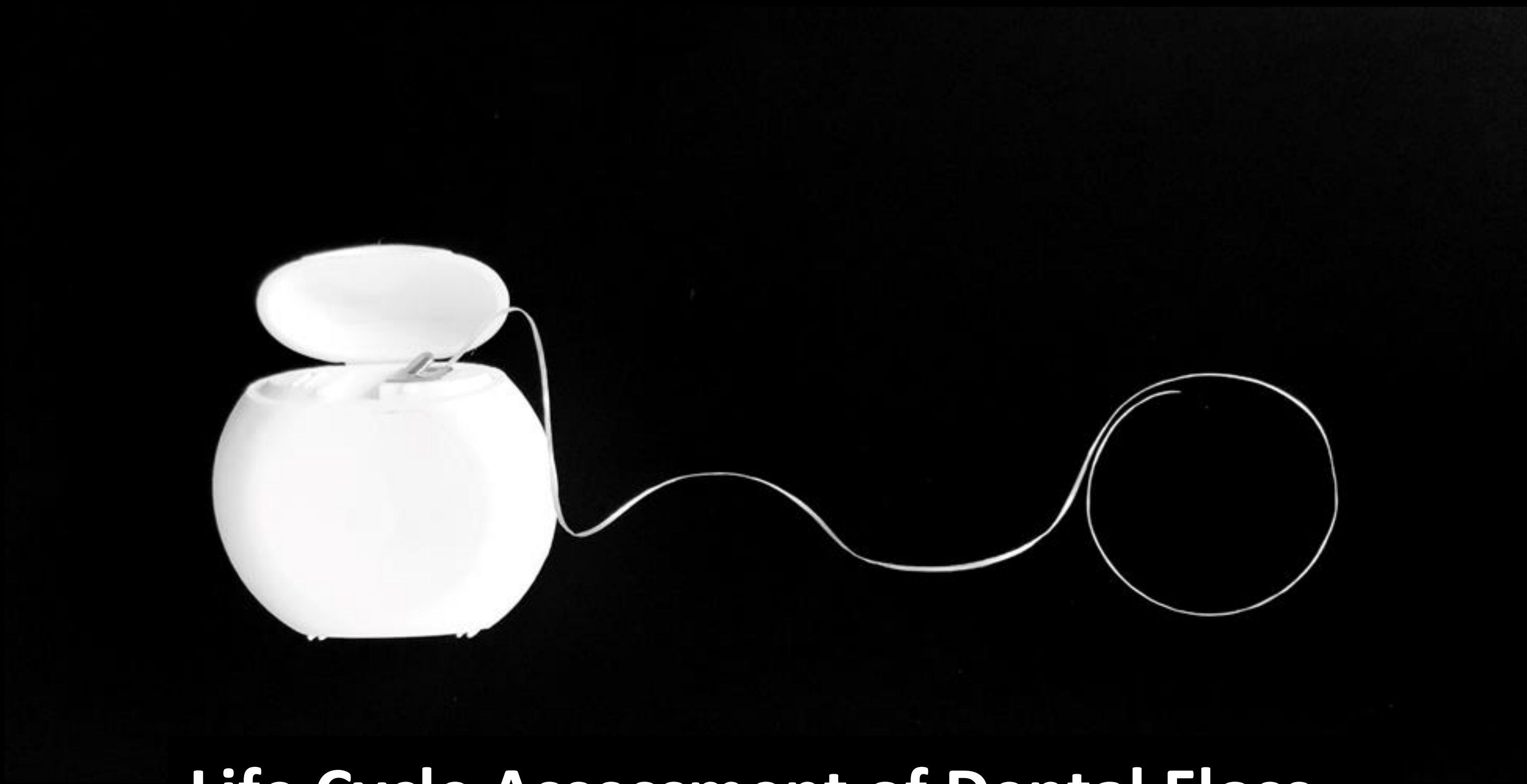

Life Cycle Assessment of Dental Floss

A comparison of nylon-based and silk-based dental floss

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Abbreviations

APOS.. Allocation at the Point of Substitution

EoL .... End of Life

GWP .... Global Warming Potential

LCA .... Life Cycle Assessment

LCI .... Life Cycle Inventory

LCIA .... Life Cycle Impact Assessment

PE .... Polyethylene

PP .... Polypropylene

TOC .... Total Organic Carbon

MSW .... Municipal Solid Waste

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Introduction

Dental floss is a thin filament used between teeth to clean them from any residual foods in areas where a toothbrush has difficulty reaching. For many people, it is a common everyday product and in fact dentists all over the world promote oral health by recommending the use of dental floss daily. While dental floss is a common product found in many corners of the world, there's still a lack of research on its environmental impacts.

Today, there are different ways of manufacturing dental floss, the most common one uses nylon, a derivative of polyamide, or Teflon (PTFE). Today, alternative types made of silk or bioplastic are widely available especially on the American and European markets. These alternatives are marketed as decomposable[1] and/or in some cases even biodegradable[2] in the case of silk dental floss, leading to argue that they are more sustainable and less environmentally harmful than their synthetic counterparts. However, based on a study published in 2013, the energy demand of raw silk production amounts to 1834 MJ for the production of 1 kg of silk fibre, compared to 260 MJ for the production of 1 kg of nylon fibre[3]. With the lack of research considering all manufacturing processes and a variety of factors (such as energy demand or water consumption), it is difficult to determine the environmental impacts of the parallel products. Therefore, a full assessment study considering all the life stages of dental floss can lead to more solid argumentation and understanding of the conventional and alternative dental floss products. This study therefore aims to evaluate the environmental impacts of silk dental floss compared to the conventional nylon dental floss. A Life Cycle Assessment (LCA) approach is adapted for that purpose.

The two types of dental floss assessed under the scope of this study are the Oral-B and the Yaweco.

Table 1 Different types of dental flosses commercially available in the European market and their main characteristics.

Process	Conventional	Silk	Bioplastic
Filament	Nylon or teflon	Silk	Corn fibre
Coating	Paraffin wax	Beeswax	Candelilla wax
Casing	Plastic (PP)	Treated plastic (PP)	Glass falcon with stainless-steel lid
Packaging	Plastic and cardboard	Cardboard	/
EoL	Landfill	Landfill & compost	Recycle & compost
Example Product Brand	Oral-B	Yaweco	Fresh Labs

This study will be conducted in compliance with the identified framework in ISO 14040 for LCA which includes four main stages for carrying out an LCA[4]:

1. Goal & Scope definition
2. Life Cycle Inventory (LCI)
3. Life Cycle Impact Assessment (LCIA)
4. Interpretation.

[1] https://yaweco.de/en/products/dental-floss/

[2] https://www.dentallace.com/collections/all-dental-lace-products/products/dental-lace-design-sea-glass

[3] (PDF) Life Cycle Analysis of Cumulative Energy Demand on Sericulture in Karnataka, IndiaLife Cycle Analysis of Cumulative Energy Demand on Sericulture in Karnataka, India (researchgate.net)

[4] ISO 14040

Life-Cycle Assessment

1. Goal & Scope Definition

This study aims to compare two different types of dental flosses from two different brands, namely the conventional dental floss from Oral-B made out of nylon and coated with paraffin wax and the silk dental floss coated with beeswax from Yaweco. The Yaweco dental floss comes in a reusable dispenser and refill dental floss is available in the market. The functional unit for both products will be the lengths of dental floss produced. All accompanying material required for the dispenser and packaging will be modelled according to the dental floss lengths. Due to the fact that one product can be refilled and will therefore require less amount of material for the dispenser, this study will compare both products based on two filament lengths. The functional unit defined for this comparison is therefore the production of:

- Case 1: 150 m and
- Case 2: 250 m of dental floss.

These differ in the number of dispensers manufactured for each product and therefore require varying amounts of raw materials and produce varying amounts of waste for Cases 1 & 2. Assessing both products based on two functional units is intended to provide a statement on the advantage or disadvantage of the reusable dispenser for the floss.

Figure 1 Types of dental flosses evaluated in this study: Oral-B (left), Yaweco (center) and Yaweco's refill pack (right).

This LCA is carried out using openLCA 1.10.3 with the database ecoinvent v.3.7.1. Ecoinvent 3.7 is a multifaceted database published in 2020. The database contains a variety of inventory for a broad range of sectors as well as processes for thousands of products[5]. Ecoinvent is compatible with the used software openLCA and retrieved from Nexus[6]. It offers three different system models which differ from one another in how activity datasets are linked to form product systems. For this study, the system model Allocation at the Point Of Substitution (APOS) is used. This system model follows the attributional approach in which burdens or impacts are attributed proportionally to specific processes and the burdens of a process do not go unaccounted for. The used dataset entails system processes or life cycle inventory (LCI, where a process is presented as a sum of aggregated processes

[5] https://www.ecoinvent.org

[6] https://nexus.openlca.org/databases

instead of a detailed large network for every process). The system process is not an independent dataset but an aggregation of flows caused by the provision of the reference product and can be calculated out of a unit process.

For the foreground model, additional, specific data is collected, from various sources:

- Research studies
- Products characteristics from the providers' webpages
- Own calculations based on weighing the single parts of each product.

Product Information

Before an LCA can be carried out, data is collected on the given products to ensure a reliable LCI. The following table entails the weighed masses of each product part, including the dental floss itself, the dispenser and the packaging. Further information on the production is collected from various studies and calculated according to the weights.

Table 2 Products' data based on weighing single elements.

Item	Conventional - Oral-B	Silk - Yaweco
Total weight	19 g	20 g
- Total weight for 3 items	57 g	46 g
- Total weight for 5 items	95 g	72 g
Filament	2.64 g	3.52 g
Coating	0.36 g	0.48
Dental Floss	50 m	40 m
Refill pack	/	1 pack = 2 x 25 m
Spool	2 g	2 g
Casing	7 g	9 g
Cardboard packaging	4 g	5 g
Plastic (PE) packaging	3 g	/

Considering that the Yaweco dental floss can be reused multiple times, this study will encompass three different modelling cases based on the number of items produced. That means that for the Oral-B product the dispenser is manufactured every time and for the Yaweco product, it is manufactured based on our assumption, in that case after a) 3 and b) 5 times of refilling. In addition, there will follow a comparison of two different recycling models for the Oral-B product to investigate the sensitivity of the overall results towards the different models (Case 3).

Table 3 Cases of the models compared.

Case	Assessment model
C1	Production of 150 m of dental floss equivalent to 3 products
C2	Production of 250 m of dental floss equivalent 5 products
C3	Recycling models (applied only for Oral-B product)

System Boundaries

For both systems, the products are modelled from cradle to grave which means that the impact is assessed from the raw material extraction, production, use, and end-of-life. The products have the same function and do not require or emit any material during the use phase. The main differences are their raw materials, the production and the treatment at the end of the product's life cycle.

