PEF shampoo screening report in the context of the study into the development of Product Environmental Footprint Category Rules (PEFCR)

14 November 2014 - v.1.2

NOTE: The purpose of this screening study was to support the creation of the 1st draft of the PEFCR. The results presented in this study have not been updated since November 2014. For this reason, some of the information in the screening study may no longer be aligned with the final draft of the PEFCR. **However, the main trends and conclusions of the screening study are still valid.**

Three supporting studies have been realized to further test the application of the PEFCR and to support the writing of the final draft of the PEFCR.

Table of Contents

Executive summary 3
List of figures 5
List of tables 5
Abbreviations and Units 7
1. Introduction 7
2. Goal of the study 7
3. Scope of the screening 8
3.1 Function, functional unit and reference flow 8
3.2 System boundaries and system boundary diagram 8
3.3 Assumptions and value judgments 9
3.4 Treatment of multi-functionality 9
3.5 Information about the data used and data gaps 9
3.6 Impact categories, models and indicators 11
3.7 Normalisation and weighting factors 12
4. Compiling and recording the life cycle inventory analysis 13
4.1 Description and documentation of all unit process data 13
4.2 Data collection procedures 13
4.3 Methodological assumptions used in the screening 13
5. Calculating PEF impact assessment results 19
5.1 Data and indicator results prior to normalisation 19
5.2 Normalised results 29
6. Interpretation 30
6.1 Environmental hotspots 30
6.2 Most relevant processes and life cycle stages 30
6.3 Most relevant impact categories 31
7. Conclusions 31
Bibliographic references 32

Executive summary

The goal of the study presented here is to perform a screening product environmental footprint fully compliant with the PEF requirements in order to identify the hot spots, most relevant and irrelevant life cycle stages and processes and most relevant and irrelevant impact categories, used for the development of the PEFCR. The target audience is mainly anyone interested in completing an environmental study on a shampoo, while respecting the guidelines of the PEFCR.

The study is intended as a preparation in the PEFCR, and the main aim is to identify hotspots, understand data quality requirements, etc. The screening is NOT intended to make statements about the shampoo impacts as such, nor is it intended to be used in the context of comparison or for comparative assertions to be disclosed to the public.

The unit of analysis (the functional unit) considered is as follows:

A hair wash carried out in Europe (EU 28), on average length hair

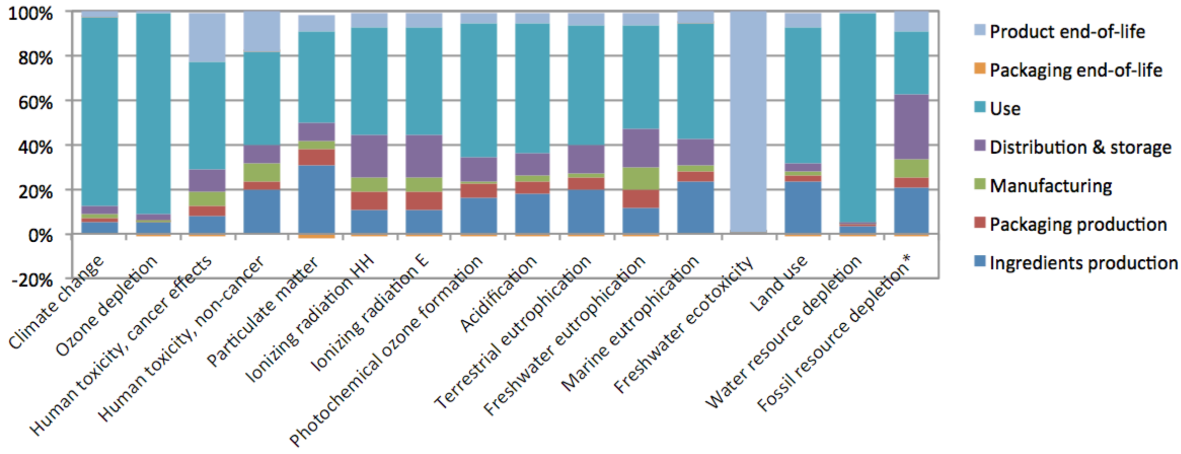
The reference flow considered, i.e., the amount of product needed to provide the defined functions, is 10.46 grams of shampoo (Hall *et al.*, 2011). This amount refers to the average daily use by European consumers but may vary depending on the technology used, such as concentrated or powder product.

The environmental assessment of the shampoo takes into account the life cycle stages shown in Figure 1, with descriptions of what is included in each life cycle stage. Capital goods are excluded from the scope of the study.

Life cycle stage	Description of activities included for each life cycle stage
1 Ingredients production	• Extraction of resources • Pre-processing of all material inputs to the studied product • Transportation from pre-processing facilities to the production facility
2 Packaging production	• Production of raw materials for packaging (plastics, cardboard, etc.) • Packaging manufacturing processes (blow molding, extrusion) • Transportation of packaging to shampoo manufacturing facility
3 Manufacturing	• Energy and water use for shampoo manufacturing • Packaging of the shampoo • Treatment of waste and wastewater • Manufacturing plant infrastructure
4 Product distribution and storage	• Energy inputs for warehouse lighting and heating • Distribution center infrastructure • Transportation from manufacturing plant to point of sale, to consumer's home
5 Use stage	• Energy use during shower • Water use during shower
6 Packaging end-of-life	• Transportation of packaging to treatment facilities • Recycling, incineration, landfilling of packaging
7 Product end-of-life	• Wastewater treatment (including infrastructure and sludge treatment) • Product end-of-life (aquatic environment)

Figure 1. System boundary diagram with the main activities included per life cycle stage.

Figure 2 presents the overall results for the shampoo life cycle. The use stage dominates results or is a significant contributor for all indicators except Freshwater ecotoxicity, which is dominated by product end-of-life. The production of the shampoo ingredients, as well as distribution and storage both contribute for several indicators. Manufacturing, packaging production and packaging end-of-life, relative to the other life cycle stages, do not have a large contribution to the overall results.



** Mineral, fossil, and renewable resource depletion*

Figure 2. Overall results for one shampoo use

Based on the normalisation results, the indicators evaluated as relevant for a shampoo are:

- Climate change
- Water resource depletion
- Mineral and fossil resource depletion
- Freshwater ecotoxicity (subject to the availability of appropriate methodology and data)

The study illustrates how the PEFCR can be used to perform a screening environmental footprint of a shampoo. The results and sensitivity analyses allowed us to evaluate relevant parameters that need to be refined in order to increase the quality of the guidance in the PEFCR. Important points identified are the following:

- The use stage shower water **temperature and quantity** are determined to have a relevant impact on results. Since these values are based on consumer habits, and it is difficult to obtain data on this subject, sensitivity analyses of these parameters should be recommended.
- The **use stage energy mix** is also found to have a relevant impact on results. It is difficult to obtain publicly available data concerning the water heating energy mix and assumptions were made based on the EU-28 heating mix. More effort should be invested in refining and improving the quality of this data.
- **Wastewater treatment efficiency** is found to have a relevant impact on freshwater ecotoxicity results. The PEFCR should investigate the possibility of recommending ingredient-specific and/or WWT technology-specific recommendations for the % removal rate.

List of figures

Figure 1. System boundary diagram with the main activities included per life cycle stage. 3

Figure 2. Overall results for one shampoo use 4

Figure 3. System boundary diagram with the main activities included per life cycle stage. 9

Figure 4. PEF guide end-of-life formula with the terms grouped by life cycle stage (see PEF guide for detailed descriptions of each term used in the equation) 16

Figure 5. Overall results for one shampoo use 20

Figure 6. Detailed results of the shampoo use stage 21

Figure 7. Sensitivity analysis of shampoo use stage, comparison of default energy mix vs. energy mix recommended by BPX 30 standard with French and UCTE grid mix (results shown for use stage only, not entire life cycle). 21

Figure 8. Shower water quantity and temperature sensitivity analysis results for Climate change (results shown for use stage only, not entire life cycle) 22

Figure 9. Shower water quantity and temperature sensitivity analysis results for Water resource depletion (results shown for use stage only, not entire life cycle) 22

Figure 10. Results for shampoo ingredients production 23

Figure 11. Results for shampoo ingredients production without consideration of heavy metals in products derived from palm oil and palm kernel oil (cocamidopropyl betaine and sodium laureth sulfate) 23

Figure 12. Detailed results for Product end-of-life stage 24

Figure 13. Sensitivity analysis results for Product end-of-life, for shower water quantities of 7, 15 and 27 litres (results shown for Product end-of-life stage only, not entire life cycle) 25

Figure 14. Sensitivity analysis results (shown for the life cycle) for different wastewater treatment efficiencies, 0%, 50%, 90% (default) and 100% 26

List of tables

Table 1. Key information regarding the unit of analysis 8

Table 2. ecoinvent processes for which allocation was necessary and corresponding allocation approach 9

Table 3. Qualitative assessment of data, per life cycle stage 10

Table 4. Recommended normalisation factors for EU 27 (2010) based on domestic inventory 12

Table 5. Conversion factors used to determine the indicators that dominate for each area of protection (Human health, Ecosystem quality, Resources) 13

Table 6. Modeling of shampoo ingredients based on ecoinvent database 14

Table 7. Packaging considered for a 250 ml shampoo bottle 14

Table 8. List of manufacturing stage data per functional unit, based on average data from four companies 15

Table 9. Assumptions related to use stage 16

Table 10. End-of-life treatment assumptions for packaging 17

Table 11. Freshwater ecotoxicity characterization factors of shampoo ingredients emitted to nature 17

Table 12. Comparison of characterization factors for certain substances 18

Table 13. Human toxicity characterization factors of shampoo ingredients emitted to nature 18

Table 14. Wastewater treatment % removal rates per substance 19

Table 15. Overall results (absolute) for one shampoo use 20

Table 16. Summary of freshwater ecotoxicity impacts of shampoo ingredients emitted to nature ... 24

Table 17. Freshwater ecotoxicity contribution using alternate characterization factors (see column 2 of Table 12) 25

Table 18. Main contributors for indicators Human toxicity, non-cancer effects, Freshwater eutrophication, and Mineral, fossil and renewable resource depletion for two infrastructure processes 26

Table 19. Sensitivity analysis of manufacturing plant and distribution center infrastructure, results shown for the entire life cycle 27

Table 20. Summary of sensitivity analyses and conclusions obtained 28

Table 21. Summary of results using recommended normalisation factors for EU 27 (2010) based on domestic inventory, to identify relevant indicators for shampoo 29

Table 22. Summary of results, using conversion factors to identify relevant indicators for shampoo 30

Abbreviations and Units

CF	Characterization factor
CFC	Chlorofluorocarbons
CTUe	PAF.m3.d/kg emitted
CTUh	cases/kg emitted
EC	European Commission
EU-28	European Union 28 member states
JRC	Joint Research Center
kBe	kiloBecquerel
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
PCR	Product Category Rules
PE	Polyethylene
PEF	Product Environmental Footprint
PEFCR	Product Environmental Footprint Category Rules
PET	Polyethylene terephthalate
PP	Polypropylene
U235	Uranium-235
WWT	Wastewater treatment

1. Introduction

The following study presents a screening product environmental footprint (PEF) of a shampoo, as defined by the CPA code (Statistical Classification of Products by Activity in the European Economic Community, 2008 version): C 20.42.16.30 “Shampoos”.

