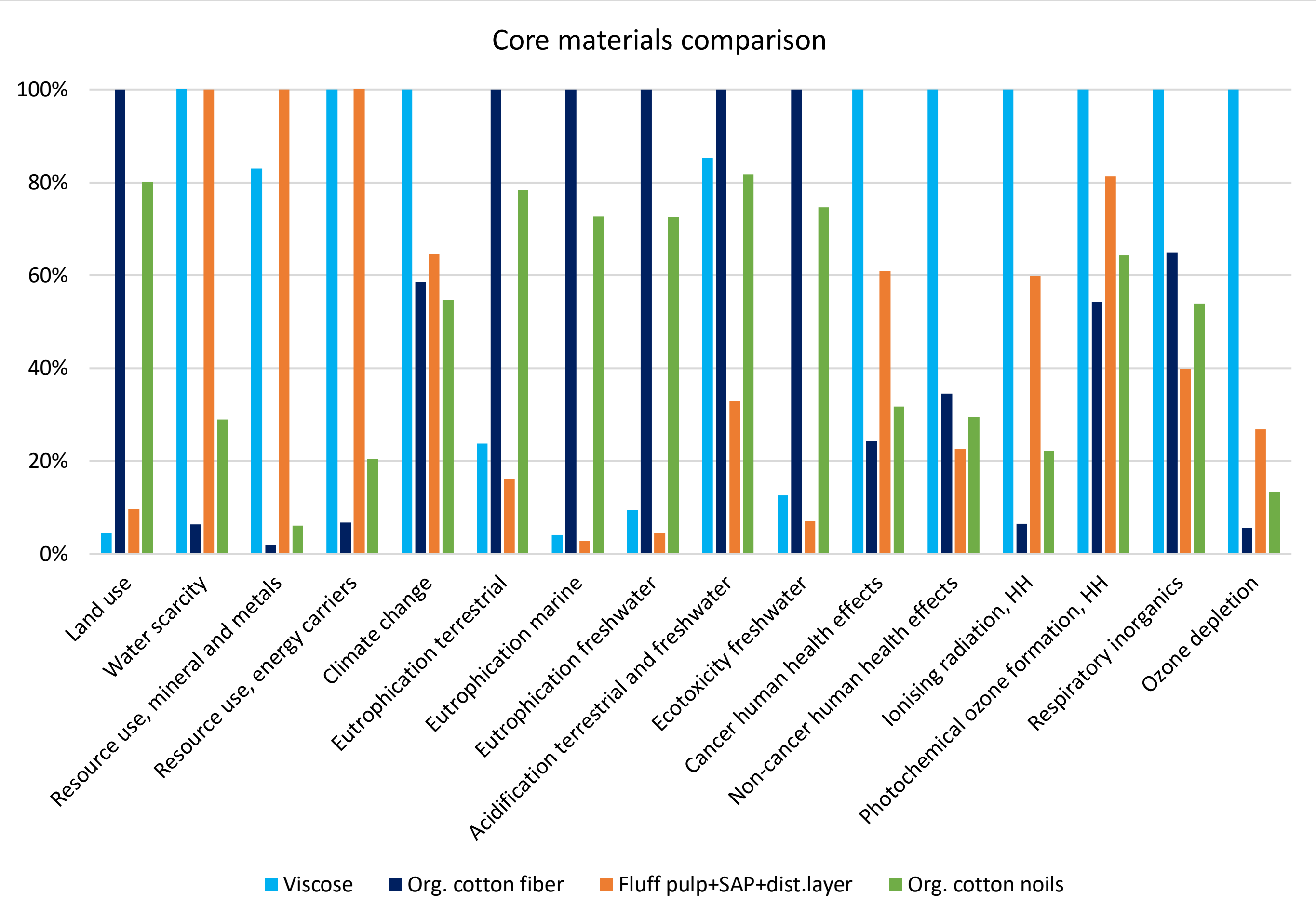

Figure 30. Comparison of the core materials impact of the single-use products: calculated for 1kg of produced material

5.2.4 Comparison of environmental impact

In this section, each impact category is analysed in detail, including (i) the elementary flows with a contribution to the overall impacts > 10%, (ii) the type of processes that are relevant for the selected flows, and (iii) the explanation of the results with the focus on understanding the different impact levels.

In the tables presenting the elementary flows, the type of flow is indicated – 'resource' if it is an input, and 'emissions' to air, water, and soil if it is an output. The type of processes that are relevant for the results, where the identified flows are inputs (resources) or outputs (emissions) are also displayed in the tables.

Energy production processes, including heat and electricity production, are often the main contributors to the impacts. From the materials used in menstrual products, including the use phase, some require a significant amount of energy for their production. Thus, they are the main contributors to the impact when energy production is a relevant process. These materials are:

- Soap for hand washing
- Toilet paper for the disposal of the product
- Viscose for TC
- Fluff pulp, viscose, and plastic for PC
- Bioplastic for PO

The effect of the emissions created in transport processes always follows the same structure – the impact of PO>PC>TO>TC. The reason is that the impact is higher if the product is heavier (see Table 18 for distribution weight). Additionally, the impact is higher if less items are sold per package (see Table 20).

Land use

As presented in Table 30, the impact on *land use* is influenced by harvesting (for organic cotton and paper production), transportation, and heat production processes. A negative value appears for the flow "occupation, dump site" since the use of an area where a dump is located, is considered positive for the *land use* impact.

Table 30. Elementary flows impact on land use (flows contributing > 10%)

Flow		Contribution to the overall impact					Consumed by
Name	Type	MC	TC	TO	PC	PO	
Occupation, dump site	Resource	-36%	-16%		-14%		Heat production
Occupation, mineral extraction site		13%					Heat production
Occupation, traffic area		60%	56%	27%	81%	27%	Heat production & transport
Transformation, to arable land, unspecified use			33%	71%	17%	71%	Paper production & org. cotton harvesting

As displayed in Figure 31, the impact for MCs is significantly lower than the other products because the transport and harvesting impacts are negligible (due to MC reusability), and electricity is hardly relevant for this category, which is reflected in low relevance of manufacturing for all products. Sterilization of the cup is the main contributor to the MC impact.

In contrast, organic pads create the highest impact, followed by TO, mainly due to the significant contribution by organic cotton harvesting. The transport for distribution and shopping trip contributes more to the impact for the pads than the tampons. The impact of the production of component for CPs, and the TC, are caused, in the main by the transport of materials. The use phase of tampons is identical for TC and TO and relevant due to the land occupation for the production of toilet paper.

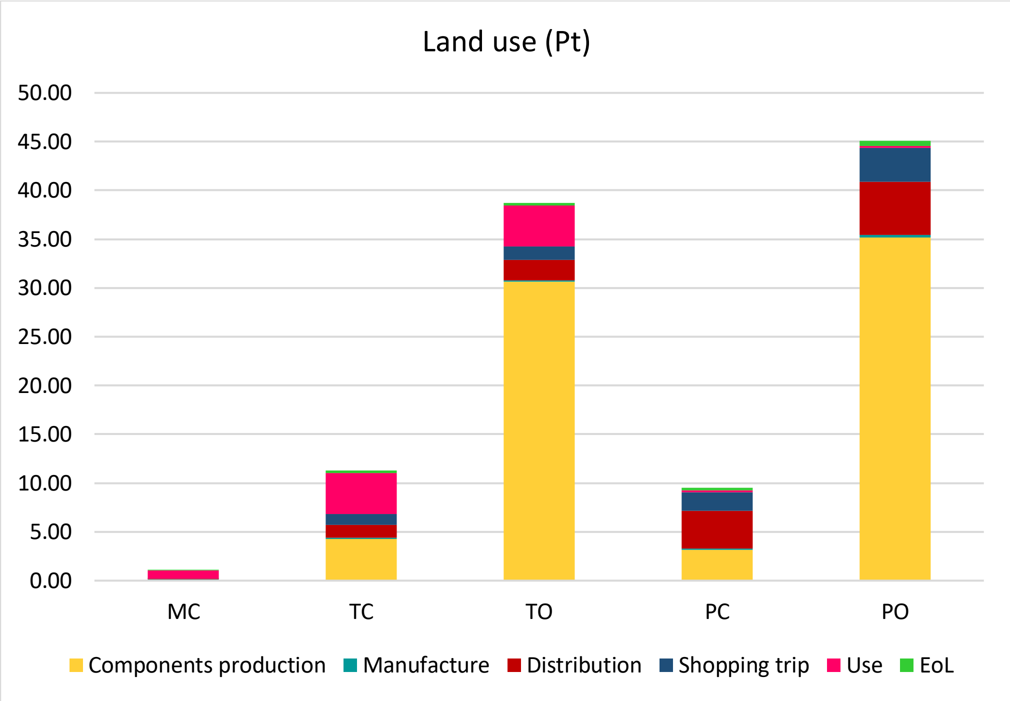

Figure 31. Land use overall results including the life cycle stages results

Water scarcity

Water scarcity is influenced by the elementary flow "water for turbine use", which is needed for electricity production from hydropower. This means that the products more strongly influenced by the production of electricity, show higher impacts. Depending on the presence of hydropower, the mix of electricity also influences the results.

Despite the electricity consumption required for sterilization, MC presents the lowest impact due to the low relevance of the other stages (see Figure 32). Viscose (TC) and plastic (PC) production require more energy for manufacture than organic products. However, the bioplastic production is responsible for the relevance of the production of PO components. Because the hydropower share in the electricity mix of the country where TO are produced is higher compared to the other products, the manufacturing impact is higher. The production of soap and toilet paper also requires a relevant amount of energy as observed in the TC and TO results.

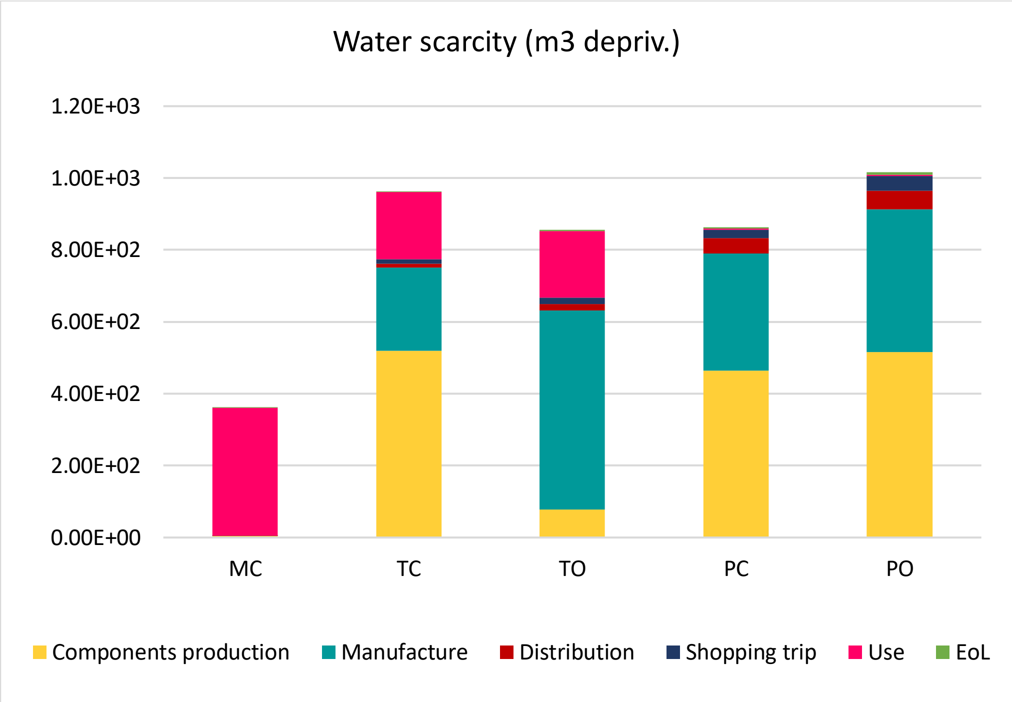

Figure 32. Water scarcity overall results including the life cycle stages results

Resource use, minerals and metals

The elementary flow "sulphur from ground" creates almost 100% of the impact on *resource use, minerals and metals*. The production of ethylene-based plastics, viscose, adhesive, the car used in the shopping trip (nylon for fibre-glass used for the car structure), and chipboard (packaging) are the main processes requiring an input of sulphur.

As observed in Figure 33, the contribution of the PC components production is very relevant due to the production of plastic and adhesive. Also, adhesive production, combined with the packaging box, influences the components production's result for PO. The contribution of viscose and the production of the packaging box are the main drivers of the TC impact. Additionally, the production of the soap packaging and tap water are relevant for the use phase of the tampons and the MC. The majority of impact for the MC is from its use, while the production of silicone plays a minor role. The car production impact used for the shopping trip is higher if the product is heavier and a lower number of items is sold per package (see Table 20).

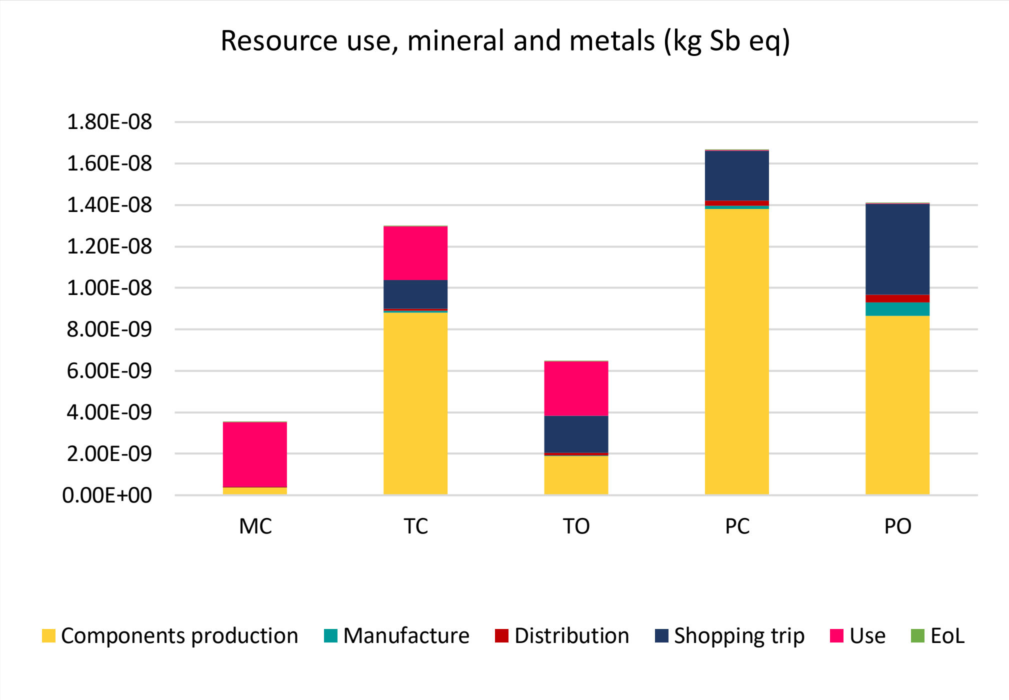

Figure 33. Resource use, mineral and metals overall results including the life cycle stages results

Resource use, energy carriers

This impact category is highly influenced by the use of energy carriers, namely coal, gas, oil and uranium, as displayed in Table 31. These flows are used in energy production processes – electricity and heat production – and processes requiring a high amount of energy – plastic, viscose, and bioplastic production. Crude oil is also used for transportation.

Table 31. Elementary flows impact on Resource use, energy carriers (flows contributing > 10%)

Flow		Contribution to the overall impact					Consumed by
Name	Type	MC	TC	TO	PC	PO	
Coal, brown, in ground	Resource	21%					Electricity prod.
Coal, hard, unspecified, in ground		20%	24%	11%	14%	15%	Energy prod.
Gas, natural, in ground		22%	30%	29%	27%	34%	Energy & plastic prod.
Oil, crude, in ground		17%	25%	32%	43%	38%	Energy, plastic prod. & transport
Uranium, in ground		20%	15%	18%	12%	10%	Energy prod.

According to the relevance of electricity production, the use phase of MC presents a relevant impact, as presented in Figure 34, influenced by the sterilization, and the production of soap and its container. The tampons' use phase presents a lower impact than MC (no sterilization) and it is equally affected by the soap and toilet paper production.

The energy input to produce viscose is much higher than to produce organic cotton, and therefore the overall impact of TC is higher than TO. Nevertheless, the components production of PO is significantly higher than TO due to the energy needed to produce bioplastic. PC presents the highest impact, influenced by the production of plastic for its components.

The impact of manufacture is similar for the single-use products, a little higher for the pads because the energy consumption is higher. The impact of shopping trip and distribution is relevant for the pads, especially for OP.

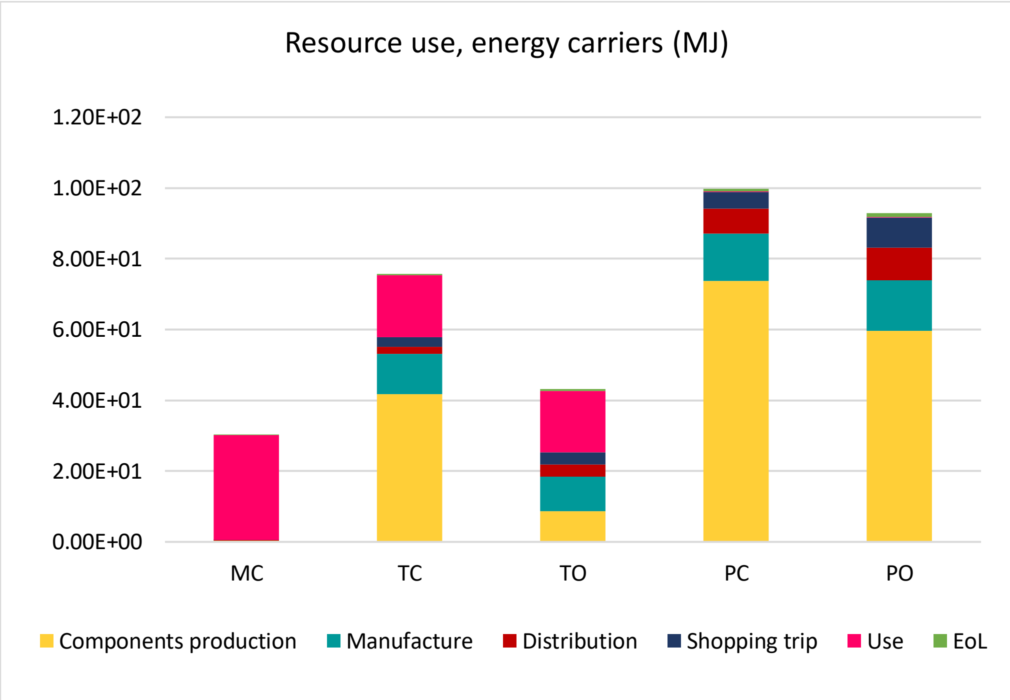

Figure 34. Resource use, energy carriers overall results including the life cycle stages results

Climate change

As observed in Table 32, fossil carbon dioxide emissions have the strongest influence on *climate change*. They are mainly created in energy production (electricity and heat) and the incineration processes. Additionally, transport processes also emit carbon dioxide, but are less relevant for menstrual products. Two important flows for the organic products are emitted during organic cotton farming – carbon dioxide, from soil or biomass stock, and dinitrogen monoxide.

Table 32. Elementary flows impact on climate change (flows contributing > 10%)

Flow		Contribution to the overall impact					Emitted by
Name	Type	MC	TC	TO	PC	PO	
Carbon dioxide, fossil	Air emissions	84%	88%	63%	86%	74%	Electricity prod., waste incineration & transport
Carbon dioxide, from soil or biomass stock				16%		9%	Org. cotton harvesting
Dinitrogen monoxide				13%		8%	Org. cotton harvesting

The flows identified in Figure 35 show that the use phase of the MC is by far the most relevant stage, and is dominated by the emissions from electricity production for sterilization, followed by soap production (liquid soap and packaging) and the incineration of soap packages. The emissions from viscose production (TC) are higher than from organic cotton production (TO) and responsible for the higher overall impact of TC compared to TO – The remaining stages show very similar results for both tampons. Hand-washing is the process which contributes the most to the use of tampons.

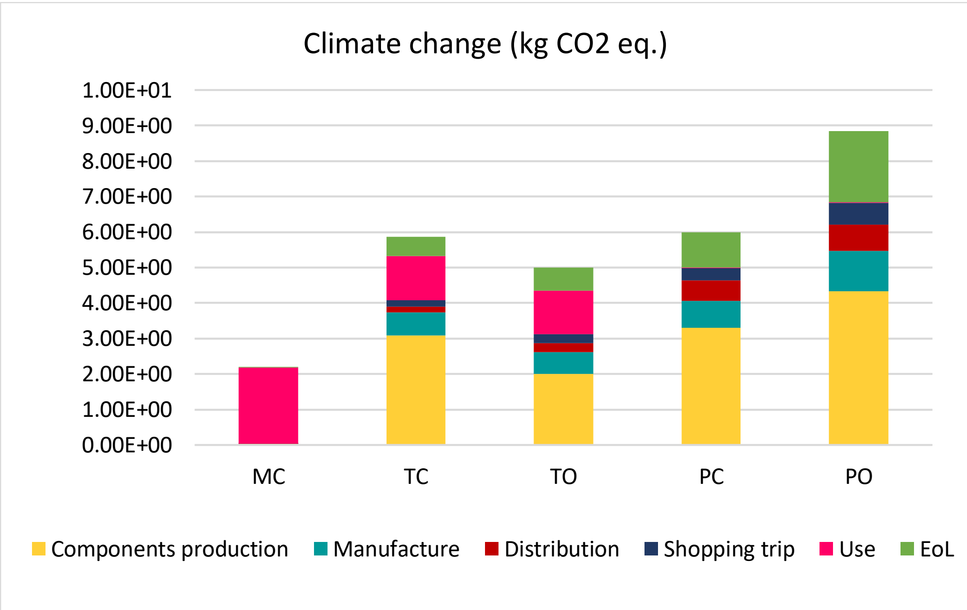

Figure 35. Climate change overall results including the life-cycle stages results

The production of the plastic for the PC core is relevant for the overall results and slightly higher (approx. 4%) than the impact from the core of PO, as displayed in Table 33. The influence of the bioplastic (high energy consumption) used for the back-sheet, wrapper, and packaging and cardboard packaging of POs, is responsible for the higher impact of the components production.

Table 33. Climate change impact comparison of the components production of PC vs PO

Product	Climate change impact (kg CO2 eq./FU)						
	Core	Back-sheet	Adhesive	Release paper	Wrapper	Packaging	TOTAL
PO	1.99[1]	0.54	0.52	0.15	0.72	0.41	4.34
PC	2.07[2]	0.33	0.33	0.06	0.44	0.09	3.31
PC/PO	104.02%	61.11%	63.46%	40.00%	61.11%	21.95%	76%

[1] Top-sheet & core
[2] Top-sheet & dist. Layer & core

Due to the higher energy consumption for the production of pads compared to tampons (Table 16), their manufacturing impact is also higher (PO>PC). Similarly, the end-of-life impact increases with the weight of the product (see Table 25), which is especially relevant for PO. Both the higher weight of the menstrual product, and also the wrapper, has a strong influence on the results.

According to the relevance identified of the incineration for PO, an estimation of the influence of the biogenic carbon content on the *climate change* result was performed. Since the carbon dioxide absorption during harvesting of organic cotton and maize (needed for the bioplastic) is not considered in the EF method, the biogenic content of both materials is considered in the incineration. The generic MSW incineration process from Ecoinvent considers a biogenic content of 61.10%, while the plastic incineration only contains fossil carbon. Considering that the biogenic carbon content of organic cotton is 90%, the calculated final content for PO MSW incineration is 61.8%, as shown in Table 34. In the case of the bioplastic incineration, a biogenic content of 30% (based on the Ecoinvent process for bioplastic production) is considered and compared to the 0% content of the generic plastic waste incineration process. The main change is created by the plastic incineration because the difference on the biogenic content compared to the generic Ecoinvent process is greater. The influence on the results amounts to 3.5%, i.e. it is low. Similarly, the emissions for TO were also modified with a lower influence on the impact of 1.41%. Thus, the Ecoinvent generic processes are adequate for the modelling.

Table 34. Influence of the biogenic content on the climate change impact

		Ecoinvent processes		PO modified processes		TO modified process
		MSW incineration	Plastic incineration	MSW incineration	Bioplastic incineration	MSW incineration
Biogenic carbon content		61.10%	0%	61.80%	30%	66.80%
Emissions (kg/FU)	Carbon dioxide, fossil	0.67	0.99	0.66	0.7	0.3
	Carbon dioxide, non-fossil	1.05	0	1.06	0.3	0.6
Reduction of the Climate change result				3.50%		1.41%

The biogenic carbon content of the menstrual products affects the emissions from incineration. Since the harvesting processes of organic cotton and maize (for bioplastic) do not consider biogenic carbon intake, it is not considered in the incineration process. A general content is assumed for all products as described in the background process for incineration (61%).

The emissions from transport are reflected in the shopping trip and distribution impact, which is more relevant for pads, especially the PO.

Terrestrial eutrophication

Table 35 shows the elementary flows being responsible for the impact on *terrestrial eutrophication* – ammonia and nitrogen oxides. The first one is often originated in cultivation and heat production (biogas) processes, while the second one in energy and chipboard (packaging) production, and transportation processes. The ammonia emissions of TO and PO are created, almost entirely in the cultivation of organic cotton.

Table 35. Elementary flows impact on terrestrial eutrophication (flows contributing > 10%)

Flow		Contribution to the overall impact					Emitted by
Name	Type	MC	TC	TO	PC	PO	
Ammonia	Air emissions	36%		72%		64%	Soap prod. & org. cotton harvesting
Nitrogen oxides		62%	85%	23%	92%	27%	Energy prod. & transport

The production of components is the most relevant stage of the impact of single-use products, as observed in Figure 36. with the lowest impact for the conventional pads. The higher ammonia emissions for organic cotton harvesting compared to viscose and plastic production (for TC and PC) cultivation explain this. The transport of the raw materials and components to the factory also influences this stage.

Regarding the MC, the nitrogen emissions from sterilization followed by the ammonia emissions from soap production (specifically coconut oil production needed in the soap) are the g processes which contribute most.

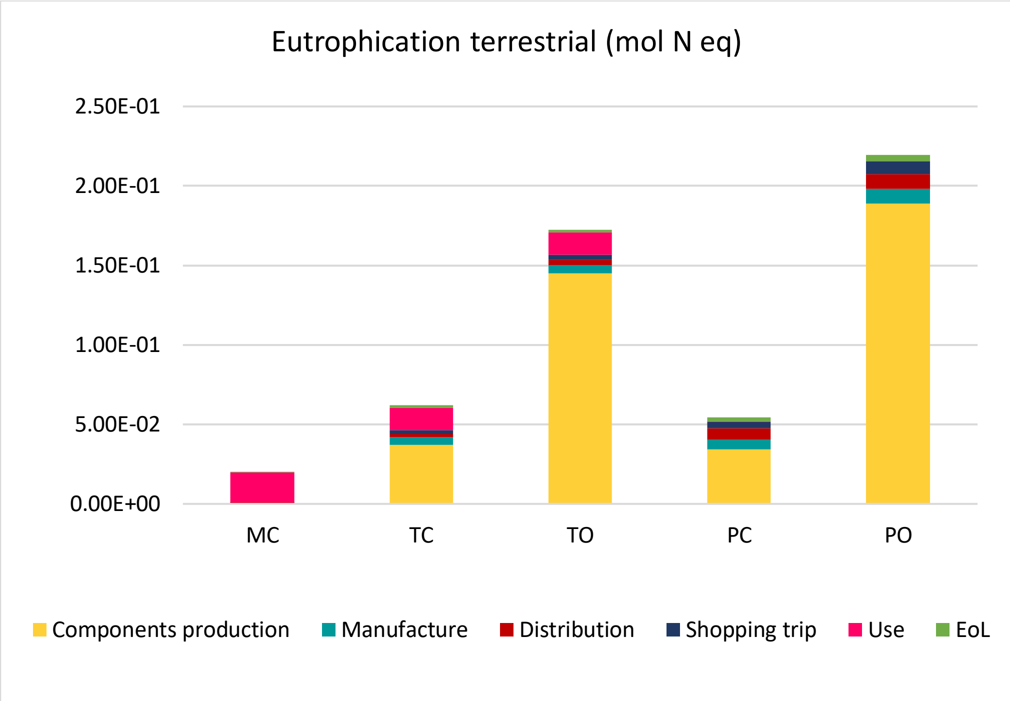

Figure 36. Eutrophication terrestrial overall results including the life cycle stages results

Marine eutrophication

Table 36 shows the elementary flows with a high influence on *marine eutrophication*. Nitrate and ammonium are mainly originated in wastewater treatment and organic cotton harvesting, while nitrogen oxides come from energy and plastic production, and transportation. The strong influence of nitrate from organic cotton (90%) production on *marine eutrophication* is the reason for the higher impact of TO and PO as observed in Figure 37.

Table 36. Elementary flows impact on marine eutrophication (flows contributing > 10%)

Flow		Contribution to the overall impact					Emitted by
Name	Type	MC	TC	TO	PC	PO	
Ammonium, ion	Water emission	29%	15%				Wastewater treatment
Nitrate		49%	30%	90%		90%	Wastewater treatment & org. cotton harvesting
Nitrogen oxides	Air emission		49%		82%		Energy & plastic production

The overall impact of PC is lower than MC due to the influence of the nitrate and ammonium emissions from the use phase of MC, specifically from the wastewater treatment process. Also, the production of coconut oil for the soap is relevant for the nitrate emissions. Nitrogen oxides is/are the most relevant flow of the conventional products' production due to the heat needed for producing viscose and the plastic present in PC.

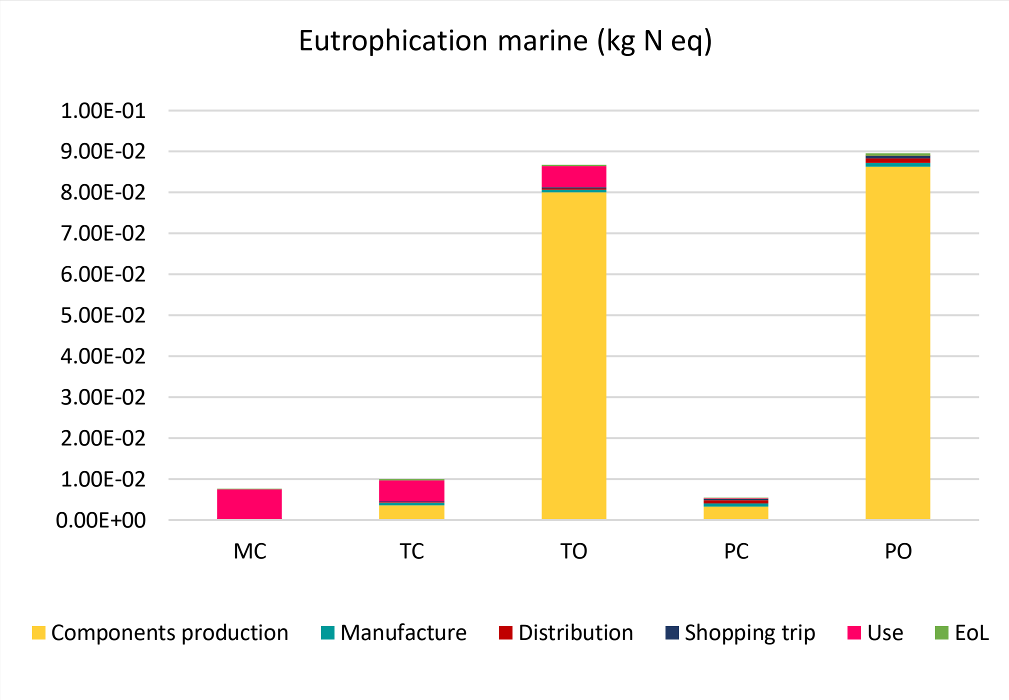

Figure 37. Marine eutrophication overall results including the life cycle stages results

Freshwater eutrophication

The water emissions with a relevant influence on *freshwater eutrophication* are presented in Table 37. Phosphate is mainly originated from electricity production from lignite (treatment of spoil from lignite mining), and at a lower level from wastewater treatment processes. The emissions of phosphorus from organic cotton cultivation are relevant for the impact from TO and PO, which is observed in Figure 38. The production of components dominates the overall results.

Table 37. Elementary flows impact on freshwater eutrophication (flows contributing > 10%)

Flow		Contribution to the overall impact					Emitted by
Name	Type	MC	TC	TO	PC	PO	
Phosphate	Water emissions	99%	98%	10%	97%	12%	Energy prod. & wastewater treat.
Phosphorus				85%		84%	Org. cotton

The electricity consumed to produce the components and to manufacture PC is the main contribution to the impact. This is similar for TC the input of electricity for the manufacture of tampons is lower and the impact of the use phase – mainly from wastewater treatment – is higher. Thus, the overall impact of TC is higher than PC. The electricity needed for the MC sterilization explains the higher impact of MC compared to PC, specifically from lignite. Additionally, the wastewater treatment impact also plays a relevant role in the MC impact.

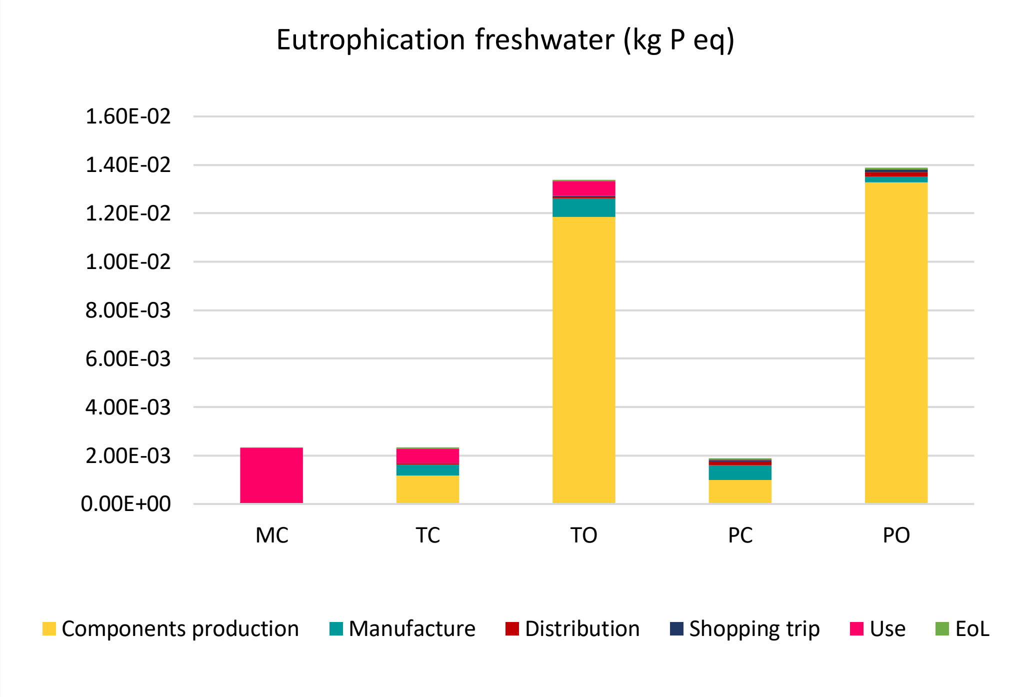

Figure 38. Freshwater eutrophication overall results including the life cycle stages results

Acidification terrestrial and freshwater

Three flows, presented in Table 38, are identified as the most relevant for the impact category of *acidification*. Sulphur dioxide is emitted in energy production processes (electricity and heat), while nitrogen oxides come from electricity, plastic and organic cotton cultivation processes, and ammonia from coconut production used in soap and organic cotton cultivation.