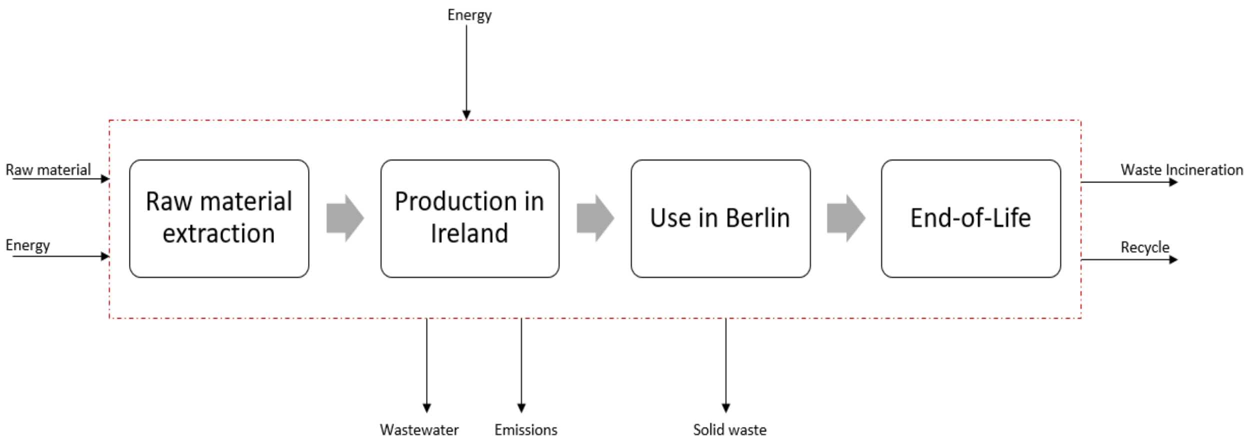

Figure 2 Process flow scheme for *the Oral-B dental floss.*

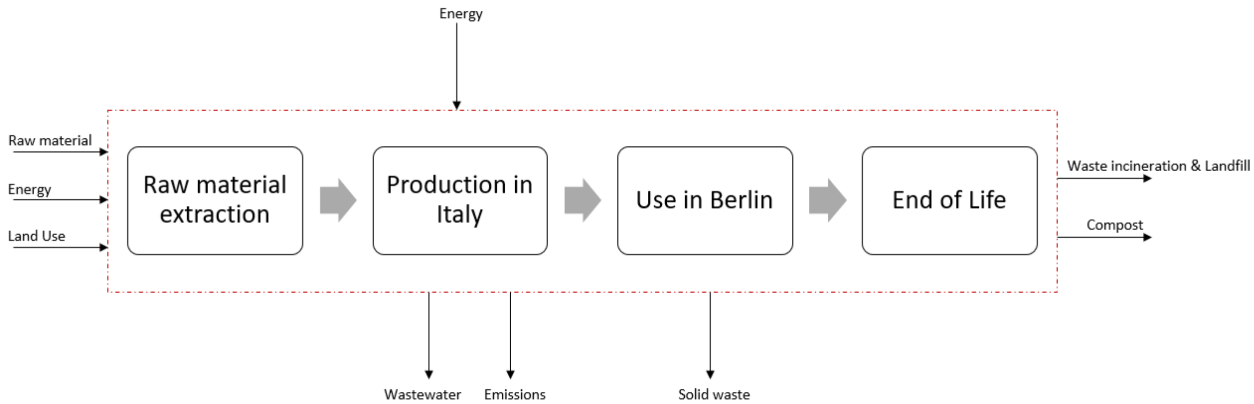

Figure 3 Process flow scheme for Yaweco dental floss.

Life Cycle Impact Assessment

The impact analysis for both products is conducted using the ReCiPe 2016 Midpoint (H) assessment method on the basis of 18 midpoint indicators. The method translates emissions and extracted resource materials and converts them into environmental indicators based on specific characterization factors.

Assumptions

As this is not an assigned project by either of the manufacturers and the exact data for the used materials and the production process cannot be attained with 100% accuracy, assumptions are to be made. Below are the relevant assumption points for the modelling and the environmental assessments of the two products.

- Both products are used and disposed of in Berlin, Germany
  - Nylon is imported from Shandong Province, China; biggest producer and importer of nylon in the world[7]
- It is assumed that the Polypropylene (PP) for the dispensers and the spools (cylindrical device that the floss is wrapped around) of both products is produced as a granulate in the Czech Republic and is then transported by road to the place of manufacturing
- At the EoL, it is assumed that any waste intended for recycling is recoverable to 70%.

[7] https://www.icis.com/explore/resources/news/2010/08/30/9388327/china-strengthens-position-in-nylon-fibers
https://www.thejournal.ie/china-export-810486-Feb2013/

2. Lifecycle Inventory

The collected data is entered in the LCA software to create the products' models and run the impact assessment. This study is carried out using openLCA software version 1.10.3.

Oral-B

The Oral-B dental floss is bought under the assumption that the lifetime of the whole product is equal to that of the floss itself which is 50 m per product. It is not considered reusable. Therefore, the model and the calculations are created once and multiplied by 3 and 5 for cases 1 (150 m) and 2 (250 m), respectively.

Model Graph

After collecting all the necessary data of the input and output flows, openLCA is used with the free database Ecoinvent to create a model graph for the product (Figure 4). From left to right, all the flows show the lifecycle of the single product's flows to the finished product. The processes are categorized following the four main stages as in Figures 2 and 3, namely the raw material extraction, the production, the use and the end of life. In each of one these stages, one or more processes take place. For example, the production phase includes the production of the dental floss – which consists of the production of the nylon filament and the production petroleum-based wax from slack wax – as well as the production of the dispenser and the packaging. Each one of these processes is broken down further into other processes reaching the point of raw material.

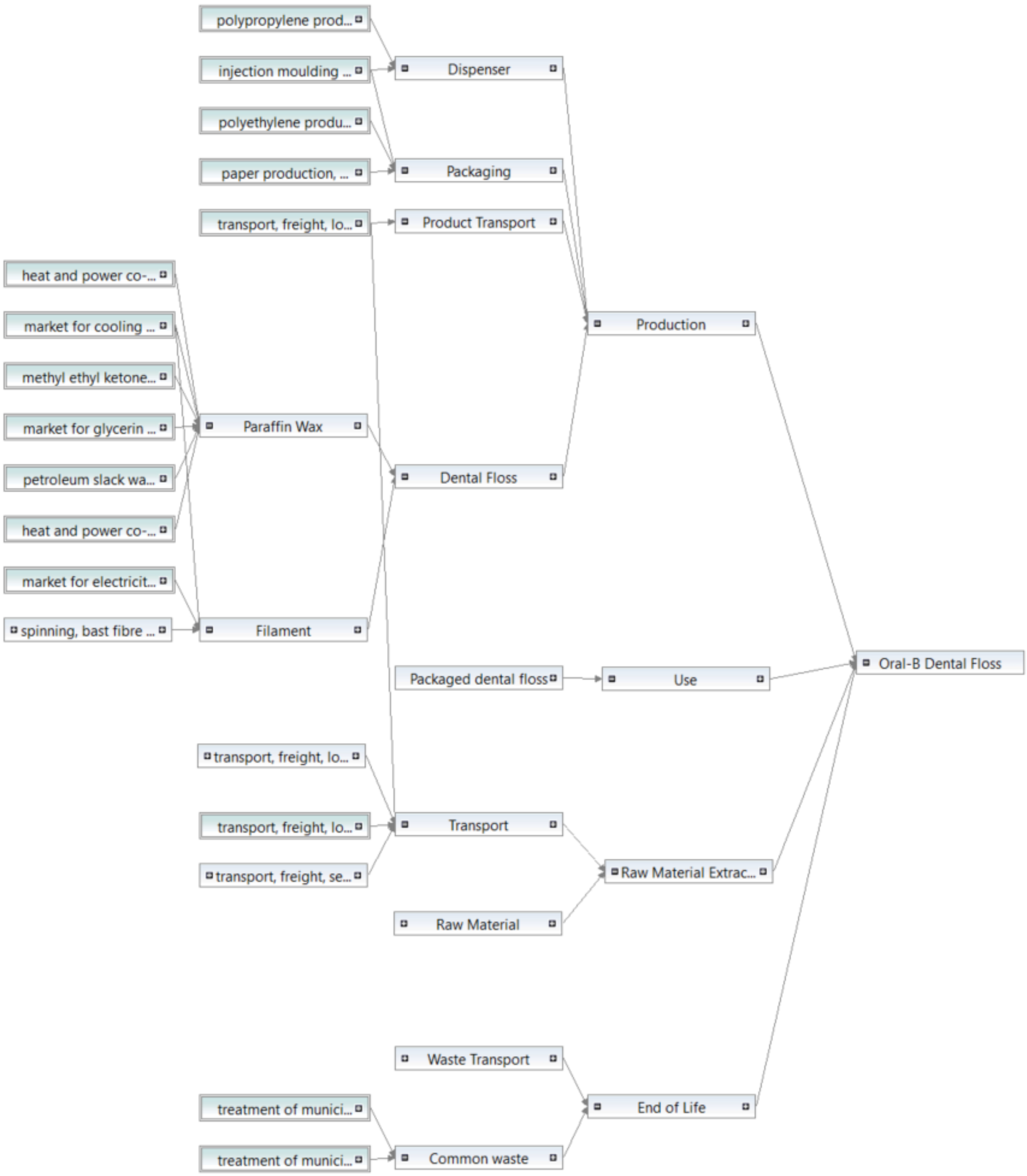

Figure 4 Model graph for the Oral-B dental floss carried out using openLCA with the database Ecoinvent.

I. Raw Material Extraction

The main materials required for the production are PP for the dispenser, and nylon for the floss. The nylon is not imported as fibres, but it is processed during the production phase to obtain nylon fibres. PP is imported from Prague and transported in a lorry whereas the nylon is imported from Shangdong, China and is first transported from Shangdong via lorry to shanghai and from Port of Shanghai to Dublin Port and from there again by a lorry to Newbridge, where it is manufactured. The resource needed to produce the wax is petroleum slack wax. It is assumed that this is available at the manufacturing location. All the transport distances are added in one flow and are modelled with the raw material extraction. The required fuel for these transports is already included in the flows.

Table 4 Distances of the raw material (Nylon & PP) for the Oral-B dental floss from the extraction point to the production station.