2. Goal of the study

The goal of the study presented here is to perform a screening product environmental footprint fully compliant with the PEF requirements in order to identify the following key information:

- Most relevant life cycle stages
- Most relevant processes;
- Preliminary indication about the most relevant life cycle impact categories
- Data quality needs
- Preliminary indication about the definition of the benchmark for the product category/sub-categories in scope

The target audience is mainly anyone interested in completing an environmental study on a shampoo, while respecting the guidelines of the PEFCR.

The screening study is NOT intended to make statements about the shampoo impacts as such, nor is it intended to be used in the context of comparison or for comparative assertions to be disclosed to the public.

The main limitations of the study lie in the uncertainty of certain modelling parameters that were found to have a relevant impact on results. The parameters identified are: definition of energy mix to heat water, shower water quantity and temperature, wastewater treatment plant connectivity and wastewater treatment plant % removal rate.

3. Scope of the screening

3.1 Function, functional unit and reference flow

The unit of analysis (functional unit) considered is as follows:

A hair wash carried out in Europe (EU 28), on average length hair

The reference flow considered, i.e., the amount of product needed to provide the defined functions, is 10.46 grams of shampoo (Hall *et al*., 2011). This amount refers to the average daily use by European consumers but may vary depending on the technology used, such as concentrated or powder product.

As the shampoo may have an additional function (e.g. anti-dandruff, sensitive scalp, etc.), this additional function must be specified at the end of the unit of analysis defined above. If the shampoo does not have any additional function, the original unit of analysis only needs to be specified. Additional functions may include:

- Hair conditioning (for damaged hair)
- Anti-dandruff activity
- Protection of sensitive target groups (children, sensitive scalp)

Of these functions, five shampoos categories can be defined which provide to the consumer a specific service. The environmental footprint must be compared only between products from the same category:

1. Hair cleansing
2. Hair cleansing and hair conditioning
3. Hair cleansing and anti-dandruff activity
4. Hair cleansing and hair conditioning and anti-dandruff activity
5. Hair cleansing and protection of sensitive target groups (children, sensitive scalp)

Additional information on the unit of analysis is described in Table 1.

Table 1. Key information regarding the unit of analysis

Aspect	Detail
[WHAT]	Shampoo
[HOW MUCH]	A 10.46 gram dose of shampoo
[HOW WELL]	Basic shampoo for normal hair and including additional functions
[HOW LONG]	One hair wash
[CPA/NACE code]	20.42.16.30

3.2 System boundaries and system boundary diagram

The environmental assessment of the shampoo takes into account the life cycle stages shown in Figure 3, with descriptions of what is to be included in each life cycle stage.

Life cycle stage	Description of activities included for each life cycle stage
1 Ingredients production	• Extraction of resources • Pre-processing of all material inputs to the studied product • Transportation from pre-processing facilities to the production facility
2 Packaging production	• Production of raw materials for packaging (plastics, cardboard, etc.) • Packaging manufacturing processes (blow molding, extrusion) • Transportation of packaging to shampoo manufacturing facility
3 Manufacturing	• Energy and water use for shampoo manufacturing • Packaging of the shampoo • Treatment of waste and wastewater • Manufacturing plant infrastructure
4 Product distribution and storage	• Energy inputs for warehouse lighting and heating • Distribution center infrastructure • Transportation from manufacturing plant to point of sale, to consumer's home
5 Use stage	• Energy use during shower • Water use during shower
6 Packaging end-of-life	• Transportation of packaging to treatment facilities • Recycling, incineration, landfilling of packaging
7 Product end-of-life	• Wastewater treatment (including infrastructure and sludge treatment) • Product end-of-life (aquatic environment)

Figure 3. System boundary diagram with the main activities included per life cycle stage.

3.3 Assumptions and value judgments

See section 4.3 for a description of all assumptions made for this study.

3.4 Treatment of multi-functionality

The allocation method chosen is by default the allocation method in ecoinvent, which subdivides multi-product activities by allocation, based on physical properties, economic, mass or other properties (Frischknecht, 2007). By-products of treatment processes are considered to be part of the waste-producing system and are allocated together (ecoinvent website). With respect to the shampoo, no allocation method is recommended between the different possible functions defined in the PEFCR.

Table 2 lists the processes for which allocation was necessary, as well as the description of the allocation method (Zah, 2007).

Table 2. ecoinvent processes for which allocation was necessary and corresponding allocation approach

Process	ecoinvent allocation approach
Fatty alcohol, petrochemical, at plant/RER Fatty alcohol, from coconut oil, at plant/RER Fatty alcohol, from palm oil, at plant/RER Fatty alcohol, from palm kernel oil, at plant/RER	Allocations in multi-output processes made using the relative mass outputs of products.

3.5 Information about the data used and data gaps

Table 3 presents a list of the data used in the study, per life cycle stage as well as a qualitative assessment of the data.

Table 3. Qualitative assessment of data, per life cycle stage

Raw ingredients		
Ingredient	**Source: ecoinvent v2.2 dataset unless otherwise specified**	**Qualitative data assessment**
Sodium laureth sulfate	Fatty alcohol sulfate, mix, at plant/RER	Fair
Cocamidopropyl betaine	25% Fatty alcohol, petrochemical, at plant/RER 25% Fatty alcohol, from coconut oil, at plant/RER 25% Fatty alcohol, from palm oil, at plant/RER 25% Fatty alcohol, from palm kernel oil, at plant/RER	Fair
Cocamide MEA	50% monoethanolamine, at plant/RER 50% fatty acids , from vegetarian oil, at plant/RER	Fair
Propylene glycol	Propylene glycol, liquid, at plant/RER	Good
Sodium benzoate	Sodium borates, at plant/US	Fair
Chlorhydric acid	Hydrochloric acid, 30% in H2O, at plant/RER	Good
Fragrance	Chemicals organic, at plant/GLO	Fair
Dimethicone	Silicone product, at plant/RER	Fair
Polyquaternium-10	Chemicals organic, at plant/GLO	Poor
Glycol distearate	Ethylene glycol, at plant/RER	Fair
Water	tap water, at user/RER	Good
Packaging production		
Packaging type	**Source: ecoinvent v2.2 dataset unless otherwise specified**	
PE bottle – virgin	Polyethylene, HDPE, granulate, at plant/RER Blow moulding/RER	Good
PE bottle – recycled material	Recycled HDPE, based on Franklin et al. 2010	Good
PP bottle cap - virgin	Polypropylene, granulate, at plant/RER Blow moulding/RER	Good
PP bottle cap – recycled material	Recycled HDPE, based on Franklin et al. 2010	Fair (PE proxy for PP)
PE labels/stickers	Polyethylene, LDPE, granulate, at plant/RER Extrusion, plastic film/RER	Good
Cardboard box	50% Corrugated board, fresh fibre, single wall, at plant/RER 50% Corrugated board, recycling fibre, single wall, at plant/RER	Good
Manufacturing		
Flow	**Source: ecoinvent v2.2 dataset unless otherwise specified**	
Electricity	Electricity, low voltage, production UCTE, at grid/UCTE	Fair
Natural gas	Natural gas, burned in industrial furnace >100kW/RER	Fair
Water use	Tap water, at user/RER	Fair
Wastewater discharged	Treatment, sewage, to wastewater treatment, class 3/CH	
Distribution		
Flow	**Source: ecoinvent v2.2 dataset unless otherwise specified**	
Transport from manufacturing to point of sale	Transport, lorry 20-28t, fleet average/CH	Good
Transport from point of sale to home	Transport, passenger car/RER	Good
Distribution center energy consumption	Electricity, low voltage, production UCTE, at grid/UCTE	Good
Shop energy consumption	Electricity, low voltage, production UCTE, at grid/UCTE	Good
Use stage		
Flow	**Source: ecoinvent v2.2 dataset unless otherwise specified**	
Shower water heating (natural gas)	Heat, natural gas, at boiler modulating <100kW/RER	Poor

Shower water heating (light fuel oil)	Heat, light fuel oil, at boiler 100kW, non-modulating/CH	Poor
Shower water	Tap water, at user/RER	Poor
Product end-of-life		
Flow/ingredients	**Source: ecoinvent v2.2 dataset unless otherwise specified**	
Sodium laureth sulfate	sodium laureth sulfate (USEtox interim)	Fair
Cocamidopropyl betaine	cocamidopropyl betaine (Cosmede)	Fair
Cocamide MEA	50% Monoethanolamine (USEtox interim) 50% Fatty acids, c9-13-neo- (USEtox interim)	Fair
Propylene glycol	Propylene glycol (USEtox default)	Fair
Sodium benzoate	Sodium benzoate (USEtox interim)	Fair
Hydrochloric acid	not characterized	Poor
Dimethicone	dimethicone (Cosmede)	Fair
Polyquaternium-10	Quaternium-18 (Cosmede)	Fair
Glycol distearate	glycol distearate (Cosmede)	Fair
alpha-hexyl cinnamaldehyde (fragrance)	alpha-hexyl cinnamaldehyde (Cosmede)	Good
beta-pinene (fragrance)	beta-pinene (USetox interim)	Good
Dihydromyrcenol (fragrance)	Dihydromyrcene (Cosmede)	Fair
Hexyl salicylate (fragrance)	Hexyl salicylate (Cosmede)	Good
Patchouli oil (fragrance)	Patchouli oil (Cosmede)	Good
Sewage treatment energy consumption/ infrastructure	Treatment, sewage, unpolluted, from residence, to wastewater treatment, class 2/CH	Good
Sludge incineration	Process-specific burdens, municipal waste incineration/CH	Fair
Slag treatment	Process-specific burdens, slag compartment/CH	
Packaging end-of-life		
Flow/ingredients	**Source: ecoinvent v2.2 dataset unless otherwise specified**	
Incineration of different materials (PE, PP, cardboard)	Disposal, polyethylene, 0.4% water, to municipal incineration/CH Disposal, polypropylene, 15.9% water, to municipal incineration/CH Disposal, packaging cardboard, 19.6% water, to municipal incineration/CH	Good
Landfilling of different materials (PE, PP, cardboard)	Disposal, polyethylene, 0.4% water, to sanitary landfill/CH Disposal, polypropylene, 15.9% water, to sanitary landfill/CH Disposal, packaging cardboard, 19.6% water, to sanitary landfill/CH	Good
Energy recovery from incineration (as heat)	Heat, light fuel oil, at boiler 100kW, non-modulating/CH	Good
Energy recovery from incineration (at electricity)	Electricity, medium voltage, production UCTE, at grid/UCTE	Good

3.6 Impact categories, models and indicators

The default 15 EF impact category indicators are used, from the PEF recommended method.