Table 38. Elementary flows impact on terrestrial and freshwater eutrophication (flows contributing > 10%)

Flow		Contribution to the overall impact					Emitted by
Name	Type	MC	TC	TO	PC	PO	
Ammonia	Air emissions	15%		56%		50%	Soap production & org. cotton harvesting
Nitrogen oxides		26%	16%	10%	36%	11%	Electricity & paper production
Sulphur dioxide		51%	64%	21%	57%	25%	Electricity & plastic production

The high contribution of ammonia emissions to the organic products can be observed in Figure 39. The impact of TO and PO is dominated by the production of components. The energy consumption to produce bioplastic for PO also influences the production of components. The impact of manufacturing of TO is higher than for the other products due to the selected electricity mix (heat and power co-generation). The production of soap for washing hands is the most relevant process within the tampons use phase. With menstrual cups, the use of soap is also relevant during use while the electricity for sterilization is the process which is most relevant.

Within the conventional products, viscose production for TCs creates a higher impact than fluff pulp and plastic production for conventional pads. This, combined with the higher use phase impact of TC, explains the lower impact of PC.

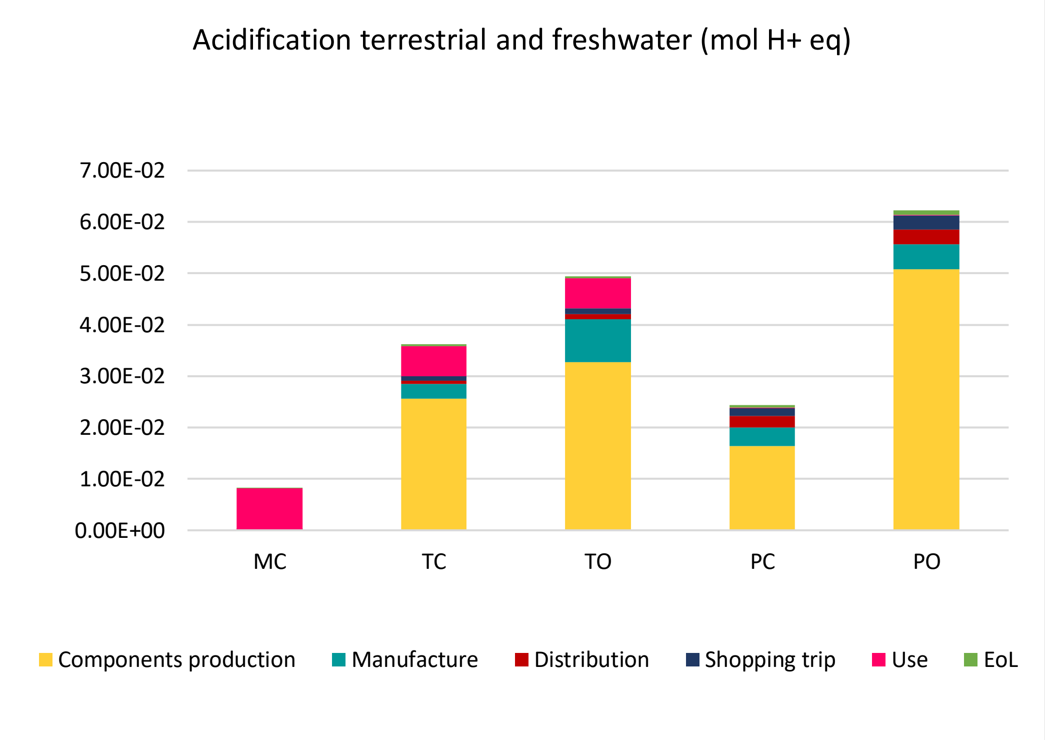

Figure 39. Terrestrial and freshwater acidification overall results including the life cycle stages results

Ecotoxicity freshwater

Many elementary flows have a relevant influence in the category *ecotoxicity freshwater* as presented in Table 39. Water emissions are the most relevant.

Table 39. Elementary flows impact on ecotoxicity freshwater (flows contributing > 10%)

Flow		Contribution to the overall impact					Emitted by
Name	Type	MC	TC	TO	PC	PO	
Antimony	Water emissions		25%	11%	50%	20%	Waste incineration
Pyrene		28%	12%				Soap prod.
Zinc, ion				36%		27%	Org. cotton harvesting
Copper, ion				24%		21%	Org. cotton harvesting
Cypermethrin	Soil emissions	16%					Soap prod.

Cypermethrin and pyrene are emitted during the production of coconut used in soap, and therefore, are relevant for the use phase of MC and in a lower level for tampons. The importance of the use phase is appreciated in Figure 40, especially for MC and TC.

The components production of conventional products is not relevant for this category since energy production is also not relevant. The use phase is the most relevant for TC, while the waste incineration is contributing the most for PC. In the case of TO, the impact of organic cotton harvesting is responsible for the strong relevance of the components production. The higher weight of PO, combined with the waste incineration impacts, explains the higher impact compared to TO.

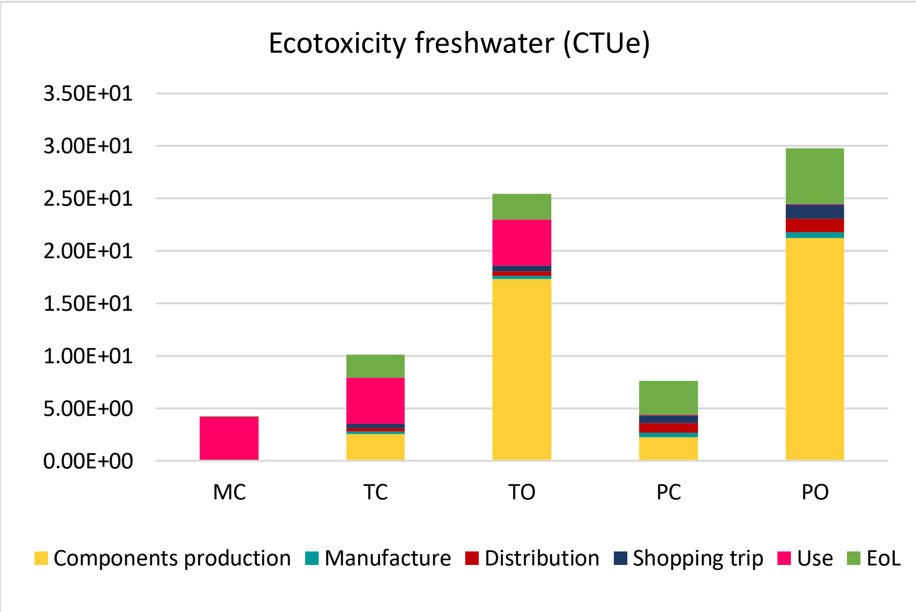

Figure 40. Freshwater ecotoxicity overall results including the life cycle stages results

Cancer human health effects

The emissions to water, air of chromium, and to air and soil of chromium VI, are the main contributors to *cancer human health effects*. As observed in Table 40, the emissions from wastewater treatment are important for this category.

Table 40. Elementary flows impact on cancer human health effects (flows contributing > 10%)

Flow		Contribution to the overall impact					Emitted by
Name	Type	MC	TC	TO	PC	PO	
Chromium	Air emissions		10%		12%	13%	Wastewater treatment, tap water & energy production
Chromium VI	Water emissions	73%	65%	69%	71%	61%	Wastewater treatment, waste incineration & energy production
Chromium VI	Soil emissions	11%					Electricity production

During the use phase of MC, the impact of wastewater treatment, followed by production of tap water and sterilization, is responsible for the overall result and the relevance of the use phase shown in Figure 41. The tampons' use phase impact is lower – less water and no electricity are needed compared to MC. The impact of the production of toilet paper is included.

The emissions from producing viscose for TC and plastic components for PC create a higher impact than emissions from organic cotton production because of the influence of energy consumption. This is reflected in the lower impact of the TO components production. The influence of the emissions from bioplastic production is responsible for the higher impact from the components production of PO. The incineration of PO is also higher compared to the other single-use products due to the greater weight of the product, the wrapper, and the packaging.

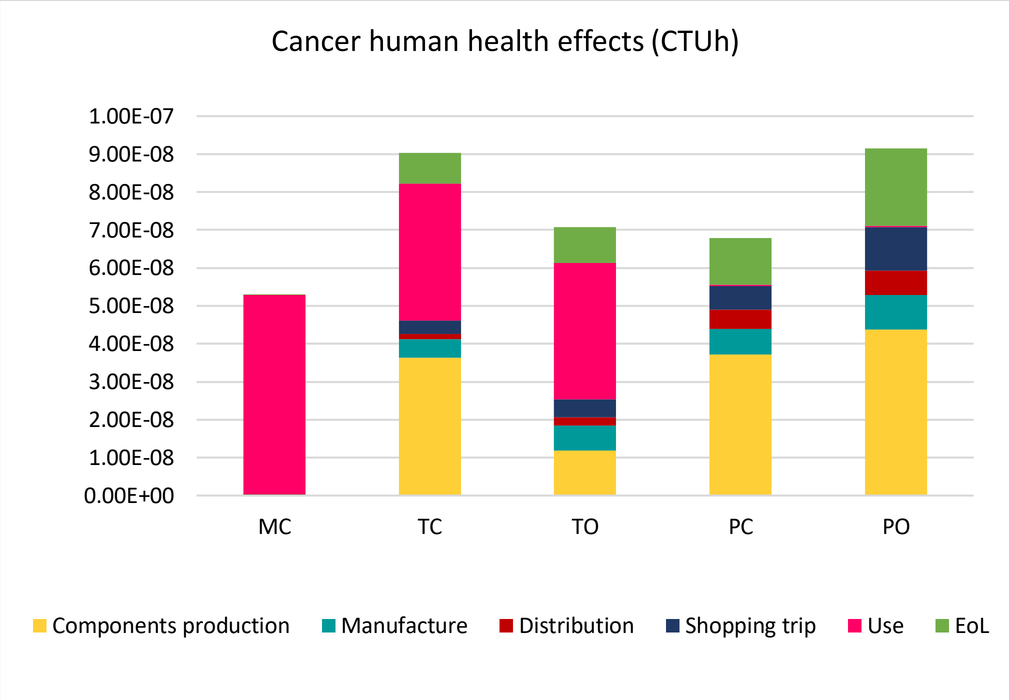

Figure 41. Cancer human health effects overall results including the life cycle stages results

Non-cancer human health effects

The emissions from wastewater treatment, paper production (packaging and release paper on the pads), viscose, plastic, electricity, and organic cotton production are responsible for most of the impacts on *non-cancer human health effects* as shown in Table 41.

Table 41. Elementary flows impact on non-cancer human health effects (flows contributing > 10%)

Flow		Contribution to the overall impact					Emitted by
Name	Type	MC	TC	TO	PC	PO	
Arsenic, ion	Water emissions				26%	11%	Energy production
Zinc, ion				17%		21%	Organic cotton harvesting
Mercury	Soil emissions				13%		Plastic production
Zinc		58%	44%	54%	16%	19%	Wastewater treatment & paper production
Zinc	Air emissions		26%		18%		Energy production

The wastewater treatment from hand and cup washing, followed by the sterilization of the cup are the main contributors to the MC impact. In Figure 42 the use phase impact of tampons is higher than MC due to the influence of toilet paper production. The emissions from viscose production explain the higher impact of the TC components production compared to the other single-use products.

Zinc emissions play a relevant role in organic products. A negative value is observed for the production of bioplastic – intake of zinc emissions from the soil to produce polyester-complexed starch biopolymer.

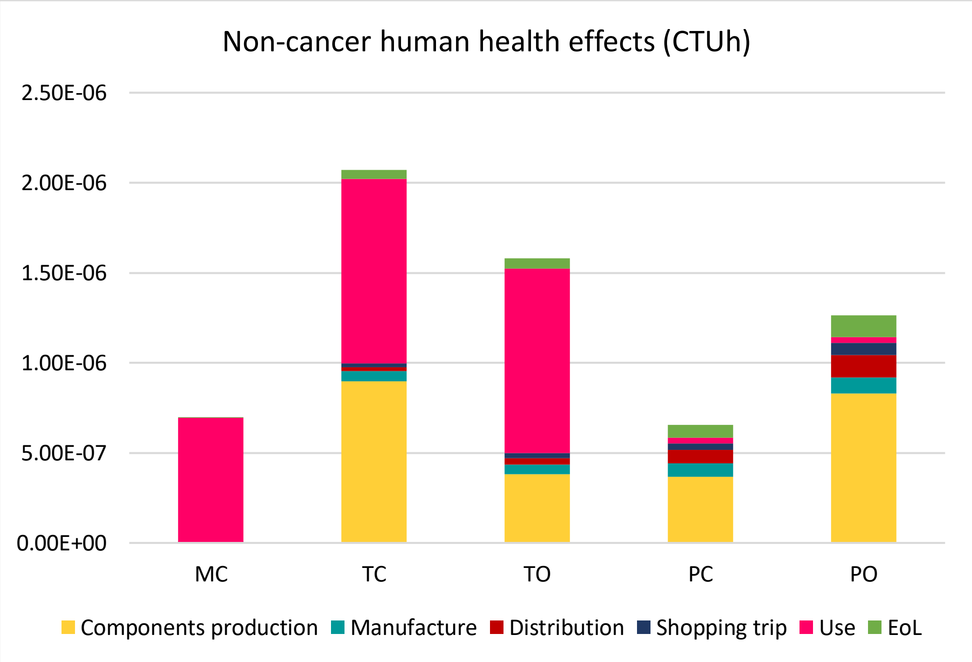

Figure 42. Non-cancer human health effects overall results including the life cycle stages results Ionizing radiation

Ionizing radiation

Ionizing radiation is influenced by the emission of radon-22 and carbon-14 arising from nuclear power (Table 42). Hence, this category is strongly affected by electricity consumption and the share of nuclear power in the electricity mix.

Table 42. Elementary flows impact on ionizing radiation (flows contributing > 10%)

Flow		Contribution to the overall impact					Emitted by
Name	Type	MC	TC	TO	PC	PO	
Carbon-14	Air emissions	26%	37%	35%	37%	45%	Electricity production
Radon-222		72%	61%	62%	60%	53%	Electricity production

Figure 43 shows the relevance of the use phase for MC dominated by the electricity consumption for sterilization. The use of tampons is mainly affected by toilet paper production and wastewater treatment. Both processes create less impact than MC sterilization.

The high electricity consumption for the production of viscose for TC, plastic for PC, and bioplastic for PO explain the higher impact of the components production compared to TO. Electricity for manufacture is very relevant for TC, TO, and PC, but lower for PO due to the smaller share of nuclear power in the selected mix.

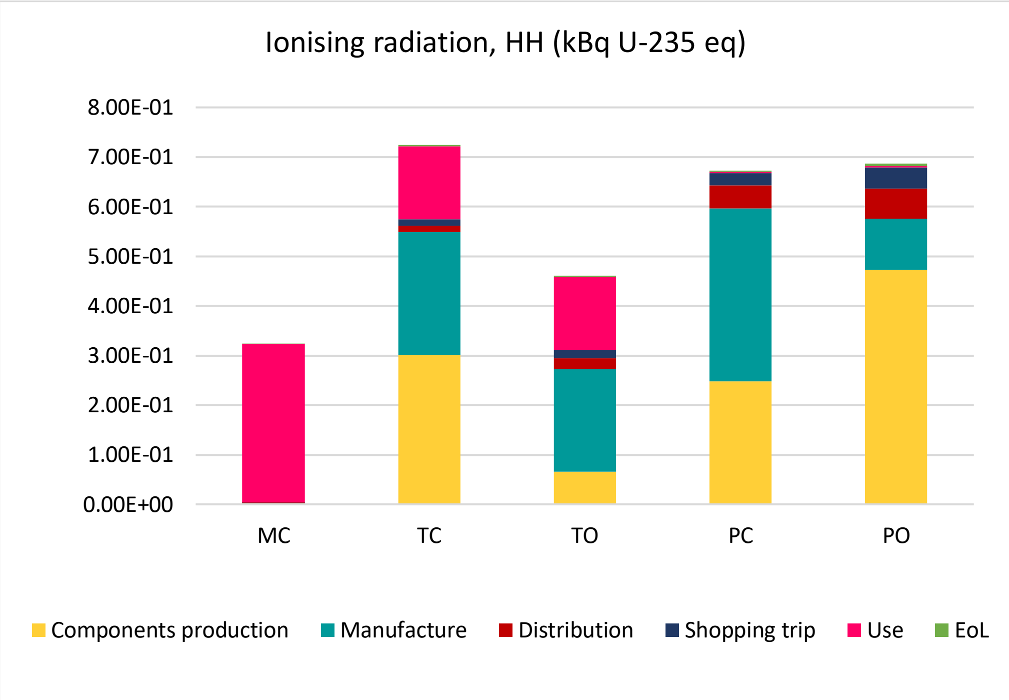

Figure 43. Ionizing radiation overall results including the life cycle stages results

Photochemical ozone formation

Nitrogen oxides emissions contribute the most to the *photochemical ozone formation impact* as presented in Table 43. They are created in energy production processes, in the harvesting of organic cotton, and in transport processes. Non-methane volatile organic compounds (NMVOC) of unspecified origin emissions also influence the results but on a lower level.

Table 43. Elementary flows impact on photochemical ozone formation (flows contributing > 10%)

Flow		Contribution to the overall impact					Emitted by
Name	Type	MC	TC	TO	PC	PO	
Nitrogen oxides	Air emissions	69%	72%	80%	63%	76%	Energy & plastic production & org. cotton harvesting
NMVOC		14%			18%		Electricity & plastic production

The energy needed to produce viscose for TC, the components for PC, and the bioplastic for PO have a strong influence on the components production impact, and in the overall impact (Figure 44). The harvesting of organic cotton is also relevant for PO and TO. The manufacturing impact comes from the electricity consumed, while the shopping trip and distribution impact is created by emissions from transportation – the heavier the product, the higher the transport impact.

Sterilization in the first place, and soap production in the second, are responsible for the MC impact. The tampons' use phase is influenced by soap and toilet paper production.

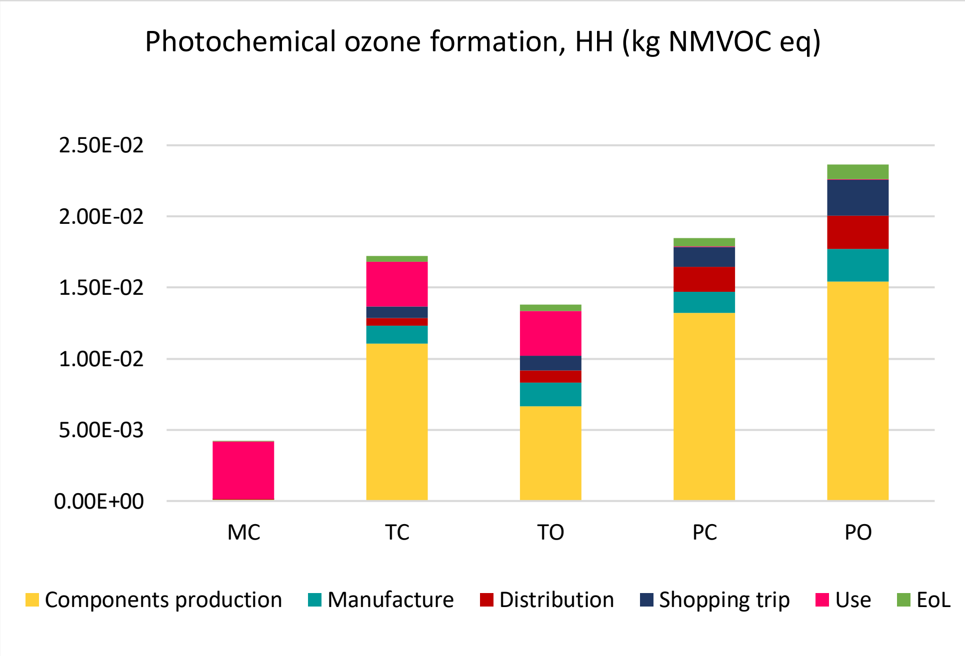

Figure 44. Photochemical ozone formation overall results including the life cycle stages results

Respiratory inorganics

The impact category *respiratory inorganics* is influenced by the flows shown in Table 44. Ammonia is emitted from the production of heat, coconut oil production for soap and from organic cotton harvesting. Viscose production, specifically heat and sulphur dioxide production, is highly affected by emissions of particulates. They are also relevant for the production of soap, transportation processes, and the production of plastic and bioplastic.

Table 44. Elementary flows impact on respiratory inorganics (flows contributing > 10%)

Flow		Contribution to the overall impact					Emitted by
Name	Type	MC	TC	TO	PC	PO	
Ammonia	Air emissions	17%		62%		46%	Soap production & org. cotton harvesting
Particulates, < 2.5 um		46%	61%	24%	72%	38%	Heat production & transport

Sterilization (heat and power co-generation, biogas, gas engine) and soap production are the processes which contribute the most to the impact of MCs. The use phase of the tampons creates a lower impact than MC (see Figure 45) and it is mostly influenced by soap and toilet paper production. Due to the high relevance of viscose production, the overall impact of TC is higher than TO.

The presence of viscose for the distribution layer, fluff pulp for the absorbent core, and plastic materials in the PC is responsible for the impact of the production of the components. The impact of the PO components production is higher due to the emissions from organic cotton cultivation combined with the bioplastic production. An influence of the particulates emissions is observed in the shopping trip and distribution impacts, especially for the pads.

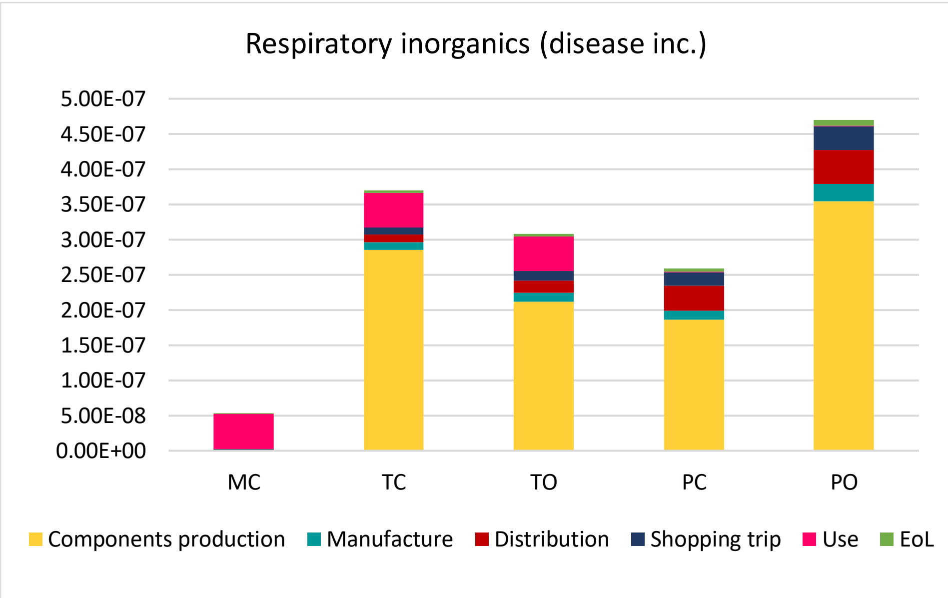

Figure 45. Respiratory inorganics overall results including the life cycle stages results

Ozone depletion

Ozone depletion is affected by the emissions presented in Table 45. The production of viscose and bioplastic is highly influenced by methane flows, while ethane is less relevant. These flows are created in energy production and transport processes.

Table 45. Elementary flows impact on ozone depletion (flows contributing > 10%)

Flow		Contribution to the overall impact					Emitted by
Name	Type	MC	TC	TO	PC	PO	
Ethane, 1,2-dichloro-1,1,2,2-tetrafluoro-, CFC-114	Air emissions	17%					Energy production
Methane, bromochlorodifluoro-, Halon 1211		31%	15%	25%	16%	28%	Energy production
Methane, bromotrifluoro-, Halon 1301		20%	28%	47%	50%	58%	Energy production & transport
Methane, tetrachloro-, R-10		27%	51%	17%	24%		Soap & sulphate pulp production

The overall impact of MCs, as shown in Figure 46, is the lowest, while the influence of viscose and bioplastic production is reflected in the highest impact of PO followed by TC. The presence of plastic and viscose components in PC explains the higher impact compared to TO, since organic cotton production is not very relevant for this category. The higher energy consumption for PO manufacturing, as well as its higher weight compared to the single-use products, is reflected in the shopping trip, distribution, and manufacturing impact. The tampons' use phase is influenced by soap, closely followed by toilet paper. For the cup, soap is the second contributor after sterilization.

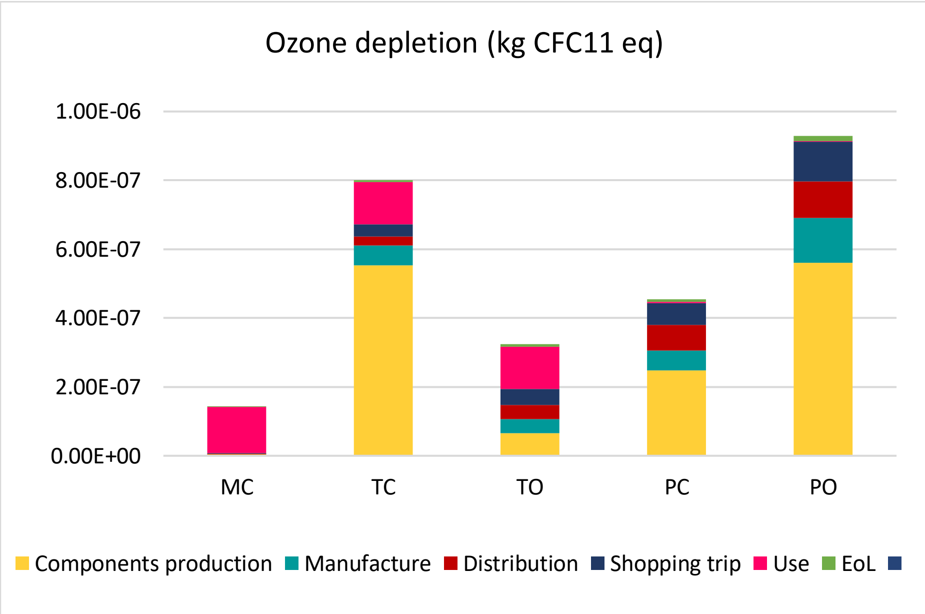

Figure 46. Ozone depletion overall results including the life cycle stages results

6 Life cycle interpretation

In the first section of the interpretation, a procedure to determine the ranking of products is explained (6.1) to support the understanding of the relevance of the sensitivity analysis performed in section 6.2. The data quality assessment results are presented in section 6.3 followed by the completeness (6.4) and consistency checks (6.5). Based on the steps performed, the discussion of the results is included in section 6.6.

6.1 Ranking of products

It is challenging to determine which product shows a better environmental performance due to the variable level of impact for the impact categories considered (see Table 29). Furthermore, the modification of assumptions and modelling decisions leads to different impact levels, which makes the comparison even more challenging. To tackle this question, a ranking of products is created. In this way, the influence of changing certain aspects of the life cycle analysis on the products' comparison can be explored. The ranking supports the goal of the study of determining which product presents the best environmental performance (see section 3.2).

Specifically, the ranking is used to analyse the importance and adequacy of the assumptions and modelling decisions in the sensitivity analysis (section 6.2).

Two rankings of products are created based on the results from Table 29: one for the cooker scenario, and one for the kettle scenario. The steps to build the ranking are explained here:

1. The environmental impact of each product is compared, independently, and for each impact category, to the other four products. For example, the MC (in the cooker or kettle scenario) is compared to the TC, TO, PC, and PO. This means that if a product is always better than the other in all impact categories, it would obtain a score of 64 points – for 4 products there are 16 impact categories.
2. The number of times corresponding to the number of impact categories, one product is better than the others, is calculated. The results of comparing each pair of products are added up to a final score. For example, the MC in the cooker scenario is better than the TC in 15 categories, 16 compared to the TO, 13 compare to the PC, and 16 compared to the PO. The addition of the scores amounts to 60 points. A product can obtain a maximum of 64 points.
3. The scores obtained for each product are compared: the higher the score and the closer to 64, then the better the environmental performance.

4. A ranking of 5 levels is created: from the product with the highest score (best results) to the product with the lowest (worst result).
5. A colour scale, from green to red, is applied for visualization purposes. The product with the highest score – best performance – is presented in green and the one with the lowest score in green – worst performance – This scale is the same as applied in section 5.1.
6. Firstly, the ranking is calculated for the baseline results. Secondly, the new rankings are calculated when changing modelling decisions (e.g. the amount of water to wash hands) and compared to the baseline ranking. The result indicates how the comparison is influenced, how much, and which products are affected.

According to the approach explained above, the baseline ranking of products is presented in Table 46 for the cooker scenario and Table 47 for the kettle. The product with a better result for a higher number of impact categories is marked in purple. The menstrual cup is the better product for most of the comparisons with a large distance from the other products, especially in the kettle scenario. The organic pad shows a better result only for 5 comparisons. Within the remaining three products, the conventional pads are slightly better than the organic tampons, while the distance to the conventional tampons is a little greater.

The ranking of the baseline results considers how many times a result is better, but not by how much. However, when calculated in the following sections it also reflects the impact differences – if the results of two products are close to each other, the scores will be more likely modified when changing modelling decisions. In contrast, when a product presents a much higher or lower impact, the comparison will probably remain the same.

The relevance of the impact categories may not always be the same. So, the ranking of products may be interpreted differently in different contexts. As explained at the beginning of the section, the application of the ranking in this study explores the influence of several aspects on the comparison of products.

Table 46. Ranking of products, cooker scenario

Comparison	No. of times a product shows a better result				
	MC	TC	TO	PC	PO
MC vs TC	16	0			
MC vs TO	16		0		
MC vs PC	13			3	
MC vs PO	16				0
TC vs TO		6	10		
TC vs PC		4		12	
TC vs PO		14			2
TO vs PC			7	9	
TO vs PO			15		1
PC vs PO				14	2

TOTAL	61	24	32	38	5
The colour scale indicates the level of impact – from green (lowest impact) to red (highest impact) Additionally, the color scale helps the understanding of how far the values are from each other; the similar the color, the closer the values are					

Table 47. Ranking of products, kettle scenario

Comparison	No. of times a product shows a better result				
	MC	TC	TO	PC	PO
MC vs TC	16	0			
MC vs TO	16		0		
MC vs PC	15			1	
MC vs PO	16				0
TC vs TO		6	10		
TC vs PC		4		12	
TC vs PO		14			2
TO vs PC			7	9	
TO vs PO			15		1
PC vs PO				14	2
TOTAL	63	24	32	36	5
The colour scale indicates the level of impact – from green (lowest impact) to red (highest impact) Additionally, the colour scale helps the understanding of how far the values are from each other; the similar the color, the closer the values are					

6.2 Sensitivity analysis

According to (i) the identified relevance of the life cycle stages and processes and (ii) the uncertainty of the modelled data, the sensitivity analyses are defined and summarized in Table 48 . In this way, the influence of modifying assumptions during the use phase is thoroughly analysed to tackle the difficulties to predict the behaviour of the users. Since the MC is the product which requires the most inputs during use, it is the objective of more sensitivity analysis than the other four products.

For the tampons, the use phase is also relevant – modifications in the wearing time, hand washing, and the amount of toilet paper used, are all considered. The addition of hand washing to the use of pads was explored as users might wash their hands before changing a pad.

According to the relevance of the components' production, the origin of core materials is modified; fluff pulp for TC and PC, and organic cotton for TO and PO. The influence of selecting economic instead of physical allocation for the production of organic cotton noils is also analysed.

Since electricity consumption is the most relevant process of the manufacture, the influence of using the European electricity mix for the production of TO and PO is explored. Additionally, the use of renewable energy for manufacturing single-use products is analysed.

It is necessary to note that the sensitivity analysis studying the influence of using renewable energy provides theoretical results. They show the reduction of the potential impact, and increase for some impact categories, resulting from the integration of renewable energy in the model, which does not necessarily represent the real modification of impacts. In reality, the impacts depend on the location of existing power plants in the area and the electricity market - the transmission capacity from the real market to the purchased electricity. [63,64]. The results provided must be understood as a theoretical calculation to estimate the potential of renewable energy.

Since the distribution, shopping trip, and end-of-life play a less relevant role compared to the other stages, the influence of modifying the assumptions is low, even irrelevant. Thus, they are not included in the sensitivity analysis.

Table 48. Overview of the sensitivity analysis

No	Life cycle stage	Modified assumption	Description baseline/modified	MC	TC	TO	PC	PO
1	All stages	Lifetime	5a/1a & 10a					
2	Components production	Origin of fluff pulp	Global production/ European production					
3	Components production	Dataset organic cotton production	Indian dataset (Ecoinvent)/Global dataset (GaBi)					
4	Components production	Organic cotton allocation	Economic/Physical					
5	Manufacture	Electricity mix	National mix/European mix					
6	Manufacture	Renewable energy manufacturing	Electricity mix/Electricity from renewable sources					
7	Use	Hand washing – amount of water & soap	50% higher & 50% lower amount					
8	Use	Hand washing – water temperature	Cold/Warm					
9	Use	Sterilization time	5.25min/3min & 10min					
10	Use	Sterilization method	Use of a lid to cover the pan on cooker					
11	Use	Sterilization – electricity source	Electricity mix/Electricity from renewable sources					
12	Use	Sterilization frequency	Between periods/After each exchange					
13	Use	Cup washing – amount of water & soap	50% higher amount					
14	Use	Wearing time	10.6h/6h & 12h					
15	Use	Wearing time	6h/4h & 8h					
16	Use	Toilet paper for tampons' disposal	3 sheets/ without toilet paper & 6 sheets					
17	Use	Hands washing – menstrual pads	No hand washing/hand washing before exchange					
			TOTAL	9	**6**	**7**	**3**	**5**

All absolute results from the sensitivity analysis as included in **Appendix F – Absolut results**.

6.2.1 Overview of the results and main findings

In this section, an overview of the sensitivity analysis results is presented to provide f the most relevant modifications. It is possible to refer directly to the analysis of interest.