Departure from	Destination	Transport method	Distance
Shangdong	Shanghai	Lorry	728 km
Port of Shanghai	Dublin Port	Ferry	11662 nm
Dublin	Newbridge	Lorry	45 km
Prague	Newbridge	Lorry	19246 km
Newbridge	Berlin	Lorry	1809 km

II. Production

The production phase starts when all the raw material is delivered to Newbridge, Ireland, where the manufacturing takes place. The production consists of three stages: the production of the dental floss (filament & wax), the production of the dispenser and the production of the packaging which is made of polyethylene (PE) and coated cardboard. For each of these processes the material is not modelled as a flow as it is already modelled in the raw material extraction. However, the energy demand and the process itself fall under the production of all the elements. Lastly, the transport of the product is modelled from the manufacturing place (Newbridge) to the place of use (Berlin). In general, machinery is left out of this model.

Filament

The filament for the Oral-B product is made of nylon, a fibre forming substance composed of a long chain synthetic polyamide. To produce nylon ribbons, nylon salt from the raw material nylon 6-6 is polymerized. These ribbons are subsequently cut into small chips, flakes, or pellets and blended, remelted, and pumped through spinnerets to form filaments. When the nylon cools, the filaments solidify and regather to form a yarn. The ends of the filaments are combined to create one strand of floss. As nylon fibre is not available as a product flow on the database Ecoinvent, it is modelled from the raw material nylon 6-6 by combining the process "spinning, bast fibre | spinning, bast fibre | Cutoff, U" with the appropriate energy demand. The required energy is calculated and modelled as an input.

- Energy demand: 260 MJ/kg nylon fibre[8]
- For 3,52 g of nylon for 1 pack -> 0,915 MJ

Paraffin Wax

For the Oral-B dental floss, the filaments are coated with paraffin wax which makes 12%[9] of the total weight of the floss[10]. The feedstock for paraffin is slack wax, which is a mixture of oil and wax, a by-product from the refining of lubricating oil. Petroleum slack wax is available as a product flow in Ecoinvent and is therefore used as a base for the modelling of the whole process. The first step in making paraffin wax is to remove the oil (de-oiling or de-waxing) from the slack wax. The oil is subsequently separated by crystallization. Most commonly, the slack wax is heated, mixed with one or more solvents such as a ketone and then cooled. As it cools, wax crystallizes out of the solution, leaving only oil.

[8] https://www.researchgate.net/publication/263238924_Life_Cycle_Analysis_of_Cumulative_Energy_Demand_on_Sericulture_in_Karnataka_IndiaLife_Cycle_Analysis_of_Cumulative_Energy_Demand_on_Sericulture_in_Karnataka_India

[9] https://patents.google.com/patent/US5220932A/en

[10] https://patents.google.com/patent/US4996056A/en

Slack wax contains varying amounts of oil (20 – 50 wt.%) which results in 50 – 80 wt.% wax. For this study, it is assumed that the ratio of wax to oil is 50:50. Therefore, for 1 item (50 m of dental floss) that contains 0,36 g of wax, 0,72 g of slack wax is required. Commonly ketone is used with a mixture of other chemicals as a solvent but in this case, it is assumed that only ketone is used as a solvent with a ratio of 6:1 (for every 1 g of slack wax, 6 g of ketone is added). The solvent is then recovered by distillation. Ketone remains in the output and needs to be accounted for. Considering that the distillation of ketone is not available in the database, an approximation process is adapted, namely that of glycerine distillation.

Energy demand for the process of producing wax from slack wax:

$$Q = Q_{wax} + Q_{solvent} = (m_{wax} * c_{p,wax} * \Delta T_{slack\ wax}) + (m_{solvent} * c_{p,solvent} * \Delta T_{slack\ wax})$$

This mixture is filtered into two streams: solid (wax plus some solvent) and liquid (oil plus solvent). The filtration is not taken into consideration in this LCA. The product wax may be further processed to remove colours and odours. This treatment phase is not taken into consideration in this LCA.

To coat the filament, oil is then heated up to liquify it and dip the filament in it. The required energy demand for the coating process:

$$Q = m_{wax} * c_{p,wax} * (T_{paraffin\ wax,\ liquid} - T_{paraffin\ wax,\ solid})\ K$$

Subsequently, the coated filament is then cooled using cooling energy with the same Q as the melting energy. It is assumed that the wax solidifies at 37°C.

Table 5 Required parameters for the calculation of the energy demand for the production of paraffin wax as well as the coating process for the Oral-B product for 1 item (=50 m of dental floss).

Parameter	Unit	Paraffin Wax	Solvent: Ketone
Specific Heat Capacity	J/g*K	$c_{p,wax} = 2,45$[12]	$c_{p,solvent} = 2,19$[13]
Mass	g	$m_{wax} = 0,36$	$m_{solvent} = 4,32$
$T_{slack\ wax,\ liquid}$	K	343,15	/
$T_{slack\ wax,\ solid}$	K	298,15	/
$T_{paraffin\ wax,\ liquid}$	K	341,15	/
$T_{paraffin\ wax,\ solid}$	K	310,15	/

Dispenser

PP is available in Ecoinvent as a granulate. The PP is formed into shape with the injection moulding technique. This process is also available in the database as "polypropylene production, granulate | polypropylene, granulate" and it contains all the upstream activities including the energy demand.

Package

The packaging is made out of a top layer of PE and a bottom sheet of coated cardboard paper. The PE is received as a granulate and moulded into the desired form. The coated cardboard paper is used directly as an input in the process and the cutting of the paper is not considered in this LCA. Both

[12] http://www.pgimpex.com/our-products/paraffin-wax/

[13] https://www.shell.com/business-customers/chemicals/our-products/solvents-chemical/ketones/_jcr_content/par/tabbedcontent/tab/textimage.stream/1459943761987/aa4a0ecc902a57b7ba182491ba379c14133dfab1/mek-s1213-global.pdf

product flows are available in the database and did not require any further modelling apart from adjusting their values based on both comparison cases (production of 150 m & 250 m of dental floss)

III. Use

During the use phase of the product, there are no emissions, only solid waste comes out as output. This consists of waste from the packaging, the dispenser as well as the dental floss itself.

IV. End-of-Life

According to the German Landfill Directive and a landfill ban introduced in 1993, untreated waste with a total organic carbon (TOC) > 3% must first be treated before it can be landfilled[14]. This means that non-hazardous waste that cannot be recycled or composted, must first be incinerated. Subsequently, the bottom ash can either be reused in construction material or can be landfilled[15].

As the dental floss cannot be composted or recycled, it is considered as Municipal Solid Waste (MSW) and therefore incinerated at a waste incineration plant. For the dispenser made out of PP without an additive, it is assumed that at the EoL (in Berlin) the dispenser is recycled 7 out of 10 times. Hence 70% of the PP used for the production of the dispenser is recycled and 30% lands into waste incineration plants. This ratio is also applied for the packaging, 70% of it is recycled and 30% is incinerated. This way the manufacturer or the product is credited for the material's recycling. For that, a semi-closed loop recycling model, namely the 50:50 method is used. This model considers that credits related to recycling are to be shared equally between the first and last use and the impacts of the recycling process are divided in half between the upstream and the downstream process. Therefore, when modelling the recycling processes of the 70% of the waste, only 50% of that is credited to the product. The other 50% are to be credited to the next lifecycle of the material or product which is not part of this LCA. Additionally, an alternative recycling model which focuses on the avoided impact of the subsequent extraction and production of the same raw material by giving credit the producer. The results of the comparison of the two recycling models is presented in Chapter 3.

Yaweco

Contrary to the previously modelled product, the Yaweco product comes in a reusable dispenser. Therefore, the dispenser is modelled only once in both cases 1 & 2. In case 1, it is assumed that after 4 refills, the dispenser is lost or disposed of. In case 2, that number is 8. The refill product including the dental floss itself, the PP-spools they are rolled around as well as the packaging are modelled in the respective stages, i.e. the raw material extraction, production and EoL.

[14] https://www.cewep.eu/wp-content/uploads/2017/12/Landfill-taxes-and-bans-overview.pdf

[15] https://www.sciencedirect.com/topics/engineering/bottom-ash

Model Graph

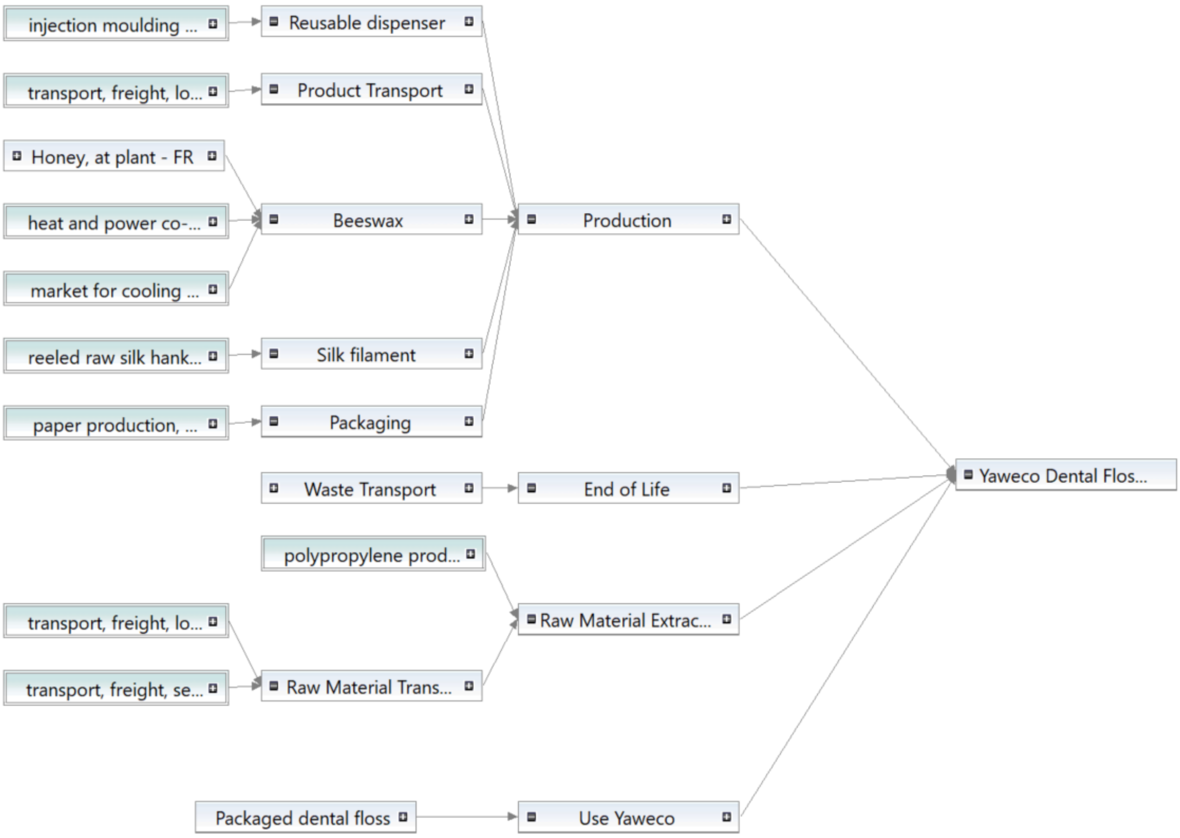

Figure 5 Model graph for the Yaweco dental floss carried out using openLCA with the database ecoinvent.