- Climate change
- Ozone depletion
- Human toxicity, cancer effects
- Human toxicity, non-cancer effects
- Particulate matter

- Ionizing radiation (Human health)
- Ionizing radiation (Ecosystem quality)
- Photochemical ozone formation
- Acidification
- Terrestrial eutrophication
- Freshwater eutrophication
- Marine eutrophication
- Freshwater ecotoxicity
- Land use
- Water resource depletion
- Mineral, fossil and renewable resource depletion

3.7 Normalisation and weighting factors

Table 4 lists the recommended normalisation factors for EU-27 based on domestic inventory. Table 5 lists the Quantis proposed conversion factors and methods used to determine the indicators that dominate for each area of protection (Human health, Ecosystem quality, Resources). Both normalisation methods are recommended, as they both have advantages and disadvantages, in order to identify the most relevant indicators for a shampoo.

Table 4. Recommended normalisation factors for EU 27 (2010) based on domestic inventory

Impact category	Unit	DOMESTIC	Normalisation Factor per Person (domestic)	Overall Robustness
Climate change	kg CO_2 eq	4.60E+12	9.19E+03	Very High
Ozone depletion	kg CFC-11 eq	1.08E+07	2.16E-02	Medium
Human toxicity- cancer effect	CTUh	1.84E+04	3.68E-05	Low
Human toxicity- non cancer effect	CTUh	2.66E+05	5.32E-04	Low
Acidification	mol H^+ eq	2.36E+10	4.72E+01	High
Particulate matter	kg $PM_{2.5}$ eq	2.30E+09	4.60E+00	Very High
Freshwater Ecotoxicity	CTUe	4.36E+12	8.71E+03	Low
Ionizing radiations	kBq U_{235} eq	5.64E+11	1.13E+03	Medium
Photochemical ozone formation	kg NMVOC eq	1.58E+10	3.16E+01	Medium
Terrestrial eutrophication	mol N eq	8.76E+10	1.75E+02	Medium
Freshwater eutrophication	kg P eq	7.41E+08	1.48E+00	Medium to Low
Marine eutrophication	kg N eq	8.44E+09	1.69E+01	Medium to Low
Land use	kg C deficit	3.41E+14	6.82E+05	Medium
Resource depletion water*	m^3 water eq	4.06E+10	8.11E+01	Medium to Low
Mineral, fossil & renewable resource depletion	kg Sb eq	5.03E+07	1.01E-01	Medium

Table 5. Conversion factors used to determine the indicators that dominate for each area of protection (Human health, Ecosystem quality, Resources)

	Indicator (ILCD Midpoint)	Conversion factor	Units	Reference
Human health	Climate change (HH)	2.55E-07	DALY/kg CO2-eq	de Schryver et al.
	Ozone depletion	1.05E-03	DALY/kg CFC-11 eq	Goedkoop et al. 2001*
	Human toxicity, cancer effects	13	DALY/CTUh	Humbert et al. 2012
	Human toxicity, n-c effects	1.3	DALY/CTUh	Humbert et al. 2012
	Particulate matter	1.80E-03	DALY/kg PM2.5 eq	Humbert 2009
	Ionizing radiation (HH)	2.10E-08	DALY/kg U235 eq	ILCD, IMPACT 2002+
	Photochemical ozone formation	1.28E-06	DALY/kg NMVOC eq	Goedkoop et al. 2001*
	Water resource depletion (HH)	n/a	DALY/m3-eq	Pfister et al. 2009
Ecosystem quality	Climate change (EQ)	0.266	PDF.m2.y/kg CO2-eq	de Schryver et al.
	Ionizing radiation (EQ)	5.48E-04	PDF.m2.y/CTUe	Humbert et al. 2012
	Acidification	6.73E-03	PDF.m2.y/molc H+ eq	ILCD, IMPACT 2002+
	Terrestrial eutrophication	1.15	PDF.m2.y/molc N eq	ILCD, IMPACT 2002+
	Freshwater eutrophication	34.9	PDF.m2.y/kg P eq	Humbert et al. 2012
	Marine eutrophication	12.5	PDF.m2.y/kg N eq	Bullet et al. 2013
	Freshwater ecotoxicity	5.48E-04	PDF.m2.y/CTUe	Humbert et al. 2012
	Land use	3.35E-03	PDF.m2.y/kg C deficit	Ecoindicator99
	Water resource depletion (EQ)	n/a	PDF.m2.y/m3-eq	Pfister et al. 2009
	Fossil resource depletion	1	kg Sb eq/kg Sb eq	

*Goedkoop et al. 2001, Jolliet et al. 2003, Humbert et al. 2012

4. Compiling and recording the life cycle inventory analysis

4.1 Description and documentation of all unit process data

See section 3.5 for a qualitative assessment of data, per life cycle stage as well as the ecoinvent datasets used to model the different unit processes. See section 4.3 for a description of all assumptions made for this screening study.

4.2 Data collection procedures

See section 4.3 for the assumptions related to each life cycle stage, the data used and how data gaps were identified and treated. The main source of secondary data is ecoinvent v2.2. Note that this is not recommended by the European Commission since the ecoinvent database is not free of charge.

4.3 Methodological assumptions used in the screening

The following limitations related to the shampoo in the screening study are identified below and the assumptions necessary to overcome these limitations.

- **Assumptions related to ingredients production**

For many shampoo ingredients, a suitable equivalent was not available in the ecoinvent database. In this case, a proxy was chosen. Table 6 summarizes common shampoo ingredients and the corresponding ecoinvent dataset selected.

Table 6. Modeling of shampoo ingredients based on ecoinvent database

Ingredient	Modeling (ecoinvent dataset)
Sodium laureth sulfate	Fatty alcohol sulphate, mix, at plant/RER
Cocamidopropyl betaine	25% Fatty alcohol, petrochemical, at plant/RER 25% Fatty alcohol, from coconut oil, at plant/RER 25% Fatty alcohol, from palm oil, at plant/RER 25% Fatty alcohol, from palm kernel oil, at plant/RER
Cocamide MEA	50% Monoethanolamine, at plant/RER 50% Fatty acids, from vegetarian oil, at plant/RER
Propylene glycol	Propylene glycol, liquid, at plant/RER
Sodium benzoate	Sodium borates, at plant/US
Chlorhydric acid	Hydrochloric acid, 30% in H2O, at plant/RER
Fragrance	Chemicals organic, at plant/GLO
Dimethicone	Silicone product, at plant/RER
Polyquaternium-10	Chemicals organic, at plant/GLO
Glycol distearate	Ethylene glycol, at plant/RER
Water	Tap water, at user/RER

A distance of 500 km by truck was assumed for the upstream transportation of raw ingredients. Of the transported weight, 20% is assumed to be packaging (Quantis internal guidelines).

The primary, secondary and tertiary packaging types and quantities are listed in Table 7 (Henkel, 2008). Also provided is the recycled material content of the packaging. A distance of 500 km by truck was assumed for the upstream transportation of all packaging.

Table 7. Packaging considered for a 250 ml shampoo bottle

Component	Material	% Recycled material	Composition (wt%)	Quantity (g per bottle*)
Primary packaging				
Bottle	Polyethylene (PE)	20	73	21
Cap	Polypropylene (PP)	20	24	6.9
Label	Printed polyethylene (PE)	0	3	0.95
Secondary packaging				
Box	Cardboard	50	98	8.8
Foil and label	Polypropylene (PP)	0	2	0.17
Tertiary packaging				
Pallet	Wood	0	34	0.37
Anti-slip sheets	Paper	0	39	0.42
Foil	Polypropylene (PP)	0	27	0.30

* one 250 ml shampoo bottle

- **Assumptions related to manufacturing stage**

Average manufacturing data (energy and water use) were used, listed in Table 8, based on four different companies located in Germany, Italy, United Kingdom and United States of America. Data from three of the four companies are specific to shampoo manufacturing while data from the fourth company are for the production of shampoo, conditioner, essential oils, creams and lotions. The UCTE electricity mix is used. For water use, 95% of water withdrawn is assumed discharged to wastewater treatment, while the remaining 5% is evaporated (i.e. consumed). For the manufacturing plant infrastructure, no primary data were available, therefore the plant was assumed to have similar characteristics to that of the ecoinvent process *Chemical plant, organics/RER* and this can be used as a proxy, scaled by the shampoo production (i.e. for 1 kg soap, 4E-10 chemical plant, therefore for 10.46 grams of shampoo, 4.18E-12 chemical plant).