Because of the number of products analysed, and the many analyses performed, it is challenging to understand the influence of each modification in the results. To overcome this difficulty and achieve an overview of the influences which have been identified, the approach to rank the products

(section 6.1) is applied to the results of the sensitivity analysis. This means, for each modified parameter a ranking of products is created. The score may be the same or different from the baseline results. When it differs, the score difference is indicated – with a negative sign (-) if the score is reduced (a worse environmental performance), and positive (+) if it is increased (a better environmental performance). If the score remains the same, it is indicated with an equal sign (=). In some cases, the score difference may cause a shift in the products' ranking.

Table 50 summarizes the results of the sensitivity analysis based on the ranking. The colour scale indicates the level of impact – from green (lowest impact) to red (highest impact). Additionally, the colour scale helps to understand how far the values are from each other; the more similar the colour, the closer are the values.

Sometimes the results of the sensitivity analysis may differ strongly from the baseline, even though the scores remain almost the same. These modifications are explained in detail in each corresponding section.

According to the scores obtained in the sensitivity analysis, the most relevant parameters are summarized in Table 49 and explained here:

- The menstrual cup is the best product from an environmental perspective when different assumptions for the use phase are explored except for an increased sterilization frequency in the cooker scenario. If the cup would be sterilized after every change, it would be the second-worst product. In the kettle scenario the menstrual cup would be the best product even for an increased sterilization frequency.
- In general, conventional tampons are more sensitive to the modified assumptions of the use phase than the organic ones, which are more stable. This can be explained by the greater influence of the use phase in the life cycle of conventional tampons.
- The addition of hand-washing before changing pads creates an significant decrease in the performance of conventional pads, which become the second-worst product after organic pads.
- When using a different dataset to produce organic cotton fibre, and when a European electricity mix is used for the manufacture, the score of the PO improves. However, it is still the worst product from an environmental perspective.

As already explained, the sensitivity analysis may have a strong influence on the results and create shifts in the ranking of products. These results support the understanding of environmental impacts and the identification of potential improvements. For example, the use of a lid to cover the pan while the menstrual cup is being sterilized, or to turn off the water tap while soaping the hands. Nevertheless, the results of parameters that may affect the correct use of menstrual products must not be understood as an indication of how to use menstrual products to be more environmentally if friendly. For example, the quantity of tap water used to clean a menstrual cup should be enough to clean it properly, and the time it is worn should not be extended simply to decrease the environmental impacts.

Table 49. Most relevant parameters of the sensitivity analysis for each menstrual product

Most relevant parameters identified from the sensitivity analysis results					
MC cooker	MC kettle	TC	TO	PC	PO
Sterilization frequency	Sterilization frequency	Hand washing – amount of water and soap	Hand washing – water temperature	Hand washing	GaBi dataset for org. cotton fibre
Cup washing – amount of water & soap	Cup washing – amount of water & soap	Hand washing – water temperature	No. of toilet paper sheets		
Wearing time, 6h	Wearing time, 6h	No. of toilet paper sheets	GaBi dataset for org. cotton fibre		

Table 50. Summary of the influence of the sensitivity analysis on the products comparison vs baseline

Parameter	Scenario	Value	MC	TC	TO	PC	PO	Section
Baseline	**Cooker**	**Baseline**	**61**	**24**	**32**	**38**	**5**	-
Baseline	**Kettle**	**Baseline**	**63**	**24**	**32**	**36**	**5**	
Lifetime (MC)	Both	1- & 10-years lifetime	Same as baseline					6.2.2
Fluff pulp origin (PC&TC)	Cooker	Europe	60 (-1)	26 (+2)	31 (-1)	38 (=)	5 (=)	6.2.3
	Kettle	Europe	63 (=)	25 (+1)	31 (-1)	36 (=)	5 (=)	
Dataset for org. cotton production (TO&PO)	Cooker	Europe	59 (-2)	20 (-4)	36 (+4)	38 (=)	7 (+2)	6.2.4
	Kettle	Europe	63 (=)	20 (-4)	35 (+3)	36 (=)	6 (+1)	
Org. cotton noils allocation (PO)	Both	Physical allocation	Same as baseline					6.2.5
Electricity source manufacture (TO&PO)	Cooker	EUR electricity mix	61 (=)	25 (+1)	32 (=)	38 (=)	4 (-1)	6.2.6
	Kettle	EUR electricity mix	63 (=)	25 (+1)	32 (=)	36 (=)	4 (-1)	
Electricity source manufacture (TC,TO,PC,PO)	Cooker	Renewable energy	59 (-2)	25 (+1)	33 (+1)	39 (+1)	4 (-1)	6.2.7
	Kettle	Renewable energy	63 (=)	24 (=)	32 (+1)	37 (+1)	4 (-1)	
Hand washing, amount water & soap (MC,CT, OT)	Cooker	50% higher	60 (-1)	21 (-3)	31 (-1)	40 (+2)	8 (+3)	6.2.8
	Cooker	50% lower	61 (=)	26 (+2)	33 (+1)	36 (-2)	4 (-1)	
	Kettle	50% higher	62 (-1)	21 (-3)	31 (-1)	39 (+3)	7 (+2)	
	Kettle	50% lower	64 (+1)	25 (1)	33 (+1)	34 (-2)	4 (-1)	
Hand washing, water temperature (MC,CT, OT)	Cooker	20°C	61 (=)	19 (-5)	29 (-3)	43 (+5)	8 (+3)	6.2.9
	Kettle	20°C	63 (=)	19 (-5)	29 (-3)	41 (+5)	8 (+3)	
Sterilization time	Cooker	3 and 10 minutes	Same as baseline					6.2.10
Sterilization method (MC)	Cooker	Lid to cover the pot	63 (+2)	24 (=)	32 (=)	36 (-2)	5 (=)	6.2.11
Electricity source sterilization (MC)	Cooker	Renewable energy	60 (-1)	25 (+1)	33 (+1)	37 (-1)	5 (=)	6.2.12
	Kettle	Renewable energy	Same as baseline					
Sterilization frequency (MC)	Cooker	After each exchange	25 (-36)	34 (+10)	42 (+10)	47 (+9)	12 (+7)	6.2.13
	Cooker	After each exchange, lid	35 (-26)	32 (+8)	38 (+6)	45 (+7)	10 (+5)	
	Kettle	After each exchange	56 (-7)	25 (+1)	35 (+3)	39 (+3)	5(=)	
Cup washing, amount water & soap (MC)	Cooker	Double	57 (-4)	26 (+2)	33 (+1)	39 (+1)	5(=)	6.2.14
	Kettle	Double	61 (-2)	25 (+1)	32 (=)	37 (+1)	5 (=)	
Wearing time (MC)	Cooker	6h	57 (-4)	26 (+2)	33 (+1)	39 (+1)	5 (=)	6.2.15
	Cooker	12h	62 (+1)	24 (=)	32 (=)	37 (-1)	5 (=)	
	Kettle	6h	59 (-4)	25 (+1)	33 (+1)	38 (+2)	5 (=)	
	Kettle	12h	Same as baseline					
Wearing time (CT,OT, CP,OP)	Cooker	4h	64 (+3)	24 (=)	32 (=)	35 (-3)	5 (=)	6.2.16
	Cooker	8h	58 (-3)	26 (+2)	32 (=)	39 (+1)	5 (=)	
	Kettle	4h	64 (+1)	24 (=)	32 (+2)	35 (-3)	5 (=)	
	Kettle	8h	62 (-1)	24 (=)	32 (=)	37 (+1)	5 (=)	
Number of toilet paper sheets for disposal (CT&OT)	Cooker	0	60 (-1)	28 (+4)	34 (+2)	35 (-3)	3 (-2)	6.2.17
	Cooker	6	61 (=)	21 (-3)	31 (-1)	40 (+2)	7 (+2)	
	Kettle	0	63 (=)	27 (+3)	34 (+2)	33 (-3)	3 (-2)	
	Kettle	6	63 (=)	21 (-3)	31 (-1)	38 (+2)	7 (+2)	
Hand washing before changing pads	Cooker	Hand washing	63 (+2)	31 (+7)	34 (+2)	29 (-9)	3 (-2)	6.2.18
	Kettle	Hand washing	64 (+1)	31 (+7)	34 (+2)	28 (-8)	3 (-2)	

The color scale indicates the level of impact – from green (lowest impact) to red (highest impact)
Additionally, the color scale helps the understanding of how far the values are from each other; the similar the color, the closer the values are

6.2.2 Sensitivity analysis 1: the lifetime of MC

Since the menstrual cup is a reusable product, its length of life influences the manufacturing, distribution, shopping trip, and end of life phases, but not the use phase. In the baseline situation, the lifetime of the menstrual cup is calculated as 5 years. When increasing the lifetime up to 10 years, as stated by many manufacturers, the reduction of impact amounts to a maximum of 8.4% in the cooker scenario, and 11.7% in the kettle scenario (see Figure 47). This is expected, as the improvement potential of the listed life-cycle stages is very low. When the lifetime is reduced to 1 year, the situation is different: the results of some impact categories strongly increase due to the higher need of raw materials. The lifetime influence is stronger in the kettle scenario because it is slightly more affected by the production of the components, and less by the use phase.

The production of the organic cotton bag contributes to the increased *land use* impact by 43% and the distribution by 22%; the printed box production and shopping trip by approximately 9.5%; and the leaflet, transport to-factory, and silicone production by approximately 5%. Regarding *resource use, minerals and metals*, the production of silicone for the cups is responsible for 72% of the increased impact.

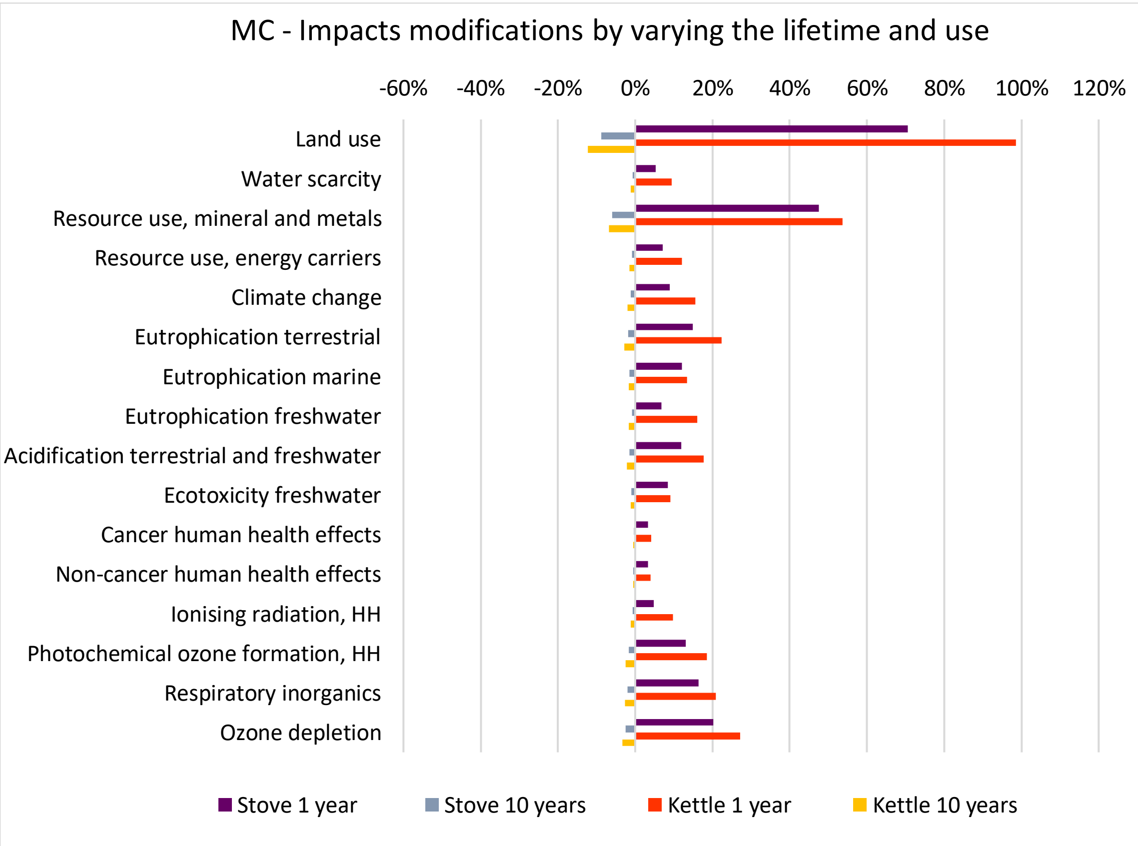

Figure 47. Influence on the results by varying the lifetime and use of the MC compared to baseline

6.2.3 Sensitivity analysis 2: the origin of sulphate pulp used in the conventional products

An analysis of the influence of the selected datasets for the core materials of the conventional products is performed. It is assumed that the sulphate pulp present in the absorbent core of the conventional pad and needed to produce viscose for the core of conventional tampons, is produced in Europe and not in the global market.

In Figure 48 a low influence in the results is observed, especially for the conventional pads. The reason is the higher contribution of the core material to the environmental impacts for tampons compared to pads. The differences are mainly created from electricity sources and transportation distances. The share of nuclear power in the European electricity mix results in a higher impact on *ionizing radiation*.

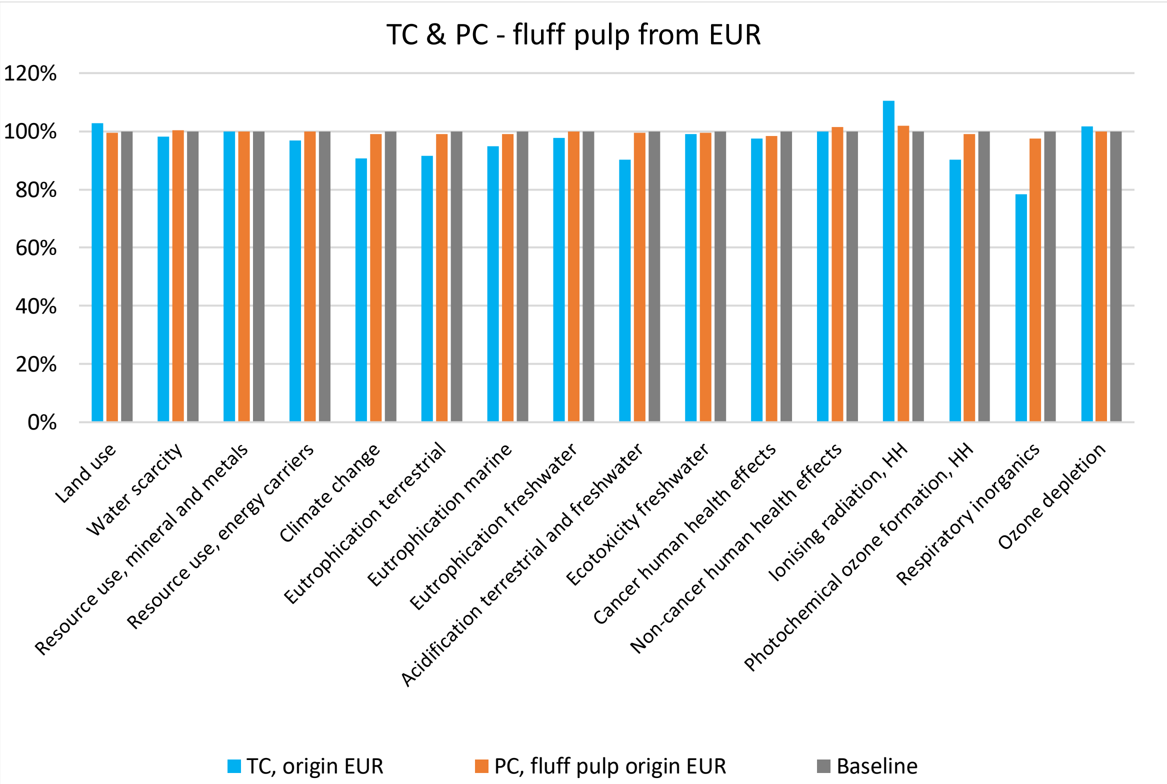

Figure 48. Impacts comparison of using a European dataset to produce sulphate pulp used in TC and PC compared to baseline

6.2.4 Sensitivity analysis 3: organic cotton fibre production with a dataset from the GaBi database

The selected dataset for the production of organic cotton fibre comes from the Indian market, particularly the Orissa region. Due to the relevance of organic cotton impacts, the influence on the results of using a different dataset is analysed. A dataset from the GaBi database SP40, representing the global market, is chosen: "cotton fibre (organic) (at gin gate), production mix, at producer (gin), technology mix"[15]. Data collected between 2011 and 2013 (compared to 2015-16 in the ecoinvent dataset) conform the dataset, for which the Indian market is the most relevant.

In Figure 49 the comparison of the two datasets is presented. For 5 impact categories, the results with the GaBi dataset are higher, while for the remaining 11 are lower. Only for 3 categories – *climate change*, *photochemical ozone formation*, and *respiratory inorganics* – the results are comparable. For the other categories, the differences between the datasets are relevant and influence the results.

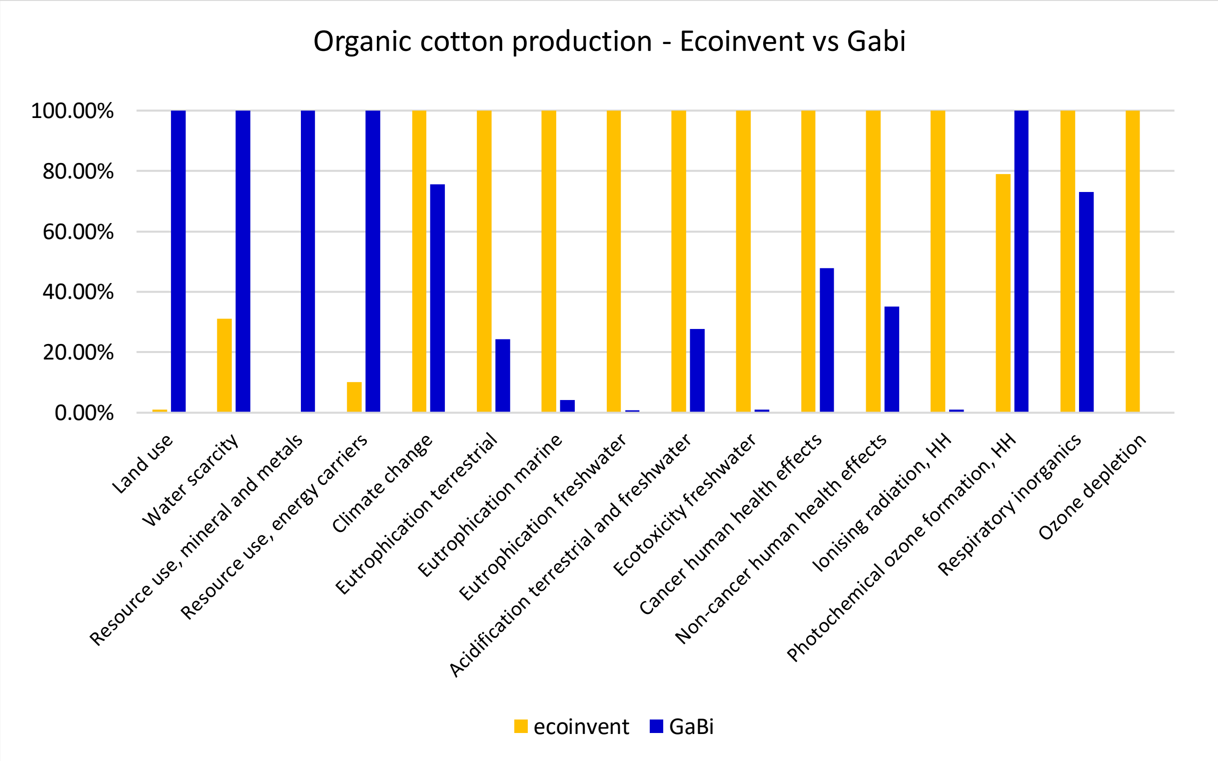

Figure 49. Comparison between the ecoinvent and GaBi datasets for organic cotton fibre production

[15] http://gabi-documentation-2020.gabi-software.com/xml-data/processes/99f8544b-0b62-457a-b246-e1b071bf6cd1.xml

A detailed comparison of the products' ranking in the baseline (Ecoinvent) vs the sensitivity analysis results (GaBi) is displayed in Table 51. Additionally, the impact difference compared to baseline, in percentage, is included in the table.

The relevant differences in the TO and PO results from Table 51 are explained by the impacts of used datasets presented in Figure 49. Not all the differences create a shift in the products' ranking – from 11 categories showing important differences, the following 6 create a shift: *resource use, mineral and metals, eutrophication freshwater, acidification terrestrial and freshwater, ecotoxicity freshwater, cancer human health effects,* and *non-cancer human health effects.* In the kettle scenario, the effect would be similar, although the ranking of *non-cancer human health effects* would remain the same.

Table 51. Ranking and impact comparison between the baseline (Ecoinvent) and sensitivity (GaBi)

Impact category	Analysis	MC	TC	TO	PC	PO
Land use	Baseline	1	3	4	2	5
	Sensitivity	1	3	4	2	5
	Impact difference			+99%		+98%
Water scarcity	Baseline	1	4	2	3	5
	Sensitivity	1	4	2	3	5
	Impact difference			+0.6%		+0.5%
Resource use, mineral and metals	Baseline	1	3	2	5	4
	Sensitivity	1	2	4	3	5
	Impact difference			+93%		+86%
Resource use, energy carriers	Baseline	1	3	2	5	4
	Sensitivity	1	3	2	5	4
	Impact difference			+10%		+5%
Climate change	Baseline	1	3	2	4	5
	Sensitivity	1	3	2	4	5
	Impact difference			-7%		-4%
Eutrophication terrestrial	Baseline	1	3	4	2	5
	Sensitivity	1	3	4	2	5
	Impact difference			-59%		-48%
Eutrophication marine	Baseline	2	3	4	1	5
	Sensitivity	2	3	4	1	5
	Impact difference			-87%		-87%
Eutrophication freshwater	Baseline	2	3	4	1	5
	Sensitivity	4	5	1	2	3
	Impact difference			-65%		-86%
Acidification terrestrial and freshwater	Baseline	1	3	4	2	5
	Sensitivity	1	4	3	2	5

Impact category	Analysis	MC	TC	TO	PC	PO
	Impact difference			-43%		-35%
Ecotoxicity freshwater	Baseline	1	3	4	2	5
	Sensitivity	1	4	3	2	5
	Impact difference			-65%		-58%
Cancer human health effects	Baseline	1	4	3	2	5
	Sensitivity	1	5	3	2	4
	Impact difference			-4%		-3%
Non-cancer human health effects	Baseline	2	5	4	1	3
	Sensitivity	3	5	4	2	1
	Impact difference			-13%		-17%
Ionising radiation, HH	Baseline	1	5	2	3	4
	Sensitivity	1	5	2	3	4
	Impact difference			-0.60%		-0.40%
Photochemical ozone formation, HH	Baseline	1	3	2	4	5
	Sensitivity	1	3	2	4	5
	Impact difference			+6%		+4%
Respiratory inorganics	Baseline	1	4	3	2	5
	Sensitivity	1	4	2	3	5
	Impact difference			-17%		-11%
Ozone depletion	Baseline	1	4	2	3	5
	Sensitivity	1	4	2	3	5
	Impact difference			-2%		-0.80%

Baseline: ranking of products in the baseline situation (cooker scenario) - from 1 (best) to 5 (worst)
Sensitivity: ranking of products when using the GaBi dataset for organic cotton production
Impact difference: increase or reduction of the impact compared to the baseline

Table 52 shows the final ranking of the product' when using the GaBi dataset in the cooker and kettle scenarios. It remains the same in the cooker scenario, while the kettle TO moves to the second position (from the third) together with PC.

Table 52. Ranking of products from using the GaBi dataset for organic cotton fibre production

No. of times a product shows a lower impact					
Scenario	MC	TC	TO	PC	PO
Cooker scenario - GaBi dataset	59 (-2)	20 (-4)	36 (+4)	38 (=)	7 (+2)
Kettle scenario – GaBi dataset	63 (=)	20 (-4)	35 (+3)	36 (=)	6 (+1)

The colour scale indicates the level of impact – from green (lowest impact) to red (highest impact)
Additionally, the colour scale helps to understanding how far the values are from each other; the more similar the colour, the closer are the values

6.2.5 Sensitivity analysis 4: physical allocation for the production of organic pads

The influence of the decision to apply economic instead of mass allocation for the modelling of the organic pads is shown in Figure 50. The impacts, as expected, are lower by using economic allocation; the mass difference between the main product and the by-product is lower than the price difference. Specifically, 11% of the impacts are economically allocated, and 15% physically. Thus, the amount of organic cotton needed to produce the noils is higher when applying physical allocation. Some impact categories are affected more by the selected allocation approach applied to organic cotton noils: those that are more affected by the production of organic cotton noils (see Figure 13).

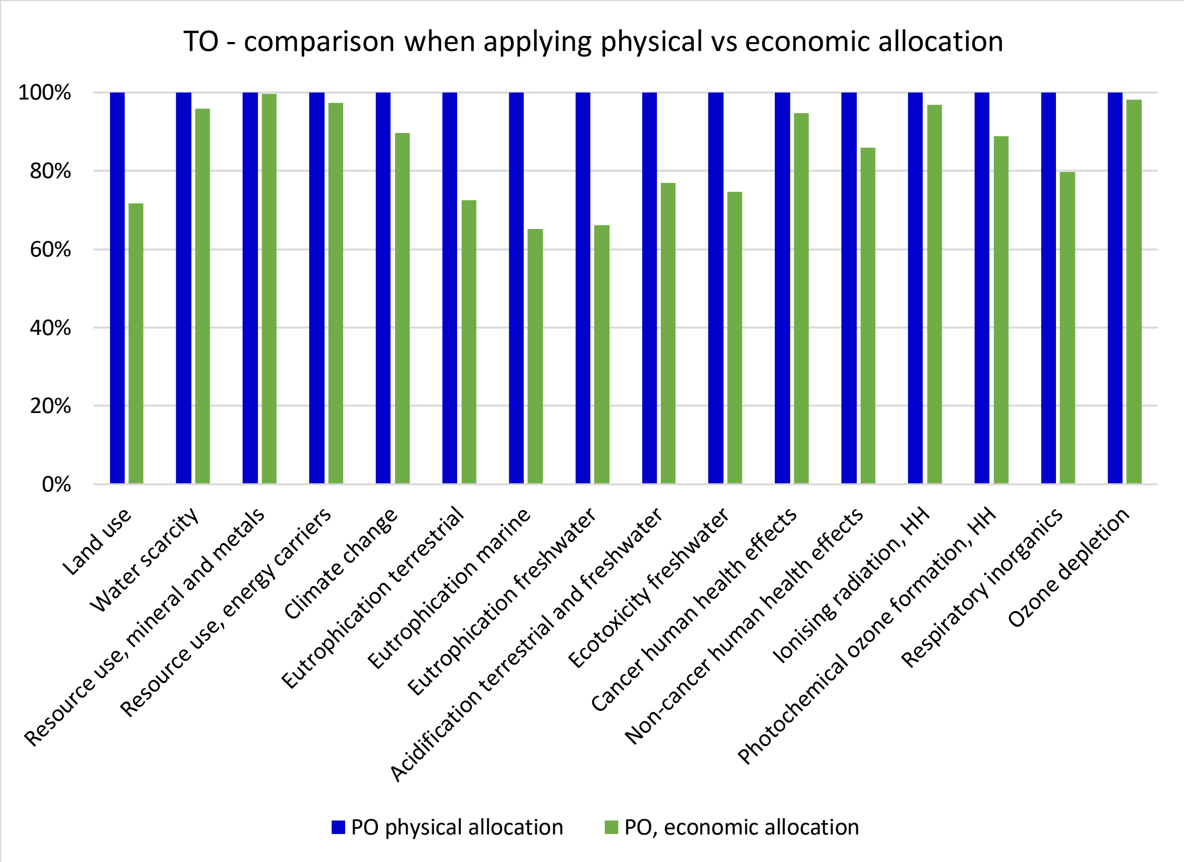

Figure 50. Physical vs economic (baseline) allocation of the combing process of organic cotton (PO)

6.2.6 Sensitivity analysis 5: electricity source for the manufacture pf organic products

The electricity mix selected for the manufacture of the organic products is specific to the country where the production is located. Both products are manufactured in Europe; however, the locations are not published due to confidentiality. The production site of the conventional products is unknown but is assumed to be in Europe. So all are produced in the same region.

In this analysis, the influence of using the same European electricity mix for the production of the organic (instead of the national specific ones) and conventional products is studied. The results in Figure 51 are similar to the baseline one. However, the OT present a lower impact on *water scarcity* due to the share of hydropower in the mix, while the impact of PO on *ionizing radiation* increases because of the share of nuclear power. Accordingly, the comparison of products remains very similar.

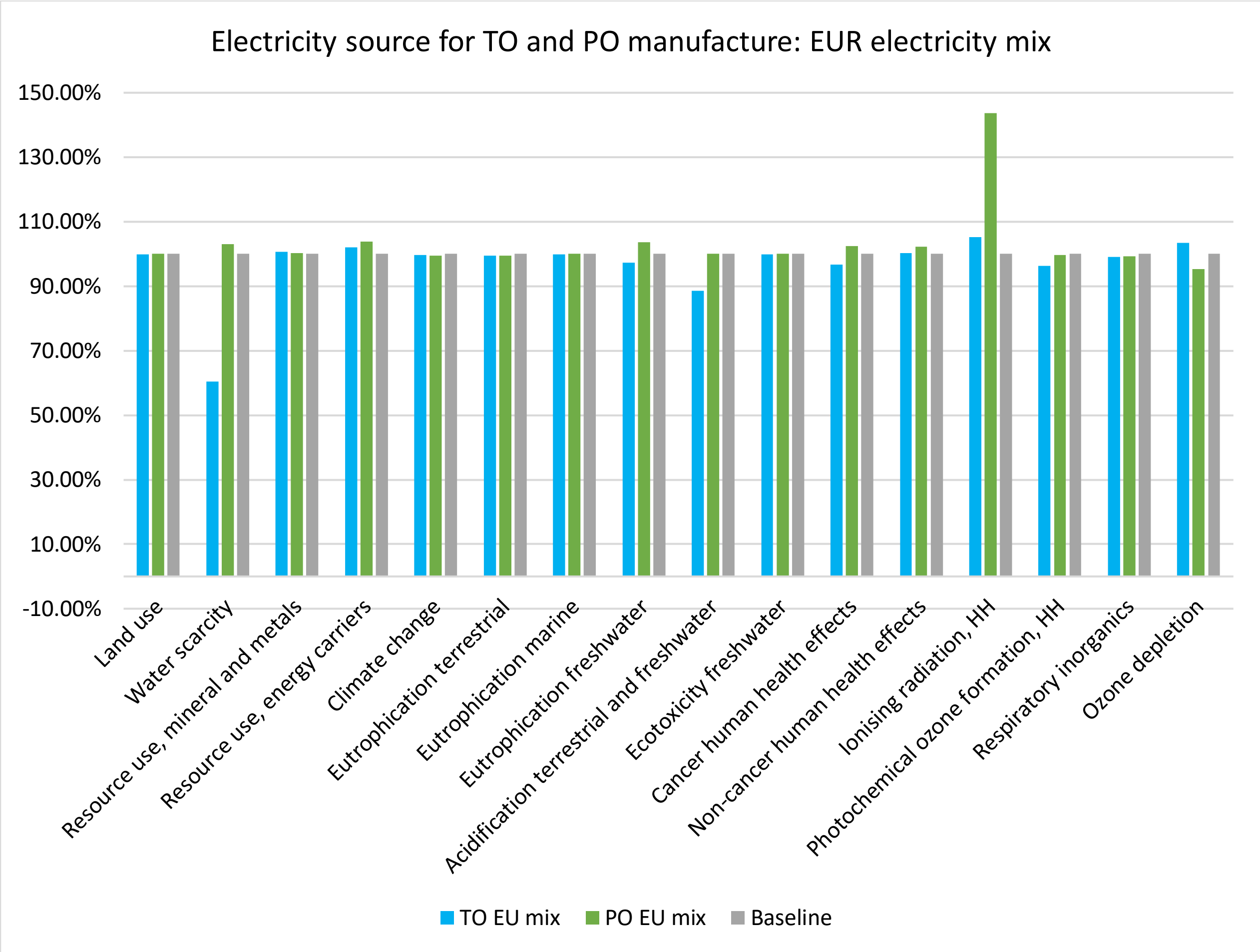

Figure 51. Comparison of using a European electricity mix vs the corresponding national mix for TO and PO

6.2.7 Sensitivity analysis 6: electricity from renewable sources to manufacture the single-use products

The use of renewable energy for the manufacturing of menstrual products is analysed and presented in Figure 52. A renewable energy mix (geothermal, hydropower, and wind power) representing the European market is selected as the energy source. Menstrual cups are excluded because their manufacturing is not relevant for these results.

Most of the impacts are reduced by using renewable energy. The impact difference depends on the relevance of manufacture for a certain category and product, and on the composition of the electricity mix in the baseline situation.

The impact on a few categories could also be increased. *Land use* increases due to the land needed for wind power; *water scarcity* due to the water needed for hydropower; and *resource use, minerals and metals* due to nylon production needed for the blades of wind turbines.

As explained in the introduction of the sensitivity analysis (6.2), the results from using renewable energy provide a theoretical indication of the potential improvements.