I. Raw Material Extraction

The Yaweco dental floss is made of silk and beeswax. Silk fibre is available in the database and includes the production from cocoons. This is therefore modelled in the 'Production' phase. Beeswax is not available and is modelled through different flows and processes in the production phase as well. PP granulate for the dispenser is modelled as a raw material in the 'Raw material extraction' phase. The transport for PP and silk is calculated and presented under this subpoint. It is assumed that the silk is imported from India – the biggest producer of silk in the world – and the beeswax is assumed to be farmed in Italy. The silk is transported by ship until it reaches Port of Bari in the southeast of Italy and then transported by lorry to the north. As with the Oral-B model, for the dispenser, PP is also imported from Prague and transported to Italy.

Table 6 Distances of the raw material (PP & silk) for the Yaweco floss from the extraction point to the production station.

Departure from	**Destination**	**Transport method**	**Distance**
Shangdong	Shanghai	Lorry	728 km
Port of Shanghai	Port of Bari	Ferry	9772 nm
Port of Mumbai	Port of Bari	Ferry	4576 nm
Bari	Northern Italy	Lorry	879 km
Prague	Northern Italy	Lorry	879 km
Northern Italy	Berlin	Lorry	1100 km

II. Production

The producer of the Yaweco dental floss only declares that the product is made in Italy. Due to the higher industrialization capacity of the North compared to the South, it is assumed that the Yaweco product is manufactured in Northern Italy, where 90% of Italy's exports are produced[16].

Filament

Reeled raw silk hank production is available as a flow in the database. It is modelled from cradle, i.e. including all upstream activities to the production of 1 kg of raw silk. This is adapted to the weight of silk required for the production of:

- Case 1: 150 m of dental floss *(under the names Oral-B_1 & Yaweco_1 in the results)*
- Case 2: 250 m of dental floss *(under the names Oral-B_2 & Yaweco_2 in the results).*

The flow in the database contains the reeling process, as well as the water and the energy consumption. Electricity is generally solar based and reeling units have their own solar panels[17].

Beeswax

The filament is coated with beeswax which is not available in the database. Therefore, it is modelled on the basis of the processes required to obtain beeswax. Since the wax makes up 12% of the total weight of the floss, the required amount of beeswax to make:

- 150 m of dental floss = 12 g of dental floss
- 250 m of dental floss = 20 g of dental floss.

Beeswax is not available in the database as a product flow and must therefore be broken into smaller process. For the production of 1 kg of beeswax, 8 – 10 kg of honey (flow available in Ecoinvent) are consumed by bees. The amount of honey required is adapted to obtain 1,44 g and 2,4 g of beeswax (Table 7).

Table 7 Parameters required for the calculation of the mass of beeswax and honey as well as the energy demand for the filament coating process for the Yaweco dental floss for Cases 1 & 2 (=150 & 250 m of dental floss).

Parameter	Unit	Case 1 = 150 m	Case 2 = 250 m
Mass of Beeswax	g	1,44	2,4
Mass of Honey	g	*13,5*	*21,6*
Specific Heat Capacity of Beeswax	J/g*K	$c_{p,beeswax} = 3,4$[18]	
$T_{beeswax,\ liquid}$	K	*336,15*[19]	
$T_{beeswax,\ solid}$	K	*310,15*	

The beeswax is subsequently melted to allow the coating of the filament. The required energy for the process is calculated based on

$$Q = m * cp * \Delta T.$$

Although it can be assumed that the finished product is left to airdry, here it is assumed that it is dried using a cooling device to speed up the process. The same energy is therefore added again as

16 Italy's North and South: What You Need to Know | Veem
17 ecoinvent
18 https://www.engineeringtoolbox.com/specific-heat-solids-d_154.html
19 http://modernistencaustic.com/portfolio-items/encaustic-wax/#:~:text=Beeswax%20floats%20in%20water%2C%20is,of%20energy%20just%20to%20melt.

cooling energy after the silk filament is coated with beeswax. It is assumed that the wax solidifies at 37°C.

While the land use for the beekeeping is considered in the modelling of the beeswax, the bees themselves are not. However, the best suitable land type for beekeeping is open meadows which is modelled as an elementary flow and does not have negative environmental impacts.

The finished product is then transported, used and disposed of in Berlin. The distance from the production point to the use point is presented in Table 6. The transport of the finished product is modelled under the Production life stage.

Dispenser

Yaweco's dispenser is reusable and refilling packs of only the silk dental floss rolled around a spool are available for purchase. The lifespan of Yaweco's reusable dispenser is equal to:

- Case 1: 150 m dental floss rolls
  - 1 dispenser including the silk dental floss + 2 refill packs (with 2 rolls each)
  - Equivalent to 3 oral-B packs
- Case 2: 250 m dental floss rolls
  - 1 dispenser including the silk dental floss + 4 refill packs (with 2 rolls each)
  - Equivalent to 5 oral-B packs

Yaweco's PP dispenser contains an additive that ensures that the material is fully decomposable within a few years if it is surrounded by organic material in the landfill. Considering the lack of information on the product's website in regard to the additive type and material, this part is not taken into consideration into this model. The dispenser is manufactured using injection moulding, a flow available in ecoinvent_aposlci. The process is modelled from cradle, i.e., including all upstream activities. This process contains the auxiliaries and energy demand for the conversion process of plastics and therefore does not require the separate modelling of energy consumption.

Package

Made entirely of coated paperboard, a flow available in the database. Machinery as well as cutting the paperboard and forming it into boxes are not considered in the process.

III. Use

The finished product is sold in pharmacies, supermarkets and drugstores alike. The use of the Yaweco dental floss results in the generation of biowaste from the silk/beeswax floss itself, paper waste from the packaging and plastic waste.

IV. End of Life

As with the Oral-B model, 30% of all recoverable, recyclable or upgradable waste streams will not be recovered and will therefore be incinerated. The remaining 70% will be modelled via the 50:50 method, meaning that 35% of the biowaste is composted and 35% of the packaging paper is recycled. Considering that the dispenser is not made of pure PP, it is not recycled and instead is disposed of to a 100% in a sanitary landfill at the EoL.

3. Impact Assessment

The LCIA for both products is carried out using the ReCiPe 2016 Midpoint (H) assessment method.

Detailed Assessment of the Life Stages of the Products

Tables 8 and 9 show a detailed assessment of the Oral-B and Yaweco dental floss products based on the four life stages of each product and the midpoint impact indicators in the used LCIA method. The data is normalized and presented in percent to compare the impact of the different stages. The colour scale tables show that for both products highest contributing life stages are the same, namely the production. The production phase has the highest environmental impact in all categories followed by the raw material extraction. In comparison, the use phase of the dental floss requires no input and emits no output and therefore remains at 0%.

The dissimilarities between the two products are showcased by the percentage of the impact of the specific lifecycle stages from the total. For the Oral-B, the raw material extraction has on average higher impact rates than the Yaweco counterpart. The Yaweco dental floss shows that the impact from the production stage nears 100% for all the impact indicators except for the fossil resource scarcity which shifts its impact to the raw material extraction stage. The great impact of the production stage can be due to the beeswax, the silk or the packaging production. The following analysis aims to evaluate the LCA data to identify the major hotspots of the production system.

Table 8 Detailed impact results distribution of the different production stages for the Oral-B dental floss.

Impact indicator	Impact result			
	Raw Material [%]	Production [%]	Use [%]	End of Life [%]
Fine particulate matter formation	18,5	80,6	0,0	1,0
Fossil resource scarcity	23,0	76,6	0,0	0,4
Freshwater ecotoxicity	3,7	77,4	0,0	18,9
Freshwater eutrophication	1,4	98,5	0,0	0,1
Global warming	15,4	76,1	0,0	8,4
Human carcinogenic toxicity	6,5	91,8	0,0	1,7
Human non-carcinogenic toxicity	3,0	84,6	0,0	12,4
Ionizing radiation	2,6	97,3	0,0	0,1
Land use	3,0	96,7	0,0	0,3
Marine ecotoxicity	3,6	76,8	0,0	19,6
Marine eutrophication	26,1	70,7	0,0	3,3
Mineral resource scarcity	12,3	86,6	0,0	1,2
Ozone formation, Human health	22,8	74,7	0,0	2,5
Ozone formation, Terrestrial ecosystems	23,1	74,5	0,0	2,5
Stratospheric ozone depletion	16,4	81,0	0,0	2,6
Terrestrial acidification	21,0	78,1	0,0	0,9
Terrestrial ecotoxicity	19,1	57,1	0,0	23,8
Water consumption	20,0	79,8	0,0	0,2

Table 9 Detailed impact result distribution of the different production stages for the Yaweco dental floss.

Impact indicator	Impact result			
	Raw Material [%]	Production [%]	Use [%]	End of Life [%]
Fine particulate matter formation	3,4	96,4	0,0	0,2
Fossil resource scarcity	19,6	80,0	0,0	0,4
Freshwater ecotoxicity	2,6	91,3	0,0	6,1
Freshwater eutrophication	1,6	98,3	0,0	0,1
Global warming	5,8	90,2	0,0	4,0
Human carcinogenic toxicity	3,4	96,0	0,0	0,6
Human non-carcinogenic toxicity	1,7	96,1	0,0	2,1
Ionizing radiation	4,6	95,3	0,0	0,1
Land use	0,1	99,8	0,0	0,0
Marine ecotoxicity	2,7	90,6	0,0	6,7
Marine eutrophication	0,1	99,8	0,0	0,1
Mineral resource scarcity	2,9	96,9	0,0	0,2
Ozone formation, Human health	6,0	93,3	0,0	0,7
Ozone formation, Terrestrial ecosystems	6,1	93,2	0,0	0,7
Stratospheric ozone depletion	0,2	99,5	0,0	0,2
Terrestrial acidification	2,6	97,2	0,0	0,2
Terrestrial ecotoxicity	7,6	87,5	0,0	4,8
Water consumption	0,3	99,7	0,0	0,0

Comparison of Cases 1 & 2

To reveal the environmental impact of the products and understand the main contributing processes to the impact indicators, Cases 1 and 2 are compared. The results for each impact indicator for both products (further abbreviated with O & Y for Oral-B and Yaweco, respectively) are evaluated based on a number of factors and presented below using different tables and chart types. The following abbreviations are also commonly used in the following chapters.