Table 8. List of manufacturing stage data per functional unit, based on average data from four companies

	Value	Units	Comment
Electricity consumption	4.75E-3	MJ/FU	
Natural gas consumption	0.0075	MJ/FU	
Oil consumption	1.0E-6	MJ/FU	
Water use	1.55E-5	m3/FU	
Wastewater treatment	1.47E-5	m3/FU	5% of water consumed, 95% to wastewater treatment

- **Assumptions related to product distribution and storage**

A distance of 500 km was considered from the manufacturing plant to the point of sale (assuming European average distribution scenario). It is assumed that the product is purchased by the consumer and is transported by car (1 person per car), considering a distance of 4 km from the point of purchase to the consumer's home with a 5% allocation of the car trip to the product.

A value of 6 kWh/m3.y is used (Humbert et al. 2009) for electricity consumption at the distribution centre; 1 shampoo bottle is assumed to occupy a volume of 2 cm x 7 cm x 20 cm (280 cm^3) and stored for a period of one month. Electricity consumption at the point of sale is assumed to be 700 kWh/m2.y (European Commission, 2013a), assuming 1 bottle occupies an area of 2 cm x 7 cm (14 cm^2) and is stored for a period of one month. The UCTE electricity mix is used.

The distribution centre was assumed to be a *Building, multi-storey/RER (m3)*. A bottle of shampoo was assumed to occupy a volume of 10 times that of the bottle volume (2 cm x 7 cm x 15 cm), is stored for 1 month and the building has a lifetime of 80 years (ecoinvent).

- **Assumptions related to use stage**

According to AFNOR (2011), "*consumers have very different usage patterns, making it difficult to make generalizations. There is no publically available statistics study establishing a relative consensus on this hair washing stage that could serve as a basis for setting hypotheses. (…) The choice of parameter values has a huge influence on the scale of the results of the cradle-to-grave life cycle analysis, but does not at all comprise cross-comparison between the shampoos. The set of hypotheses for this stage is actually considered as identical, whatever the shampoo studied in the pilot-project. It thus follows that the use stage will intrinsically have exactly the same environmental impact in absolute terms (…)*".

The use stage assumptions listed in Table 9. Tap water infrastructure is included in the modelling (supply network, treatment of potable water, etc.). Note that according to Eurostat, little electricity is used for heating water[1], therefore the energy mix is assumed to be natural gas (87%) and fuel oil (13%) (IEA, 2011).

[1] Source: http://appsso.eurostat.ec.europa.eu/nui/submitViewTableAction.do

Table 9. Assumptions related to use stage

Assumption	Value	Unit*	Comment
Water used per hair wash	15	litre	
Energy used for heating the water per hair wash	1.6	MJ	From 15°C to 38°C, assume a 90 % energy efficiency for heating systems
Energy mix for heating the water			
Electricity	0	%	Eurostat 2012
Natural gas	87	%	IEA 2011, EU-27
Heating fuel oil	13	%	IEA 2011, EU-27

* per unit of analysis

- **Assumptions related to Packaging end-of-life**

Packaging end-of-life is modelled according to recommendations provided by the European Commission to deal with multi-functionality in end-of-life situations (European Commission, 2013). The excel file named "RecyclingFormula-v1-EFPilot-ems24Jan2014.xls" (sent by e-mail on 29th January 2014) is considered, which describes the 50:50 end-of-life formula. Figure 4 illustrates which elements of the formula are to be considered within the life cycle stages Packaging production and Packaging end-of-life.

$$\underbrace{\left(1-\frac{R_1}{2}\right)\times E_V+\frac{R_1}{2}\times E_{recycled}}_{\text{Packaging production}}\underbrace{+\frac{R_2}{2}\times\left(E_{recyclingEoL}-E^*_V\times\frac{Q_S}{Q_P}\right)+R_3\times}_{\text{Packaging end-of-life}}$$

$$\underbrace{\left(E_{ER}-LHV\times X_{ER,heat}\times E_{SE,heat}-LHV\times X_{ER,elec}\times E_{SE,elec}\right)+\left(1-\frac{R_2}{2}-R_3\right)E_D}_{\text{Packaging end-of-life}}\underbrace{-\frac{R_1}{2}\times E^*_D}_{\text{Packaging production}}$$

Figure 4. PEF guide end-of-life formula with the terms grouped by life cycle stage (see PEF guide for detailed descriptions of each term used in the equation)

Waste treatment at the end-of-life of the pallet is considered to be negligible and can be excluded from the system. All packaging waste not recycled can be assumed incinerated or landfilled according to the municipal solid waste treatment rates of the corresponding market. For EU-28, 38% of municipal solid waste is incinerated and 62% is landfilled (Eurostat 2011). Heat recovery is assumed for incineration, with recovery rates of 10% for electricity and 20% for heat (Quantis internal guidelines). The electricity recovery is assumed to offset the UCTE grid mix and the heat recovery is assumed to offset light fuel oil. These assumptions should be adapted to the local context if possible.

Table 10 summarizes the packaging end-of-life assumptions.

Table 10. End-of-life treatment assumptions for packaging

Component	Material	Recycling rate at EoL (%)[1]	% incinerated (of non recycled)	% landfilled (of non recycled)
Primary packaging				
Bottle	Polyethylene (PE)	34.3%	38%	62%
Cap	Polypropylene (PP)	34.3%	38%	62%
Label	Polyethylene (PE)	34.3%	38%	62%
Secondary packaging				
Box	Cardboard	83%	38%	62%
Foil and label	Polypropylene (PP)	0%	38%	62%
Tertiary packaging				
Pallet	Wood	50 reuses	excluded	excluded
Anti-slip sheets	Paper	0%	38%	62%
Foil	Polypropylene (PP)	0%	38%	62%

[1] Source of recycling rates: Eurostat 2011

- **Assumptions related to Product end-of-life**

The scope of the environmental information is the use of shampoo distributed on the European market, and therefore product end-of-life modelling must represent an average situation in Europe.

The composition of the fragrance is based on five substances, 20% alpha-hexyl cinnamaldehyde, 10% beta-pinene, 50% dihydromyrcenol, 15% hexyl salicylate, 5% patchouli oil. The substances are based on the IFRM study (IFRM, 2013) and the quantities are based on a consultation among the Cosmetics Europe task force.

Table 11 summarizes the characterization factors and data sources for the Freshwater ecotoxicity indicator for the different shampoo substances at the product end-of-life. If USEtox characterization factors were available, these were used in priority. Otherwise, the Cosmede database was used, from the Environmental Footprinting with USEtox website (http://usetox.tools4env.com/).

Table 11. Freshwater ecotoxicity characterization factors of shampoo ingredients emitted to nature

Substance emitted	Ecotoxicity (CTUe/kg)	Source
Sodium laureth sulfate	12081	USEtox interim
Cocamidopropyl betaine	783	Cosmede
Cocamide MEA (monoethanolamine)	2.8E-4	USEtox
Cocamide MEA (Fatty acids, C9-13-neo)	2.9E-2	USEtox interim
Propylene glycol	9.2E-1	USEtox recommended
Sodium benzoate	4.9E-11	USEtox interim
Hydrochloric acid	not modelled	n/a
Dimethicone	5.3	Cosmede
Polyquaternium-10[1]	42146	Cosmede
Glycol distearate	4.56E-6	Cosmede
alpha-hexyl cinnamaldehyde (fragrance)	1.57E5	Cosmede
beta-pinene (fragrance)	4.2E3	USEtox interim
Dihydromyrcenol[2] (fragrance)	2.36E4	Cosmede
Hexyl salicylate (fragrance)	6.09E3	Cosmede
Patchouli oil (fragrance)	1.58E2	Cosmede

[1] Quaternium-18 used as a proxy for polyquaternium-10
[2] Dihydromyrcene is used as a proxy for dihydromyrcenol

Note that alternate characterization factors are available for sodium laureth sulfate, cocamidopropyl betaine, dimethicone, polyquaternium-10 and glycol distearate. Table 12 compares the different characterization factors and sources of data for these five substances. This comparison illustrates that significant differences in characterization factors may exist, depending on the data source.

Table 12. Comparison of characterization factors for certain substances

Substance	Ecotoxicity (CTUe/kg)	
	Value used	Alternate value
Sodium laureth sulfate	12081 (USEtox)	804 (Cosmede)
Cocamidopropyl betaine	783 (Cosmede)	4600 (custom[2])
Dimethicone	5.3 (Cosmede)	0.091 (custom)
Polyquaternium-10	42146[1] (Cosmede)	158.44 (custom)
Glycol distearate	4.56E-6 (Cosmede)	1.29E-4 (custom)
beta-pinene (fragrance)	4.2E3 (USEtox)	82.5 (Cosmede)

[1]Quaternium-18 used as a proxy for polyquaternium-10
[2]Quantis internal database

Table 13 summarizes the characterization factors used for the human toxicity indicator, for both cancer and non-cancer effects. If a value of "n/a" is indicated in the table, this means that no data was available in the USEtox, Cosmede or Quantis internal custom calculated database and thus the value used in the model is 0. Note that for the Human toxicity indicator, the characterization factors take into account impacts related to the emission of the substance to nature; they do not take into account human toxicity impacts related to the substance coming into contact with the user's skin during showering. Consumer safety is outside of the scope and validity range of the USEtox model and the PEFCR. This type of impact (ingestion or direct update of a substance) is currently being studied at the University of Michigan by Professor O. Jolliet[2] and once characterization factors are developed, may be included in this PEFCR at a later date.

Table 13. Human toxicity characterization factors of shampoo ingredients emitted to nature

Substance emitted	Human toxicity, cancer (CTUh/kg)	Human toxicity, non-cancer (CTUh/kg)	Source
Sodium laureth sulfate	n/a	n/a	n/a
Cocamidopropyl betaine	n/a	2.85E-7	custom
Cocamide MEA (monoethanolamine)	n/a	n/a	n/a
Cocamide MEA (Fatty acids, C9-13-neo)	n/a	n/a	n/a
Propylene glycol	n/a	n/a	n/a
Sodium benzoate	n/a	n/a	n/a
Hydrochloric acid	n/a	n/a	n/a
Dimethicone	n/a	2.36E-6	custom
Polyquaternium-10[1]	n/a	2.26E-8	custom
Glycol distearate	n/a	5.84E-9	custom
alpha-hexyl cinnamaldehyde (fragrance)	n/a	n/a	n/a
beta-pinene (fragrance)	n/a	n/a	n/a
Dihydromyrcenol[2] (fragrance)	n/a	n/a	n/a
Hexyl salicylate (fragrance)	n/a	n/a	n/a
Patchouli oil (fragrance)	n/a	n/a	n/a

n/a: data not available in USEtox, Cosmede or Quantis internal custom calculated database. Value used in model is 0.