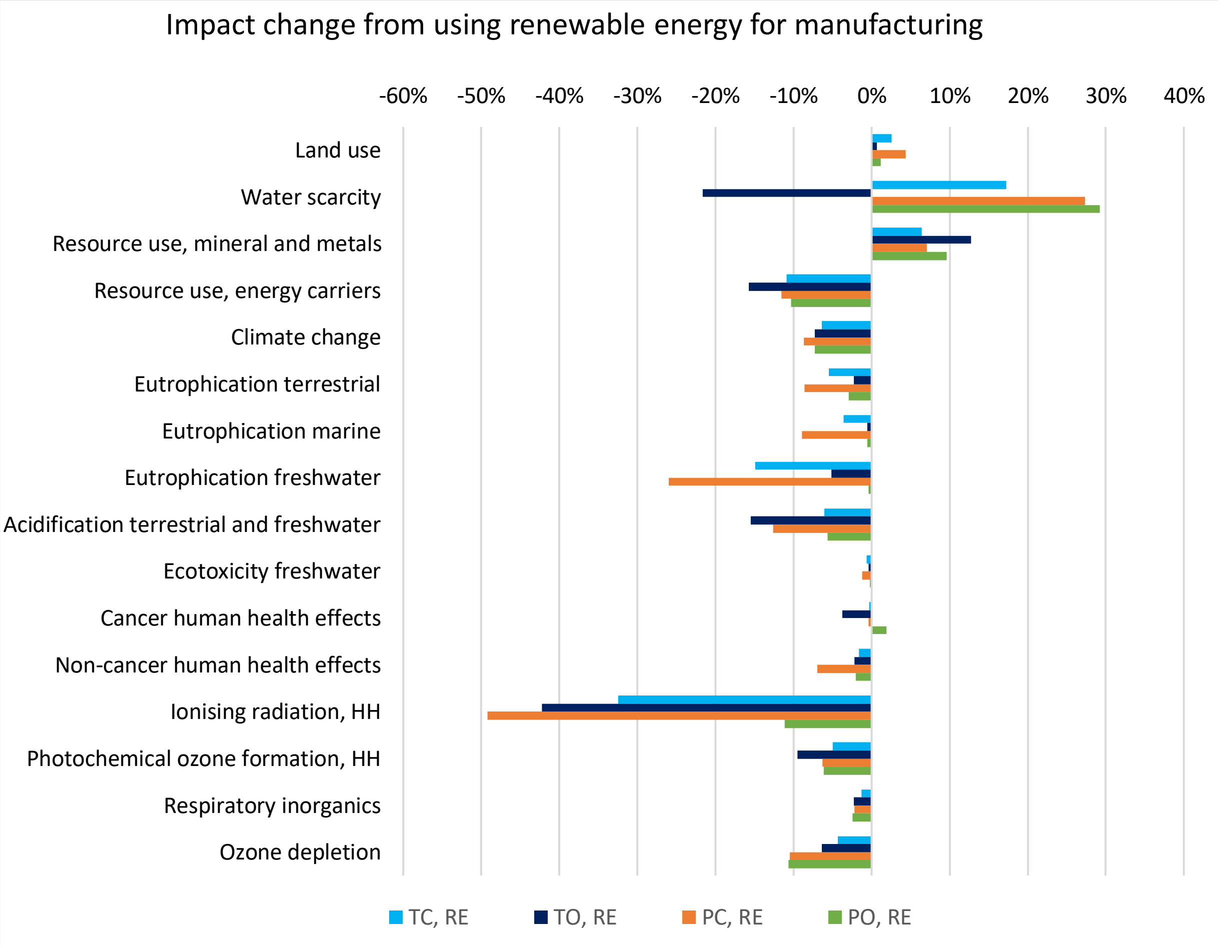

Figure 52. Influence on the overall impacts of using renewable energy for the manufacture of tampons and pads compared to baseline

6.2.8 Sensitivity analysis 7: hand washing during tampons and cup use – amount of water and soap

In goal and scope, it is recommended to wash hands before and after changing a menstrual cup and a tampon. The amount of water and soap is based on literature (see section 4.6.1), but given each person may do it differently, it is difficult to predict. A survey carried out by the French Agency for Food, Environmental and Occupational Health & Safety (L'Agence nationale de sécurité sanitaire de l'alimentation, de l'environnement et du travail) shows that 39% of the participants in the study do not wash their hands before changing a menstrual product. But it is not specified which product and menstrual pads are considered in this calculation. For this reason, it is not possible to use the value for a sensitivity analysis. To address the tendency that hands are not always washed or properly washed, the influence of using a higher or lower amount of water and soap is analysed.

Specifically, the sensitivity analysis includes the impact reduction or increase if the amount of water and soap used is 50% higher or lower. Within the hand washing process, the impacts would be respectively halved or doubled because of a linear relationship between the inputs and the impacts. The influence on the life cycle results of the tampons and the menstrual cup in the cooker scenario is represented in Figure 53 when the amount used is higher; and if the amount is halved the results are reduced by the same percentage. It is observed that the influence of the hand washing process is stronger for the menstrual cup than for the tampons because it is more relevant for the life cycle of the cup. In the kettle scenario, the influence is stronger due to the greater importance of hand washing during the use phase. Within the tampons, the product most affected depends on the impact category. The categories that are more strongly affected by the use phase are also more affected in this analysis (see Figure 18 for TC and Figure 20 for TO). For example, the use phase of the conventional tampons influences the category *eutrophication marine* more than for the organic tampons. Thus, as observed in Figure 53, the impact on *eutrophication marine* is more sensitive for conventional tampons.

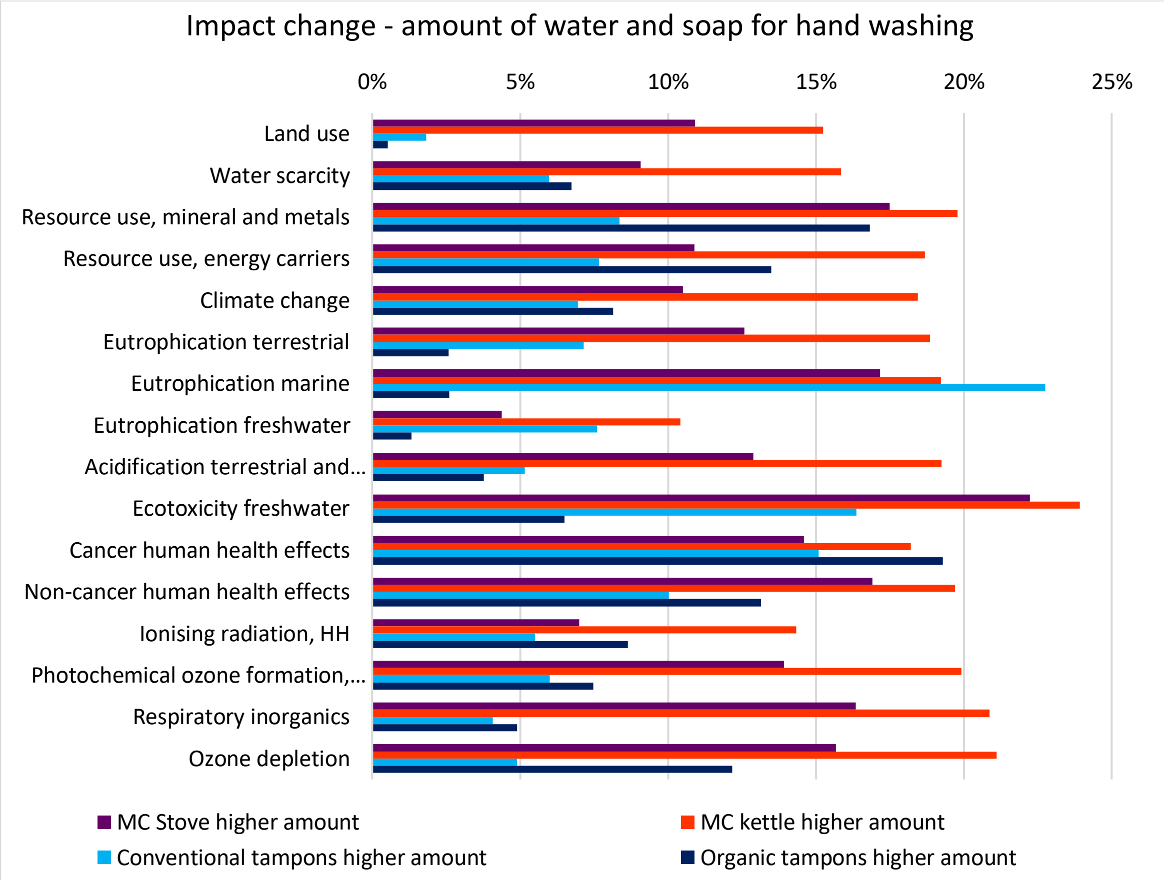

Figure 53. Influence on the overall results when the amount of water and soap for washing hands is increased by 50%

6.2.9 Sensitivity analysis 8: hand washing during tampons and cup use – water temperature

In section 4.6.1, it was established that the water for hand washing is assumed to be cold. The effect of using warm water is also studied with a temperature of 20°C. A small-scale boiler using light fuel-oil is modelled for heating the water (selected dataset: "heat production, light fuel oil, at boiler 10kW, non-modulating | heat, central or small-scale, other than natural gas", EUR without Switzerland). The energy input per hand wash amounts to 0.05342 MJ and is based on the process "hand washing, solid hand soap, T=20C" from the ESU-food database [12]. Figure 54 shows the impacts increase when using hot water instead of cold water. The MC is the product most influenced (the kettle scenario more than the cooker). The products and categories which are more influenced by hand-washing are also more influenced by the use of warm water. Organic tampons are more affected than TC for the categories which are more influenced by the TO use phase, e.g. *resource use, energy carriers*. In contrast, TO are less affected than TC for *land use* – the influence of the use phase is very low because of the relevancy of organic cotton production. *Ozone depletion* is the impact category most affected by using fuel oil: the cup impact is more than doubled, the organic cotton tampons impact is increased by 88%, and the conventional tampons by 35%.

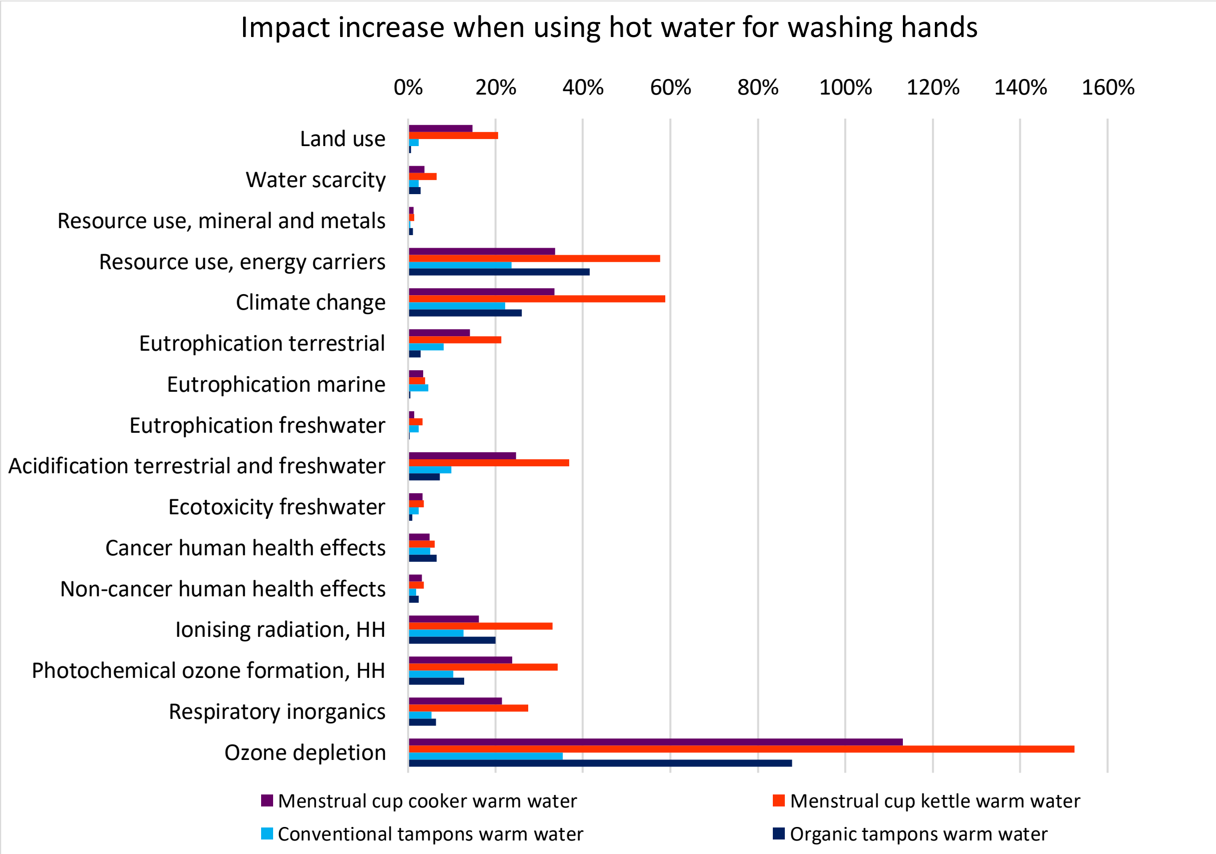

Figure 54. Impacts increase when using warm water for hand washing compared to baseline

6.2.10 Sensitivity analysis 9: sterilization time

The baseline sterilization time is 5.25 minutes, which is a weighted average of the recommended time, from 3 to 10 minutes (see Appendix A- 2). The influence of the sterilization time is very low as observed in Figure 55. The highest amount of energy for the sterilization process is required for bringing the water to boiling point, while the energy needed for continuing to boil the cup is much lower. Thus, the boiling time is not considered as a significant parameter. Even so, it is important to boil the water for the necessary time and not longer.

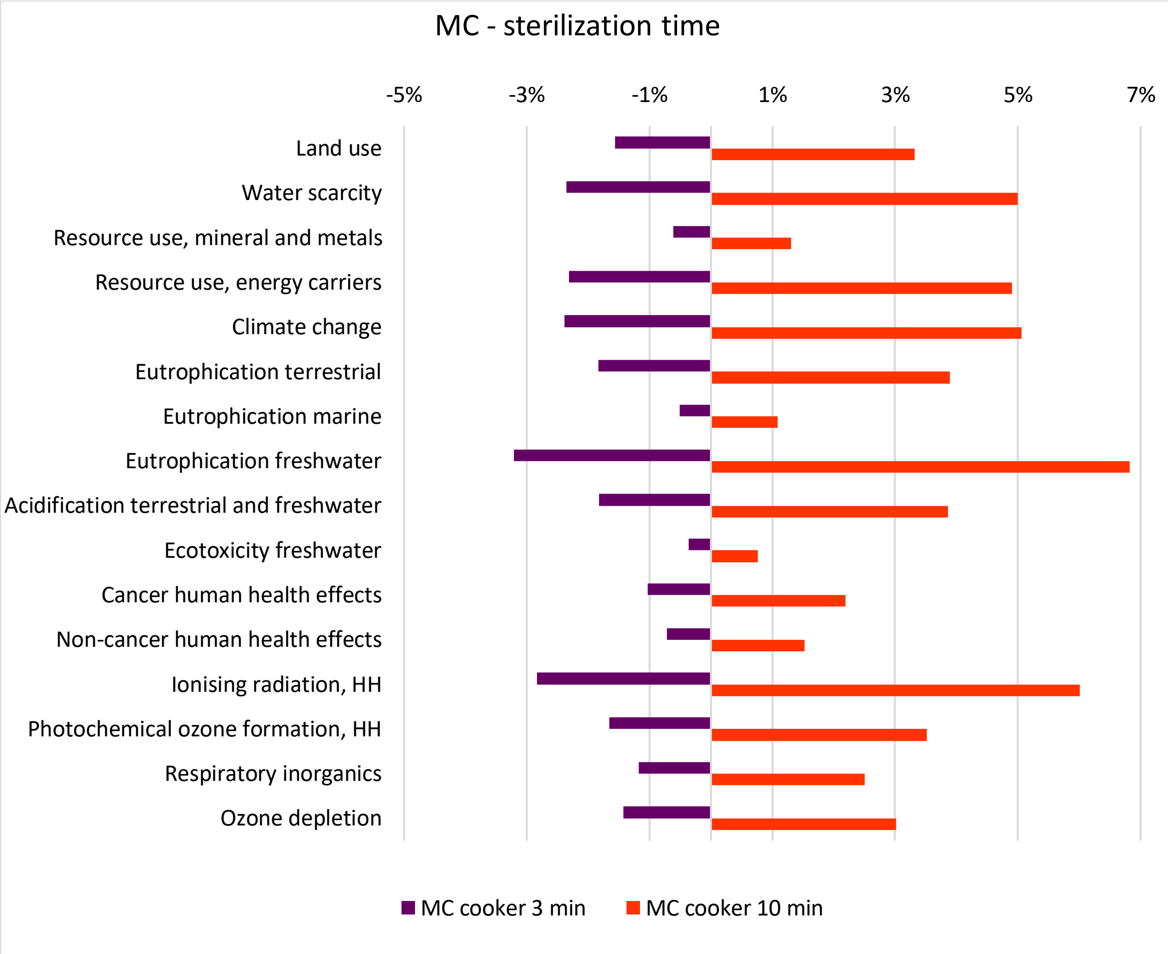

Figure 55. Effect of the boiling time on the MC impacts in the cooker scenario compared to baseline

6.2.11 Sensitivity analysis 10: use of a lid to cover the pan during the sterilization of the menstrual cup

The sterilization process of the menstrual cup is an important element for impacts on the environmental. Thus, the influence of using a lid to cover the pan for sterilizing the cup in the cooker scenario is analysed and displayed in Figure 56. This reduces the impacts on all categories to a maximum of 31% for *eutrophication of freshwater*. *Climate change* can be reduced by 23%.

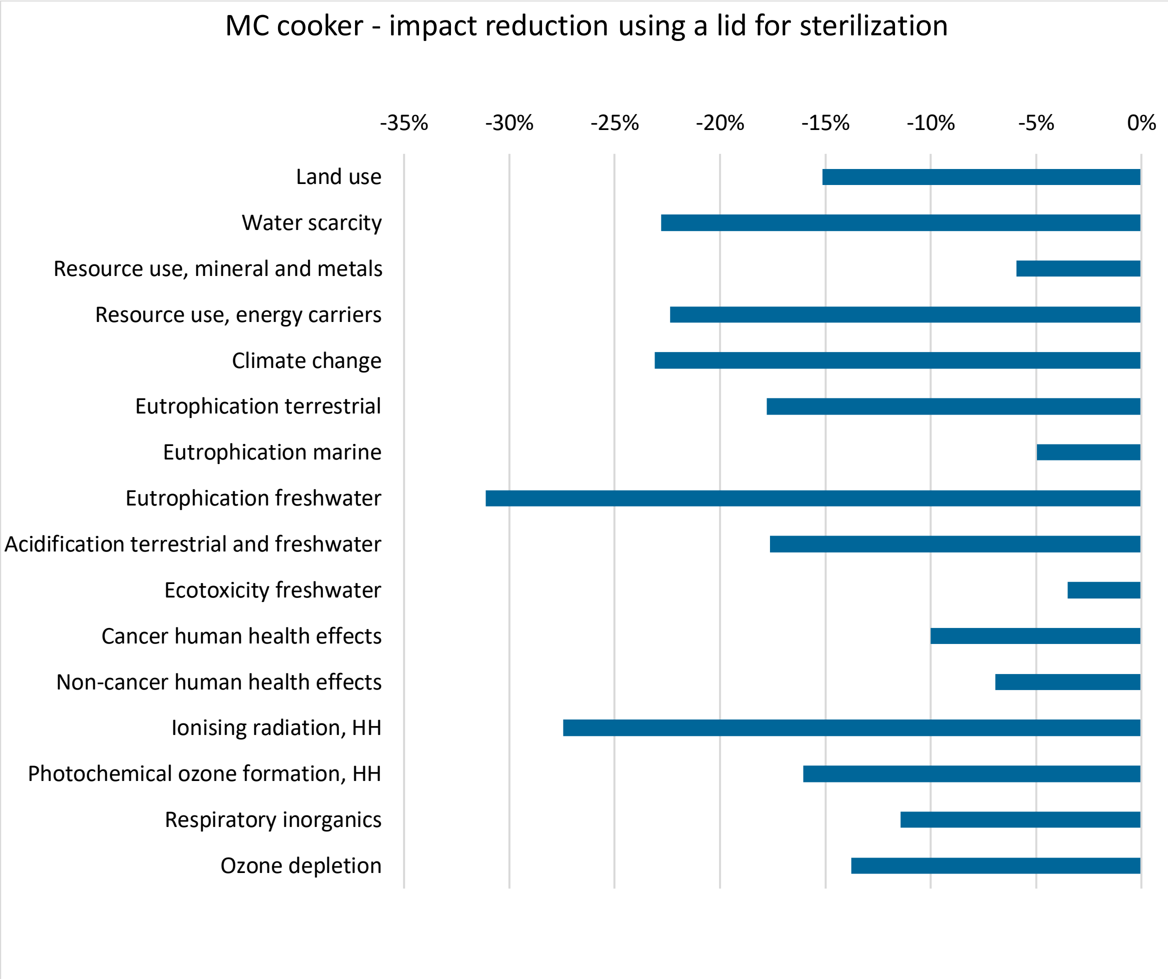

Figure 56. Menstrual cup impacts reduction when covering the pan for sterilization with a lid – cooker scenario

6.2.12 Sensitivity analysis 11: menstrual cup sterilization: use of renewable energy

Due to the relevancy of the impacts of the cup sterilization, the influence of using renewable energy instead of the German electricity mix is explored. The selected renewable sources are taken from the renewable share modelled in the Ecoinvent process for energy production in the German market (see Table 24).

Most of the impacts are reduced by using renewable energy, but there is an increase in 3 impact categories. The impact on *land use* increases due to the land needed for wind power; on *water scarcity* due to the water needed for hydropower; and on *resource use, minerals and metals* due to nylon production needed for the blades of wind turbines.

As explained in the introduction of the sensitivity analysis (6.2), the results from using renewable energy provide a theoretical indication of the potential improvements.

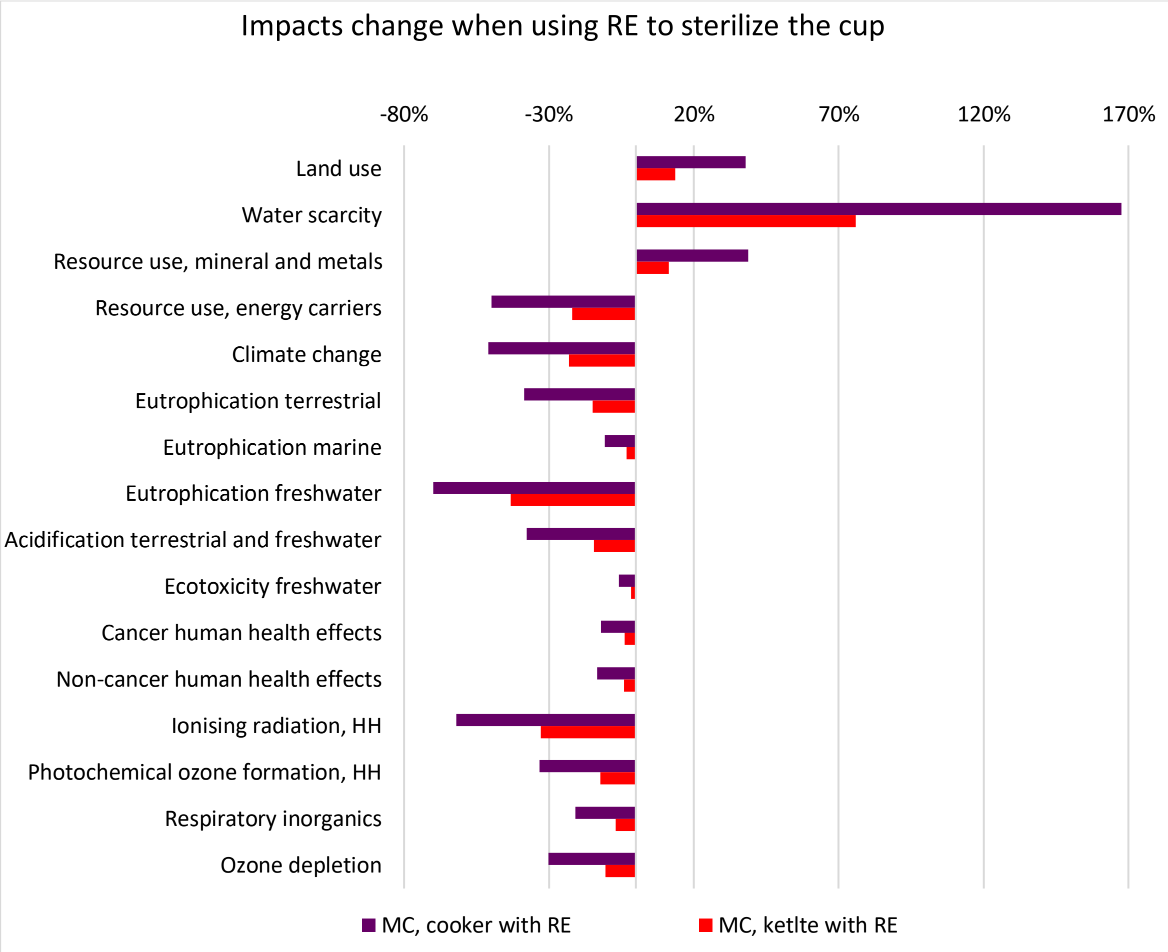

Figure 57. Modification of the impacts when using renewable energy for the cup sterilization compared to baseline

6.2.13 Sensitivity analysis 12: sterilization frequency of the menstrual cup

Although only one producer recommends sterilizing the cup after every change (introduced in section 3.4.3), we studied if more frequent sterilization may affect the results. Specifically, the cup would be sterilized 147 times per year (see Table 2). After it is removed, it must be cleaned with water to remove the blood before boiling it, though soap is not necessary. The cup is then boiled as in the cooker scenario, with 650 ml of water for 5.25 minutes, or in the kettle scenario with 250 ml of water. An important increase in the impacts can be seen due to the higher electricity consumption as presented in Table 53. The cooker scenario is influenced more strongly. The cup remains the best product in only 3 categories: *land use*, *freshwater ecotoxicity*, and *respiratory inorganics*. In the kettle scenario, the cup is still the best in 10 impact categories. If a lid is used to cover the pot in the cooker scenario, the impact increase can be minimized, although it remains high.

Table 53. Impact increase created bya higher sterilization frequency compared to baseline

Impact category	Impact increase for a higher sterilization frequency		
	Cooker	Cooker with lid	Kettle
Land use	489.93%	217.54%	102.25%
Water scarcity	544.64%	305.11%	190.56%
Resource use, mineral and metals	133.66%	70.89%	35.22%
Resource use, energy carriers	521.04%	285.25%	182.16%
Climate change	547.93%	301.55%	192.68%
Eutrophication terrestrial	406.29%	222.40%	126.48%
Eutrophication marine	133.25%	81.55%	26.32%
Eutrophication freshwater	750.44%	420.14%	348.26%
Acidification terrestrial and freshwater	406.63%	222.71%	125.59%
Ecotoxicity freshwater	57.76%	22.54%	18.25%
Cancer human health effects	249.04%	145.85%	61.94%
Non-cancer human health effects	179.44%	106.46%	39.08%
Ionising radiation, HH	652.11%	363.12%	267.50%
Photochemical ozone formation, HH	363.70%	197.64%	109.45%
Respiratory inorganics	257.52%	138.57%	70.03%
Ozone depletion	308.73%	163.69%	88.71%

According to the increase of impacts identified, the scores for the menstrual cup for ranking the products are influenced strongly. As observed in Table 54, the score of the cup is reduced by 36 points in the cooker scenario and by 25 when using a lid. This effect means that the cup then takes the second or third worst position in the ranking of products. In the kettle scenario, the products' ranking remains the same; though the cup score worsens for 8 categories of impact.

Table 54. Ranking of products for a higher sterilization frequency compared to baseline

No. of times a product shows a lower impact					
Scenario	MC	TC	TO	PC	PO
Cooker scenario – sterilization after every change	25 (-36)	34 (+10)	42 (+10)	47 (+9)	12 (+7)
Cooker scenario – sterilization after every change with lid	35 (-26)	32 (+8)	38 (+6)	45 (+7)	10 (+5)
Kettle scenario – sterilization after every change	56 (-7)	25 (+1)	35 (+3)	39 (+3)	5(=)

The colour scale indicates the level of impact – from green (lowest impact) to red (highest impact)
Additionally, the colour scale helps to understand how far the values are from each other; the more similar the colour, the closer the values are

6.2.14 Sensitivity analysis 13: amount of water and soap to wash the menstrual cup

The process of washing the cup is very relevant for the use phase, especially in the kettle scenario. Hence, as reflected in

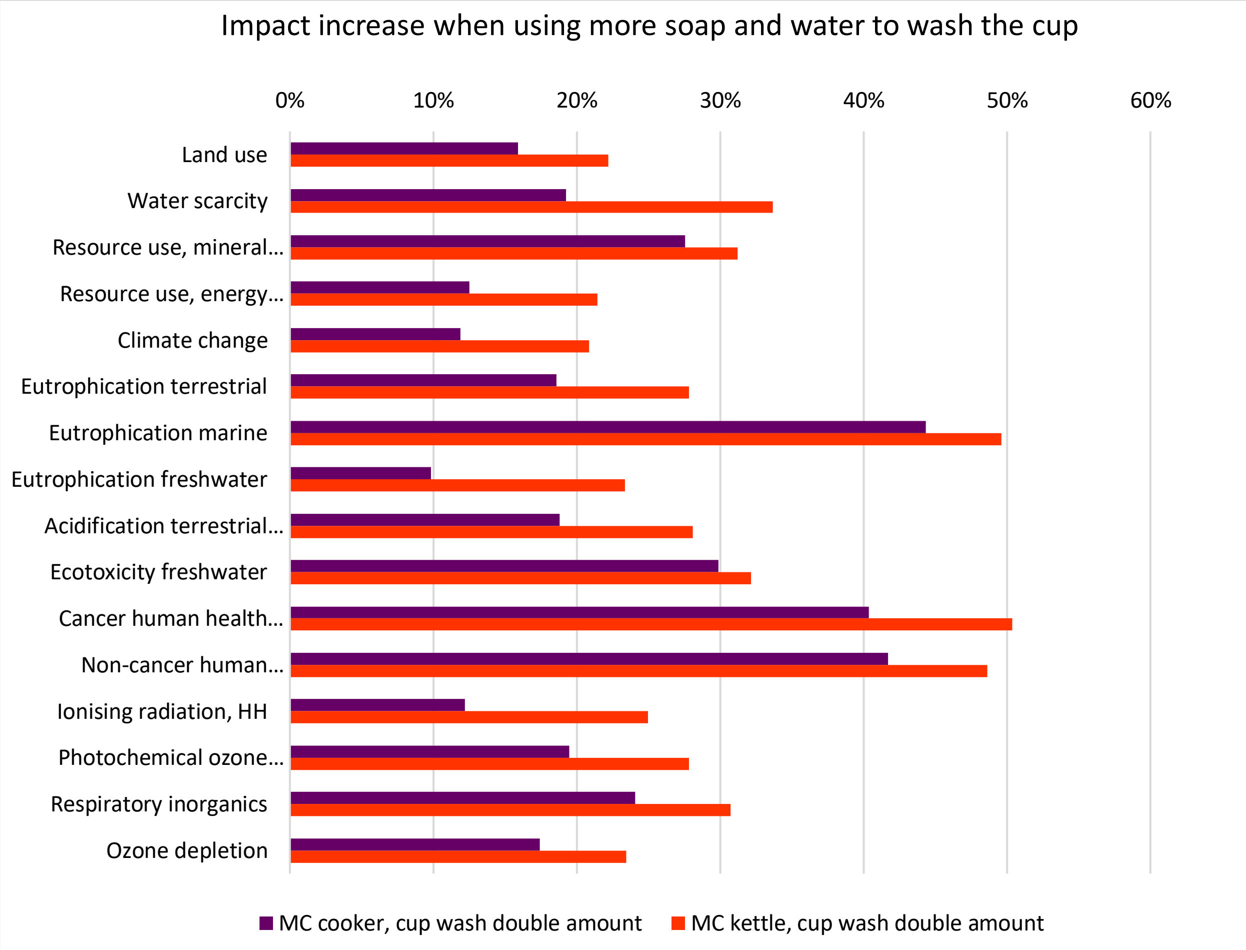

Figure 58, the kettle scenario is the most affected. The impact categories strongly influenced by wastewater treatment are affected the most, i.e. the higher use of water creates greater differences than the larger amount of soap. The increased amount of wastewater is responsible for the most relevant increases. These impact categories are *marine eutrophication*, *cancer and non-cancer human health effects*.

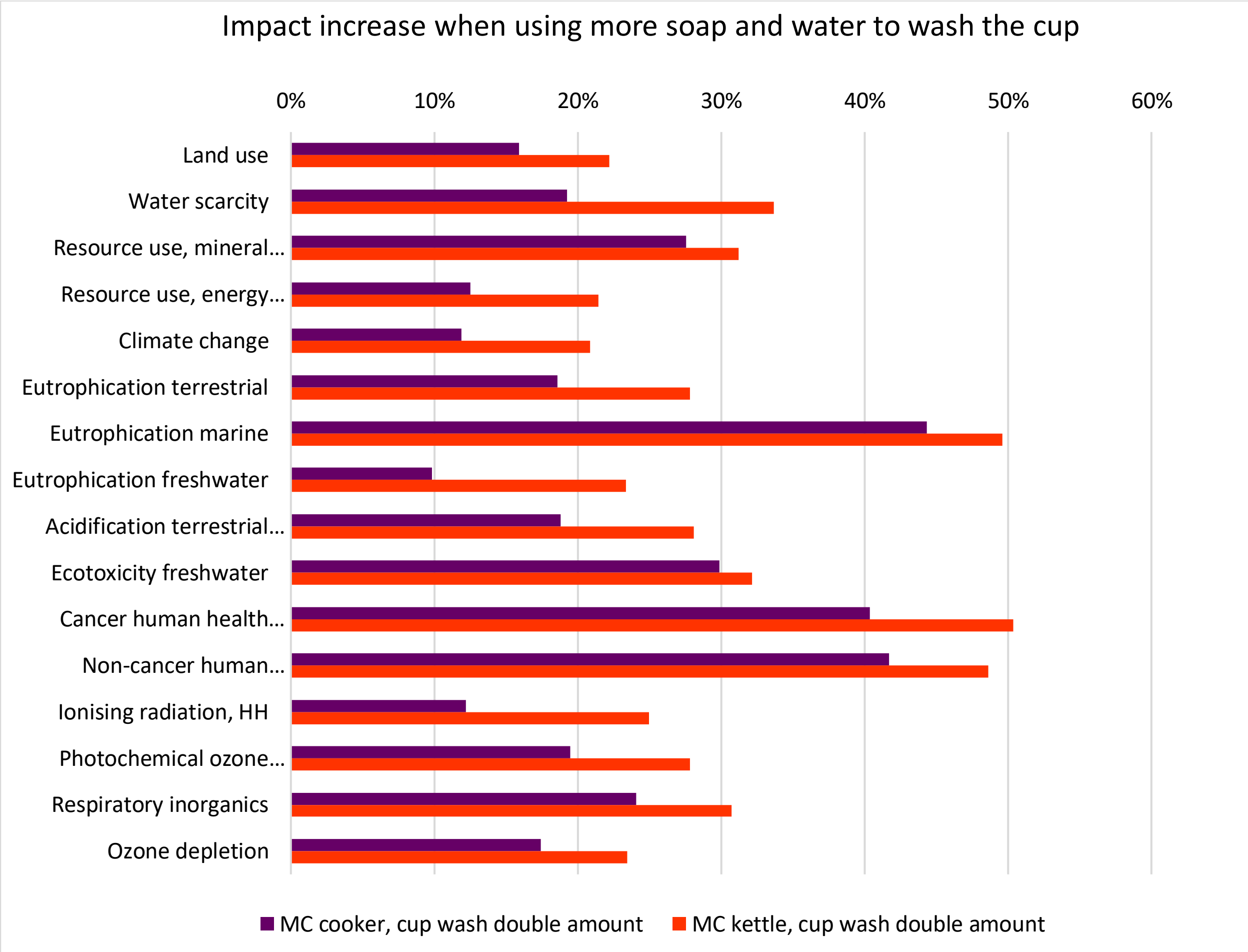

Figure 58. Impacts increase when using 50% higher amount of water and soap to wash the cup

6.2.15 Sensitivity analysis 14: menstrual cup wearing time

The effect of the wearing time of the cup is analysed from 6 hours to 12 hours for both scenarios. For a 12h wearing time, the impacts are similar for both scenarios and reduced by a maximum of 12% when wearing the cup for 12h. This is expected, as the assumed 10.6h wearing time for the baseline case is close to 12h. Figure 59 shows a different situation if the cup is worn for 6h. In this case, the impacts increase from 15% to almost 70% in the cooker scenario, and from 36% to 70% in the kettle one.