Table 10 Commonly adopted abbreviations in this study.

Abbreviation	Comparison	Model
Oral-B_1 / Yaweco_1	Case 1	150 m of dental floss
Oral-B_2 / Yaweco_2	Case 2	250 m of dental floss
Oral-b_avoided.impact	Case 3	Oral-B, recycling model: avoided impact

The following chart shows the indicator results of the respective product types. For each indicator, the maximum result is set to 100% and the results of the other variants are displayed in relation to the total result. Figure 6 reveals that for Case 1 (represented in darker shades of blue (O) and orange (Y)), 6 out of 18 impact indicators, the Oral-B impact results are higher, while in Case 2, all of the impact indicators are higher for the Yaweco dental floss. On the one hand, in Case 1, the Oral-B contributes more to the fossil resource scarcity as well as the freshwater and marine ecotoxicity. The impact shifts, however in Case 2. On the other hand, in Case 2, the impact of the Yaweco dental floss is higher in all categories. In fact, it is more than double (both in Cases 1 & 2) that of the Oral-B for 9 different impact indicators, such as land use, marine eutrophication, mineral resource scarcity and terrestrial acidification to name a few. This indicates that the refilling pack does not necessarily contribute to a decreased environmental impact over the long-term use of the product.

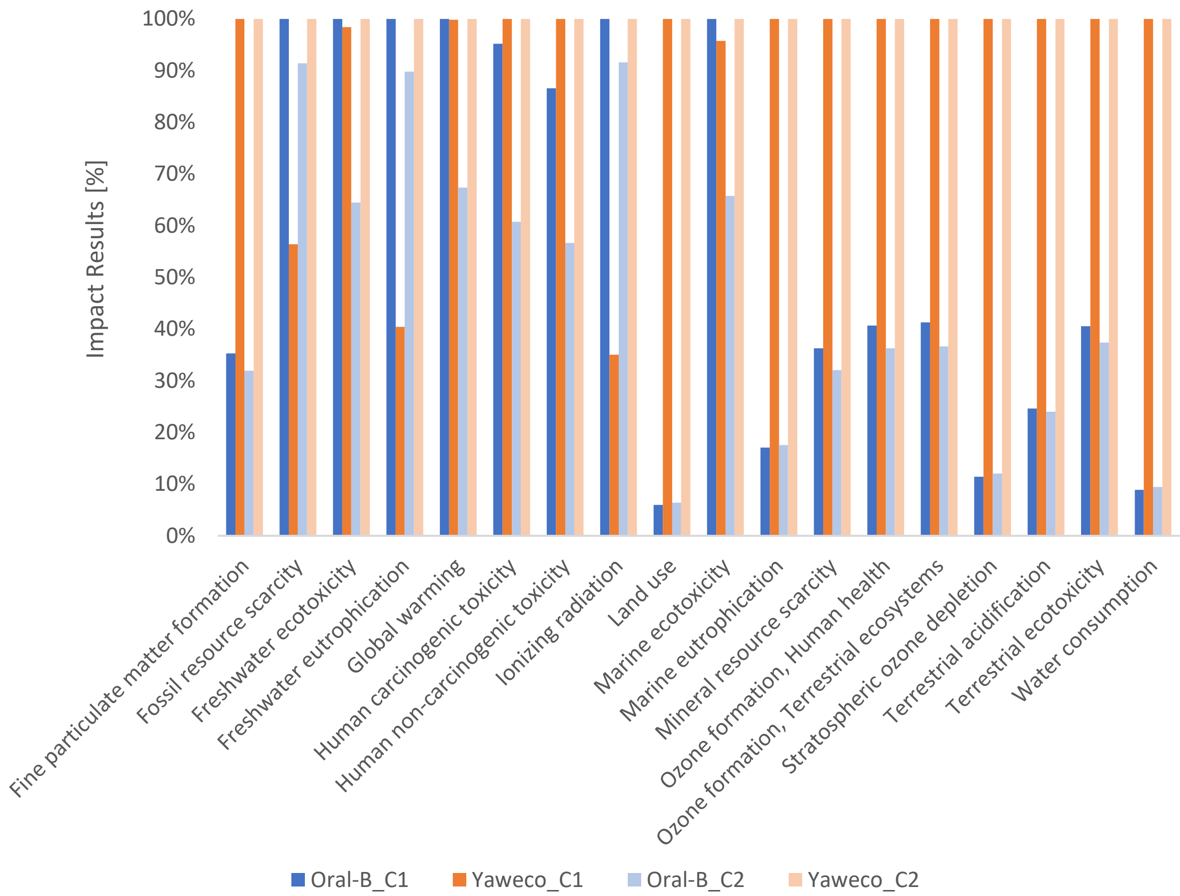

Figure 6 Visual comparison of the relative impact indicator results of the respective products.

A more detailed analysis of the impact categories showing the specific processes of the Oral-B and Yaweco products that contribute to the highest scoring categories is presented below (s. Table 11 & 12). The following tables only show (sub-)processes with contributions >10% to facilitate the focus on the most impactful processes.

For the Oral-B dental floss production, the highest impacts are recorded in the categories, fossil resource scarcity, global warming, ionizing radiation and freshwater eutrophication and marine ecotoxicity. Taking a closer look into the detailed processes and their contribution to the impact indicators (Table 11), a number of processes show the highest impact cumulatively. These processes are electricity production, polypropylene and nylon production and the process of injection moulding to form polymers into shapes. This goes to show that the accumulation of different impacts from different product flows generate the overall environmental impact and that changing one process in particular may not have a great effect on the end result. This matches the results of Table 8, where the production stage did in fact deliver the highest impact compared to the overall lifecycle stages, but the raw material extraction and the EoL lifecycles stage of the Oral-B product have significant impacts as well.

Similarly, to the Oral-B product, the production of electricity has a high impact on different categories in the Yaweco dental floss system. However, only one other single process affects the impact results of that product, namely the silk production (s. Table 12). The main difference between the two products is that the Yaweco dental floss has one single process that contributes significantly to all impact indicators. This phenomenon is not observed for the Oral-B dental floss. This indicates that, despite the composting of the product at the EoL, the production of the raw material has a high energy and water demand, as opposed to the commonly used synthetic nylon fibre. However, with that one process being that influential on the whole process, it can be concluded that the rest of the Yaweco's dental floss production process including the refillable, reusable pack is evidently more sustainable. But an alternative material to silk is necessary to reduce the overall environmental impact of the product.

Table 11 Impact analysis from the ReCiPe Midpoint (H) impact assessment method for the Oral-B dental floss with contributions >10%.