[2] http://www.sph.umich.edu/iscr/faculty/profile.cfm?uniqname=ojolliet

After use in the shower, a part of the product ingredients is assumed to go to nature and the rest to wastewater treatment. The ultimate fate of the shampoo end-of-life is calculated based on the following equation:

$$\text{Fate} = \text{substance} \times [(1 - \text{HH connectivity}) + \text{HH connectivity} \times (1 - \text{WWT efficiency})]$$

where, fate = the fate of the substance in the environment (grams)
substance = the substance that goes down the shower drain (grams)
HH connectivity = household connectivity
WWT efficiency = wastewater treatment plant efficiency

A household connectivity of 85% is assumed (OECD). The wastewater treatment plant is assumed to have a default removal rate of 90% for all substances, meaning 10% of the substance entering the wastewater treatment plant is discharged to nature (Hera, 2004), unless a substance specific removal rate is known. Table 14 lists the % removal rates per substance.

Table 14. Wastewater treatment % removal rates per substance

Substance	WWT % removal rate	Source
Sodium laureth sulfate	90%	Hera, 2004 (default)
Cocamidopropyl betaine	90%	Hera, 2004 (default)
Cocamide MEA (monoethanolamine)	90%	Hera, 2004 (default)
Cocamide MEA (Fatty acids, C9-13-neo)	90%	Hera, 2004 (default)
Propylene glycol	90%	Hera, 2004 (default)
Sodium benzoate	90%	Hera, 2004 (default)
Hydrochloric acid	90%	Hera, 2004 (default)
Dimethicone	90%	Hera, 2004 (default)
Polyquaternium-10	90%	Hera, 2004 (default)
Glycol distearate	90%	Hera, 2004 (default)
alpha-hexyl cinnamaldehyde (fragrance)	99.9% [1]	Klaschka et al. 2013
beta-pinene (fragrance)	90%	Hera, 2004 (default)
Dihydromyrcenol[2] (fragrance)	99.9% [1]	Klaschka et al. 2013
Hexyl salicylate (fragrance)	99.8% [2]	Simonich et al. 2002
Patchouli oil (fragrance)	90%	Hera, 2004 (default)

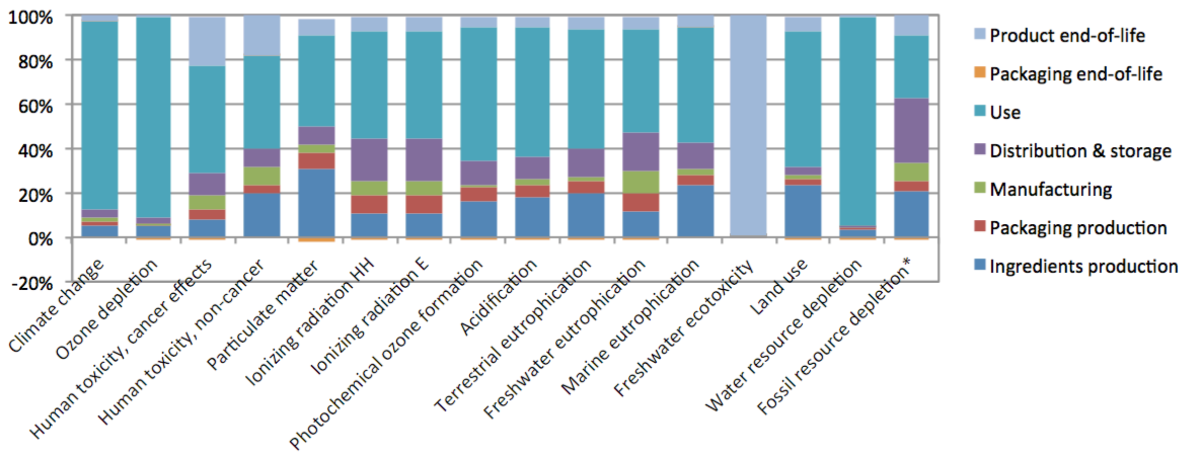
[1] Based on data from 5 German sewage treatment plants
[2] Based on data from 17 U.S. and European wastewater treatment plants between 1997 and 2000

An overall sludge absorption of 2% is assumed (source: (EPI) Suite™) and the sludge is assumed incinerated (source: ecoinvent). After incineration, the slag (18% of sludge) is disposed of in the slag compartment of a landfill (source: ecoinvent). The sludge treatment is found to have negligible impacts (see Table 20).

5. Calculating PEF impact assessment results

5.1 Data and indicator results prior to normalisation

Figure 5 presents the overall results for the shampoo life cycle. Absolute values for each indicator are also presented in Table 15. The use stage dominates results for the indicators Climate change, Ozone depletion, Photochemical ozone formation, Land use and Water resource depletion, while it has a significant contribution to all other indicators except freshwater ecotoxicity, which is dominated by product end-of-life. The production of the shampoo ingredients, as well as distribution and storage both contribute for several indicators. The manufacturing stage contributes for Ionizing radiation and Freshwater eutrophication. The packaging production and end-of-life, relative to the other life cycle stages, does not have a large contribution to the overall results.



** Mineral, fossil, and renewable resource depletion*

Figure 5. Overall results for one shampoo use

Table 15. Overall results (absolute) for one shampoo use

Indicator	Value	Units
Climate change	0.154	kg-CO_2 eq
Ozone depletion	2.16E-8	kg CFC-11 eq
Human toxicity, cancer effects	4.00E-9	CTUh
Human toxicity, non-cancer effects	4.69E-9	CTUh
Particulate matter	2.64E-5	kg PM2.5
Ionizing radiation (Human health)	1.20E-2	kBe U235 eq
Ionizing radiation (Ecosystem quality)	3.71E-8	CTUe
Photochemical ozone formation	2.49E-4	kg NMVOC eq
Acidification	3.13E-4	molc H+ eq
Terrestrial eutrophication	7.01E-4	molc N eq
Freshwater eutrophication	1.64E-5	kg P eq
Marine eutrophication	7.02E-5	kg N eq
Freshwater ecotoxicity	4.85	CTUe
Land use	0.288	kg C deficit
Water resource depletion	2.98E-3	m^3 water eq
Mineral, fossil and ren. resource depletion	2.80E-7	kg Sb eq

- **Use stage detailed results**

Figure 6 illustrates the detailed results of the use stage, which is dominated by the natural gas used to heat the shower water, except for Water resource depletion, which is dominated by the shower water use.

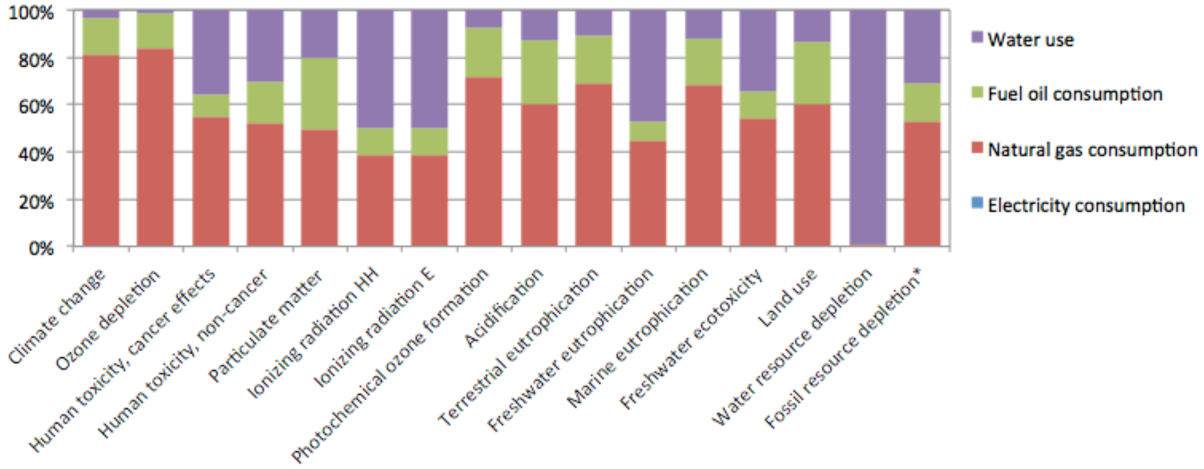


Figure 6. Detailed results of the shampoo use stage

The shower water energy mix to heat the water is assumed to be 87% natural gas and 13% fuel oil. Figure 7 presents a sensitivity analysis of the energy mix, comparing the default energy mix with the energy mix recommended by the BPX 30 standard (43% electricity, 37% natural gas, 20% fuel oil). The BPX 30 electricity is modelled with the French grid mix and the UCTE grid mix. Results are shown for the use stage life cycle only, and not the life cycle of the shampoo. The shower water default value of 15 litres is maintained for both scenarios and only the energy mix is modified. For all indicators except Ozone depletion, the BPX 30 UCTE energy mix use stage has higher potential impacts. The BPX 30 French energy mix use stage has impacts closer to the default energy mix, but is still higher than the default use stage for most impact categories (except for Climate change and Ozone depletion). It can be concluded that the **energy mix is a relevant modelling parameter** and should be refined with quality data if possible.