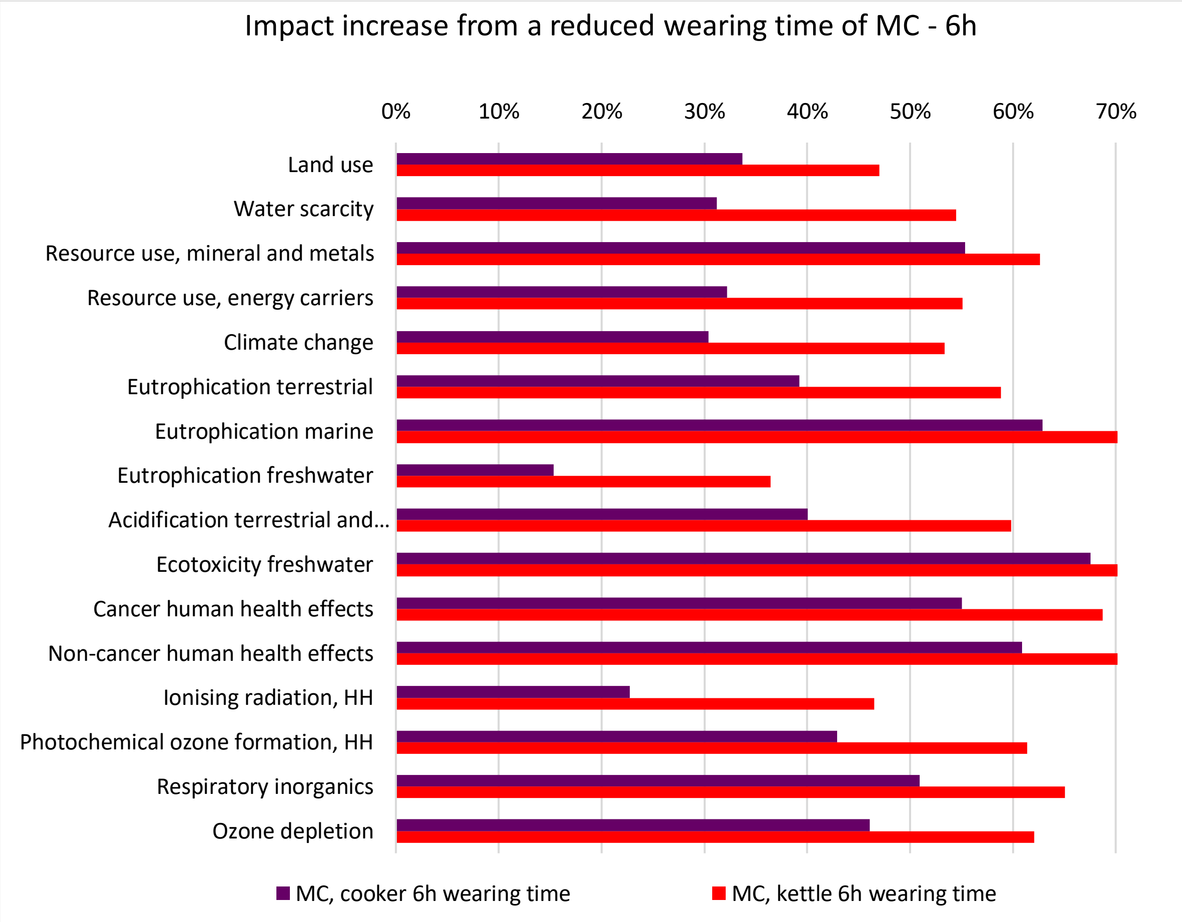

Figure 59. Impact increase for a reduced wearing time of the cup (6h) compared to baseline

6.2.16 Sensitivity analysis 15: wearing time of tampons and menstrual pads

The influence of the wearing time of tampons and pads from 6h to 4h and 8h are similar for all products and impact categories. For a 4-hour wearing time, 390 items are needed, and for 8 hours only 195 items. If the wearing time is reduced, the impacts are increased by approximately 50%, while they are reduced by approximately 25% for a wearing time of 8 hours.

6.2.17 Sensitivity analysis 16: use of toilet paper for the disposal of tampons

The use of a lower or higher amount of toilet paper to dispose of the tampons has a strong influence on the results. Specifically, the use of a double amount of toilet paper – 6 sheets – and no toilet paper – 0 sheets. The most affected categories, as appreciated in Figure 60, are those most influenced by the use of toilet paper: *non-cancer human health effects* and *land use*.

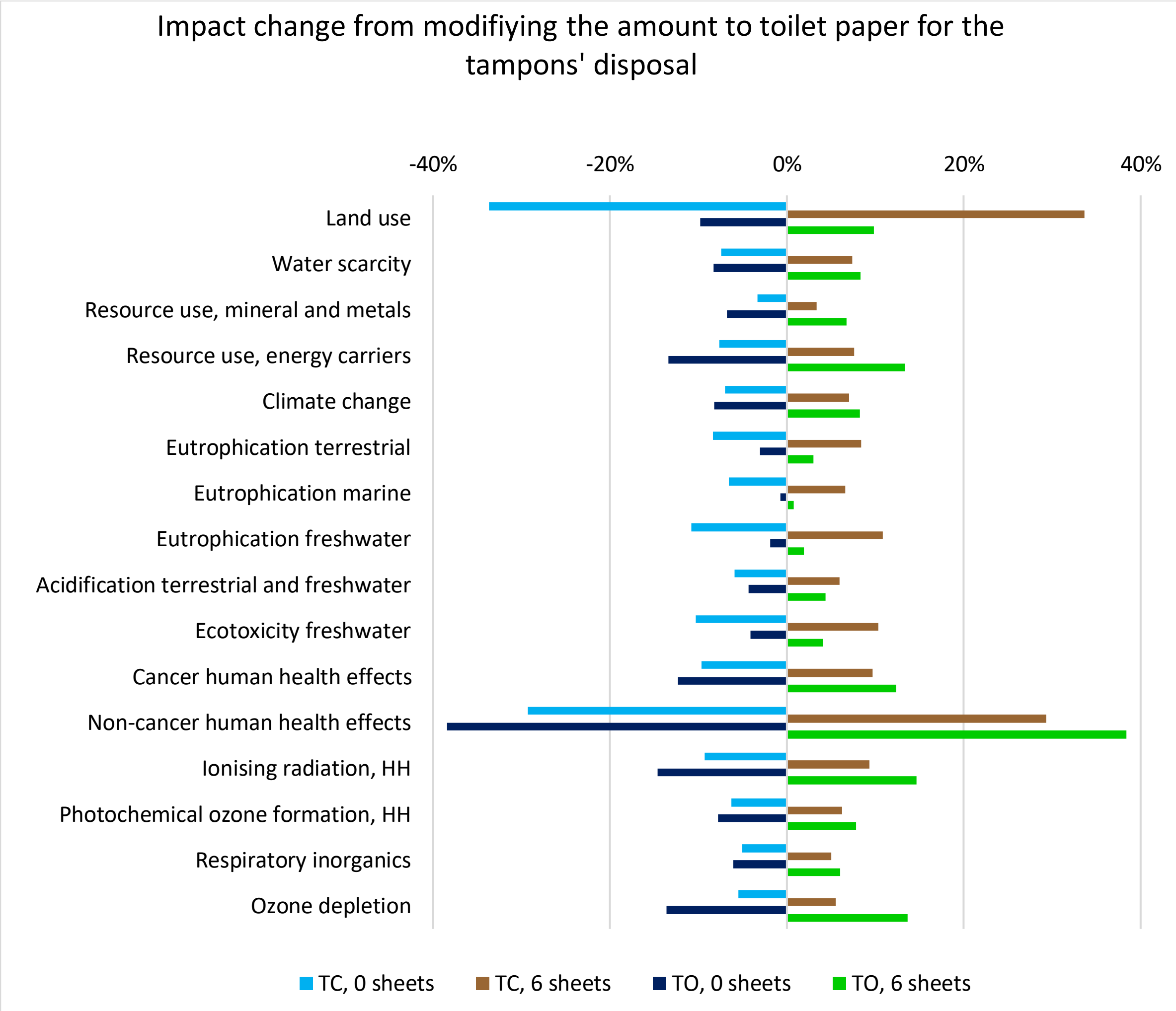

Figure 60. Influence on the tampons' impacts when using a different amount of toilet paper for disposal compared to baseline

6.2.18 Sensitivity analysis 17: hand washing before changing the menstrual pad

As was discussed in section 3.5, the assumption that hand washing is not needed prior to changing a menstrual pad is based on assumed practice. Figure 61 shows how the results of how the menstrual pads would be influenced by adding hand washing. The impact categories most affected are *marine eutrophication*, *cancer*, *and non-cancer human health effects* mainly because of wastewater treatment, and *ecotoxicity freshwater* due to use of soap.

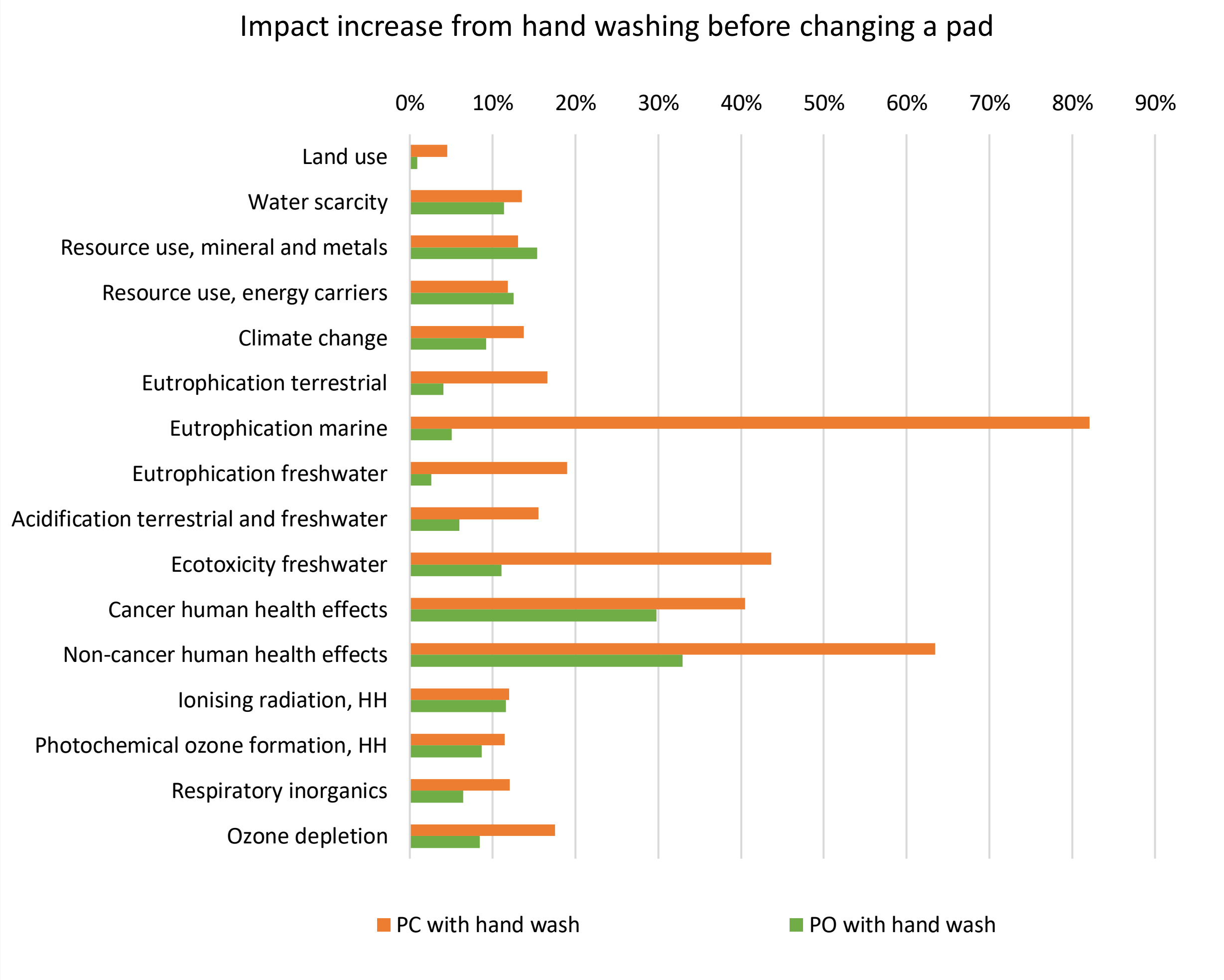

Figure 61. Increase of the menstrual pads impacts when adding hand washing before changing the pad

The differences regarding the comparison of products are very strong for the PC and small for the PO as observed in Table 55. The reason is that the PO already presents the highest result in the baseline results. The products' ranking is shifted – the TO is the second-best product, the TC the third, and the PC the second worst after PO. The TC is more strongly affected than the TO because their results are closer to PC in the baseline situation. Hence, they are more likely to be modified.

Table 55. Ranking of products from adding hand washing to the menstrual pads use compared to baseline

No. of times a product shows a better result					
Scenario	MC	TC	TO	PC	PO
Cooker scenario –hand washing	63 (+2)	31 (+7)	33 (+1)	29 (-9)	4 (-1)
Kettle scenario –hand washing	64 (+1)	31 (+7)	33 (+1)	28 (-8)	4 (-1)

6.3 Data quality assessment results

The results of the data quality assessment, performed as explained in section 3.9.2, are presented separately for the foreground and background systems.

6.3.1 Foreground system

For the foreground system, the data quality entry is given for the processes which contribute most. These are identified in Appendix E – Processes' contribution. Specifically, all processes contributing more than 20% to any of the impact categories are selected. For single-use products, some processes presented contribute less than 20%. However, they support a similar structure. Results of the data quality assessment are displayed in Table 56 for MC, Table 57 for TC, Table 58 for TO, Table 59 for PC, and Table 60 for PO.

The data quality of the processes from the use phase is, in general, lower than for the production and manufacturing of the components because it depends on the users' behaviour, which is difficult to predict. This is observed for the menstrual cup and the tampons – the data quality for the use phase (hand washing and toilet paper use) is worse than for other life cycle stages. For the menstrual cup, hand washing and cup washing show different results for reliability and temporal correlation. Reliability is better for hand washing according to the applied literature source (see sections 4.6.1 and 4.6.3). Data for washing the cup was obtained from non-verified measured values. However, the measurements are very recent compared to the data for hand washing (better temporal correlation).

Data for the organic products and the conventional tampons were provided by manufacturers, and thus the results for quality are better than for the conventional pads. In general, data quality is very good for the components production and manufacture, though the data quality for the conventional pads can be improved. To keep the use phase uncertainties to a minimum, numerous sensitivity analyses were performed in section 6.2.

Table 56. Data quality results - MC

Process		Reliability	Completeness	Temporal correlation	Geographical correlation	Further tech. correlation
Electricity for sterilization		3	2	2	1	2
Hand washing	Water	2	2	2	2	2
	Soap	2	2	2	2	2
	Wastewater	2	2	2	3	2
Cup washing	Water	3	2	1	2	2
	Soap	3	2	1	2	2
	Wastewater	3	2	1	3	2

Table 57. Data quality results - TC

Process		Reliability	Completeness	Temporal correlation	Geographical correlation	Further tech. correlation
Viscose production		1	2	1	2	1
Packaging box		2	2	1	2	2
Electricity for manufacture		1	2	1	1	1
Transport for distribution		2	2	1	2	2
Car use for shopping trip		2	2	1	2	2
Toilet paper		2	2	1	2	2
Hand washing	Water	2	2	2	2	2
	Soap	2	2	2	2	2
	Wastewater	2	2	2	3	2
Tampon incineration		1	1	1	1	2

Table 58. Data quality results -TO

Process		Reliability	Completeness	Temporal correlation	Geographical correlation	Further tech. correlation
Organic cotton fibre production		1	2	1	2	1
Printed box production		2	2	1	2	2
Electricity for manufacture		1	2	1	1	1
Transport for distribution		2	2	1	2	2
Car use for shopping trip		2	2	1	2	2
Toilet paper		2	2	1	2	2
Hand washing	Water	2	2	2	2	2
	Soap	2	2	2	2	2
	Wastewater	2	2	2	3	2
Tampon incineration		1	1	1	1	2

Table 59. Data quality results - PC

Process		Reliability	Completeness	Temporal correlation	Geographical correlation	Further tech. correlation
Distribution layer		3	2	1	2	2
Top-sheet		3	2	1	2	2
Adhesive		3	2	2	2	2
Absorbent core	Fluff pulp	3	2	2	2	2
	SAP	3	2	2	2	2
Electricity for manufacture		3	2	2	1	2
Transport for distribution		2	2	1	2	2
Car use for shopping trip		2	2	1	2	2
Pad incineration		1	1	1	1	2

Table 60. Data quality results - PO

Process	Reliability	Completeness	Temporal correlation	Geographical correlation	Further tech. correlation
Organic cotton noils production	2	2	1	1	2
Wrapper production	1	2	1	2	1
Adhesive production	1	2	1	2	1
Electricity for manufacture	1	2	1	1	1
Transport for distribution	2	2	1	2	2
Car use for shopping trip	2	2	1	2	2
Pad incineration	1	1	1	1	2

6.3.2 Background system

Table 61 presents the data quality assessment results, performed as explained in 3.9.2. The results are influenced by the quality of the introduced data, but also by the relevance of a certain process, i.e. the menstrual cup results are influenced by the use phase, while the organic pad results depend on the production of organic cotton noils.

Results for the temporal correlation are the best possible for all products. As introduced in section 3.9.2, the background data was adapted to the reference year of the study (2019). Because the datasets are valid from the year 2018 to 2020, the value of the temporal correlation indicator is always 1. The results of the remaining 4 indicators are usually influenced by processes located in the supply chain that are not directly connected to the results of this study. Hence, they indicate the data quality of the background data.

The data quality of the organic cotton dataset can be observed for the impact categories which are strongly affected by organic cotton production. The *land use* results cannot be considered, as no data quality entry is available for the processes concerning this category. The reliability, temporal correlation, geographical correlation, and further technological correlation indicators show good results, while the completeness indicator presents a worse result for *marine* and *freshwater eutrophication*.

Table 61. Data quality assessment results of the background data

Impact category	Reliability						Completeness						Temporal Correlation						Geographical Correlation						Further Technological Correlation					
	MC¹	MC²	TC	TO	PC	PO	MC¹	MC²	TC	TO	PC	PO	MC¹	MC²	TC	TO	PC	PO	MC¹	MC²	TC	TO	PC	PO	MC¹	MC²	TC	TO	PC	PO
Land use	2	2	2	2	2	2	2	2	1	2	2	2	1	1	1	1	1	1	4	4	4	4	4	4	3	4	3	3	4	4
Water scarcity	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	5	5	5	5	5	5	1	1	1	1	1	1
Resource use, mineral and metals	1	1	1	1	1	1	2	2	3	3	3	3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Resource use, energy carriers	1	1	2	1	2	1	1	1	2	2	2	2	1	1	1	1	1	1	2	2	2	2	2	2	1	1	2	1	1	1
Climate change	3	2	2	2	2	2	2	2	2	2	2	2	1	1	1	1	1	1	2	2	3	2	3	2	1	1	2	1	2	1
Eutrophication terrestrial	3	2	2	1	2	1	3	2	2	3	2	3	1	1	1	1	1	1	2	2	3	1	3	1	2	1	2	1	2	1
Eutrophication marine	1	1	2	1	2	1	1	1	2	4	2	4	1	1	1	1	1	1	1	1	2	1	3	1	1	1	1	1	2	1
Eutrophication freshwater	1	1	1	1	1	1	1	1	1	4	1	4	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Ac. terrestrial and freshwater	3	3	3	2	3	2	2	2	3	3	3	3	1	1	1	1	1	1	2	2	3	1	3	2	2	2	2	1	2	1
Ecotoxicity freshwater	2	2	2	1	1	1	2	2	2	3	1	3	1	1	1	1	1	1	3	3	3	2	1	1	2	2	1	1	1	1
Cancer human health effects	1	1	1	1	1	1	1	1	1	1	1	2	1	1	1	1	1	1	3	3	3	3	3	3	1	1	1	1	1	1
Non-cancer human health effects	2	1	1	1	2	2	2	1	1	2	2	3	1	1	1	1	1	1	2	2	4	3	3	3	1	1	1	1	2	1
Ionizing radiation, HH	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	1	1	1	1	1	1
Photoch. ozone formation, HH	2	2	2	2	2	2	2	2	3	2	2	3	1	1	1	1	1	1	2	2	3	2	3	2	1	1	2	1	2	1
Respiratory inorganics	3	2	3	2	3	2	3	3	3	3	3	3	1	1	1	1	1	1	3	2	3	2	3	2	2	1	1	1	1	1
Ozone depletion	3	3	2	2	2	2	3	3	3	3	3	3	1	1	1	1	1	1	3	3	4	4	4	5	2	2	2	3	3	3

MC¹ = cooker scenario; MC² = scenario kettle

6.4 Completeness check

In the Life-cycle inventory, thorough documentation of the collected data is provided. Further detailed information can be found in Appendix D – Life cycle inventory.

For all processes inside the system boundaries (see Figure 7) data were collected, and the cut-off criteria defined in section 3.6.1 are systematically applied. Thus, all processes with a relevant contribution to the results, and therefore necessary to meet the goal and scope, are included in the assessment.

The database Ecoinvent 3.6 is used for the background data. It is a widely used and recognized database compliant with ISO 14040 and 14044. Hence, the background data completeness is satisfied.

6.5 Consistency check

The assumptions used methods, and applied data are consistent with the goal and scope of the study. Relevant elements to check the consistency regarding the methodology, data quality, regional differences, and allocation rules are explained here:

- The assessed menstrual products are widely used in Germany, and therefore are representative of this study.
- The defined system boundaries (see Figure 7) are the same for all menstrual products – all life cycle stages are included.
- Data are collected at the same level of detail. Further, the same cut-off criteria are applied to all products as explained in section 3.6.1.
- The LCIA results are equally analysed for all assessed products. Special attention is given to the components production and use stages due to their environmental relevance.
- The best available data are selected for the modelling of the menstrual products – primary data are applied if available, otherwise secondary data are used. An overview of the data sources is provided in Table 4. The main difference regarding data sources between the product systems is that primary data for the breakdown of the material and the manufacture are applied to all products, except the conventional pad. Ideally, primary data should be used.
- The selected datasets for modelling the production of the core materials represent the global market. In the case of the organic products, data from India, the global leading

producer of organic cotton (see Organic cotton tampons (TO)) are applied. Global datasets are used for the conventional products core materials production. The influence of modifying the origin region is studied in the sensitivity analysis in sections 6.2.3 and 6.2.4.

- Economic allocation is applied to produce the organic pads. No other allocation procedures are needed in the foreground systems. In the sensitivity analysis (section 6.2.5) the results of applying physical allocation are evaluated.
- The background data for modelling the components production other than the core represents the European market, where possible. Otherwise, global datasets are used.
- A European electricity mix is modelled for the electricity consumption during the conventional products' manufacture, while the country-specific mix is selected for the organic products since the location is known. In this way, the producers obtain the results for their specific sites. The analysis of using a European mix for the organic products is performed in section 6.2.6 to understand the influence of the mix in the results, which is identified as low. This provides a comparison based only on the amount of electricity consumed. Primary data are available for all products, except for the conventional pad.
- Primary data are used for the distribution of the organic products and the menstrual cup, while assumptions are made for the conventional pads and tampons. Given the rather low influence of distribution, the differences in the data quality are not considered as relevant.
- The shopping trip is equally modelled for all products (see Table 20).
- Many uncertainties are related to the use phase of menstrual products. The followed approach to model this stage is based on the recommendations of the menstrual products industry on how to use the modelled products safely. A thorough evaluation of the relevant parameters of the use phase is performed in section 6.2. Since no specific recommendations are available for the menstrual pads regarding hand washing before changing the pad, and the wearing time, both parameters are studied in the sensitivity analysis in sections 6.2.16 and 6.2.18.

Background data applied for the modelling of the use, and end of life stages represent the German market.

6.6 Discussion

As defined in section 3, the goal of the study is “to identify which menstrual products, from the selected ones - namely conventional pads (PC), organic pads (PO), conventional tampons (TC), organic tampons (TO), and menstrual cups (MC), are more beneficial from an environmental perspective”. To meet the goal, it is essential that all life cycle stages that are needed to fulfil the functional unit (see section 3.5), are included in the study, and the data collected are equivalent and modelled in the same way. The completeness and consistency checks support the comparability of the products.

Although the impacts of all products are analysed independently, their comparison is the focus of the analysis of the results and of the sensitivity analysis; the purpose is to determine to which extent the decisions and assumptions affect the products comparison. Thus, in this section, the main findings from the LCIA are discussed together with the results of the sensitivity analysis and the data quality assessment, with special attention to comparison of the products. The results of this study are compared to the literature results.

6.6.1 Products comparison

From the LCIA results, it is possible to say that the MC creates the lowest environmental impact. In contrast, PO creates the highest impact. In the middle, between MC and PO are tampons and PC . PC creates, in general, lower impacts than tampons – very closely followed by TO and a further by TC.

Since the MC is very strongly influenced by the use phase (see Figure 14), two scenarios were defined – cooker and kettle (see Table 3). The kettle scenario significantly reduces the impacts of the MC. Such reduction is also observed when the menstrual products are compared – the MC is the best in 13 categories out of 16 in the cooker scenario, and in 15 categories in the kettle scenario (see Table 29). From the 9 sensitivity analyses of the MC, in only one analysis – the higher sterilization frequency of MC in the cooker scenario – the MC is not the best product (see section 6.2.13). Though sterilizing the MC after every change is only recommended by one producer in the German market, and it is very likely that most users are sterilizing the cup once, after each period.

Although the baseline results of the TO are better than PO and TC, they are not better than the PC, which may be a different outcome than expected. In literature pads show, in general, higher impacts than tampons (see section 0), and organic cotton is related to lower impacts. The explanation is easily found in the addition of the use phase impacts to the TO, i.e. hand washing before tampon use and the use of toilet paper for disposal. Following the same reasoning, the higher impact of TC compared to PC is also explained through the modelling of the use phase. In section 6.2.18, the effects of adding hand washing to the use of pads show the relevance of the use phase regarding the comparison of products. This means that when analysing the components production of TO, TC, and PC, the pad is no longer the second-best product– it is the second-worst after PO.

Since manufacturing, distribution, shopping trip, use, and end of life are very similar for both tampons, the production of viscose and organic cotton determines the impact difference between TC and TO. Specifically, TO is better than TC in 10 categories and worse in the 6 categories strongly influenced by organic cotton production (see section 5.1.3).

Regarding the sensitivity analyses of the tampons, the use phase parameters have a relevant influence on the results for tampons, especially the water temperature and the use of toilet paper. A different origin of viscose production is studied in section 6.2.3; however, the influence in the TC results is small. Given the relevance of organic cotton for certain categories, the use of a GaBi dataset for organic cotton production is tested (section 6.2.4). It shows an impact reduction for most of the categories, while the comparison to the other products remains similar.

The PO creates the highest impact on 12 out of 16 categories (see Table 29). Additionally, the distance to the conventional products and the MC is significant (see Figure 25 and Figure 26) in the categories strongly affected by organic cotton production – *land use*, *terrestrial*, *marine*, and *freshwater eutrophication*, *acidification*, *ecotoxicity freshwater*, and *respiratory inorganics*.

The PO impact may be surprising because organic cotton is associated with lower environmental impacts. However, not only the organic cotton itself but other reasons, listed here, explain the PO results.

- From the comparison of core materials for single-use products in section 5.2.3., it can be concluded that organic noils show a good performance compared to the core materials of TC, TO, and PC. Since the impact for producing the noils is allocated, the fibre input is higher for TO than for PO (for 1kg of material). However, the combing process to produce the noils needs higher energy consumption.
- The relatively high amount of organic cotton needed in the PO. The core materials input

amounts to 2.34g for TC; 2.70g for PC; 2.79g for TO; and 3.22 for PO. Further, when comparing the pads, the total weight per product, including packaging, is significantly higher for PO – 9.11g for PO and 5 for PC.

- The energy consumption to produce the bioplastic present in the wrapper, back-sheet, and packaging bag of the organic pad also plays a relevant role (see Figure 24).

From the sensitivity analysis results, it can be concluded that the use of the GaBi dataset (see section 6.2.4) for organic cotton production implies a relevant reduction of the impacts for some categories (see Table 51).

The comparison of products remains similar for the majority of the analyses – from 17 analyses, only 3 influence the products' ranking:

- Menstrual cup sterilization frequency (section 6.2.13).
- Use of a different dataset for organic cotton production used in TO (section 6.2.4).
- Addition of hand washing to the pads' use phase (section 6.2.18).

Furthermore only 1 sensitivity analysis would change the interpretation: the frequency of MC sterilization. The products' comparison of the baseline results is stable along the sensitivity analyses. Thus, the decisions and assumptions are validated.

The data quality assessment of the foreground system shows very good results, especially for MC, TC, TO, and PO since primary data were used for their modelling. The results for PC show that the use of primary data would improve the data quality. However, the selected data for the components production and manufacture is plausible compared to the other products.

Since the use phase is challenging to predict, especially for MC due to sterilization, the data quality, mainly reliability, is lower than for other stages. However, the sensitivity analysis results demonstrate that the products' comparison is stable despite the relevant effects of identified parameters.

6.6.2 Organic cotton production

As determined in section 5.1.3 for TO and section 5.1.5 for PO, organic cotton production has a strong influence on the impact categories *land use*, *terrestrial*, *marine*, and *freshwater eutrophication*, *acidification*, *ecotoxicity freshwater*, and *respiratory inorganics* is . For this reason, the use of a different dataset is explored in section 6.2.4. Table 51 shows strong differences in the results – in general, they are lower with the GaBi dataset. Although the differences in the products' comparison are not strong, it is interesting to understand why the results between the datasets differ. However, it is not possible because the GaBi dataset is aggregated, and the contributors to the impacts cannot be separated.

In Table 61 the quality of background data is assessed for each impact category. The impact categories strongly affected by the production of organic cotton show lower quality values for completeness, specifically *marine and freshwater eutrophication*. So the results must be interpreted cautiously. Ideally, the data quality would be compared to the GaBi dataset. However, a comparable data quality entry is not available. According to the GaBi dataset information, the overall data quality is good.

6.6.3 Comparison to previous literature: impact on climate change

Within different impact assessment methods used in previous research, the calculation of the impact category *climate change* is very similar for them all. An overview of the *climate change* results is presented and analysed together with the results of this assessment.

The literature was selected on the comparability of the results and the availability of *climate change* absolute results. The Hait and Powers LCA study [16] is used for tampons, pads and menstrual cups, and the report of the EU Commission for the tampons and pads [23].

A common conclusion from literature and this study is that the production of components is the stage most relevant for all menstrual products when the use phase is not considered. The three menstrual products are analysed separately in the following sections.

Menstrual cup

The Hait and Powers study provides lower impacts from the menstrual cup on climate change due to the inputs considered during the use phase, (this only includes washing the cup with tap water). Table 62 shows that the complete modelling of the use phase drastically changes the results– from 0.0154 to 2.15 kg of CO2 equivalents. In addition, this study shows higher results than in the literature for the components production, manufacturing, and end of life. The reason is the greater weight of the cotton bag delivered with the cup. The emissions from silicone production are similar.

Table 62. Overview of the impact of the menstrual cup on climate change from literature

Menstrual cup			
Source	**Lifetime (years)**	**Weight (g/item)**	**Climate change (Kg CO2 eq./FU)**
Powers	10	14.8	0.0129 for components production, manufacturing and EoL
			0.0154 including the cup washing
Calculated in this study, cooker	10	11.37	0.034 for components production, manufacturing and EoL
			2.19 including all life cycle stages

Tampons

The main difference from previous LCA studies is the consideration of the use phase of tampons: – hand-washing and toilet paper used for disposal. Primary data were applied for the manufacturing of tampons, including the raw materials input and the energy consumption and production waste, while in literature, secondary data were used. In Table 63 an overview of the *climate change* results is presented. When comparing the overall results, the impact of this assessment is higher, except for the TO, which shows a lower result than Powers claims. This is expected because the tampons modelled in the literature include an applicator. Even so, if the use phase is not considered, the results of this study would be lower for all comparisons. Compared to Powers, the manufacturing and end of life results are almost similar.

Table 63. Overview of the impact of tampons on climate change from literature

Tampons				
Source	Type	Weight (g/item)	Climate change (kg CO2 eq./**FU**)	Scope
Powers	Conventional, with applicator	5.41	5.62	Exclusion of use phase, shopping trip, and secondary packaging
EU Commission	With applicator, cotton core	5.4	4.94	Exclusion of use phase, shopping trip, and secondary packaging
Calculated in this study	Conventional, regular (TC)	2.88	5.87	Complete life cycle
			4.44	Same scope as Powers
	Organic cotton, regular (TO)	3.71	5.01	Complete life cycle
			3.53	Same scope as EU Commission

Pads

The *climate change* impact differences within previous studies are summarized in Table 64. This is explained through the different sizes of pads (Maxi and ultra-pads), materials used (mainly plastic or cotton for the top-sheet), and availability of data. The Hait and Powers study uses secondary data, and the EU Commission study is based on data for baby nappies. The Natracare EPD is based on primary data.

The wood pulp input for the maxi-pad and the ultra-pad modelled in the EU-Commission study is similar (also the climate change results). This is confusing, as the ultra-pad has an SAP, which should be translated into a lower input of wood pulp, as with the conventional pads assessed in this study – the CO2 emissions created are lower than in the literature. The lower pad weight may explain such a difference.

Due to the use of primary data used in the Natracare EPD, the results may be handled as a reference. The climate change values are similar to the *einhorn* pads the results, although the core material is not the same; however, the weight of both pads is comparable.