Name	Category	Impact result	Unit
P market for electricity, medium voltage | electricity, medium voltage | APOS, S - DE	351:Electric power generation, transmission and distribution / 3510:Electric power generation, ...	0.00038	kg PM2.5 eq
P polypropylene production, granulate | polypropylene, granulate | APOS, S - RER	201:Manufacture of basic chemicals, fertilizers and nitrogen compounds, plastics and synthetic...	0.00015	kg PM2.5 eq
Fossil resource scarcity		0.49712	kg oil eq
P market for electricity, medium voltage | electricity, medium voltage | APOS, S - DE	351:Electric power generation, transmission and distribution / 3510:Electric power generation, ...	0.18439	kg oil eq
P polypropylene production, granulate | polypropylene, granulate | APOS, S - RER	201:Manufacture of basic chemicals, fertilizers and nitrogen compounds, plastics and synthetic...	0.16103	kg oil eq
Freshwater ecotoxicity		0.07247	kg 1,4-DCB
P market for electricity, medium voltage | electricity, medium voltage | APOS, S - DE	351:Electric power generation, transmission and distribution / 3510:Electric power generation, ...	0.04218	kg 1,4-DCB
P market for waste polypropylene | waste polypropylene | APOS, S - DE	382:Waste treatment and disposal / 3821:Treatment and disposal of non-hazardous waste	0.01102	kg 1,4-DCB
Freshwater eutrophication		0.00132	kg P eq
P market for electricity, medium voltage | electricity, medium voltage | APOS, S - DE	351:Electric power generation, transmission and distribution / 3510:Electric power generation, ...	0.00113	kg P eq
Global warming		1.49616	kg CO2 eq
P market for electricity, medium voltage | electricity, medium voltage | APOS, S - DE	351:Electric power generation, transmission and distribution / 3510:Electric power generation, ...	0.74583	kg CO2 eq
P market for waste polypropylene | waste polypropylene | APOS, S - DE	382:Waste treatment and disposal / 3821:Treatment and disposal of non-hazardous waste	0.15613	kg CO2 eq
P polypropylene production, granulate | polypropylene, granulate | APOS, S - RER	201:Manufacture of basic chemicals, fertilizers and nitrogen compounds, plastics and synthetic...	0.19714	kg CO2 eq
Human carcinogenic toxicity		0.09605	kg 1,4-DCB
P market for electricity, medium voltage | electricity, medium voltage | APOS, S - DE	351:Electric power generation, transmission and distribution / 3510:Electric power generation, ...	0.06815	kg 1,4-DCB
Human non-carcinogenic toxicity		1.33775	kg 1,4-DCB
P market for electricity, medium voltage | electricity, medium voltage | APOS, S - DE	351:Electric power generation, transmission and distribution / 3510:Electric power generation, ...	0.90200	kg 1,4-DCB
Ionizing radiation		0.17788	kBq Co-60 eq
P injection moulding | injection moulding | APOS, S - RER	222:Manufacture of plastics products / 2220:Manufacture of plastics products	0.02386	kBq Co-60 eq
P market for electricity, medium voltage | electricity, medium voltage | APOS, S - DE	351:Electric power generation, transmission and distribution / 3510:Electric power generation, ...	0.13048	kBq Co-60 eq
Land use		0.04890	m2a crop eq
P market for electricity, medium voltage | electricity, medium voltage | APOS, S - DE	351:Electric power generation, transmission and distribution / 3510:Electric power generation, ...	0.02140	m2a crop eq
P paper production, woodcontaining, lightweight coated | paper, woodcontaining, lightweight coated | APOS, S - RER	170:Manufacture of paper and paper products / 1701:Manufacture of pulp, paper and paperb...	0.01753	m2a crop eq
Marine ecotoxicity		0.09779	kg 1,4-DCB
P market for electricity, medium voltage | electricity, medium voltage | APOS, S - DE	351:Electric power generation, transmission and distribution / 3510:Electric power generation, ...	0.05612	kg 1,4-DCB
P market for waste polypropylene | waste polypropylene | APOS, S - DE	382:Waste treatment and disposal / 3821:Treatment and disposal of non-hazardous waste	0.01588	kg 1,4-DCB
Marine eutrophication		0.00013	kg N eq
P market for electricity, medium voltage | electricity, medium voltage | APOS, S - DE	351:Electric power generation, transmission and distribution / 3510:Electric power generation, ...	7.76643E-5	kg N eq
P nylon 6-6 production | nylon 6-6 | APOS, S - RoW	201:Manufacture of basic chemicals, fertilizers and nitrogen compounds, plastics and synthetic...	3.29203E-5	kg N eq
Mineral resource scarcity		0.00169	kg Cu eq
P injection moulding | injection moulding | APOS, S - RER	222:Manufacture of plastics products / 2220:Manufacture of plastics products	0.00024	kg Cu eq
P market for electricity, medium voltage | electricity, medium voltage | APOS, S - DE	351:Electric power generation, transmission and distribution / 3510:Electric power generation, ...	0.00078	kg Cu eq
P polypropylene production, granulate | polypropylene, granulate | APOS, S - RER	201:Manufacture of basic chemicals, fertilizers and nitrogen compounds, plastics and synthetic...	0.00035	kg Cu eq
Ozone formation, Human health		0.00209	kg NOx eq
P market for electricity, medium voltage | electricity, medium voltage | APOS, S - DE	351:Electric power generation, transmission and distribution / 3510:Electric power generation, ...	0.00082	kg NOx eq
P polypropylene production, granulate | polypropylene, granulate | APOS, S - RER	201:Manufacture of basic chemicals, fertilizers and nitrogen compounds, plastics and synthetic...	0.00034	kg NOx eq
Ozone formation, Terrestrial ecosystems		0.00217	kg NOx eq
P market for electricity, medium voltage | electricity, medium voltage | APOS, S - DE	351:Electric power generation, transmission and distribution / 3510:Electric power generation, ...	0.00083	kg NOx eq
P polypropylene production, granulate | polypropylene, granulate | APOS, S - RER	201:Manufacture of basic chemicals, fertilizers and nitrogen compounds, plastics and synthetic...	0.00037	kg NOx eq
Stratospheric ozone depletion		7.64318E-7	kg CFC11 eq
P market for electricity, medium voltage | electricity, medium voltage | APOS, S - DE	351:Electric power generation, transmission and distribution / 3510:Electric power generation, ...	5.10878E-7	kg CFC11 eq
P nylon 6-6 production | nylon 6-6 | APOS, S - RoW	201:Manufacture of basic chemicals, fertilizers and nitrogen compounds, plastics and synthetic...	1.06985E-7	kg CFC11 eq
Terrestrial acidification		0.00290	kg SO2 eq
P electricity, high voltage, import from RS | electricity, high voltage | APOS, S - AL	351:Electric power generation, transmission and distribution / 3510:Electric power generation, ...	0.00030	kg SO2 eq
P market for electricity, medium voltage | electricity, medium voltage | APOS, S - DE	351:Electric power generation, transmission and distribution / 3510:Electric power generation, ...	0.00110	kg SO2 eq
P nylon 6-6 production | nylon 6-6 | APOS, S - RoW	201:Manufacture of basic chemicals, fertilizers and nitrogen compounds, plastics and synthetic...	0.00032	kg SO2 eq
P polypropylene production, granulate | polypropylene, granulate | APOS, S - RER	201:Manufacture of basic chemicals, fertilizers and nitrogen compounds, plastics and synthetic...	0.00044	kg SO2 eq
Terrestrial ecotoxicity		1.57536	kg 1,4-DCB
P market for electricity, medium voltage | electricity, medium voltage | APOS, S - DE	351:Electric power generation, transmission and distribution / 3510:Electric power generation, ...	0.24780	kg 1,4-DCB
P market for transport, freight, lorry, unspecified | transport, freight, lorry, unspecified | APOS, S - RER	492:Other land transport / 4923:Freight transport by road	0.33039	kg 1,4-DCB
P market for waste polypropylene | waste polypropylene | APOS, S - DE	382:Waste treatment and disposal / 3821:Treatment and disposal of non-hazardous waste	0.46133	kg 1,4-DCB
P market group for transport, freight, lorry, unspecified | transport, freight, lorry, unspecified | APOS, S - GLO	492:Other land transport / 4923:Freight transport by road	0.21906	kg 1,4-DCB
Water consumption		0.01976	m3
P market for electricity, medium voltage | electricity, medium voltage | APOS, S - DE	351:Electric power generation, transmission and distribution / 3510:Electric power generation, ...	0.00892	m3
P nylon 6-6 production | nylon 6-6 | APOS, S - RoW	201:Manufacture of basic chemicals, fertilizers and nitrogen compounds, plastics and synthetic...	0.00298	m3
P polypropylene production, granulate | polypropylene, granulate | APOS, S - RER	201:Manufacture of basic chemicals, fertilizers and nitrogen compounds, plastics and synthetic...	0.00212	m3
P spinning, bast fibre | spinning, bast fibre | Cutoff, U - RoW	131:Spinning, weaving and finishing of textiles / 1311:Preparation and spinning of textile fibres	0.00226	m3

Table 12 Impact indicators from the ReCiPe Midpoint (H) impact assessment method for the Yaweco dental floss with contributions >10%.

Name	Category	Impact result	Unit
Fine particulate matter formation		0.00351	kg PM2.5 eq
P reeled raw silk hank production | reeled raw silk hank | APOS, S - IN	131:Spinning, weaving and finishing of textiles / 1311:Preparation and spinning of t...	0.00255	kg PM2.5 eq
Fossil resource scarcity		0.54228	kg oil eq
P market for electricity, medium voltage | electricity, medium voltage | APOS, S - DE	351:Electric power generation, transmission and distribution / 3510:Electric power g...	0.13975	kg oil eq
P polypropylene production, granulate | polypropylene, granulate | APOS, S - RER	201:Manufacture of basic chemicals, fertilizers and nitrogen compounds, plastics an...	0.11060	kg oil eq
P reeled raw silk hank production | reeled raw silk hank | APOS, S - IN	131:Spinning, weaving and finishing of textiles / 1311:Preparation and spinning of t...	0.15963	kg oil eq
Freshwater ecotoxicity		0.09917	kg 1,4-DCB
P market for electricity, medium voltage | electricity, medium voltage | APOS, S - DE	351:Electric power generation, transmission and distribution / 3510:Electric power g...	0.03196	kg 1,4-DCB
P reeled raw silk hank production | reeled raw silk hank | APOS, S - IN	131:Spinning, weaving and finishing of textiles / 1311:Preparation and spinning of t...	0.04671	kg 1,4-DCB
Freshwater eutrophication		0.00147	kg P eq
P market for electricity, medium voltage | electricity, medium voltage | APOS, S - DE	351:Electric power generation, transmission and distribution / 3510:Electric power g...	0.00086	kg P eq
P reeled raw silk hank production | reeled raw silk hank | APOS, S - IN	131:Spinning, weaving and finishing of textiles / 1311:Preparation and spinning of t...	0.00040	kg P eq
Global warming		2.10255	kg CO2 eq
P market for electricity, medium voltage | electricity, medium voltage | APOS, S - DE	351:Electric power generation, transmission and distribution / 3510:Electric power g...	0.56526	kg CO2 eq
P reeled raw silk hank production | reeled raw silk hank | APOS, S - IN	131:Spinning, weaving and finishing of textiles / 1311:Preparation and spinning of t...	0.98310	kg CO2 eq
Human carcinogenic toxicity		0.15630	kg 1,4-DCB
P market for electricity, medium voltage | electricity, medium voltage | APOS, S - DE	351:Electric power generation, transmission and distribution / 3510:Electric power g...	0.05165	kg 1,4-DCB
P reeled raw silk hank production | reeled raw silk hank | APOS, S - IN	131:Spinning, weaving and finishing of textiles / 1311:Preparation and spinning of t...	0.07722	kg 1,4-DCB
Human non-carcinogenic toxicity		2.17013	kg 1,4-DCB
P market for electricity, medium voltage | electricity, medium voltage | APOS, S - DE	351:Electric power generation, transmission and distribution / 3510:Electric power g...	0.68362	kg 1,4-DCB
P reeled raw silk hank production | reeled raw silk hank | APOS, S - IN	131:Spinning, weaving and finishing of textiles / 1311:Preparation and spinning of t...	1.16687	kg 1,4-DCB
Ionizing radiation		0.19405	kBq Co-60 eq
P injection moulding | injection moulding | APOS, S - RER	222:Manufacture of plastics products / 2220:Manufacture of plastics products	0.04386	kBq Co-60 eq
P market for electricity, medium voltage | electricity, medium voltage | APOS, S - DE	351:Electric power generation, transmission and distribution / 3510:Electric power g...	0.09889	kBq Co-60 eq
P reeled raw silk hank production | reeled raw silk hank | APOS, S - IN	131:Spinning, weaving and finishing of textiles / 1311:Preparation and spinning of t...	0.02457	kBq Co-60 eq
Land use		0.76078	m2a crop eq
P reeled raw silk hank production | reeled raw silk hank | APOS, S - IN	131:Spinning, weaving and finishing of textiles / 1311:Preparation and spinning of t...	0.69640	m2a crop eq
Marine ecotoxicity		0.13070	kg 1,4-DCB
P market for electricity, medium voltage | electricity, medium voltage | APOS, S - DE	351:Electric power generation, transmission and distribution / 3510:Electric power g...	0.04253	kg 1,4-DCB
P reeled raw silk hank production | reeled raw silk hank | APOS, S - IN	131:Spinning, weaving and finishing of textiles / 1311:Preparation and spinning of t...	0.05990	kg 1,4-DCB
Marine eutrophication		0.00074	kg N eq
P reeled raw silk hank production | reeled raw silk hank | APOS, S - IN	131:Spinning, weaving and finishing of textiles / 1311:Preparation and spinning of t...	0.00066	kg N eq
Mineral resource scarcity		0.00524	kg Cu eq
P market for electricity, medium voltage | electricity, medium voltage | APOS, S - DE	351:Electric power generation, transmission and distribution / 3510:Electric power g...	0.00059	kg Cu eq
P reeled raw silk hank production | reeled raw silk hank | APOS, S - IN	131:Spinning, weaving and finishing of textiles / 1311:Preparation and spinning of t...	0.00361	kg Cu eq
Ozone formation, Human health		0.00568	kg NOx eq
P market for electricity, medium voltage | electricity, medium voltage | APOS, S - DE	351:Electric power generation, transmission and distribution / 3510:Electric power g...	0.00062	kg NOx eq
P reeled raw silk hank production | reeled raw silk hank | APOS, S - IN	131:Spinning, weaving and finishing of textiles / 1311:Preparation and spinning of t...	0.00390	kg NOx eq
Ozone formation, Terrestrial ecosystems		0.00581	kg NOx eq
P market for electricity, medium voltage | electricity, medium voltage | APOS, S - DE	351:Electric power generation, transmission and distribution / 3510:Electric power g...	0.00063	kg NOx eq
P reeled raw silk hank production | reeled raw silk hank | APOS, S - IN	131:Spinning, weaving and finishing of textiles / 1311:Preparation and spinning of t...	0.00397	kg NOx eq
Stratospheric ozone depletion		6.22829E-6	kg CFC11 eq
P reeled raw silk hank production | reeled raw silk hank | APOS, S - IN	131:Spinning, weaving and finishing of textiles / 1311:Preparation and spinning of t...	5.66401E-6	kg CFC11 eq
Terrestrial acidification		0.01201	kg SO2 eq
P reeled raw silk hank production | reeled raw silk hank | APOS, S - IN	131:Spinning, weaving and finishing of textiles / 1311:Preparation and spinning of t...	0.00959	kg SO2 eq
Terrestrial ecotoxicity		3.62766	kg 1,4-DCB
P market for transport, freight, lorry, unspecified | transport, freight, lorry, unspecified | APOS, S - RER	492:Other land transport / 4923:Freight transport by road	0.59133	kg 1,4-DCB
P reeled raw silk hank production | reeled raw silk hank | APOS, S - IN	131:Spinning, weaving and finishing of textiles / 1311:Preparation and spinning of t...	2.24110	kg 1,4-DCB
Water consumption		0.20839	m3
P reeled raw silk hank production | reeled raw silk hank | APOS, S - IN	131:Spinning, weaving and finishing of textiles / 1311:Preparation and spinning of t...	0.19322	m3