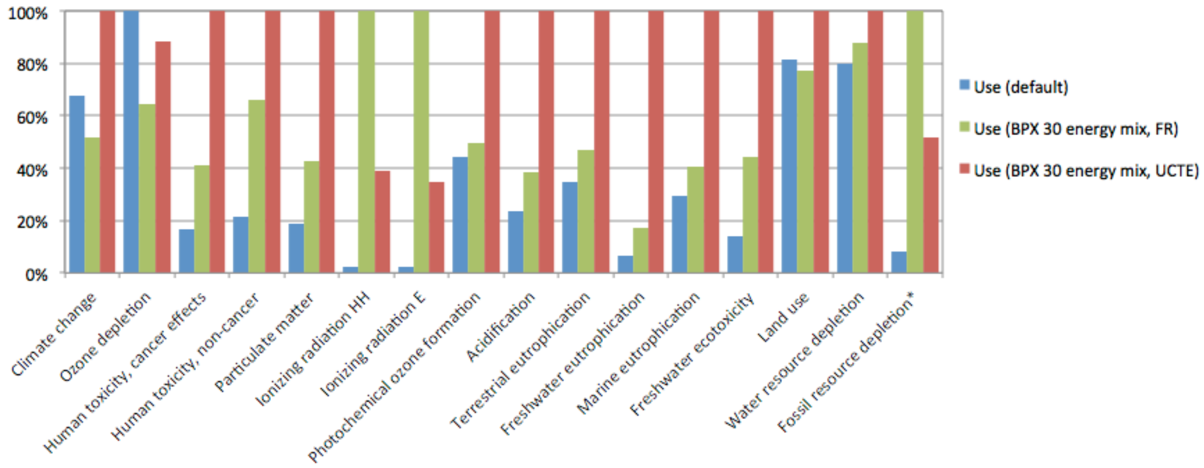


Figure 7. Sensitivity analysis of shampoo use stage, comparison of default energy mix vs. energy mix recommended by BPX 30 standard with French and UCTE grid mix (results shown for use stage only, not entire life cycle).

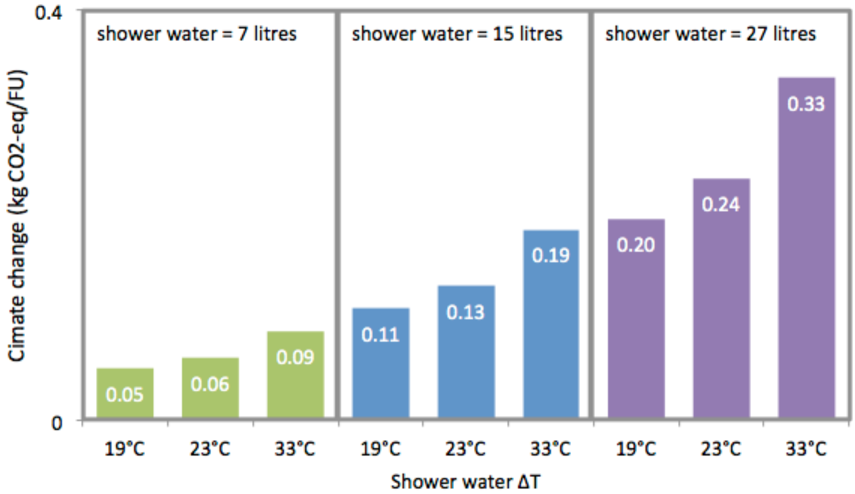


Figure 8 and Figure 9 show sensitivity analysis results for Climate change and Water resource depletion, respectively. Three different water quantities are considered: 7 litres, 15 litres (default) and 27 litres; three different water temperature differences are considered: 34 – 15 = 19°C, 38 – 15 = 23°C (default) and 43 – 10 = 33°C. For Climate change, water quantity and temperature difference are identified as relevant modelling parameters (similar conclusions were seen for the other indicators except Water resource depletion). For Water resource depletion, the water quantity (and not the temperature difference) is identified as a relevant parameter.

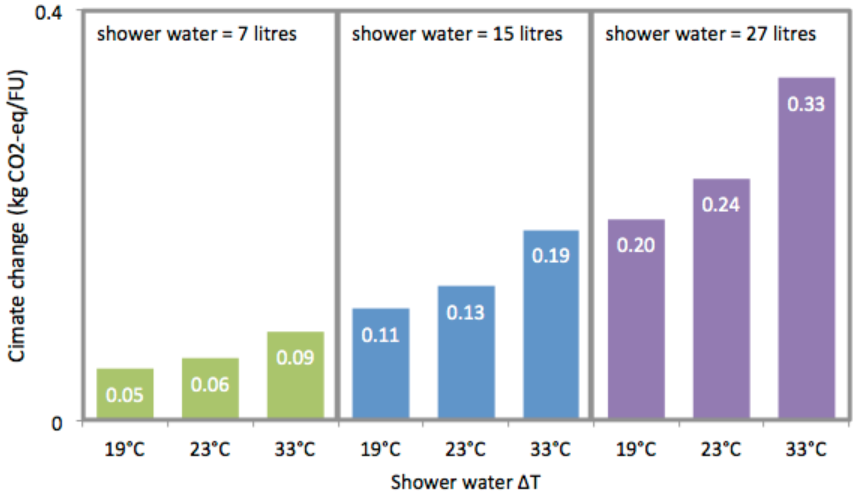


Figure 8. Shower water quantity and temperature sensitivity analysis results for Climate change (results shown for use stage only, not entire life cycle)

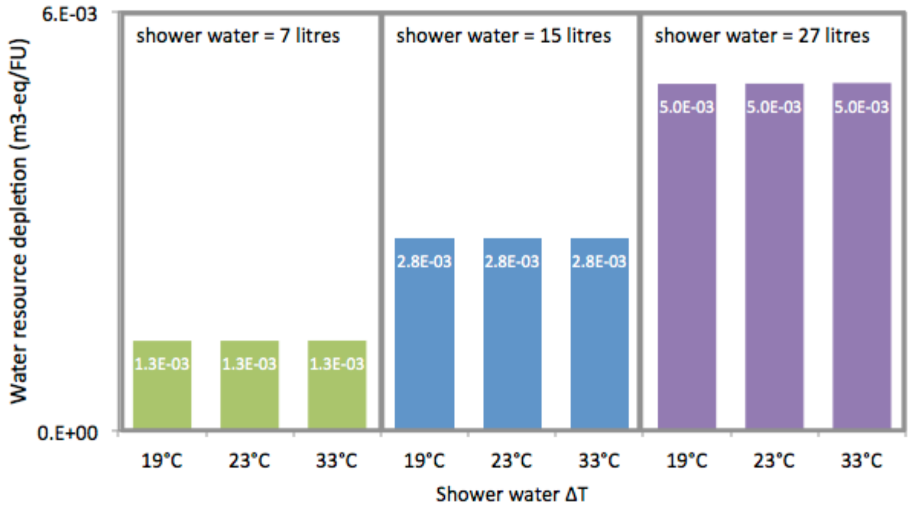


Figure 9. Shower water quantity and temperature sensitivity analysis results for Water resource depletion (results shown for use stage only, not entire life cycle)

- **Ingredients detailed results**

Figure 10 presents the detailed results for ingredients production. The negative value (or benefit) for Human toxicity, non-cancer is associated with Cocamidopropyl betaine. This ingredient is modelled as a fatty alcohol mix of petrochemical, coconut oil, palm oil and palm kernel oil origin and the benefit is due to the uptake of heavy metals such as zinc and copper during the agricultural phase of palm oil and palm kernel oil. It can be assumed that part or all of the heavy metals are later released to the environment, yet this is not taken into account in the modelling. Due to the large uncertainty related to heavy metal uptake it is recommended to exclude this from the results.

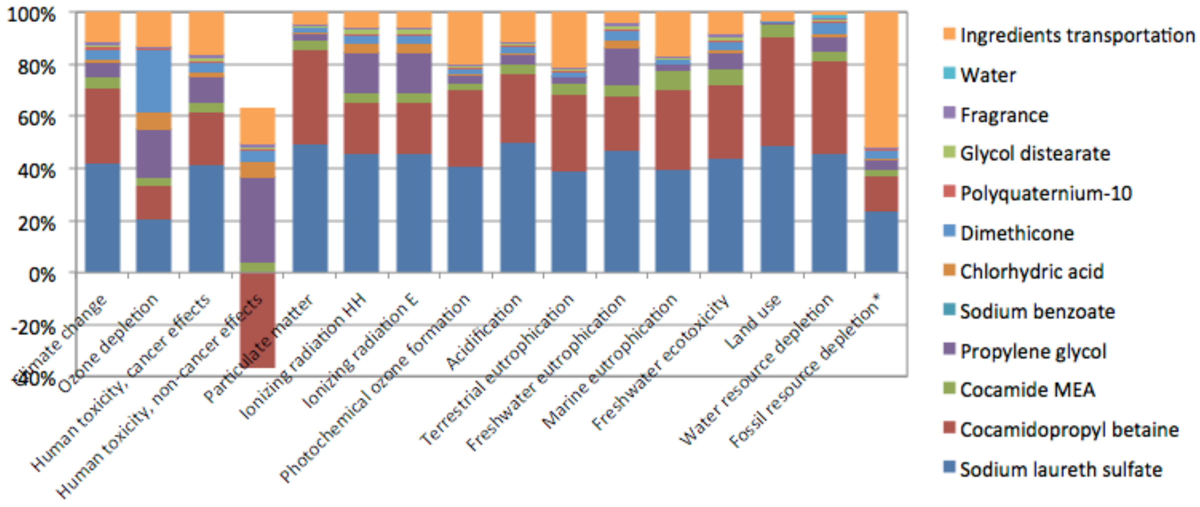


Figure 10. Results for shampoo ingredients production

Figure 11 presents detailed results for the ingredients, excluding the heavy metals from palm oil and palm kernel oil derived ingredients (cocamidopropyl betaine and sodium laureth sulfate). For most indicators, cocamidopropyl betaine and sodium laureth sulfate are the two dominating ingredients. Transportation of the ingredients contributes to all indicator categories except water resource depletion. The ingredients are assumed to be transported 500 km by truck and ingredients packaging is assumed to represent 20% of the total weight transported. It can be concluded that the modelling of these two ingredients is relevant and should be refined if possible.