Table 64. Overview of the impact of pads on climate change from literature

Menstrual pads				
Source	Type	Weight (g/item)	Climate change (kg CO2 eq./**FU**)	Main differences to calculated in this study
Powers	Conventional Maxi-pad	10.02[1]	9.1	Exclusion of the shopping trip and secondary packaging
EU Commission	Conventional Ultra-pad	8.94[2]	7.54	Exclusion of the shopping trip and secondary packaging
Natracare	Ultra-pad, organic, wood pulp core, organic cotton, top-sheet	9.01[3]	7.9	Not clear, but no shopping trip
Calculated in this study	Conventional ultra-pad	6.3[3]	5.99	Complete life cycle
			5.63	Without shopping trip and use
	Organic cotton pad	10.5[3]	8.84	Complete life cycle
			7.48	Without shopping trip and use

[1] Including primary packaging
[2] Without packaging
[3] Including primary and secondary packaging

7 Limitations

There are general limitations of the LCA methodology, as well as specific ones for this assessment. The general limitation is that LCA provides the potential impacts of the defined product systems, but not measured impacts. According to ISO 14044:2006 [1], the life cycle impact assessment results are relative expressions that do not predict impacts on category endpoints, exceeding thresholds, safety margins, or risks.

Based on the data quality assessment results and the sensitivity analysis, the specific limitations of the study are listed here:

- A theoretical, not real behaviour of the user is considered in terms of the frequency of product change, hand washing, and menstrual cup sterilization.
- Primary data are available for the menstrual cup, the tampons, and the organic pads, while secondary data are used for the conventional pads.
- The materials share of the conventional pads' distribution layer is unknown. It is assumed to be 25% for each of the four materials.
- The core and top-sheet of the organic pads go through a pre-manufacturing process before the manufacture of pads. This is not included in the study due to a lack of data. However, an increase in the organic pad impact would be minimally relevant for the comparison of the menstrual products.
- The fragrance present in the conventional pad is not considered as data are not available.
- The disposal of the menstrual product after use excludes collected blood.
- The flushing of menstrual products in the toilet is not included.

8 Conclusions

Considering the baseline and sensitivity analysis results, it can be concluded that the cup delivers the best environmental performance in the defined scenarios – cooker and kettle (see Table 3). The impacts of the menstrual cup are mainly driven (approximately 95%) by the use phase. In the cooker scenario, the electricity consumption for sterilization is the process most relevant, followed by soap production for washing hands before the cup is changed and for washing the cup between changes. Due to a reduction of consumed energy for sterilization in the kettle scenario, the production of soap is the process which contributes most. In addition, water use, especially its treatment as wastewater, also has an important influence on the impacts.

All these processes are carefully analysed in the sensitivity analysis. The results prove that the handling of the cup by the user has a great influence on the results. However, the good performance of the cup remains constant. The sterilization frequency can be identified as a determinant parameter for the cup's impacts; the environmental impact of the cup increases with sterilization. The kettle scenario is affected, but less – the cup still shows a better performance in comparison to single-use products.

Sterilization of the cup after every change is unlikely, as it was recommended by only one producer. The sterilization method in the kettle scenario is proved by a new study to be sufficient for using the cup safely and significantly decreases the impacts of the cup [65]. However, it can be assumed that currently, most users clean the cup using the cooker scenario, because it is widely recommended by menstrual cup brands. The simple use of a lid to cover the pan significantly reduces the environmental impacts. Besides the sterilization, other processes of the use phase were identified as relevant in the sensitivity analysis – the lifetime of the cup; the amount of water and soap used to wash the cup; a reduced wearing time of 6 hours; the use of warm water; and the amount of water and soap used to wash the hands. The potential modification of impacts from different behaviours in the use phase does not influence the position of the cup as the best product from an environmental perspective.

The impact of the conventional pad is mainly driven by the production of the components. Although the impacts are distributed through the different components, the production of plastic and viscose for distribution layer in the first place, followed by the top- and back-sheets and the wrapper are the main contributors. The conventional pads show, in general, lower impacts than the organic pad, and in many categories lower than the tampons. They also show lower impacts than the cup in the cooker scenario on 3 categories.

The impacts of producing 1kg of the core of conventional pad are often higher than the impact of 1kg of organic cotton noils. However, since the weight of the conventional pad is lower than the organic one, the overall impacts are lower – for both the pad itself, and also the packaging.

There is an increase of impact by adding hand washing before changing a menstrual pad. With the organic pad, the impacts are increased, but the ranking remains the same. Whereas with the conventional pad, the ranking compared to the tampons is significantly worse. Thus, it can be concluded that the decision of including hand washing for pads is very relevant for LCA studies. The comparison to the other products is strongly influenced by this.

The impacts from organic tampons are in general lower than the conventional tampons (in 10 out of 16 impact categories). Only the core production shows a difference between the two types of tampons: the remaining life cycle stages are exactly the same (use phase) or very similar (the rest). Thus, the higher impacts of the conventional tampons are explained by the impacts related to the production of viscose (for the conventional tampons), which are higher than for the organic cotton fibres. As in the case of the menstrual cup, it is essential to consider the use phase of tampons. The impacts from this stage are in some cases as important as the production of the raw materials. The water temperature for washing hands and the number of toilet paper sheets used for the disposal of tampons are also relevant for the results.

The relevance of the organic cotton production and the results of TO and mainly PO may be unexpected since organic cotton is believed to have to lower environmental impacts. Not only does organic cotton influences the results, but also the use phase is relevant for TO and the production of bioplastic for PO, and the greater weight of the pad compared to the other products, play a relevant role. Also, in the sensitivity analysis, the influence of using a different dataset is explored, showing a relevant impact reduction. The strong differences between the two datasets cannot be deeply analysed, since the GaBi dataset is not disaggregated. Thus, the impacts of organic cotton should be interpreted cautiously. Nevertheless, the products' comparison remains very similar, and PO still shows the worst performance.

The modelling decisions and assumptions were thoroughly analysed and validated in the sensitivity analysis. Although the results are affected by the modifications, the products' comparison remains stable in most of the cases. Only if the frequency of sterilization in the cooker scenario is increased, would the interpretation of the results be different. However, there is no proof so far that this is necessary. The cup still shows the best environmental performance.

Regarding data quality, the use of secondary data for the modelling of conventional pads is a limitation of the study.

The goal of the study is "to identify which menstrual products, from the selected ones - namely conventional pads, organic pads, conventional tampons, organic tampons, and menstrual cups, are more beneficial from an environmental perspective". The results and conclusions meet the defined goal and can be summarized as:

- The menstrual cup shows the best environmental performance, also for different use cases. By following the kettle scenario, the impacts can be significantly reduced.
- The organic pad presents the worst environmental performance. Although the production of 1kg of organic cotton, compared to the core materials of the single-use products, shows a good result for many categories, the higher weight of the organic pad is a determinant for its higher impacts.
- In the middle area between the menstrual cup and the organic pads, are the tampons and conventional pads. The conventional pads cause, in general, lower impacts than the tampons – very closely followed by organic tampons and further by conventional ones. The main reason for the higher impacts of the tampons compared to the conventional pad is the influence of the use phase – the inputs for the use of tampons are much higher than for the use of pads.

As presented in the Introduction, and included in the Limitations, the consideration of flushing menstrual products in the toilet would improve the quality of the life cycle assessment. It has a potentially harmful effect on the environment, that would be more severe for products containing a higher amount of plastic.

This study represents an important improvement in the life cycle assessment of menstrual products. In the literature, no other study compares so many different products – not only the cup, the tampons, and the pads but also different materials for tampons and pads. This assessment proves the relevance of the use phase in the life cycle of menstrual products. Thus, it should not be neglected in similar studies, or the comparison would be incomplete. The large amount of primary data applied in the study increases the quality of the results.

9 Recommendations and next steps

The recommendation and next steps are presented separately for the users of menstrual products, the menstrual hygiene industry, and the research community.

9.1 Menstrual products industry

The results of this study can be used as an orientation of the environmental impacts of the menstrual products, and what are the main contributors. A summary is presented in Box 1 and Table 26. According to the findings, the raw materials play a very important role in the impacts of single-use products; in both the material itself and also the quantity. When considering the impacts of organic cotton, it is important to remember that the secondary data from the different datasets for organic cotton fibre production strongly influences the results, as presented in section 6.2.4. For example, the region where cotton harvesting occurs may have a relevant influence on the results.

Regarding the manufacturing process, electricity consumption is clearly the most relevant process by far, as explained in section 5.1.6. How the use of renewable energy can influence the results was analysed. As presented in 6.2.7, the impacts would in general be reduced. However, they could also increase for some categories. But, as explained in the introduction of the sensitivity analysis (6.2), the modelling of renewable energy represents only an indication and it would need to be calculated in each specific case to obtain accurate results.

The availability of primary data for the conventional pads, and from more producers for all products, would improve the quality of the environmental impact calculation. Moreover, the publication and communication of performed studies would allow comparison of results of different products and improve transparency.

The better performance of the menstrual cup places a certain pressure on the hygiene industry to produce more environmentally friendly single-use products. According to the relevance of the components' production found in this study, the use of materials creating lower environmental impacts would be key for improving their performance. This pressure may increase if the flushing of single-use menstrual products down toilets is included in a life cycle assessment study. This would significantly worsen their environmental performance.

The use phase is relevant for the impacts of the tampons and contributes the most only for the menstrual cup (over 95% for almost all categories). If hand washing is added to the use of the pads, their impacts would increase significantly. Thus, the industry should also support studies.

to determine clear recommendations for the users of menstrual products and investigate the behaviour of users of menstrual products. They must be provided with clear and scientifically based information on the safe and environmentally friendly handling of menstrual products.

Producers and brands of menstrual cups should standardize their recommendations for the cleaning and sterilization of products, thus guiding a safe and environmentally friendly use of the product and avoiding confusion among users. This can be underlined by the high importance of the use phase towards the environmental impact of the menstrual cup.

9.2 Users of menstrual products

It may be surprising that the environmental performance of the organic cotton pads is worse than for the other single-use products and that the conventional pads often show better results than the tampons, both conventional and organic. Organic cotton should not be automatically understood as bad for the environment (it is indeed better than conventional cotton) – other reasons, like the greater weight of the pad and the packaging are also relevant. Since organic pads contain no plastic in their core to improve the absorption (the conventional pads have a super absorbent polymer made of plastic), a higher amount of organic cotton is needed to maintain the same absorption capacity.

When using the menstrual cup, which shows the best performance, it is important to pay attention to the recommendations on how to deal with the cup during the use phase. The kettle scenario (boiling water in a kettle and pouring it over the menstrual cup in a mug) shows the best performance because it significantly reduces the energy consumption during sterilization, compared to using a pan on the cooker. If the cup is sterilized with the cooker scenario (boiling the cup in a pan on the cooker), the use of a lid to cover the pan can improve the results considerably. The same accounts for using renewable energy for the cooker.

For all products, the responsible use of water and soap for washing hands, and specifically the menstrual cup, avoids an increase of the environmental impacts.

Although not included in this assessment, the negative influence of flushing menstrual products in the toilet instead of properly disposing of them in the rubbish bin, is explained in the introduction of this report. Hence, it is very important to encourage users of menstrual products to dispose of the menstrual products properly, and never flush them down the toilet.

This study intends to bring clarity to menstrual products users, and the public in general, about the environmental impacts of the products available. It is not intended to tell the users what the best product is, or which product they should buy. This is a personal decision influenced by many factors other than the environment, such as health, costs and practicability.

9.3 Research community

At the beginning of this study, a literature review was performed. It is clear there is a lack of studies assessing the environmental impacts of menstrual products. Moreover, the existing studies do not consider all life-cycle stages properly, especially the use phase. The comparison of products without including the use phase is clearly unrealistic.

A hurdle when performing the life cycle assessment of menstrual products is the variable recommendations, and even opinions, on how menstrual products must be used. Not only for research purposes, but also for the users of menstrual products, clear information related to the safe use of the products is needed.

There is a need for more research-based data on the use of the menstrual cup. Producers make recommendations, but it is not clear why, and so far, there is no legal basis for them.

The life cycle inventory of organic cotton harvesting should be improved – the datasets analysed in this assessment show very different results. The reasons for such variations are not possible to explain with the available information. In addition, the absorption of heavy metals during harvesting of organic cotton and maize should be further studied. Otherwise, the presence of heavy metals in products like organic cotton or maize is confusing for the consumers.

In the introduction of this report, the issues related to flushing menstrual products instead of disposing of them in the rubbish bin is described. The addition of an end-of-life situation would probably change the results of the tampons and pads significantly by increasing their environmental impacts. Hence, the modelling of the flushing of menstrual products and their impact on the environment would be a great improvement for assessments.

10 Critical review

Critical Review Report according to ISO 14040 and 14044

of the study

Comparative Life cycle assessment of menstrual products

Conducted by GreenDelta, Berlin, Germany
(the "Practitioner")

Performed for
einhorn products GmbH
(the "Commissioner")

by
Alexandra Pehlken (chair)
Ran Liu
Annemarie Harant

16th December 2020

Content

1 Procedure of the Critical Review

The critical review was commissioned by GreenDelta, Germany 23rd March 2020 as a three-stage process: review of the goal and scope definition; review of interim reports and interim results after data collection and modelling; review of the final report. The critical review reflects the "comparative life cycle assessment of menstrual products"study performed by GreenDelta, Berlin. This critical review statement refers to the final report submitted by GreenDelta on 16th December 2020 and, in accordance with the requirements of the ISO 14040/44 standard, forms an integral part of the GreenDelta's life cycle assessment report.

The critical review team consists of three independent experts:

- Dr. Alexandra Pehlken (Head of the critical review), Head of Steinbeis Tranfercentre Resource, Bad Zwischenahn (Germany). She has a strong history in LCA engagement and sustainable product development since more than 15 years.
- Ran Liu, LCA expert, Senior searcher from Öko-Institut e.V (Germany).
- Annemarie Harant, a founder and CEO of the erdbeerwoche GmbH (Austria) and an expert in menstrual products and menstrual topics.

The review was carried out as an accompanying review. Telephone conferences were held on 18th May 2020 (Goal and Scope of the study), 25th June 2020 (Life Cycle Inventory), 6th August 2020 (1st draft of full report received on 22nd July), 12th Nov.2020 (2nd draft of the full report received on 27th October). All versions of draft reports provided were commented on by the panel numbers. During the conference calls the comments were discussed in detail with the practitioner. Meanwhile, during the period, clarification, exchanges and discussion have also been held via emails between the CR panel and the practitioner. The practitioner has considered most of the comments and significantly modified and improved their report. A spot check of the underlying LCI modelling was performed by one of the panel members (Ran Liu) on the 11st. Nov. 2020.

The statements and comments below are based on this final version received on 16th December 2020.

The type of this critical review is a review by "interested parties" according to ISO 14040, Clause 7.7.3 and ISO 14044, Clause 6.3. The members of the CR panel are independent from the commissioner and practitioner of the study and declare no commercial interest in the topic or any consequences of the study, beyond those related to the critical review process. Generally, according to ISO 14040, Clause 7.1 "critical review is a process to verify whether an LCA met the requirements for methodology, data, interpretation and reporting and whether it is consistent with the principles". "A critical review can neither verify nor validate the goals that are chosen for an LCA by the study commissioner, nor the ways in which the LCA results are used".

The panel would like to highlight the open and constructive working atmosphere throughout the review process. Upon request, all necessary data and modelling were presented to the reviewers and all issues raised by the review panel were discussed openly. The comments of the panel have been addressed by the practitioner adequately in the final report.

Disclaimer: The present CR report is delivered to the practitioner and commissioner. The CR panel cannot be held responsible for the subsequent use by any third party. The conclusions of the panel refer strictly to the full report from the study "Comparative Life cycle assessment of menstrual products – 16th December 2020" and no other report, extract thereof or subsequent publication. The conclusions made by the CR panel are specific to the context and content of the present study and shall not be generalized beyond that.

2 General comments

The reviewed LCA study investigates the life cycle environmental impacts of three common menstrual products (tampons, pads, menstrual cups) with the purpose to identify which one is more beneficial from an environmental perspective. In addition, as for single-use products (tampons and pads), conventional and organic types are investigated, respectively. The only reusable type is the menstrual cup. Two scenarios (cooker and kettle) for menstrual cups are analysed due to both possibilities for sterilization in the use phase.

The goal of the study, the intended application and intended audience are clearly described. The provided results and conclusions meet the defined goal. The compared product systems have different materials, weight, specifications, components as well as different packaging size. In order to avoid potential misinterpretation, the panel emphasizes particularly that the results of the study refer exclusively to the goal and scope defined and investigated scenarios and should not be used in any other contexts.

The results of the LCA study contains comparative assertions and are intended for the external communication in the areas of menstrual producers, users and general public.

3 Result of the critical review by the reviewers as required by ISO 14044

The ISO 14044 standard clause 6.1 concretizes this process in such a way that "the critical review shall ensure that:

- *the methods used to carry out the LCA are consistent with this International Standard,*
- *the methods used to carry out the LCA are scientifically and technically valid,*
- *the data used are appropriate and reasonable in relation to the goal of the study,*
- *the interpretations reflect the limitations identified and the goal of the study, and*
- *the study report is transparent and consistent. "*

In the following sections 3.1 to 3.5, these aspects are described considering the ISO standards 14040 and 14044.

3.1 Consistency of the methods with ISO 14040 and 14044

The reviewed LCA study has been performed according to the general structure of LCA required in ISO 14040 and ISO 14044. The structure of the report reflects the general structure of LCA (Goal & Scope definition – Life cycle inventory analysis (LCI) – Life cycle impact assessment (LCIA) and Interpretation). Conclusions, limitations and recommendations are clearly presented.

The definitions of functional unit, reference flows and the system boundary are appropriate and discussed soundly according to the goal of the study.

The inventory analysis methods applied are consistent with the ISO standards 14040 and 14044. The choice of impact categories and characterization models is justified.

The CR panel would like to highlight 17 sensitivity analyses, in which various assumptions and uncertainty of data and of allocation methods as well as potential influencing parameters on the results, were performed to check the robustness of the results and also to identify the potential improvement by certain changes (e.g. renewable energy in the manufacturing or use of a lid to cover the pot). The choice of the considered sensitivity analyses is comprehensible and justified within the context of the study addressing users and manufacturers. The findings are discussed. All results are available in the Appendix.

The CR panel concludes that the methods used are consistent with the international standards.

3.2 Scientific and technical validity of the methods used

The methods used in the study are appropriate. Some specific aspects performed in the study are highlighted below:

As part of the critical review, one member of the panel (Ran Liu) conducted a spot check to the LCI modelling, such as allocation was correctly modelled, different processes along the life cycle were correctly connected in the software, material quantities in the excel table are consistent with the those in software. No deficiencies were identified.

In ISO 14040/14044, the choice of impact categories must be substantiated, meaningful and support the goal and scope of the study. These have been selected appropriately in the study and the impact categories considered in the study and the characterization models chosen are state of the art. The results are clearly presented in tables, figures and discussed.

A wide range of sensitivity analyses is conducted. The reasons and relevance of results are evaluated. Influence of the core materials and comparison to previous literature are analysed. All results are discussed considering data and model limitations, completeness and consistency. The conclusions take these limitations into account.

The CR panel concludes that the methods used are scientifically and technically valid.

3.3 Appropriateness of data in relation to the goal of the study

It should be stressed that the correctness of all primary and secondary data as well as each calculation step could not be checked in the usual practice in critical reviews. However, the type and sources of data was reviewed for general plausibility, plausibility of the relevance of results in the critical review process. The handling of data and the detailed sensitivity analyses demonstrate a sufficient robustness of the calculated data. The data and calculation methods were judged to be appropriate for the goal of the study. All data were available to the review panel on request. As there is hardly any information on menstrual products available in standard data bases new data was gathered from the manufacturer and experts.

The CR panel concludes that the data used are appropriate and reasonable in relation to the goal of the study.

3.4 Assessment of interpretation referring to limitations and goal of the study

The interpretation is based on a detailed data quality analysis and is meaningfully performed regarding the limitations and the goal of the study. Limitations, especially for data quality, are thoroughly described.

Clearly arranged tables and charts including numerical results and contribution analyses are presented so that the interpretation of data is comprehensible. A highly informative Appendix provides information regarding some definitions, a detailed LCI, process contribution, impact of organic cotton contribution, the detailed results of the sensitivity analysis and the absolute results.

The derivation of the conclusions and recommendations focusing on different target groups is comprehensible from the interpretation undertaken.

The CR panel concludes that the interpretations reflect the limitations identified and the goal of the study.

3.5 Transparency and consistency of study report

The report is clearly presented and follows the specification in ISO 14040 and 14044. The data documentation in respective tables and figures supplement the text and allow a deep understanding of the results. Inconsistencies in the report could not be identified. The line of argument is transparent and comprehensible.

The CR panel concludes that the report is transparent and consistent.

4 Conclusion

The CR panel considers that the study has been conducted according to and in compliance with the ISO standards 14040 and 14044.

Bad Zwischenahn, Berlin, Vienna, 16. December 2020

Dr. Alexandra Pehlken | Ran Liu | Annemarie Harant

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Appendix A – Analysis of the recommendations of menstrual cup producers

The tables in this appendix show the recommendations of the menstrual cup producers regarding wearing time (see Appendix A- 1), and boiling time between periods (see Appendix A- 1) and before the first use (see Appendix A- 3). The listed brands are the ones included in the Öko-Test magazine, except for Dr. Wolff/Safe Cup. This brand recommends sterilizing the cup after every exchange. This recommendation is not covered by the other brands and is therefore included here.

Appendix A- 1. Recommended maximum wearing time of the menstrual cup

Brand	Recommended wearing time				
	6h	8h	10h	12h	Average (h)
Duchesse		from	up to		9
Facelle				up to	12
Lunette				up to	12
Merula (TPE)		up to			8
OrganicCup				up to	12
Selenacup		from		up to	10
t.o.c				up to	12
Lady Cup				up to	12
RubyCup				up to	12
My Lily		up to			8
Intimimna Lily				up to	12
Femometer				up to	12
einhorn				up to	12
Dr. Wolff/Safe Cup	up to				6
Weighted average of the recommended wearing time					**10.6h**

Appendix A- 2. Recommended boiling time to sterilize the menstrual cup after a menstrual cycle

Brand	Recommended boiling time after a menstrual cycle						
	3 min	5 min	7 min	8 min	10 min	N/S	Average (min)
Duchesse						-	-
Facelle						-	-
Lunette		-					5
Merula (TPE)		-					5
OrganicCup	from	up to					4
Selenacup	-						3
t.o.c						-	-
Lady Cup						-	-
RubyCup	from	up to					4
My Lily						-	-
Intimimna Lily		from		up to			6.5
Femometer						-	-
einhorn		from			up to		7.5
Dr. Wolff/Safe Cup			-				7[1]
Weighted average of the recommended boiling time after a menstrual cycle							**5.25**

[1] Every time the cup is exchanged

Appendix A- 3. Recommended boiling time to sterilize the menstrual cup before the first use

Brand	Recommended boiling time before the first use							
	3 min	4 min	5 min	7 min	8 min	20 min	N/S	Average (min)
Duchesse							-	-
Facelle							-	
Lunette						-		20
Merula (TPE)			-					5
OrganicCup	from		up to					4
Selenacup							-	-
t.o.c							-	-
Lady Cup			-					5
RubyCup							-	-
My Lily		-						4
Intimimna Lily			from		up to			6.5
Femometer							-	-
einhorn						-		20
Dr. Wolff/Safe Cup				-				7
Weighted average of the recommended boiling time before the first use								**5.25**

Appendix B – Definition of the impact categories included in the EF method

The EF method is the impact assessment method of the Environmental Footprint initiative. The implementation is based on the EF method 2.0. The impact categories are explained hereunder:

- EF-Climate Change - Impact indicator: Global Warming Potential 100 years - Baseline model of the IPCC 2013 + some factors Calculated from JRC;
- EF-Ozone depletion - Impact indicator: Ozone Depletion Potential (ODP) calculating the destructive effects on the stratospheric ozone layer over a time horizon of 100 years;
- EF-ionizing radiation - human health - Impact indicator: Ionizing Radiation Potentials: Quantification of the impact of ionizing radiation on the population, in comparison to Uranium 235;
- EF-Photochemical ozone formation - human health - Impact indicator: Photochemical ozone creation potential (POCP): Expression of the potential contribution to photochemical ozone formation. Only for Europe. Includes spatial differentiation. Considering a marginal increase in ozone formation, the LOTOS-EUROS spatially differentiated model averages over 14000 grid cells to define European factors.
- EF-Respiratory inorganics - Impact indicator: Disease incidence due to kg of PM2.5 emitted. The indicator is calculated by applying the average slope between the Emission Response Function (ERF) working point and the theoretical minimum-risk level. The exposure model is based on archetypes that include urban environments, rural environments, and indoor environments within urban and rural areas.
- EF-Non-cancer human health effects - Impact indicator: Comparative Toxic Unit for human (CTUh) expressing the estimated increase in morbidity in the total human population per unit mass of a chemical emitted (cases per kilogram). USEtox consensus model (multimedia model). No spatial differentiation beyond the continent and world compartments. Specific groups of chemicals require further works (cf. details in other sections).
- EF-Cancer human health effects - Impact indicator: Comparative Toxic Unit for human (CTUh) expressing the estimated increase in morbidity in the total human population/unit mass of a chemical emitted (cases per kilogram). USEtox consensus model (multimedia model). No spatial differentiation beyond the continent and world compartments. Specific groups of chemicals require further works (cf. details in other sections).
- EF-Acidification terrestrial and freshwater - Impact indicator: Accumulated Exceedance

(AE) characterizing the change in critical load exceedance of the sensitive area in terrestrial and main freshwater ecosystems, to which acidifying substances deposit.

- EF-Eutrophication freshwater - Impact indicator: Phosphorus equivalents: Expression of the degree to which the emitted nutrients reach the freshwater end compartment (phosphorus considered as limiting factor in freshwater). European validity. Averaged characterization factors from country dependent characterization factors.
- EF-Eutrophication marine - Impact indicator: Nitrogen equivalents: Expression of the degree to which the emitted nutrients reach the marine end compartment (nitrogen considered as a limiting factor in marine water).
- EF-Eutrophication terrestrial - Impact indicator: Accumulated Exceedance (AE) characterizing the change in critical load exceedance of the sensitive area, to which atrophying substances deposit.
- EF-Ecotoxicity freshwater - Impact indicator: Comparative Toxic Unit for ecosystems (CTUe) expressing an estimate of the potentially affected fraction of species (PAF) integrated over time and volume per unit mass of a chemical emitted (PAF m3 year/kg). USEtox consensus model (multimedia model). No spatial differentiation beyond the continent and world compartments. Specific groups of chemicals require further works (cf. details in other sections).
- EF-Land Use - Impact indicator: Soil quality index. CFs set was re-Calculated by JRC starting from LANCA® v 2.2 as a baseline model. Out of 5 original indicators only 4 have been included in the aggregation (Physico-chemical filtration was excluded due to the high correlation with the mechanical filtration).
- EF-Water scarcity - Impact indicator: m3 water eq. deprived. Relative Available WAter REmaining (AWARE) per area in a watershed, after the demand of humans and aquatic ecosystems, has been met.
- EF-Resource use, energy carriers - Impact indicator: Abiotic resource depletion fossil fuels (ADP-fossil); based on lower heating value. ADP for energy carriers, based on van Oers et al. 2002 as implemented in CML, v. 4.8 (2016). The depletion model is based on the use-to-availability ratio. Full substitution among fossil energy carriers is assumed.
- EF-Resource use, mineral, and metals - Impact indicator: Abiotic resource depletion (ADP ultimate reserve). ADP for mineral and metal resources, based on van Oers et al. 2002 as implemented in CML, v. 4.8 (2016). The depletion model is based on the use-to availability ratio. Full substitution among fossil energy carriers is assumed.

Appendix C – Definition of the indicators to assess data quality

Appendix C- 1. Data quality indicators from the Ciroth_Muller_Weidema_Lesage data quality system in openLCA

	Reliability	Completeness	Temporal correlation	Geographical correlation	Further technological correlation
1	Verified data based on measurements	Representative data from all sites relevant for the market considered, over an adequate period to even out normal fluctuations	Less than 3 years of difference to the time period of the data set	Data from area under study	Data from enterprises, processes and materials understudy
2	Verified data partly based on assumptions or non-verified data based on measurements	Representative data from > 50% of the sites relevant for the market considered, over an adequate period to even out normal fluctuations	Less than 6 years of difference to the time period of the data set	Average data from larger area in which the area under study is included	Data from processes and materials under study (i.e. identical technology) but from different enterprises
3	Non-verified data partly based on qualified estimates	Representative data from only some sites (<< 50%) relevant for the market considered or > 50% of sites but from shorter periods	Less than 10 years of difference to the time period of the data set	Data from area with similar production conditions	Data from processes and materials under study but from different technology
4	Qualified estimate (e.g. by industrial expert)	Representative data from only one site relevant for the market considered or some sites but from shorter periods	Less than 15 years of difference to the time period of the data set	Data from area with slightly similar production conditions	Data on related processes or materials
5	Non-qualified estimates	Representativeness unknown or data from a small number of sites and from shorter periods	Age of data unknown or more than 15 years of difference to the time period of the data set	Data from unknown or distinctly different area (North America instead of Middle East, OECD-Europe instead of Russia)	Data on related processes on laboratory scale or from different technology

Appendix D – Life cycle inventory

This appendix contains life cycle inventory data used for the modelling of the menstrual products that are not included in section 4. The components production is displayed in Appendix D- 1 to Appendix D-5 Waste percentages during manufacturing (see Appendix D- 6) are accounted for the components production and the waste treatment is modelled during manufacturing. Manufacturing data is presented in Appendix D-7 to Appendix D-12. Regarding distribution, the inventory to produce one EUR-pallet is shown in Appendix D- 12 . The production of soap needed during the use phase is displayed in Appendix D- 13.

Appendix D- 1. Modelling of the components' production for the conventional tampons

TC components production				
Component	Material	Amount (kg/FU)	Dataset	Transport
Core	Viscose	6.48E-01	fibre production, viscose, GLO	Assumed: GLO transport of fluff pulp
Core cover	Nonwoven, PE and PP	2.82E-02	market for textile, nonwoven polypropylene, GLO market for packaging film, low-density polyethylene, GLO	Included in the dataset
String	Polyester	6.44E-02	production of polyester fibre, GLO	
Wrapper	PE film	1.83E-02	production of polyethylene film, extruded, GLO	
Leaflet	Paper	8.42E-03	market production of wood-free, uncoated paper, EUR	
Printed box	Chipboard, at least 79% recycling content	7.65E-02	production of chipboard (86.6% input of recycled paper), EUR	Within EUR

Appendix D- 2. Modelling of the components' production for the organic tampons

TO components production				
Component	Material	Amount (kg/FU)	Dataset	Transport
Core	Organic cotton fibre	7.58E-01	fibre production, cotton, organic, ginning, IN	Assumed to be the same as in the Ecoinvent process "market for fibre, cotton, organic"
String	Organic cotton yarn	2.71E-02	global yarn production from organic cotton (fibre input same as core, IN)	
Bleaching of core and string: see Table 15				
Wrapper	PP film	2.71E-02	market PP packing film production, EUR	880 km
Leaflet	Paper	2.36E-02	production of wood-free, uncoated paper, EUR	17 km
Printed box	Chipboard, 100% recycled	1.67E-01	production of chipboard, 100% recycled paper, GLO	1,100 km

Appendix D- 3. Modelling of the components' production for the conventional pads

PC components production					
Component	Material	Amount (kg/FU)	Source	Dataset	Transport
Top-sheet	PE	2.18E-01	Own measurements	market for polyethylene, low density, granulate, extruded, GLO	Included in dataset
Distribution layer	25% PE	2.43E-01	Own measurements, distribution assumed	market for polyethylene, low density, granulate, extruded, GLO	Included in dataset
	25% polyester			market for fibre, polyester, GLO	
	25% PP			market for textile, nonwoven polypropylene, GLO	
	25% viscose			fibre production, viscose, GLO	Same as TC core
Core	Fluff pulp	4.47E-01	Own measurements, distribution from EDANA	market for sulfate pulp, bleached, GLO	Included in dataset
	SAP	7.31E-02		See Table 13	Within EUR
Back-sheet	PE	1.06E-01	Own measurements, distribution assumed	market for polyethylene, low density, granulate, extruded (50%), GLO	Included in dataset
	PP			market for textile, nonwoven polypropylene (50%), GLO	
Release/ protective paper	Silicone paper	5.60E-02	Own measurements	85.7% market for paper, woodfree, uncoated, EUR	Included in dataset
				14.3 % sodium silicate production, spray powder, 80%, EUR	Within EUR
Adhesive	Epoxy resin-based	9.20E-02	EDANA report	market for adhesives, for metal-epoxy resin-based, EUR	Included in dataset
Wrapper	LDPE	1.36E-01	Own measurements	market for packaging film, low-density polyethylene, GLO	Included in dataset
Packaging bag		2.95E-02	Own measurements		Included in dataset

Appendix D- 4. Modelling of the components' production for the organic pads

PO components production			
Component	Material	Dataset	Transport
Top-sheet	Organic cotton noils	See Table 14	Assumed to be the same as in the Ecoinvent process "market for fibre, cotton, organic"
Core			
Bleaching of core and string: see Table 15			
Release/protective paper	Silicone paper	85.7% EUR market production of wood-free, uncoated paper, EUR	Primary data
		14.3 % sodium silicate production, spray powder, 80%, EUR	
Adhesive	Epoxy resin-based	market for adhesives, for metal-epoxy resin-based, EUR	
Back-sheet	Mater-Bi	production of polyester-complexed starch biopolymer production, extruded, EUR	
Wrapper			
Packaging bag			
Printed box	Chipboard, 100% recycled	production of chipboard, 100% recycled paper, GLO	

Appendix D- 5. Modelling of the components' production for the menstrual cup

MC components production					
Component	Material	Amount/FU (kg)	Dataset		Transport to manufacture
Cup	Medical liquid silicone rubber	2.43E-03	silicone product production, EUR		402 km
Pigment	Pigment dispersion, yellow and pink	4.20E-05	50% Yellow 53NiO3Ti (Germany)	Pigments database from Evah Institute	324 km
			12.5% White 6TiO2 (China)		
			12.5 % White 4ZnOBiocideKicker (Europe)		
			25% Make Red 101 Iron Oxide (Germany)		
Storage bag	Organic cotton textile	1.51E-03	textile production, cotton, air-jet loom weaving, IN		230 km
Leaflet	Paper	4.69E-04	market production of wood-free, uncoated paper, EUR		10 km
Printed box	Chipboard, 100% recycled	6.68E-03	production of chipboard, 100% recycled paper, GLO		507 km

Appendix D- 6. Waste percentages from manufacturing

Manufacturing waste (waste/input) (%)					
	TC	TO	PC		PO
Core	6.15	4.20	Fluff pulp	9.67	Confidential. However, total waste percentage is similar to the other products
String	14.62	16.40	SAP	11.60	
Printed box	7.20	1.50	Adhesive	13.74	
Leaflet	0.70	0.70	Back-sheet	3.60	
Wrapper	14.90	9.90	Distribution layer	3.85	
Nonwoven	7.93	-	Release paper	7.06	
			Wrapper	4.55	
			Top-sheet	4.55	