Furthermore, Cases 1 & 2 are compared to understand the effect of the reusable pack in the modelling process. The following table shows the impact of both products individually as well as in relativity to one another presented through a relativity factor x = Y/O. A complete table with the specific processes that influence these indicators is presented in the Appendix. Factor x is applied to understand the impact of the reusable dispenser on the total environmental assessment. Factor x represents the relativity between the impact results of O & Y for Cases 1 & 2 in respect. If x is 1, it means that the impact results are infinitesimally close. The higher or lower it is, the more varying the results.

Table 13 Comparison of the impacts of the Oral-B and the Yaweco dental floss products based on environmental indicators.

Impcat Categories	Oral-B_C1	Yaweco_C1	Oral-B_C2	Yaweco_C2	Relativity Factor x = Y/O [/]	
					Case 1	Case 2
Fine particulate matter formation	0,001	0,0019	0,001	0,004	2,834	3,141
Fossil resource scarcity	0,297	0,1677	0,496	0,542	0,564	1,094
Freshwater ecotoxicity	0,041	0,0399	0,068	0,099	0,984	1,468
Freshwater eutrophication	0,001	0,0003	0,001	0,001	0,404	1,114
Global warming	0,855	0,8539	1,425	2,103	0,999	1,476
Human carcinogenic toxicity	0,057	0,0601	0,095	0,156	1,050	1,640
Human non-carcinogenic toxicity	0,779	0,8991	1,298	2,170	1,155	1,673
Ionizing radiation	0,107	0,0374	0,178	0,194	0,350	1,091
Land use	0,029	0,4916	0,049	0,761	16,780	15,582
Marine ecotoxicity	0,054	0,0521	0,091	0,131	0,958	1,440
Marine eutrophication	0,000	0,0005	0,000	0,001	5,858	5,654
Mineral resource scarcity	0,001	0,0028	0,002	0,005	2,756	3,129
Ozone formation, Human health	0,001	0,0030	0,002	0,006	2,460	2,767
Ozone formation, Terrestrial ecosystems	0,001	0,0031	0,002	0,006	2,422	2,732
Stratospheric ozone depletion	0,000	0,0000	0,000	0,000	8,752	8,336
Terrestrial acidification	0,002	0,0070	0,003	0,012	4,062	4,200
Terrestrial ecotoxicity	0,825	2,0346	1,375	3,628	2,467	2,639
Water consumption	0,012	0,1336	0,020	0,208	11,283	10,560
Average:					3,7	3,9

Figure 7 shows that the average x for Case 1 is higher with an average of 3,7 while the average x for Case 2 is 3,9. This indicates that the refilling of the dispenser does not positively impact the product and that the production of silk cannot be mitigated or compensated for by another process.

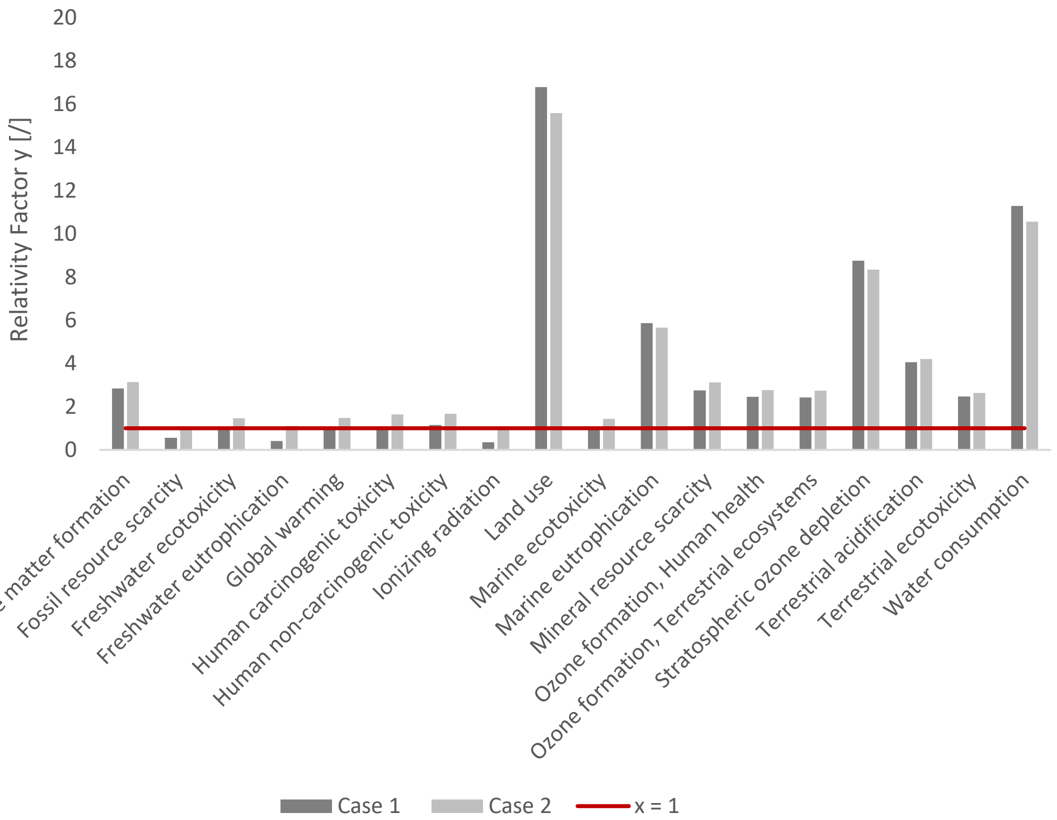

Figure 7 Comparison of the impacts of the Oral-B and the Yaweco dental floss products based on environmental indicators.

Case 3

Considering that the Yaweco dispenser is made out of treated PP and the dental floss is compostable, the product cannot be recycled to the most part. Therefore, Case 3 is only carried out for the Oral-B product, and it showcases the comparison between two different recycling models: the 50:50 model and the avoided impact model. The 50:50 model is in that case equivalent to Oral-B Case 2, where 50% of the recycled waste is credited to the manufacturer. The results of the impact indicators are shown below in Figure 8 (entire product system) and Figure 9 (EoL phase).

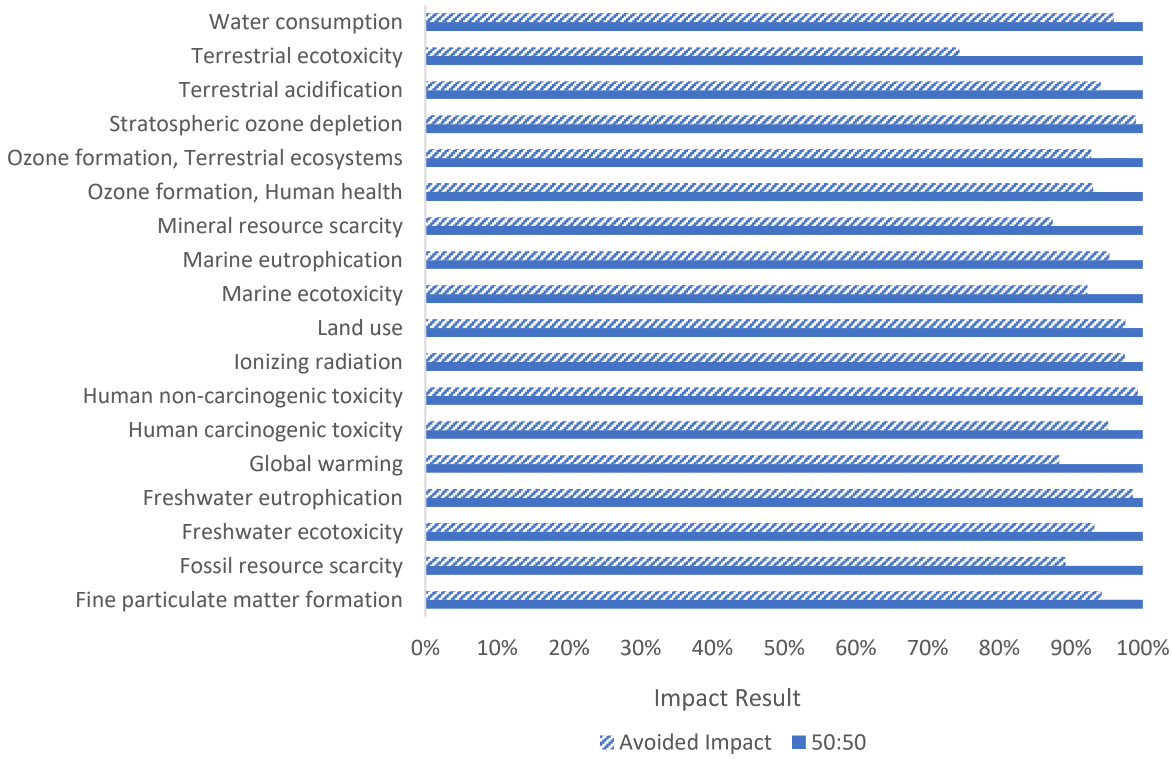

Figure 8 Comparison of the impact indicators for different recycling methods (50:50 & avoided impact) using the entire product system for the Oral-B model.