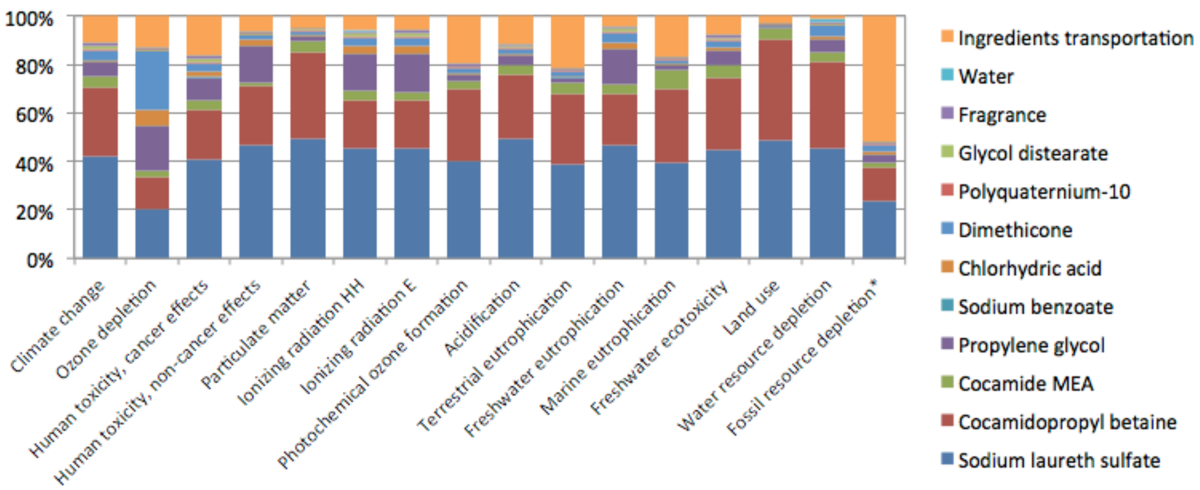


Figure 11. Results for shampoo ingredients production without consideration of heavy metals in products derived from palm oil and palm kernel oil (cocamidopropyl betaine and sodium laureth sulfate)

- **Product end-of-life detailed results**

Figure 12 shows detailed results for the product end-of-life stage only. It can be seen that the sludge treatment is negligible. Wastewater treatment dominates all indicators except Freshwater ecotoxicity. This is mainly due to infrastructure such as the sewer grid and the WWT plant.

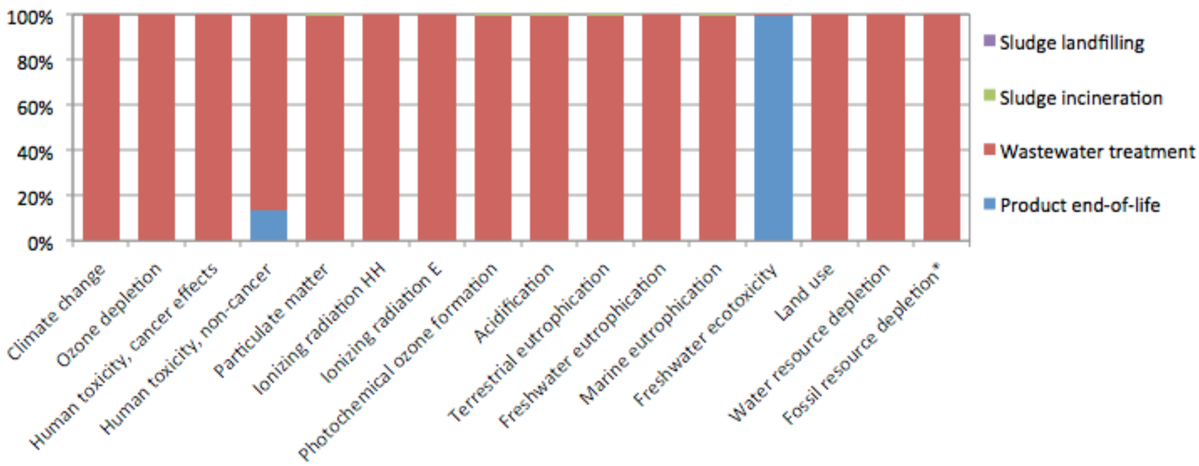


Figure 12. Detailed results for Product end-of-life stage

Table 16 summarizes Freshwater ecotoxicity results and substance contribution for Product end-of-life. The most toxic substances on a per kg basis are alpha-hexyl cinnamaldehyde, polyquaternium-10, dihydromyrcenol, and sodium laureth sulfate. When weighted by the shampoo formulation, sodium laureth sulfate, polyquaternium-10 and alpha-hexyl cinnamaldehyde are the main Freshwater ecotoxicity contributors, 81%, 8.7% and 5.2%, respectively. Note that quaternium-18 was used as a proxy for ecotoxicity modelling of polyquaternium-10 and dihydromyrcene was used as a proxy for dihydromyrcenol, since data was not available for these two substances.

Table 16. Summary of freshwater ecotoxicity impacts of shampoo ingredients emitted to nature

Substance emitted	Ecotoxicity (CTUe/kg)	Ecotoxicity (CTUe/FU)	Ecotoxicity contribution (%)
Sodium laureth sulfate	12081	3.86	81%
Cocamidopropyl betaine	783	0.15	3%
Cocamide MEA (monoethanolamine)	2.8E-4	4.3E-9	0%
Cocamide MEA (Fatty acids, C9-13-neo)	2.9E-2	4.4E-7	0%
Propylene glycol	0.92	2.3E-5	0%
Sodium benzoate	4.9E-11	3.6E-16	0%
Hydrochloric acid	not modelled	0	0%
Dimethicone	5.3	1.3E-4	0%
Polyquaternium-10[1]	42146	0.41	8.7%
Glycol distearate	4.56E-6	5.6E-11	0%
alpha-hexyl cinnamaldehyde (fragrance)	1.57E5	0.249	5.2%
beta-pinene (fragrance)	4.2E3	5.2E-3	0.1%
Dihydromyrcenol[2] (fragrance)	2.36E4	0.094	2.0%
Hexyl salicylate (fragrance)	6.09E3	7.2E-3	0.2%
Patchouli oil (fragrance)	1.58E2	9.7E-5	0%
Colour code for characterization factor data sources:	USEtox	Cosmede	custom calculated

[1] Quaternium-18 used as a proxy for polyquaternium-10 since this substance was not found in any of the databases.
[2] Dihydromyrcene used as a proxy for dihydromyrcenol since this substance was not found in any of the databases.

A sensitivity analysis was performed using freshwater ecotoxicity characterization factors in the second column of Table 12. The ecotoxicity contribution results are shown in Table 17. The substances for which characterization factors were updated are highlighted; cells not highlighted (i.e. white) indicate that the values remained the same as the default scenario (Table 16).

Cocamidopropyl betaine is the main contributor, contributing 60% to Freshwater ecotoxicity impacts, followed by alpha-hexyl cinnamaldehyde, at 16% and sodium laureth sulfate, at 17%. These results show a high variability of toxicity for the shampoo ingredients and thus a high variability of results for Freshwater ecotoxicity.

Table 17. Freshwater ecotoxicity contribution using alternate characterization factors (see column 2 of Table 12)

Substance emitted	Ecotoxicity contribution (%)
Sodium laureth sulfate	17%
Cocamidopropyl betaine	60%
Cocamide MEA (monoethanolamine)	0%
Cocamide MEA (Fatty acids, C9-13-neo)	0%
Propylene glycol	0%
Sodium benzoate	0%
Hydrochloric acid	0%
Dimethicone	0%
Polyquaternium-10	0.1%
Glycol distearate	0%
alpha-hexyl cinnamaldehyde (fragrance)	16%
beta-pinene (fragrance)	0%
Dihydromyrcenol[2] (fragrance)	6.2%
Hexyl salicylate (fragrance)	0.5%
Patchouli oil (fragrance)	0%
CF data sources: USEtox / Cosmede / custom calculated	

Figure 13 shows results for the Product end-of-life stage for shower water quantities of 7, 15 and 27 litres. When less water is treated in wastewater treatment, this reduces impacts associated with this process. Freshwater ecotoxicity is not sensitive to the change in water quantity as it is highly dominated by the substances treated.

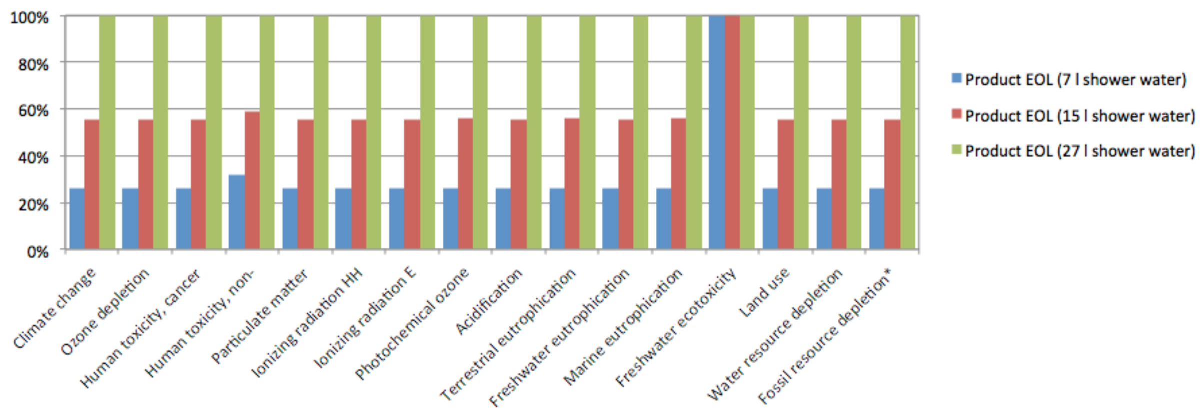


Figure 13. Sensitivity analysis results for Product end-of-life, for shower water quantities of 7, 15 and 27 litres (results shown for Product end-of-life stage only, not entire life cycle)

Figure 14 presents results over the life cycle for different wastewater treatment plant efficiencies, showing two extremes of 0% (all substances emitted to nature) and 100% efficiency. Note that 100% efficiency does not mean 100% of all substances are treated; a household connectivity of 85% is assumed, meaning 15% of substances are emitted directly to nature. This parameter has an influence on the indicators Freshwater ecotoxicity and Human toxicity, non-cancer effects. An increase in the default efficiencies to 100% results in a 36% decrease in Freshwater ecotoxicity and a 1% decrease in Human toxicity, non-cancer effects.