Appendix D- 7. Conventional tampons manufacturing

TC manufacture. Source: primary data from producer				
Input	Amount/FU	Unit	Dataset	
Electricity	3.83	MJ	market group for electricity, medium voltage, EUR	
Heat	2.26	MJ	market group for heat, district or industrial, natural gas, EUR	
	0.564	MJ	market group for heat, district or industrial, other than natural gas, EUR	
Output			Components Included	Dataset
MSW	3.99E-02	kg	Core	market group for municipal solid waste, EUR
Waste plastic	5.80E-03	kg	String and nonwoven cover	market group for waste plastic, mixture EUR
Waste PE	2.73E-03	kg	Wrapper	market group for waste polyethylene, EUR
Wastepaper	1.77E-05	kg	Leaflet	market for waste graphical paper in EUR
	4.12E-05	kg		waste paper woodfree, uncoated to recycle, unsorted
Waste paperboard	2.28E-02	kg	Printed box	paper waste market group for waste paperboard, EUR
	5.33E-02	kg		waste paperboard to recycle, unsorted

Appendix D- 8. LCI of organic tampons manufacturing

TO manufacturing. Source: primary data from producer				
Input	Amount/FU	Unit	Dataset	
Electricity	3.56	MJ	market group for electricity, medium voltage from the manufacturing region (confidential)	
Heat	2.10	MJ	market group for heat, district or industrial, natural gas, EUR	
	0.524	MJ	market group for heat, district or industrial, other than natural gas, EUR	
Output	Amount/FU	Unit	Components Included	Dataset
MSW	3.63E-02	kg	Core and string	market group for municipal solid waste, EUR
Waste PP	2.68E-03	kg	Wrapper	market group for waste polypropylene, EUR
Waste graphical paper	4.95E-05	kg	Leaflet	market for waste graphical paper in the manufacturing region (confidential)
	1.15E-04	kg		waste paper woodfree, uncoated to recycle, unsorted
Waste paperboard	7.52E-04	kg	Printed box	market for waste paperboard in the manufacturing region (confidential)
	1.75E-03	kg		waste paperboard to recycle, unsorted

Appendix D- 9. LCI of conventional pads manufacturing

PC manufacturing: secondary data from literature					
Input	Amount/FU	Unit	Comments	Dataset	
Electricity	5.41E00	MJ	From literature [44], Converted to the weight of the studied pad	market group for electricity, medium voltage, EUR	
Heat	4.55E-01	MJ		market group for heat, district or industrial, natural gas, EUR	
	1.14E-01	MJ		market group for heat, district or industrial, other than natural gas, EUR	
Output			Amount	Components Included	Dataset
MSW	5.48E-02	kg	Waste % from literature [43,44]. Calculated from the pad final weight	Fluff pulp, distribution layer, adhesive, release paper	market group for municipal solid waste, EUR
Waste plastic	1.76E-02	kg		SAP, top- and back-sheet	market group for waste plastic, mixture, EUR
Waste PE	5.97E-03	kg		Wrapper and packaging waste	market group for waste polyethylene, EUR

Appendix D- 10. LCI of organic pads manufacturing

Manufacture of organic pads. Source: primary data from producer		
Input	Dataset	
Electricity fossil	market group for electricity, medium voltage from the manufacturing region (confidential)	
Electricity solar	electricity production, photovoltaic, 570kWp open ground installation, multi-Si in the manufacturing region (confidential)	
Heat	80% market group for heat, district or industrial, natural gas, EUR	
	20% market group for heat, district or industrial, other than natural gas, EUR	
Output	Components Included	Dataset
MSW	Top-sheet, core, adhesive, release paper	market for municipal solid waste, manufacturing region (confidential)
Waste plastic	Back-sheet, wrapper, packaging bag	market for waste plastic, mixture, manufacturing region (confidential)

Appendix D- 11. LCI of menstrual cup manufacturing

Manufacture of menstrual cups: amount from producer for the inputs and silicone waste. Packaging waste taken from the organic tampons					
Input	Amount/FU	Unit	Comments	Dataset	
Electricity	4.47E-04	MJ	Primary data	market for electricity, medium voltage, DE	
Output			Comments	Components Included	Dataset
MSW	2.24E-05	kg	Assumed same % as printed box	Storage bag	market for municipal solid waste, DE
Waste graphical paper	4.89E-06	kg	Assumed same % as TO	Leaflet	market for waste graphical paper, DE
	1.14E-05	kg			waste paper woodfree, uncoated to recycle, unsorted
Waste paperboard	1.48E-04	kg		Printed box	paper waste market group for waste paperboard, EUR
	3.45E-04	kg			waste paperboard to recycle, unsorted
Waste plastic	2.01E-04	kg	Primary data	Silicone	market for waste plastic, mixture, DE

Appendix D- 12. Production of one EUR-pallet [ESU food database http://esu-services.ch/data/data-on-demand/]

Production of 1 EUR pallet			
Input	Amount	Unit	Dataset
particleboard, uncoated	0.0117	m3	market for particleboard, uncoated | particleboard, uncoated | Cutoff, U - GLO
sawn wood, hardwood, raw, dried (u=20%)	0.0335	m3	market for sawn wood, hardwood, raw, dried (u=20%) | sawn wood, hardwood, raw, dried (u=20%) | Cutoff, U - RER
steel, low-alloyed	0.195	kg	market for steel, low-alloyed | steel, low-alloyed | Cutoff, U - GLO

Appendix D- 13. Production of 1kg of liquid soap [57]

Input	Amount	Unit	Dataset (all in EUR)
benzoic compound	0.0019	kg	benzoic-compound production
benzyl alcohol	0.002	kg	benzyl alcohol production
electricity, medium voltage	0.0183	kWh	market group for electricity, medium voltage
fatty alcohol	0.0255	kg	fatty alcohol production, from coconut oil
fatty alcohol	0.005	kg	fatty alcohol production, from coconut oil
fatty alcohol	0.0105	kg	fatty alcohol production, from coconut oil
fatty alcohol	0.012	kg	fatty alcohol production, petrochemical
heat, district, or industrial, natural gas	2.352	MJ	market group for heat, district or industrial, natural gas
heat, district or industrial, other than natural gas	1.568	MJ	market group for heat, district or industrial, other than natural gas
polycarboxylates, 40% active substance	0.005	kg	market for polycarboxylates, 40% active substance
potassium hydroxide	3.00E-04	kg	potassium hydroxide production
sodium chloride, powder	0.0055	kg	sodium chloride production, powder
sodium chloride, powder	0.002	kg	sodium chloride production, powder
sodium sulfate, anhydrite	0.0687	kg	sodium sulfate production, from natural sources
water, deionized	0.84	kg	water production, deionized
Output	Amount	Unit	Dataset (all in EUR)
Liquid soap production	1	kg	-

Appendix E – Processes' contribution

In this appendix, the contribution of the processes comprising the life cycle of the menstrual products is presented. For the menstrual cup, only the processes belonging to the use phase are shown in Appendix E- 1 because the other stages are not relevant. The most relevant stages of the tampons are the components production and the use phase and therefore all processes are displayed. For the remaining stages, only the most relevant processes are shown. Results are presented in Appendix E- 2 for TC and Appendix E- 3 for TO. The same procedure is followed for the pads; however, the use phase is not included because it is not relevant. In Appendix E- 4, the results of the PC are presented, and in Appendix E-5 for the PO.

Appendix E- 1. Life cycle stages and processes' contribution to the life cycle impacts of MC

Stove scenario (use phase)				
Impact category	Electricity	Soap	Tap water	Wastewater
Land use	37.83%	27.05%	5.65%	10.91%
Water scarcity	56.98%	14.36%	11.13%	16.09%
Resource use, mineral and metals	14.85%	42.66%	22.93%	7.66%
Resource use, energy carriers	55.95%	33.91%	4.85%	3.41%
Climate change	57.79%	22.20%	3.94%	4.80%
Eutrophication terrestrial	44.43%	31.92%	4.62%	14.36%
Eutrophication marine	12.45%	14.59%	1.27%	68.54%
Eutrophication freshwater	77.90%	6.09%	2.76%	11.74%
Acidification terrestrial and freshwa	44.06%	33.47%	6.06%	12.88%
Ecotoxicity freshwater	8.76%	56.31%	3.15%	24.22%
Cancer human health effects	25.00%	8.06%	18.26%	46.58%
Non-cancer human health effects	17.36%	16.92%	5.79%	58.63%
Ionising radiation, HH	68.59%	15.28%	9.33%	5.53%
Photochemical ozone formation, HH	40.03%	37.17%	6.92%	11.38%
Respiratory inorganics	28.56%	42.38%	8.33%	16.19%
Ozone depletion	34.45%	49.75%	5.36%	4.89%
The presented processes contribute, in total, more than 80% to the overall impact				

Kettle scenario (use phase)				
Impact category	Electricity	Soap	Tap water	Wastewater
Land use	13.97%	38.56%	7.89%	15.23%
Water scarcity	25.81%	25.10%	19.06%	27.54%
Resource use, mineral and metals	4.36%	48.32%	25.44%	8.49%
Resource use, energy carriers	24.87%	58.17%	8.14%	5.74%
Climate change	26.34%	39.06%	6.79%	8.26%
Eutrophication terrestrial	17.23%	47.79%	6.77%	21.08%
Eutrophication marine	3.59%	16.32%	1.39%	74.99%
Eutrophication freshwater	47.42%	14.42%	6.40%	27.23%
Acidification terrestrial and freshw	17.09%	50.00%	8.87%	18.85%
Ecotoxicity freshwater	2.44%	60.65%	3.33%	25.54%
Cancer human health effects	8.09%	10.06%	22.33%	56.96%
Non-cancer human health effects	5.24%	19.73%	6.61%	66.92%
Ionising radiation, HH	36.39%	31.28%	18.72%	11.10%
Photochemical ozone formation, H	14.97%	53.06%	9.68%	15.90%
Respiratory inorganics	9.43%	53.99%	10.39%	20.20%
Ozone depletion	12.06%	67.20%	7.09%	6.47%
The presented processes contribute, in total, more than 80% to the overall impact				

Appendix E- 2. Life cycle stages and processes' contribution to the life cycle impacts of TC

	Conventional tampons													
Life cycle stage	Components production					Manufacture	Distribution		Shopping trip	Use				EoL
Process	Core	Core cover	String	Wrapper	Printed box	Electricity	Transport	Cardboard	Car use	Soap productio	Water use	Wastewate	Toilet paper	Incineration
Land use	14.39%	0.61%	0.83%	0.38%	17.78%	0.97%	9.36%	2.51%	8.73%	2.48%	0.35%	0.68%	33.66%	1.87%
Water scarcity	41.01%	1.11%	1.48%	0.82%	8.60%	23.95%	0.33%	0.62%	1.24%	5.22%	2.77%	3.99%	7.40%	0.24%
Resource use, mineral and meta	30.13%	2.65%	3.15%	2.19%	29.40%	0.74%	0.38%	0.15%	10.68%	11.22%	4.12%	1.38%	3.36%	0.09%
Resource use, energy carriers	37.08%	3.20%	2.82%	2.09%	8.95%	12.10%	1.73%	0.90%	3.30%	13.13%	1.28%	0.90%	7.61%	0.57%
Climate change	40.15%	1.51%	1.84%	1.01%	7.26%	7.63%	1.48%	0.81%	3.11%	8.07%	0.98%	1.19%	6.74%	8.39%
Eutrophication terrestrial	45.97%	1.35%	1.58%	0.89%	8.60%	6.38%	1.87%	1.26%	3.01%	10.01%	1.00%	3.06%	8.36%	2.34%
Eutrophication marine	27.41%	0.81%	1.10%	0.54%	5.42%	4.22%	1.10%	0.90%	1.71%	10.64%	0.63%	34.14%	6.53%	1.81%
Eutrophication freshwater	38.52%	1.03%	1.28%	0.71%	7.70%	18.83%	0.28%	1.09%	1.27%	5.99%	1.80%	7.70%	10.70%	1.56%
Acidification terrestrial and fres	60.37%	1.08%	1.35%	0.72%	6.18%	6.82%	0.99%	0.63%	2.10%	7.37%	0.91%	1.93%	5.93%	0.91%
Ecotoxicity freshwater	18.17%	0.41%	0.62%	0.27%	4.68%	1.25%	2.14%	0.72%	4.27%	22.81%	0.87%	6.70%	10.12%	21.51%
Cancer human health effects	32.39%	0.87%	1.49%	0.58%	3.84%	4.07%	0.75%	0.59%	3.87%	4.59%	7.11%	18.12%	9.62%	8.93%
Non-cancer human health effec	37.89%	0.29%	0.52%	0.20%	2.83%	2.26%	0.64%	0.36%	1.01%	5.53%	1.29%	13.09%	29.31%	2.38%
Ionising radiation, HH	25.70%	0.90%	0.99%	0.62%	12.24%	33.94%	0.94%	0.78%	1.70%	6.61%	2.76%	1.64%	9.33%	0.27%
Photochemical ozone formation	49.13%	1.92%	2.79%	1.40%	7.79%	5.81%	2.09%	0.87%	3.78%	8.78%	1.10%	1.86%	6.22%	2.15%
Respiratory inorganics	66.89%	0.85%	1.19%	0.59%	5.62%	1.83%	1.63%	1.03%	2.50%	5.82%	0.78%	1.52%	5.04%	0.86%
Ozone depletion	60.42%	0.43%	0.81%	0.25%	6.30%	4.68%	2.46%	0.72%	4.16%	8.56%	0.63%	0.58%	5.49%	0.72%
The presented processes contribute, in total, more than 90% to the overall impact														

Appendix E- 3. Life cycle stages and processes' contribution to the life cycle impacts of TO

	Organic tampons												
Life cycle stage	Components production				Manufactu	Distribution		Shopping trip	Use				EoL
Process	Core	String	Wrapper	Printed box	Electricity	Transport	Cardboard	Car use	Soap production	Water use	Wastewater	Toilet paper	Incineration
Land use	73.85%	3.06%	0.23%	2.09%	0.30%	3.66%	1.57%	3.26%	0.72%	0.10%	0.20%	9.79%	0.60%
Water scarcity	1.91%	1.92%	0.94%	3.77%	64.64%	0.50%	1.49%	1.79%	5.87%	3.11%	4.49%	8.33%	0.30%
Resource use, mineral and meta	1.82%	0.26%	3.75%	23.06%	0.62%	1.02%	0.66%	27.53%	22.56%	8.29%	2.77%	6.76%	0.20%
Resource use, energy carriers	5.89%	1.84%	5.41%	6.16%	17.69%	4.08%	3.40%	7.42%	23.06%	2.25%	1.59%	13.36%	1.10%
Climate change	32.40%	2.52%	1.69%	3.34%	8.61%	2.34%	2.04%	4.68%	9.46%	1.15%	1.40%	7.90%	10.84%
Eutrophication terrestrial	79.13%	3.58%	0.43%	1.22%	2.56%	0.90%	0.97%	1.39%	3.60%	0.36%	1.10%	3.01%	0.93%
Eutrophication marine	88.78%	3.75%	0.08%	0.24%	0.63%	0.16%	0.22%	0.25%	1.22%	0.07%	3.92%	0.75%	0.22%
Eutrophication freshwater	84.68%	3.74%	0.14%	0.52%	5.75%	0.06%	0.41%	0.28%	1.05%	0.31%	1.35%	1.87%	0.30%
Acidification terrestrial and fres	60.71%	3.05%	0.73%	1.78%	15.97%	0.97%	1.01%	1.96%	5.40%	0.67%	1.41%	4.35%	0.75%
Ecotoxicity freshwater	64.71%	2.76%	0.17%	0.74%	0.63%	1.15%	0.62%	2.18%	9.07%	0.35%	2.66%	4.02%	9.41%
Cancer human health effects	11.99%	1.19%	1.03%	1.89%	8.15%	1.29%	1.63%	6.34%	5.86%	9.09%	23.16%	12.29%	12.57%
Non-cancer human health effec	20.28%	1.13%	0.35%	1.45%	3.02%	1.13%	1.03%	1.70%	7.24%	1.69%	17.14%	38.40%	3.44%
Ionising radiation, HH	3.39%	1.65%	0.95%	7.49%	44.36%	1.98%	2.63%	3.43%	10.38%	4.33%	2.57%	14.65%	0.46%
Photochemical ozone formation	39.19%	2.61%	2.03%	3.84%	10.42%	3.47%	2.39%	6.01%	10.93%	1.38%	2.32%	7.74%	2.97%
Respiratory inorganics	61.17%	3.15%	1.04%	2.63%	2.88%	2.62%	2.65%	3.84%	6.97%	0.94%	1.82%	6.04%	1.14%
Ozone depletion	11.13%	1.27%	0.88%	6.17%	7.25%	8.20%	3.86%	13.22%	21.23%	1.56%	1.43%	13.62%	1.98%
The presented processes contribute, in total, more than 80% to the overall impact													

Appendix E- 4. Life cycle stages and processes' contribution to the life cycle impacts of PC

	Conventional pads													
Life cycle stage	Components production									Manufacture	Distribution		Shopping tri	EoL
Process	Top-sheet	Distribution laye	Back-sheet	Wrapper	Packaging bag	SAP	Core	Adhesive	Release pap	Electricity	Transport	Cardboard	Car use	Incineartion
Land use	3.03%	6.54%	2.17%	3.35%	0.70%	2.06%	8.33%	2.17%	4.99%	1.63%	22.41%	17.03%	17.95%	2.80%
Water scarcity	10.58%	13.68%	4.59%	6.78%	1.42%	6.46%	3.71%	5.60%	1.24%	37.76%	0.75%	3.95%	2.40%	0.34%
Resource use, mineral and metals	19.84%	17.12%	7.69%	12.68%	2.66%	1.87%	1.54%	19.36%	0.22%	0.81%	0.60%	0.68%	14.45%	0.09%
Resource use, energy carriers	18.25%	18.29%	9.01%	11.78%	2.47%	4.66%	3.02%	5.83%	0.88%	12.99%	2.66%	3.92%	4.35%	0.54%
Climate change	11.46%	14.46%	5.48%	7.37%	1.54%	4.63%	4.12%	5.43%	1.02%	10.56%	2.94%	4.55%	5.29%	10.38%
Eutrophication terrestrial	11.26%	15.87%	5.62%	7.54%	1.59%	4.24%	11.23%	5.01%	2.01%	10.32%	4.33%	8.24%	5.99%	3.39%
Eutrophication marine	10.83%	15.52%	5.24%	7.22%	1.50%	3.97%	10.11%	4.69%	1.99%	10.65%	3.79%	9.39%	5.42%	3.97%
Eutrophication freshwater	10.08%	13.79%	4.72%	6.36%	1.36%	4.98%	4.05%	5.83%	1.47%	32.88%	0.69%	7.96%	2.73%	2.44%
Acidification terrestrial and freshw	12.32%	20.24%	5.99%	8.01%	1.68%	4.68%	7.72%	5.87%	1.60%	14.33%	2.96%	5.50%	5.38%	1.72%
Ecotoxicity freshwater	3.89%	6.54%	1.93%	2.71%	0.57%	1.48%	3.80%	7.39%	1.58%	2.34%	5.76%	5.51%	9.85%	36.10%
Cancer human health effects	8.78%	13.91%	4.29%	5.75%	1.20%	3.06%	11.50%	5.53%	1.72%	7.65%	2.02%	4.54%	8.95%	15.02%
Non-cancer human health effects	7.02%	19.13%	3.33%	4.64%	0.97%	3.36%	7.67%	4.97%	5.64%	10.07%	4.07%	6.58%	5.55%	9.49%
Ionising radiation, HH	6.79%	9.10%	3.37%	4.92%	1.03%	4.30%	2.56%	3.66%	1.40%	51.56%	2.04%	4.80%	3.18%	0.36%
Photochemical ozone formation, H	14.69%	18.37%	6.61%	9.65%	2.01%	3.79%	9.48%	6.23%	1.41%	7.64%	3.90%	4.72%	6.07%	2.55%
Respiratory inorganics	9.70%	18.33%	4.49%	6.31%	1.32%	3.52%	22.45%	4.55%	3.19%	3.69%	4.71%	8.44%	6.21%	1.56%
Ozone depletion	4.32%	16.54%	2.61%	3.29%	0.69%	7.65%	7.72%	10.17%	2.34%	11.64%	8.77%	7.31%	12.73%	1.61%
The presented processes contribute, in total, more than 80% to the overall impact														

Appendix E- 5. Life cycle stages and processes' contribution to the life cycle impacts of PO

	Organic pads													
Life cycle stage	Components production								Manufacture		Distribution		Shopping trip	EoL
Process	Top-sheet	Core	Back-sheet	Release paper	Wrapper	Adhesive	Packaging bag	Packaging box	Electricity mix	Electricity solar	Transport	Cardboard	Car use	Incineartion
Land use	18.56%	49.39%	1.54%	2.91%	2.06%	0.74%	0.45%	2.42%	0.25%	0.15%	7.93%	4.01%	6.89%	0.85%
Water scarcity	2.48%	6.61%	10.16%	2.29%	13.54%	7.66%	3.00%	5.02%	33.30%	5.68%	1.07%	3.73%	3.71%	0.42%
Resource use, mineral and me	0.39%	1.05%	2.18%	0.47%	2.91%	36.84%	0.64%	16.79%	0.87%	3.84%	1.18%	0.90%	31.06%	0.15%
Resource use, energy carriers	1.84%	4.90%	15.57%	2.16%	20.75%	10.08%	4.59%	4.36%	11.91%	1.09%	4.78%	4.69%	8.48%	0.84%
Climate change	6.14%	16.35%	6.13%	1.68%	8.17%	5.93%	1.81%	2.88%	8.62%	0.95%	3.34%	3.44%	6.53%	10.16%
Eutrophication terrestrial	18.62%	49.56%	5.02%	1.28%	6.70%	2.00%	1.48%	1.40%	3.39%	0.46%	1.79%	2.27%	2.69%	1.21%
Eutrophication marine	25.19%	67.05%	1.15%	0.32%	1.53%	0.47%	0.34%	0.35%	0.63%	0.11%	0.40%	0.64%	0.60%	0.36%
Eutrophication freshwater	24.03%	63.95%	1.94%	0.46%	2.59%	1.22%	0.57%	0.79%	1.37%	0.35%	0.16%	1.15%	0.67%	0.48%
Acidification terrestrial and fr	14.78%	39.33%	7.65%	1.51%	10.18%	3.69%	2.25%	2.12%	6.28%	0.90%	1.93%	2.41%	3.84%	0.96%
Ecotoxicity freshwater	16.17%	43.03%	2.71%	1.17%	3.61%	3.02%	0.80%	0.89%	0.51%	0.38%	2.45%	1.56%	4.54%	13.21%
Cancer human health effects	3.83%	10.18%	8.29%	3.14%	11.04%	6.59%	2.45%	2.22%	4.01%	3.80%	2.51%	3.75%	12.06%	16.07%
Non-cancer human health eff	7.96%	21.18%	7.29%	10.59%	9.72%	4.16%	2.15%	2.73%	3.72%	2.20%	3.55%	3.81%	5.25%	7.12%
Ionising radiation, HH	2.11%	5.63%	16.88%	3.14%	22.49%	5.77%	4.98%	7.88%	13.56%	1.04%	3.34%	5.24%	5.67%	0.51%
Photochemical ozone formatio	7.91%	21.05%	8.41%	3.04%	11.20%	7.86%	2.45%	3.21%	7.10%	1.44%	5.11%	4.10%	8.66%	2.83%
Respiratory inorganics	12.28%	32.69%	7.01%	5.47%	9.34%	4.04%	2.07%	2.52%	3.08%	1.19%	4.34%	5.18%	6.22%	1.24%
Ozone depletion	1.77%	4.71%	15.20%	2.85%	20.26%	8.03%	4.48%	3.13%	11.17%	0.89%	7.20%	3.99%	11.35%	1.14%
The presented processes contribute, in total, more than 80% to the overall impact														

Appendix F – Absolut results

All results calculated in the study that are not shown in the main text are collected in this appendix.

- Appendix F- 2. Impact of the life cycle stages - MC
- Appendix F- 3. Impact of the life cycle stages - MC kettle
- Appendix F- 4. Impact of the life cycle stages - TC
- Appendix F- 5. Impact of the life cycle stages - TO
- Appendix F- 6. Impact of the life cycle stages - PC
- Appendix F- 7. Impact of the life cycle stages - PO
- Appendix F- 8. Impact of the processes comprising the supply chain of organic cotton
- Appendix F- 9. Impact of the processes comprising the supply chain of organic cotton noils
- Appendix F- 10. Impact of TO and PO when using the GaBi dataset for organic cotton fibre production
- Appendix F- 11. Impact results of the production of 1kg of the main materials in the single-use products
- Appendix F- 12. Impact results of the menstrual cup for a shorter and longer lifetime
- Appendix F- 13. Impact results for modified production region of the core materials of TC and PC
- Appendix F- 14. Impact results of the organic cotton pad, applying physical allocation for the production of organic cotton noils.
- Appendix F- 15. Impact results of the organic products when using EUR electricity mix for manufacture
- Appendix F-16. Impact results of the single-use products when using renewable energy for manufacturing
- Appendix F- 17. Impact results when modifying the amount and water used for hand washing
- Appendix F- 18. Impact results of sterilizing the menstrual cup after every in the cooker scenario
- Appendix F- 19. Impact results of modifying the amount of water and soap for washing the menstrual cup
- Appendix F- 20. Impact results when modifying the wearing time of the menstrual cup
- Appendix F- 21. Impact results of modifying the wearing time of the tampons

- Appendix F- 22. Impact results of modifying the wearing time of the pads
- Appendix F-23. Impact results of modifying the number toilet paper sheets used to disposed of the tampon.
- Appendix F- 24. Impacts results when hands are washed prior to the exchange of a menstrual cup.

Appendix F- 2. Impact of the life cycle stages - MC cooker

MC - cooker							
Impact category	Components production	Manufacture	Distribution	Shopping trip	Use	EoL	Unit
Land use	1.08E-01	7.29E-05	6.26E-02	1.59E-02	8.76E-01	1.54E-03	Pt
Water scarcity	4.02E+00	1.24E-02	6.01E-01	1.88E-01	3.55E+02	1.86E-02	m3 depriv.
Resource use, mineral and metals	3.91E-10	2.33E-14	6.66E-12	2.01E-11	3.10E-09	9.30E-14	kg Sb eq
Resource use, energy carriers	3.69E-01	1.15E-03	1.21E-01	3.89E-02	2.97E+01	2.80E-03	MJ
Climate change	2.81E-02	5.00E-04	9.10E-03	2.83E-03	2.15E+00	8.23E-03	kg CO2 eq
Eutrophication terrestrial	5.90E-04	1.05E-06	1.10E-04	3.52E-05	1.92E-02	1.16E-05	mol N eq
Eutrophication marine	2.10E-04	1.35E-07	1.16E-05	3.24E-06	7.25E-03	2.52E-06	kg N eq
Eutrophication freshwater	3.64E-05	1.11E-07	1.95E-06	4.35E-07	2.26E-03	8.62E-08	kg P eq
Acidification terrestrial and freshwater	1.90E-04	3.15E-07	3.51E-05	1.26E-05	7.97E-03	2.65E-06	mol H+ eq
Ecotoxicity freshwater	5.71E-02	5.70E-04	1.47E-02	6.33E-03	4.13E+00	1.10E-02	CTUe
Cancer human health effects	2.42E-10	2.81E-12	9.07E-11	5.17E-11	5.25E-08	4.92E-11	CTUh
Non-cancer human health effects	4.06E-09	1.90E-11	1.19E-09	3.12E-10	6.91E-07	3.00E-10	CTUh
Ionizing radiation, HH	2.91E-03	1.41E-05	7.50E-04	1.90E-04	3.18E-01	1.20E-05	kBq U-235 eq
Photochemical ozone formation, HH	9.14E-05	2.35E-07	2.98E-05	1.16E-05	4.06E-03	3.53E-06	kg NMVOC eq
Respiratory inorganics	1.41E-09	1.81E-12	5.32E-10	1.54E-10	5.01E-08	4.09E-11	disease inc.
Ozone depletion	5.10E-09	4.40E-12	1.48E-09	5.26E-10	1.35E-07	3.76E-11	kg CFC11 eq

Appendix F- 3. Impact of the life cycle stages - MC kettle

MC - kettle							
Impact category	Components production	Manufacture	Distribution	Shopping trip	Use	EoL	Unit
Land use	1.08E-01	7.29E-05	6.26E-02	1.59E-02	5.74E-01	1.54E-03	Pt
Water scarcity	4.02E+00	1.24E-02	6.01E-01	1.88E-01	2.01E+02	1.86E-02	m3 depriv.
Resource use, mineral and metals	3.91E-10	2.33E-14	6.66E-12	2.01E-11	2.69E-09	9.30E-14	kg Sb eq
Resource use, energy carriers	3.69E-01	1.15E-03	1.21E-01	3.89E-02	1.71E+01	2.80E-03	MJ
Climate change	2.81E-02	5.00E-04	9.10E-03	2.83E-03	1.20E+00	8.23E-03	kg CO2 eq
Eutrophication terrestrial	5.90E-04	1.05E-06	1.10E-04	3.52E-05	1.26E-02	1.16E-05	mol N eq
Eutrophication marine	2.10E-04	1.35E-07	1.16E-05	3.24E-06	6.45E-03	2.52E-06	kg N eq
Eutrophication freshwater	3.64E-05	1.11E-07	1.95E-06	4.35E-07	9.30E-04	8.62E-08	kg P eq
Acidification terrestrial and freshwater	1.90E-04	3.15E-07	3.51E-05	1.26E-05	5.25E-03	2.65E-06	mol H+ eq
Ecotoxicity freshwater	5.71E-02	5.70E-04	1.47E-02	6.33E-03	3.83E+00	1.10E-02	CTUe
Cancer human health effects	2.42E-10	2.81E-12	9.07E-11	5.17E-11	4.20E-08	4.92E-11	CTUh
Non-cancer human health effects	4.06E-09	1.90E-11	1.19E-09	3.12E-10	5.92E-07	3.00E-10	CTUh

Ionizing radiation, HH	2.91E-03	1.41E-05	7.50E-04	1.90E-04	1.54E-01	1.20E-05	kBq U-235 eq
Photochemical ozone formation, HH	9.14E-05	2.35E-07	2.98E-05	1.16E-05	2.80E-03	3.53E-06	kg NMVOC eq
Respiratory inorganics	1.41E-09	1.81E-12	5.32E-10	1.54E-10	3.88E-08	4.09E-11	disease inc.
Ozone depletion	5.10E-09	4.40E-12	1.48E-09	5.26E-10	9.83E-08	3.76E-11	kg CFC11 eq

Appendix F- 4. Impact of the life cycle stages - TC

TC							
Impact category	Components production	Manufacture	Distribution	Shopping trip	Use	EoL	Unit
Land use	4.26E+00	1.27E-01	1.36E+00	1.10E+00	4.21E+00	2.22E-01	Pt
Water scarcity	5.19E+02	2.32E+02	9.82E+00	1.30E+01	1.87E+02	2.43E+00	m3 depriv.
Resource use, mineral and metals	8.80E-09	9.86E-11	8.12E-11	1.39E-09	2.61E-09	1.20E-11	kg Sb eq
Resource use, energy carriers	4.17E+01	1.14E+01	2.10E+00	2.69E+00	1.74E+01	4.44E-01	MJ
Climate change	3.09E+00	6.47E-01	1.58E-01	1.96E-01	1.23E+00	5.54E-01	kg CO2 eq
Eutrophication terrestrial	3.72E-02	4.81E-03	2.04E-03	2.44E-03	1.41E-02	1.52E-03	mol N eq
Eutrophication marine	3.61E-03	5.30E-04	2.10E-04	2.20E-04	5.19E-03	1.90E-04	kg N eq
Eutrophication freshwater	1.17E-03	4.50E-04	3.35E-05	3.01E-05	6.10E-04	3.66E-05	kg P eq
Acidification terrestrial and freshwater	2.56E-02	2.92E-03	6.20E-04	8.80E-04	5.89E-03	3.50E-04	mol H+ eq
Ecotoxicity freshwater	2.55E+00	2.48E-01	2.99E-01	4.39E-01	4.36E+00	2.22E+00	CTUe
Cancer human health effects	3.64E-08	4.80E-09	1.38E-09	3.58E-09	3.60E-08	8.22E-09	CTUh
Non-cancer human health effects	8.99E-07	5.48E-08	2.20E-08	2.16E-08	1.02E-06	5.07E-08	CTUh
Ionizing radiation, HH	3.00E-01	2.48E-01	1.29E-02	1.35E-02	1.47E-01	1.98E-03	kBq U-235 eq
Photochemical ozone formation, HH	1.11E-02	1.26E-03	5.50E-04	8.00E-04	3.14E-03	3.90E-04	kg NMVOC eq
Respiratory inorganics	2.85E-07	1.08E-08	1.04E-08	1.07E-08	4.89E-08	3.54E-09	disease inc.
Ozone depletion	5.53E-07	5.72E-08	2.61E-08	3.64E-08	1.23E-07	6.00E-09	kg CFC11 eq

Appendix F- 5. Impact of the life cycle stages - TO

TO							
Impact category	Components production	Manufacture	Distribution	Shopping trip	Use	EoL	Unit
Land use	3.87E+01	3.07E+01	1.30E-01	2.06E+00	1.41E+00	2.22E-01	Pt
Water scarcity	8.56E+02	7.70E+01	5.55E+02	1.82E+01	1.67E+01	2.43E+00	m3 depriv.
Resource use, mineral and metals	6.46E-09	1.88E-09	4.24E-11	1.34E-10	1.78E-09	1.20E-11	kg Sb eq
Resource use, energy carriers	4.31E+01	8.63E+00	9.73E+00	3.42E+00	3.45E+00	4.44E-01	MJ
Climate change	5.01E+00	2.01E+00	5.99E-01	2.67E-01	2.51E-01	5.54E-01	kg CO2 eq
Eutrophication terrestrial	1.72E-01	1.45E-01	5.18E-03	3.40E-03	3.13E-03	1.52E-03	mol N eq
Eutrophication marine	8.67E-02	8.00E-02	6.40E-04	3.70E-04	2.90E-04	1.90E-04	kg N eq
Eutrophication freshwater	1.34E-02	1.18E-02	7.80E-04	6.61E-05	3.86E-05	3.66E-05	kg P eq
Acidification terrestrial and freshwater	4.95E-02	3.27E-02	8.31E-03	1.04E-03	1.12E-03	3.50E-04	mol H+ eq
Ecotoxicity freshwater	2.55E+01	1.73E+01	2.52E-01	4.66E-01	5.62E-01	2.22E+00	CTUe
Cancer human health effects	7.07E-08	1.18E-08	6.59E-09	2.34E-09	4.59E-09	8.22E-09	CTUh
Non-cancer human health effects	1.58E-06	3.82E-07	5.47E-08	3.60E-08	2.77E-08	5.07E-08	CTUh
Ionizing radiation, HH	4.61E-01	6.58E-02	2.06E-01	2.20E-02	1.73E-02	1.98E-03	kBq U-235 eq
Photochemical ozone formation, HH	1.38E-02	6.64E-03	1.68E-03	8.70E-04	1.03E-03	3.90E-04	kg NMVOC eq