Figure 8 shows that the application of a different recycling models yields an average of 7% lower impact results in the system, meaning that the difference between the impact results of the total product is considerably small. However, the evaluation of only the EoL phase reveals significant changes between the two recycling models. Since the production of PE and PP for other product systems will be avoided, the impact result is negative, meaning that the avoided impact method can have a positive impact (Figure 9). Although the avoided impact of the waste and the production of the material may be small in the grand scheme of the whole product's lifecycle, it is still relevant enough to show lower impact rates.

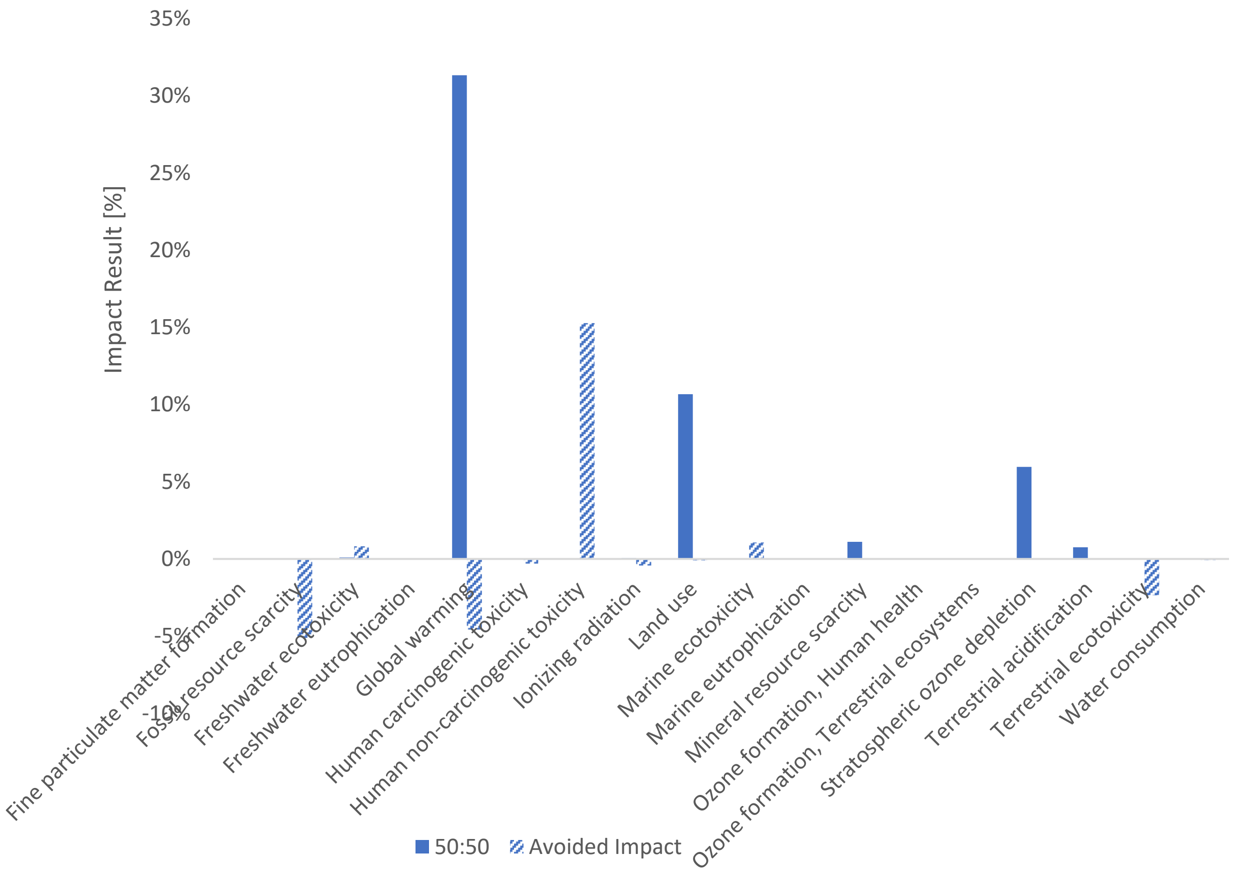

Figure 9 Comparison of the impact indicators for different recycling methods (50:50 & avoided impact) using the EoL phase of the Oral-B model.

As opposed to the Oral-B dental floss, the dispenser of the Yaweco product contains an additive to facilitate decomposition in a sanitary landfill. This, however, makes it difficult to recycle and therefore it does not credit the product anything when using the avoided impact model. Only the paper packaging can be recycled to 70% and used for another production system.

4. Interpretation

A thorough analysis of the impact results based on the different life stages (raw material extraction, production, use, EoL), reveals that the commonality between the two studied products is that one of the primary hotspot for both products lies in the production stage and that the electricity production for both products contributes significantly to the environmental impact. However, based on the above presented data, it is concluded that both products have their different hotspots within the production stage. On the one hand the production of the organic material silk has undeniable impact on all assessed indicators, whereas the production of the synthetic material nylon negatively affects the marine and soil environments and has an overall high global warming potential. This alone is an indicator that the silk dental floss is not sustainable on a large scale. This is also not taking into consideration the potential social impact of the extensive production of silk fibre in India which is likely run at unregulated enterprises and could potentially be run primarily through child labour[21].

In addition, the two products vary greatly in terms of the dispenser. While one is reusable, the other is not. However, the calculated x factor indicates that even after a certain number of reuses, the two

[21] https://www.responsiblesourcingtool.org/commodities/69.pdf

products will not even out in terms of environmental impact. Furthermore, the untreated one-time use PP dispenser gives way to recycling compared to a treated one that must undergo incineration. While in fact the Yaweco dispenser that is treated with a biopolymer can decompose to an extent, it will eventually be incinerated and not recycled. Therefore, in countries like Germany where recycling rate can reach almost 70%[22], it might be useful to produce pure polymer dispenser to facilitate recycling. In other countries, where waste separation is not commonly adapted, a decomposable dispenser would be favourable. For future research, a third alternative such as the assessment of bioplastic-based dental floss made of PLA and stored in refillable glass or stainless container shall be carried out.

This paper focuses not only on the comparison of the two products but also of the change in results when using different models. The data prove that the fraction changed at the EoL does not majorly intervene with the results for each respective indicator. However, obtaining certain waste fractions and recycling them does lower the overall environmental impact of a product. Lastly, it is important to note that these data are closely intertwined with the assumptions, calculations as well as the collected data and the chosen recycling model. Changing any or several of these factors can instigate different results. These uncertainties shall be taken into consideration.

Appendix

The following model (Figure 10) shows the Oral-B product based on an alternative EoL recycling method, namely the avoided impact. Shown in the figure under the EoL stage are the inputs and outputs with the recyclable material marked in grey to showcase that it is avoided waste. The avoided impact recycling model does not only take into account the impact of recycling the product, but it also considers the impacts of the inevitable extraction and production of the new raw materials that are 'avoided' by the production of the secondary raw material. This method can result in an overestimation of the credits that will be assigned to the product or the product manufacturer. Nevertheless, if enough data is available from the supply chain to the manufacturer, the avoided impact method can be applied with more certainty. For the Oral-B dental floss, the PP dispenser is recycled to 70% and therefore PP is used as secondary raw material for another system. With that the production of PP granulate is avoided for said system. The same applies to HDPE and paper in the packaging material.

[22] https://www.eea.europa.eu/data-and-maps/indicators/waste-recycling-1/assessment-1

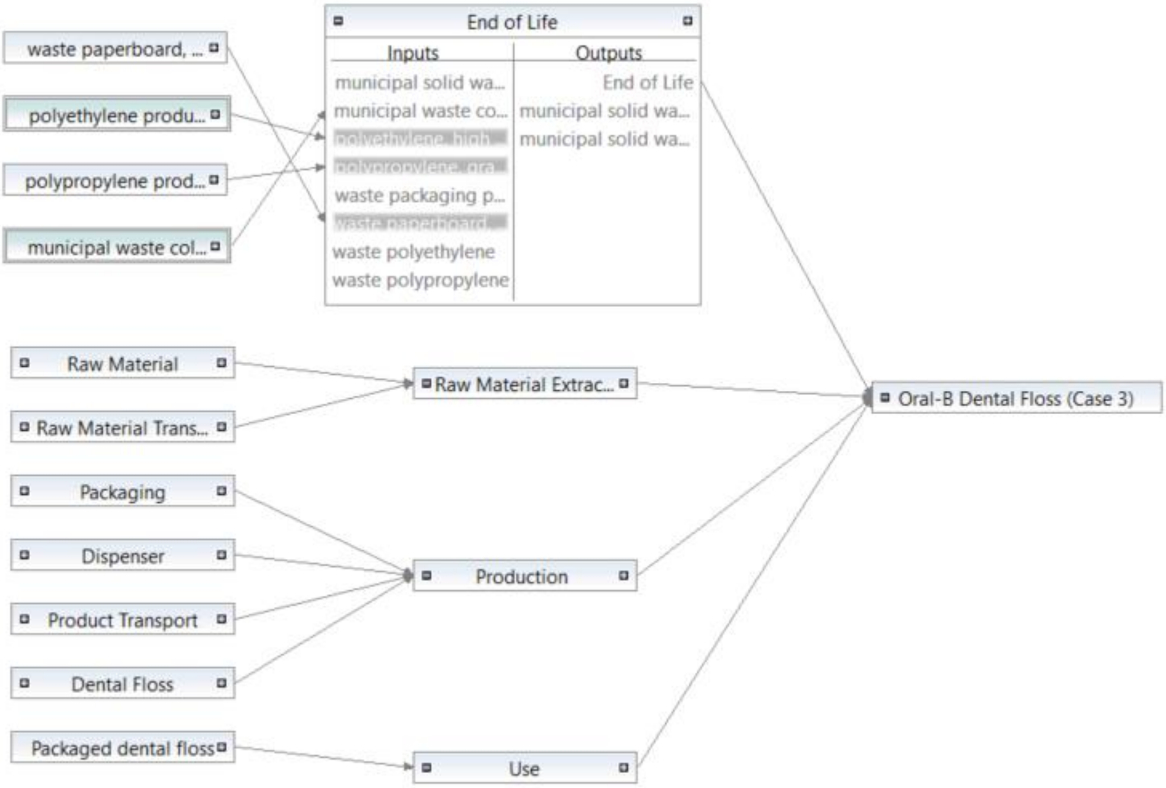

Figure 10 Model graph for the lifecyle of Oral-B dental floss with a variation of the EoL recycling model. Recycling model: avoided impact. Shown in the graph through the grey marked flow(s) at the EoL stage.

Contact

If there are other questions not addressed by this document, or if any further clarifications on any of the points is needed, then please contact us:

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