Respiratory inorganics	3.09E-07	2.12E-07	1.23E-08	1.73E-08	1.37E-08	3.54E-09	disease inc.
Ozone depletion	3.23E-07	6.56E-08	4.17E-08	3.98E-08	4.67E-08	6.00E-09	kg CFC11 eq

Appendix F- 6. Impact of the life cycle stages - PC

PC							
Impact category	Components production	Manufacture	Distribution	Shopping trip	Use	EoL	Unit
Land use	3.11E+00	1.91E-01	3.81E+00	1.91E+00	1.90E-01	3.02E-01	Pt
Water scarcity	4.64E+02	3.26E+02	4.27E+01	2.26E+01	3.57E+00	3.62E+00	m3 depriv.
Resource use, mineral and metals	1.38E-08	1.37E-10	2.66E-10	2.41E-09	2.18E-11	1.78E-11	kg Sb eq
Resource use, energy carriers	7.37E+01	1.34E+01	6.94E+00	4.67E+00	2.88E-01	6.32E-01	MJ
Climate change	3.31E+00	7.59E-01	5.67E-01	3.40E-01	2.06E-02	9.97E-01	kg CO2 eq
Eutrophication terrestrial	3.44E-02	5.91E-03	7.13E-03	4.24E-03	2.60E-04	2.28E-03	mol N eq
Eutrophication marine	3.33E-03	6.90E-04	8.20E-04	3.90E-04	3.27E-05	2.70E-04	kg N eq
Eutrophication freshwater	9.90E-04	6.20E-04	1.60E-04	5.23E-05	1.27E-05	4.71E-05	kg P eq
Acidification terrestrial and freshwater	1.64E-02	3.61E-03	2.17E-03	1.52E-03	1.10E-04	5.10E-04	mol H+ eq
Ecotoxicity freshwater	2.25E+00	4.05E-01	8.94E-01	7.61E-01	5.22E-02	3.25E+00	CTUe
Cancer human health effects	3.72E-08	6.79E-09	5.00E-09	6.22E-09	4.37E-10	1.22E-08	CTUh
Non-cancer human health effects	3.69E-07	7.26E-08	7.43E-08	3.75E-08	3.04E-08	7.36E-08	CTUh
Ionizing radiation, HH	2.48E-01	3.48E-01	4.75E-02	2.34E-02	3.38E-03	2.76E-03	kBq U-235 eq
Photochemical ozone formation, HH	1.32E-02	1.51E-03	1.73E-03	1.39E-03	5.38E-05	5.80E-04	kg NMVOC eq
Respiratory inorganics	1.86E-07	1.21E-08	3.62E-08	1.85E-08	9.33E-10	4.60E-09	disease inc.
Ozone depletion	2.49E-07	5.74E-08	7.46E-08	6.32E-08	2.20E-09	8.55E-09	kg CFC11 eq

Appendix F- 7. Impact of the life cycle stages - PO

PO							
Impact category	Components production	Manufacture	Distribution	Shopping trip	Use	EoL	Unit
Land use	3.52E+01	2.52E-01	5.46E+00	3.48E+00	1.90E-01	5.07E-01	Pt
Water scarcity	5.16E+02	3.98E+02	5.17E+01	4.10E+01	3.57E+00	6.26E+00	m3 depriv.
Resource use, mineral and metals	8.65E-09	6.68E-10	3.54E-10	4.39E-09	2.18E-11	3.08E-11	kg Sb eq
Resource use, energy carriers	5.97E+01	1.41E+01	9.27E+00	8.50E+00	2.88E-01	1.06E+00	MJ
Climate change	4.34E+00	1.13E+00	7.34E-01	6.19E-01	1.98E-02	2.00E+00	kg CO2 eq
Eutrophication terrestrial	1.89E-01	9.37E-03	9.33E-03	7.71E-03	2.60E-04	3.97E-03	mol N eq
Eutrophication marine	8.63E-02	9.30E-04	1.04E-03	7.10E-04	3.26E-05	5.20E-04	kg N eq
Eutrophication freshwater	1.33E-02	2.50E-04	1.90E-04	9.52E-05	1.27E-05	6.99E-05	kg P eq
Acidification terrestrial and freshwater	5.08E-02	4.90E-03	2.84E-03	2.77E-03	1.10E-04	8.90E-04	mol H+ eq
Ecotoxicity freshwater	2.12E+01	5.66E-01	1.25E+00	1.38E+00	5.12E-02	5.33E+00	CTUe
Cancer human health effects	4.37E-08	9.19E-09	6.45E-09	1.13E-08	4.35E-10	2.05E-08	CTUh
Non-cancer human health effects	8.31E-07	8.66E-08	1.25E-07	6.82E-08	3.04E-08	1.22E-07	CTUh
Ionizing radiation, HH	4.73E-01	1.02E-01	6.09E-02	4.25E-02	3.38E-03	4.57E-03	kBq U-235 eq
Photochemical ozone formation, HH	1.54E-02	2.30E-03	2.35E-03	2.53E-03	5.35E-05	1.02E-03	kg NMVOC eq
Respiratory inorganics	3.54E-07	2.50E-08	4.75E-08	3.37E-08	9.32E-10	8.43E-09	disease inc.
Ozone depletion	5.61E-07	1.30E-07	1.06E-07	1.15E-07	2.20E-09	1.43E-08	kg CFC11 eq

Appendix F- 8. Impact of the processes comprising the supply chain of organic cotton fibre

TO					
Impact category	Bleaching	Transport from IN to EUR	Fibre production	Seed-cotton production	Unit
Land use	1.10E-01	3.30E-01	5.95E-02	2.81E+01	Pt
Water scarcity	1.31E+01	9.88E-01	2.31E-01	2.05E+00	m3 depriv.
Resource use, mineral and metals	9.10E-11	1.00E-11	1.99E-12	1.48E-11	kg Sb eq
Resource use, energy carriers	1.65E+00	3.47E-01	6.98E-02	4.78E-01	MJ
Climate change	2.32E-01	2.41E-02	4.87E-03	1.36E+00	kg CO2 eq
Eutrophication terrestrial	5.91E-03	8.51E-04	9.67E-05	1.30E-01	mol N eq
Eutrophication marine	6.77E-04	7.71E-05	9.67E-06	7.62E-02	kg N eq
Eutrophication freshwater	2.69E-05	2.38E-06	0.00E+00	1.13E-02	kg P eq
Acidification terrestrial and freshwater	1.41E-03	2.51E-04	1.93E-05	2.84E-02	mol H+ eq
Ecotoxicity freshwater	1.86E-01	4.92E-02	1.05E-02	1.62E+01	CTUe
Cancer human health effects	3.24E-09	2.52E-10	3.78E-11	4.95E-09	CTUh
Non-cancer human health effects	1.17E-08	3.24E-09	7.55E-10	3.05E-07	CTUh
Ionizing radiation, HH	1.12E-02	1.73E-03	2.90E-04	2.42E-03	kBq U-235 eq
Photochemical ozone formation, HH	1.50E-03	2.32E-04	2.90E-05	3.65E-03	kg NMVOC eq
Respiratory inorganics	4.88E-09	1.86E-09	3.52E-10	1.82E-07	disease inc.
Ozone depletion	2.36E-08	5.04E-09	8.50E-10	6.52E-09	kg CFC11 eq

Appendix F- 9. Impact of the processes comprising the supply chain of organic cotton noils

PO						
Impact category	Bleaching	Combing	Transport from IN to EUR	Fibre production	Seed-cotton production	Unit
Land use	1.69E-01	3.99E-02	4.08E-01	6.35E-02	3.00E+01	Pt
Water scarcity	2.10E+01	6.77E+01	1.29E+00	2.46E-01	2.19E+00	m3 depriv.
Resource use, mineral and metals	1.49E-10	2.28E-11	1.31E-11	2.12E-12	1.58E-11	kg Sb eq
Resource use, energy carriers	2.58E+00	2.65E+00	4.54E-01	7.45E-02	5.10E-01	MJ
Climate change	2.90E-01	2.08E-01	3.15E-02	5.20E-03	1.45E+00	kg CO2 eq
Eutrophication terrestrial	8.06E-03	1.99E-03	1.11E-03	1.00E-04	1.38E-01	mol N eq
Eutrophication marine	8.60E-04	2.00E-04	1.00E-04	1.00E-05	8.14E-02	kg N eq
Eutrophication freshwater	4.33E-05	9.69E-05	3.11E-06	1.00E-05	1.21E-02	kg P eq
Acidification terrestrial and freshwater	1.99E-03	1.06E-03	3.30E-04	3.00E-05	3.03E-02	mol H+ eq
Ecotoxicity freshwater	2.99E-01	7.07E-02	6.44E-02	1.13E-02	1.73E+01	CTUe
Cancer human health effects	5.18E-09	2.00E-09	3.30E-10	4.04E-11	5.28E-09	CTUh
Non-cancer human health effects	1.83E-08	1.92E-08	4.23E-09	8.06E-10	3.26E-07	CTUh
Ionizing radiation, HH	1.81E-02	2.99E-02	2.27E-03	3.10E-04	2.58E-03	kBq U-235 eq
Photochemical ozone formation, HH	2.08E-03	5.40E-04	3.00E-04	3.00E-05	3.90E-03	kg NMVOC eq
Respiratory inorganics	6.86E-09	7.72E-09	2.43E-09	3.76E-10	1.94E-07	disease inc.
Ozone depletion	3.70E-08	8.72E-09	6.60E-09	9.07E-10	6.97E-09	kg CFC11 eq

Appendix F- 10. Impact of TO and PO when using the GaBi dataset for organic cotton fibre production

Impact category	TO	PO	Unit
Land use	2.69E+03	2.82E+03	Pt
Water scarcity	8.61E+02	1.02E+03	m3 depriv.
Resource use, mineral and metals	8.76E-08	9.89E-08	kg Sb eq
Resource use, energy carriers	4.81E+01	9.81E+01	MJ
Climate change	4.65E+00	8.49E+00	kg CO2 eq
Eutrophication terrestrial	7.06E-02	1.15E-01	mol N eq
Eutrophication marine	1.12E-02	1.16E-02	kg N eq
Eutrophication freshwater	1.79E-03	1.93E-03	kg P eq
Acidification terrestrial and freshwater	2.82E-02	4.04E-02	mol H+ eq
Ecotoxicity freshwater	8.83E+00	1.29E+01	CTUe
Cancer human health effects	6.80E-08	8.88E-08	CTUh
Non-cancer human health effects	1.38E-06	1.05E-06	CTUh
Ionizing radiation, HH	4.58E-01	6.84E-01	kBq U-235 eq
Photochemical ozone formation, HH	1.48E-02	2.47E-02	kg NMVOC eq
Respiratory inorganics	2.57E-07	4.18E-07	disease inc.
Ozone depletion	3.16E-07	9.21E-07	kg CFC11 eq

Appendix F- 11. Impact results of the production of 1kg of the main materials in the single-use products

Impact category	Viscose	Org. cotton fibre	Fluff pulp+SAP+dist.layer	Org. cotton noils	Unit
Land use	1.64E+00	3.70E+01	3.59E+00	2.96E+01	Pt
Water scarcity	6.06E+02	2.01E+01	3.15E+02	9.11E+01	m3 depriv.
Resource use, mineral and metals	6.01E-09	1.41E-10	7.24E-09	4.39E-10	kg Sb eq
Resource use, energy carriers	4.24E+01	2.87E+00	4.85E+01	8.64E+00	MJ
Climate change	3.57E+00	2.09E+00	2.30E+00	1.95E+00	kg CO2 eq
Eutrophication terrestrial	4.21E-02	1.77E-01	2.85E-02	1.39E-01	mol N eq
Eutrophication marine	4.04E-03	1.01E-01	2.73E-03	7.31E-02	kg N eq
Eutrophication freshwater	1.38E-03	1.48E-02	6.60E-04	1.07E-02	kg P eq
Acidification terrestrial and freshwater	3.32E-02	3.90E-02	1.28E-02	3.18E-02	mol H+ eq
Ecotoxicity freshwater	2.70E+00	2.15E+01	1.50E+00	1.60E+01	CTUe
Cancer human health effects	4.43E-08	1.08E-08	2.70E-08	1.40E-08	CTUh
Non-cancer human health effects	1.20E-06	4.15E-07	2.70E-07	3.53E-07	CTUh
Ionizing radiation, HH	2.82E-01	1.81E-02	1.69E-01	6.24E-02	kBq U-235 eq
Photochemical ozone formation, HH	1.25E-02	6.78E-03	1.02E-02	8.03E-03	kg NMVOC eq
Respiratory inorganics	3.76E-07	2.44E-07	1.50E-07	2.03E-07	disease inc.
Ozone depletion	7.34E-07	4.04E-08	1.96E-07	9.75E-08	kg CFC11 eq

Appendix F- 12. Impact results of the menstrual cup for a shorter and longer lifetime

Impact category	Scenario cooker		Scenario kettle		Unit
	1 year	10 years	1 year	10 years	
Land use	1.81E+00	9.70E-01	1.51E+00	7.62E-01	Pt
Water scarcity	3.79E+02	3.58E+02	2.25E+02	2.06E+02	m3 depriv.
Resource use, mineral and metals	5.19E-09	3.31E-09	4.78E-09	3.11E-09	kg Sb eq
Resource use, energy carriers	3.23E+01	2.99E+01	1.98E+01	1.76E+01	MJ
Climate change	2.39E+00	2.17E+00	1.45E+00	1.25E+00	kg CO2 eq
Eutrophication terrestrial	2.30E-02	1.96E-02	1.63E-02	1.33E-02	mol N eq
Eutrophication marine	8.37E-03	7.36E-03	7.57E-03	6.68E-03	kg N eq
Eutrophication freshwater	2.45E-03	2.28E-03	1.12E-03	9.66E-04	kg P eq
Acidification terrestrial and freshwater	9.19E-03	8.09E-03	6.48E-03	5.50E-03	mol H+ eq
Ecotoxicity freshwater	4.58E+00	4.17E+00	4.28E+00	3.92E+00	CTUe
Cancer human health effects	5.47E-08	5.27E-08	4.42E-08	4.24E-08	CTUh
Non-cancer human health effects	7.20E-07	6.94E-07	6.21E-07	5.98E-07	CTUh
ionizing radiation, HH	3.38E-01	3.20E-01	1.73E-01	1.57E-01	kBq U-235 eq
Photochemical ozone formation, HH	4.74E-03	4.13E-03	3.48E-03	2.93E-03	kg NMVOC eq
Respiratory inorganics	6.08E-08	5.12E-08	4.95E-08	4.09E-08	disease inc.
Ozone depletion	1.71E-07	1.38E-07	1.34E-07	1.05E-07	kg CFC11 eq

Appendix F- 13. Impact results for modified production region of the core materials of TC and PC

Impact category	PC, EUR	TC, EUR	Unit
Land use	9.46E+00	1.16E+01	Pt
Water scarcity	8.67E+02	9.44E+02	m3 depriv.
Resource use, mineral and metals	1.67E-08	1.30E-08	kg Sb eq
Resource use, energy carriers	9.96E+01	7.34E+01	MJ
Climate change	5.94E+00	5.32E+00	kg CO2 eq
Eutrophication terrestrial	5.38E-02	5.68E-02	mol N eq
Eutrophication marine	5.49E-03	9.44E-03	kg N eq
Eutrophication freshwater	1.89E-03	2.28E-03	kg P eq
Acidification terrestrial and freshwater	2.43E-02	3.27E-02	mol H+ eq
Ecotoxicity freshwater	7.58E+00	1.00E+01	CTUe
Cancer human health effects	6.68E-08	8.81E-08	CTUh
Non-cancer human health effects	6.67E-07	2.07E-06	CTUh
ionizing radiation, HH	6.86E-01	7.99E-01	kBq U-235 eq
Photochemical ozone formation, HH	1.83E-02	1.55E-02	kg NMVOC eq
Respiratory inorganics	2.53E-07	2.90E-07	disease inc.
Ozone depletion	4.54E-07	8.16E-07	kg CFC11 eq

Appendix F- 14. Impact results of the organic cotton pad, applying physical allocation for the production of organic cotton noils.

Impact category	Physical allocation	Unit
Land use	6.29E+01	Pt
Water scarcity	1.06E+03	m3 depriv.
Resource use, mineral and metals	1.42E-08	kg Sb eq
Resource use, energy carriers	9.54E+01	MJ
Climate change	9.85E+00	kg CO2 eq
Eutrophication terrestrial	3.03E-01	mol N eq
Eutrophication marine	1.37E-01	kg N eq
Eutrophication freshwater	2.10E-02	kg P eq
Acidification terrestrial and freshwater	8.09E-02	mol H+ eq
Ecotoxicity freshwater	4.03E+01	CTUe
Cancer human health effects	9.67E-08	CTUh
Non-cancer human health effects	1.47E-06	CTUh
ionizing radiation, HH	7.09E-01	kBq U-235 eq
Photochemical ozone formation, HH	2.66E-02	kg NMVOC eq
Respiratory inorganics	5.90E-07	disease inc.
Ozone depletion	9.46E-07	kg CFC11 eq

Appendix F- 15. Impact results of the organic products when using EUR electricity mix for manufacture

Impact category	TO, EUR-mix	PO, EUR-mix	Unit
Land use	3.87E+01	4.51E+01	Pt
Water scarcity	5.17E+02	1.05E+03	m3 depriv.
Resource use, mineral and metals	6.51E-09	1.41E-08	kg Sb eq
Resource use, energy carriers	4.40E+01	9.66E+01	MJ
Climate change	4.99E+00	8.79E+00	kg CO2 eq
Eutrophication terrestrial	1.72E-01	2.18E-01	mol N eq
Eutrophication marine	8.66E-02	8.96E-02	kg N eq
Eutrophication freshwater	1.30E-02	1.44E-02	kg P eq
Acidification terrestrial and freshwater	4.39E-02	6.23E-02	mol H+ eq
Ecotoxicity freshwater	2.54E+01	3.01E+01	CTUe
Cancer human health effects	6.84E-08	9.38E-08	CTUh
Non-cancer human health effects	1.59E-06	1.29E-06	CTUh
ionizing radiation, HH	4.85E-01	9.87E-01	kBq U-235 eq
Photochemical ozone formation, HH	1.33E-02	2.36E-02	kg NMVOC eq
Respiratory inorganics	3.06E-07	4.66E-07	disease inc.
Ozone depletion	3.35E-07	8.85E-07	kg CFC11 eq

Appendix F- 16. Impact results of the single-use products when using renewable energy for manufacturing

Impact category	TC, RE	TO, RE	PC, RE	PO, RE	Unit
Land use	1.16E+01	3.90E+01	9.94E+00	4.56E+01	Pt
Water scarcity	1.13E+03	6.71E+02	1.10E+03	1.31E+03	m3 depriv.
Resource use, mineral and metals	1.38E-08	7.28E-09	1.79E-08	1.55E-08	kg Sb eq
Resource use, energy carriers	6.75E+01	3.64E+01	8.82E+01	8.34E+01	MJ
Climate change	5.49E+00	4.64E+00	5.47E+00	8.19E+00	kg CO2 eq
Eutrophication terrestrial	5.87E-02	1.69E-01	4.96E-02	2.13E-01	mol N eq
Eutrophication marine	9.60E-03	8.62E-02	5.05E-03	8.91E-02	kg N eq
Eutrophication freshwater	1.99E-03	1.27E-02	1.40E-03	1.38E-02	kg P eq
Acidification terrestrial and freshwater	3.40E-02	4.18E-02	2.13E-02	5.88E-02	mol H+ eq
Ecotoxicity freshwater	1.01E+01	2.54E+01	7.52E+00	3.00E+01	CTUe
Cancer human health effects	9.01E-08	6.81E-08	6.76E-08	9.33E-08	CTUh
Non-cancer human health effects	2.04E-06	1.55E-06	6.11E-07	1.24E-06	CTUh
ionizing radiation, HH	4.89E-01	2.66E-01	3.42E-01	6.11E-01	kBq U-235 eq
Photochemical ozone formation, HH	1.63E-02	1.25E-02	1.73E-02	2.22E-02	kg NMVOC eq
Respiratory inorganics	3.65E-07	3.01E-07	2.53E-07	4.59E-07	disease inc.
Ozone depletion	7.67E-07	3.03E-07	4.07E-07	8.30E-07	kg CFC11 eq

Appendix F- 17. Impact results when modifying the amount and water used for hand washing

Impact category	MC		TC		TO		Unit
	Double	Half	Double	Half	Double	Half	
Land use	1.18E+00	9.47E-01	1.15E+01	1.11E+01	3.89E+01	3.85E+01	Pt
Water scarcity	3.93E+02	3.27E+02	1.02E+03	9.05E+02	9.14E+02	7.98E+02	m3 depriv.
Resource use, mineral and metals	4.13E-09	2.90E-09	1.41E-08	1.19E-08	7.55E-09	5.38E-09	kg Sb eq
Resource use, energy carriers	3.35E+01	2.69E+01	8.16E+01	6.99E+01	4.90E+01	3.73E+01	MJ
Climate change	2.43E+00	1.97E+00	6.28E+00	5.46E+00	5.41E+00	4.60E+00	kg CO2 eq
Eutrophication terrestrial	2.25E-02	1.75E-02	6.65E-02	5.76E-02	1.77E-01	1.68E-01	mol N eq
Eutrophication marine	8.75E-03	6.19E-03	1.22E-02	7.69E-03	8.90E-02	8.45E-02	kg N eq
Eutrophication freshwater	2.40E-03	2.20E-03	2.51E-03	2.16E-03	1.36E-02	1.32E-02	kg P eq
Acidification terrestrial and freshwater	9.27E-03	7.16E-03	3.81E-02	3.44E-02	5.13E-02	4.76E-02	mol H+ eq
Ecotoxicity freshwater	5.16E+00	3.28E+00	1.18E+01	8.46E+00	2.71E+01	2.38E+01	CTUe
Cancer human health effects	6.07E-08	4.52E-08	1.04E-07	7.67E-08	8.44E-08	5.71E-08	CTUh
Non-cancer human health effects	8.14E-07	5.79E-07	2.28E-06	1.86E-06	1.79E-06	1.37E-06	CTUh
ionizing radiation, HH	3.45E-01	3.00E-01	7.64E-01	6.84E-01	5.01E-01	4.21E-01	kBq U-235 eq
Photochemical ozone formation, HH	4.78E-03	3.61E-03	1.82E-02	1.62E-02	1.48E-02	1.28E-02	kg NMVOC eq
Respiratory inorganics	6.08E-08	4.37E-08	3.85E-07	3.55E-07	3.24E-07	2.93E-07	disease inc.
Ozone depletion	1.64E-07	1.20E-07	8.41E-07	7.62E-07	3.63E-07	2.84E-07	kg CFC11 eq

Appendix F- 18. Impact results of sterilizing the menstrual cup after every exchange in the cooker scenario

Impact category	Cooker	With lid	Kettle	Unit
Land use	4.83E+00	3.13E+00	1.45E+00	Pt
Water scarcity	2.33E+03	1.46E+03	6.06E+02	m3 depriv.
Resource use, mineral and metals	8.20E-09	6.00E-09	3.82E-09	kg Sb eq
Resource use, energy carriers	1.88E+02	1.16E+02	4.58E+01	MJ
Climate change	1.41E+01	8.72E+00	3.42E+00	kg CO2 eq
Eutrophication terrestrial	1.03E-01	6.56E-02	2.85E-02	mol N eq
Eutrophication marine	1.76E-02	1.37E-02	9.84E-03	kg N eq
Eutrophication freshwater	1.94E-02	1.19E-02	4.40E-03	kg P eq
Acidification terrestrial and freshwater	4.21E-02	2.68E-02	1.17E-02	mol H+ eq
Ecotoxicity freshwater	6.98E+00	5.42E+00	3.88E+00	CTUe
Cancer human health effects	1.89E-07	1.33E-07	7.77E-08	CTUh
Non-cancer human health effects	1.95E-06	1.44E-06	9.36E-07	CTUh
ionizing radiation, HH	2.42E+00	1.49E+00	5.70E-01	kBq U-235 eq
Photochemical ozone formation, HH	1.98E-02	1.27E-02	5.67E-03	kg NMVOC eq
Respiratory inorganics	1.89E-07	1.26E-07	6.37E-08	disease inc.
Ozone depletion	5.81E-07	3.75E-07	1.71E-07	kg CFC11 eq

Appendix F- 19. Impact results of modifying the amount of water and soap for washing the menstrual cup

Impact category	Cooker	Kettle	Unit
Land use	1.23E+00	9.31E-01	Pt
Water scarcity	4.29E+02	2.75E+02	m3 depriv.
Resource use, mineral and metals	4.49E-09	4.08E-09	kg Sb eq
Resource use, energy carriers	3.40E+01	2.14E+01	MJ
Climate change	2.46E+00	1.51E+00	kg CO2 eq
Eutrophication terrestrial	2.37E-02	1.70E-02	mol N eq
Eutrophication marine	1.08E-02	9.99E-03	kg N eq
Eutrophication freshwater	2.52E-03	1.19E-03	kg P eq
Acidification terrestrial and freshwater	9.76E-03	7.04E-03	mol H+ eq
Ecotoxicity freshwater	5.48E+00	5.18E+00	CTUe
Cancer human health effects	7.43E-08	6.38E-08	CTUh
Non-cancer human health effects	9.87E-07	8.88E-07	CTUh
ionizing radiation, HH	3.61E-01	1.97E-01	kBq U-235 eq
Photochemical ozone formation, HH	5.01E-03	3.75E-03	kg NMVOC eq
Respiratory inorganics	6.48E-08	5.35E-08	disease inc.
Ozone depletion	1.67E-07	1.30E-07	kg CFC11 eq

Appendix F- 20. Impact results when modifying the wearing time of the menstrual cup

Impact category	Cooker scenario		Kettle scenario		Unit
	6 h	12 h	6 h	12 h	
Land use	1.42E+00	1.01E+00	1.12E+00	7.07E-01	Pt
Water scarcity	4.72E+02	3.43E+02	3.18E+02	1.89E+02	m3 depriv.
Resource use, mineral and metals	5.46E-09	3.22E-09	5.05E-09	2.81E-09	kg Sb eq
Resource use, energy carriers	3.99E+01	2.87E+01	2.73E+01	1.61E+01	MJ
Climate change	2.86E+00	2.09E+00	1.92E+00	1.15E+00	kg CO2 eq
Eutrophication terrestrial	2.78E-02	1.88E-02	2.12E-02	1.21E-02	mol N eq
Eutrophication marine	1.22E-02	6.76E-03	1.14E-02	5.96E-03	kg N eq
Eutrophication freshwater	2.65E-03	2.24E-03	1.32E-03	9.13E-04	kg P eq
Acidification terrestrial and freshwater	1.15E-02	7.72E-03	8.79E-03	5.00E-03	mol H+ eq
Ecotoxicity freshwater	7.07E+00	3.79E+00	6.77E+00	3.49E+00	CTUe
Cancer human health effects	8.21E-08	4.85E-08	7.16E-08	3.80E-08	CTUh
Non-cancer human health effects	1.12E-06	6.32E-07	1.02E-06	5.33E-07	CTUh
ionizing radiation, HH	3.95E-01	3.11E-01	2.31E-01	1.46E-01	kBq U-235 eq
Photochemical ozone formation, HH	6.00E-03	3.92E-03	4.73E-03	2.66E-03	kg NMVOC eq
Respiratory inorganics	7.89E-08	4.82E-08	6.75E-08	3.69E-08	disease inc.
Ozone depletion	2.08E-07	1.32E-07	1.71E-07	9.55E-08	kg CFC11 eq

Appendix F- 21. Impact results of modifying the wearing time of the tampons

Impact category	TC		TO		Unit
	4 h	8 h	4 h	8 h	
Land use	1.69E+01	8.45E+00	5.81E+01	2.91E+01	Pt
Water scarcity	1.44E+03	7.22E+02	1.28E+03	6.42E+02	m3 depriv.
Resource use, mineral and metals	1.95E-08	9.75E-09	9.69E-09	4.85E-09	kg Sb eq
Resource use, energy carriers	1.14E+02	5.68E+01	6.47E+01	3.24E+01	MJ
Climate change	8.80E+00	4.40E+00	7.51E+00	3.75E+00	kg CO2 eq
Eutrophication terrestrial	9.31E-02	4.65E-02	2.59E-01	1.29E-01	mol N eq
Eutrophication marine	1.49E-02	7.47E-03	1.30E-01	6.51E-02	kg N eq
Eutrophication freshwater	3.50E-03	1.75E-03	2.01E-02	1.00E-02	kg P eq
Acidification terrestrial and freshwater	5.43E-02	2.72E-02	7.42E-02	3.71E-02	mol H+ eq
Ecotoxicity freshwater	1.52E+01	7.59E+00	3.82E+01	1.91E+01	CTUe
Cancer human health effects	1.36E-07	6.78E-08	1.06E-07	5.30E-08	CTUh
Non-cancer human health effects	3.11E-06	1.55E-06	2.37E-06	1.19E-06	CTUh
ionizing radiation, HH	1.09E+00	5.43E-01	6.91E-01	3.46E-01	kBq U-235 eq
Photochemical ozone formation, HH	2.58E-02	1.29E-02	2.07E-02	1.04E-02	kg NMVOC eq
Respiratory inorganics	5.55E-07	2.77E-07	4.63E-07	2.31E-07	disease inc.
Ozone depletion	1.20E-06	6.01E-07	4.85E-07	2.43E-07	kg CFC11 eq

Appendix F- 22. Impact results of modifying the wearing time of the pads

Impact category	PC		PO		Unit
	4 h	8 h	4 h	8 h	
Land use	1.42E+01	7.20E+00	6.75E+01	3.39E+01	Pt
Water scarcity	1.29E+03	6.49E+02	1.52E+03	7.63E+02	m3 depriv.
Resource use, mineral and metals	2.50E-08	1.25E-08	2.12E-08	1.06E-08	kg Sb eq
Resource use, energy carriers	1.50E+02	7.49E+01	1.39E+02	6.98E+01	MJ
Climate change	8.98E+00	4.51E+00	1.32E+01	6.63E+00	kg CO2 eq
Eutrophication terrestrial	8.14E-02	4.09E-02	3.29E-01	1.65E-01	mol N eq
Eutrophication marine	8.31E-03	4.17E-03	1.34E-01	6.72E-02	kg N eq
Eutrophication freshwater	2.83E-03	1.42E-03	2.08E-02	1.04E-02	kg P eq
Acidification terrestrial and freshwater	3.66E-02	1.83E-02	9.33E-02	4.67E-02	mol H+ eq
Ecotoxicity freshwater	1.14E+01	5.74E+00	4.50E+01	2.25E+01	CTUe
Cancer human health effects	1.02E-07	5.12E-08	1.37E-07	6.88E-08	CTUh
Non-cancer human health effects	9.72E-07	5.02E-07	1.88E-06	9.55E-07	CTUh
ionizing radiation, HH	1.01E+00	5.06E-01	1.03E+00	5.16E-01	kBq U-235 eq
Photochemical ozone formation, HH	2.77E-02	1.39E-02	3.55E-02	1.78E-02	kg NMVOC eq
Respiratory inorganics	3.89E-07	1.95E-07	7.04E-07	3.53E-07	disease inc.
Ozone depletion	6.83E-07	3.43E-07	1.39E-06	6.97E-07	kg CFC11 eq

Appendix F- 23. Impact results of modifying the number of toilet paper sheets used to dispose of the tampons

Impact category	TO		TC		Unit
	TC, 0 sheets	TC, 6 sheets	TO, 0 sheets	TO, 6 sheets	
Land use	7.47E+00	1.51E+01	3.49E+01	4.25E+01	Pt
Water scarcity	8.92E+02	1.03E+03	7.85E+02	9.28E+02	m3 depriv.
Resource use, mineral and metals	1.26E-08	1.34E-08	6.03E-09	6.90E-09	kg Sb eq
Resource use, energy carriers	7.00E+01	8.15E+01	3.74E+01	4.89E+01	MJ
Climate change	5.46E+00	6.28E+00	4.59E+00	5.42E+00	kg CO2 eq
Eutrophication terrestrial	5.69E-02	6.73E-02	1.67E-01	1.78E-01	mol N eq
Eutrophication marine	9.31E-03	1.06E-02	8.61E-02	8.74E-02	kg N eq
Eutrophication freshwater	2.08E-03	2.59E-03	1.31E-02	1.36E-02	kg P eq
Acidification terrestrial and freshwater	3.41E-02	3.84E-02	4.73E-02	5.16E-02	mol H+ eq
Ecotoxicity freshwater	9.08E+00	1.12E+01	2.44E+01	2.65E+01	CTUe
Cancer human health effects	8.16E-08	9.91E-08	6.20E-08	7.95E-08	CTUh
Non-cancer human health effects	1.46E-06	2.68E-06	9.74E-07	2.19E-06	CTUh
ionizing radiation, HH	6.56E-01	7.91E-01	3.93E-01	5.28E-01	kBq U-235 eq
Photochemical ozone formation, HH	1.61E-02	1.83E-02	1.27E-02	1.49E-02	kg NMVOC eq
Respiratory inorganics	3.51E-07	3.88E-07	2.90E-07	3.27E-07	disease inc.
Ozone depletion	7.57E-07	8.46E-07	2.79E-07	3.67E-07	kg CFC11 eq

Appendix F- 24. Impacts results when hands are washed prior to the exchange of a menstrual cup

Impact category	PC hand washing	PO hand washing	Unit
Land use	9.94E+00	4.55E+01	Pt
Water scarcity	9.80E+02	1.13E+03	m3 depriv.
Resource use, mineral and metals	1.89E-08	1.63E-08	kg Sb eq
Resource use, energy carriers	1.11E+02	1.05E+02	MJ
Climate change	6.81E+00	9.65E+00	kg CO2 eq
Eutrophication terrestrial	6.33E-02	2.28E-01	mol N eq
Eutrophication marine	1.01E-02	9.41E-02	kg N eq
Eutrophication freshwater	2.24E-03	1.43E-02	kg P eq
Acidification terrestrial and freshwater	2.81E-02	6.60E-02	mol H+ eq
Ecotoxicity freshwater	1.09E+01	3.33E+01	CTUe
Cancer human health effects	9.53E-08	1.19E-07	CTUh
Non-cancer human health effects	1.07E-06	1.68E-06	CTUh
ionizing radiation, HH	7.54E-01	7.66E-01	kBq U-235 eq
Photochemical ozone formation, HH	2.06E-02	2.57E-02	kg NMVOC eq
Respiratory inorganics	2.90E-07	5.00E-07	disease inc.
Ozone depletion	5.35E-07	1.01E-06	kg CFC11 eq


THANKS FOR YOUR CURIOSITY!


AND WE THANK OUR CREATOR!