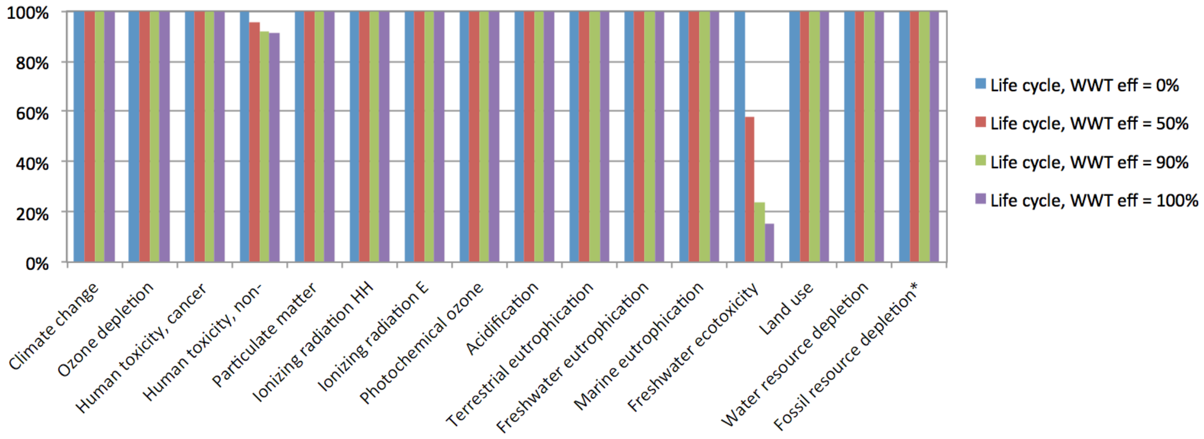


Figure 14. Sensitivity analysis results (shown for the life cycle) for different wastewater treatment efficiencies, 0%, 50%, 90% (default) and 100%

- **Sensitivity analysis of Manufacturing/Distribution and storage stages infrastructure**

A sensitivity analysis was performed by excluding the manufacturing plant and distribution centre buildings. Table 19 shows the percent (%) difference in results between the model with and without infrastructure. Main differences are for the indicators Human toxicity, non-cancer effects, Freshwater ecotoxicity, and Mineral, fossil and renewable resource depletion, for which results are 6%, 5% and 6% lower, respectively, when infrastructure is excluded. For all other indicators, results without infrastructure are from 0% to 4% lower. The main contributors for both infrastructure processes, for the indicators Human toxicity, non-cancer effects, Freshwater eutrophication, and Mineral, fossil and renewable resource depletion are shown in Table 18.

Table 18. Main contributors for indicators Human toxicity, non-cancer effects, Freshwater eutrophication, and Mineral, fossil and renewable resource depletion for two infrastructure processes

Process	Human toxicity, non-cancer effects	Freshwater eutrophication	Mineral, fossil and ren. resource depletion
Chemical plant, organics/RER	copper	tailings from copper production, spoil from lignite mining	zinc
Building, multi-storey/RER	copper	tailings from copper production,	zinc

Table 19. Sensitivity analysis of manufacturing plant and distribution center infrastructure, results shown for the entire life cycle

Indicator	Value with buildings[1]	Value without buildings[1]	Units	% difference
Climate change	0.154	0.154	kg-CO_2 eq	0%
Ozone depletion	2.16E-8	2.16E-8	kg CFC-11 eq	0%
Human toxicity, cancer effects	4.00E-9	3.83E-9	CTUh	-4%
Human toxicity, non-cancer effects	4.69E-9	4.39E-9	CTUh	-6%
Particulate matter	2.64E-5	2.60E-5	kg PM2.5	-2%
Ionizing radiation (HH)	1.20E-2	1.18E-2	kBq U235 eq	-2%
Ionizing radiation (EQ)	3.71E-8	3.65E-8	CTUe	-2%
Photochemical ozone formation	2.49E-4	2.48E-4	kg NMVOC eq	-1%
Acidification	3.13E-4	3.09E-4	molc H+ eq	-1%
Terrestrial eutrophication	7.01E-4	6.94E-4	molc N eq	-1%
Freshwater eutrophication	1.64E-5	1.55E-5	kg P eq	-5%
Marine eutrophication	7.02E-5	6.96E-5	kg N eq	-1%
Freshwater ecotoxicity	4.85	4.85	CTUe	0%
Land use	0.288	0.286	kg C deficit	-1%
Water resource depletion	2.98E-3	2.97E-3	m^3 water eq	0%
Mineral, fossil and ren. Resource depletion	2.80E-7	2.62E-7	kg Sb eq	-6%

[1] manufacturing plant and distribution center buildings

- **Sensitivity analysis of end-of-life formula**

According to the PEF guide, the default end-of-life formula recommended is 50:50, however, alternative formulas may be tested in a sensitivity analysis. The 0:100 approach was selected as a sensitivity analysis; the formula is shown here:

Packaging production

Packaging end-of-life

$$\boxed{E_V} + R_2 \times \left(E_{recyclingEoL} - E^{*}_{V} \times \frac{Q_S}{Q_P} \right) + R_3 \times \left(E_{ER} - LHV \times X_{ER,heat} \times E_{SE,heat} - LHV \times X_{ER,elec} \times E_{SE,elec} \right) + (1 - R_2 - R_3) \times E_D$$

In the 0:100 approach, the recycled content of the packaging materials is not taken into account (i.e. $R_1 = 0$), however, all benefits of recycling at the end-of-life are allocated to the packaging end-of-life stage (i.e. R_2 is not divided by 2, as in the 50:50 approach). Results show that when applying the 0:100 approach, the overall life cycle impacts range from 0.6% smaller (land use) to 0.1% higher (ionizing radiation E), depending on the indicator. This result is not surprising since the packaging production and end-of-life stages are a small part of the life cycle impacts. It can be concluded from this sensitivity analysis, that within the context of the assumptions taken in this screening study, the selection of end-of-life approach has little impact on the total results.

- **Summary of sensitivity analysis and conclusions**

A description of the different sensitivity analyses is provided in Table 20 along with the conclusions obtained from each analysis. Important parameters were identified such as water quantity and temperature, energy mix to heat water and wastewater treatment (WWT) efficiency. Other parameters were identified as being negligible such as the manufacturing and distribution centre buildings and wastewater sludge treatment.

Table 20. Summary of sensitivity analyses and conclusions obtained

Life cycle stage	Base case	Sensitivity analysis	Results
Ingredients production	default ecoinvent processes are used	Uptake of heavy metals is neglected for palm oil derived ingredients	A benefit is seen due to heavy metal uptake for the indicator Human toxicity, non-cancer. **This aspect is neglected from the study due to high uncertainty.**
Manufacturing / distribution and storage	Modeling of the manufacturing and distribution center buildings	Manufacturing and distribution center **buildings** excluded	Impacts increase by 0-4% over the life cycle for most indicators[1] when buildings are included. Infrastructure considered to be non negligible.
Use stage	Use stage dominates results for all indicators except freshwater ecotoxicity	Shower water **temperature** is varied	For temperature differences of 19°C (best case), 23°C (base case) and 33°C (worst case), results are approx. 1.7x higher for the worst case compared to the best case. **This parameter is determined to be relevant.**
Use stage	Use stage dominates results for all indicators except freshwater ecotoxicity	Shower water **quantity** is varied	For water quantities of 7 l (best case), 20 l (base case) and 27 l (worst case), results are approx. 4x higher for the worst case compared to the best case. **This parameter is determined to be relevant.**
Use stage	Use stage dominates results for all indicators except freshwater ecotoxicity	Energy mix recommended by BPX 30 (for France) is used.	Use stage results for the base case are significantly lower, up to 95% depending on the indicator. **The energy mix is an relevant parameter.**
Product end-of-life	Product-end-of-life dominates results for freshwater ecotoxicity	**WWT efficiency** is varied: 0%, 50%, 90% (base case), 100%	Freshwater ecotoxicity results are approximately 5x higher for the worst case compared to best base. **This parameter is determined to be relevant.**
Product end-of-life	Wastewater treatment (WWT) sludge is not considered	WWT sludge absorption of 2% is considered. Sludge is incinerated.	Sludge treatment represents less than 0.1% of overall impacts. **Sludge treatment is found to be negligible.**
Product end-of-life	Freshwater ecotoxicity CFs selected for shampoo ingredients	Alternate CFs used for Freshwater ecotoxicity	High variability of CFs and thus high variability of results. **High uncertainty associated with toxicity modelling**.
Packaging end-of-life	50:50 modelling approach (as recommended in the PEF guide)	Tested the 0:100 modelling approach	Total impacts range from 0.6% smaller to 0.1% higher depending on the indicator. **The end-of-life modelling approach is not found to have a significant impact on results.**

[1] except for Human toxicity, non-cancer effects, Freshwater eutrophication and Mineral, fossil and renewable resource depletion for which results are 7%, 5% and 7% higher, respectively.

5.2 Normalised results

Based on the screening study results, Table 21 shows results obtained with the EU 27 normalisation factors and Table 22 illustrates results with the Quantis proposed conversion factors. The European Commission normalisation factors are applied at the midpoint level while the Quantis proposed conversion factors are applied at the endpoint level, which allows one to identify the relative contribution of midpoint indicators to the endpoints' results (areas of protection). These factors are taken from various LCA methodologies and publications.

Based on an analysis of both normalization methods, the impact categories evaluated as relevant for a shampoo are:

- Climate change
- Water resource depletion
- Mineral and fossil resource depletion
- Freshwater ecotoxicity (subject to the availability of appropriate methodology and data)

When considering the European Commission (EC) and Quantis proposed methods, the impact category Human toxicity, cancer effects, is also identified as being relevant, however, the main contribution for this impact category is from energy use during the use stage and this indicator is thus correlated with the Climate change indicator. When considering all the Human Health related indicators, global damage to this area of protection[3] linked to the use of shampoo appears to be negligible. Based on the previous analysis and considering that the positive impacts linked to personal hygiene cannot be adequately assessed in LCA, it is proposed not to consider Human Health in the final list of impact categories.

The safety of personal care products such as shampoos is guaranteed by toxicity risk assessment and thus differs from potential indirect impacts on human health (particulate matter impacts, toxicity of substances bioaccumulated in food, etc.). The environmental (LCA) evaluation of a shampoo attempts to provide information on what we could refer to as "Public health effects", meaning these impacts more globally highlight "indirect" effects on the population over the life cycle of a shampoo.

Table 21. Summary of results using recommended normalisation factors for EU 27 (2010) based on domestic inventory, to identify relevant indicators for shampoo

Indicator (ILCD Midpoint)	Value	Units/FU	ILCD Normalisation factor	Units	Normalised	Important?
Climate change	0.154	kg CO2 eq	9.19E+03	kg CO2 eq/pers.y	1.67E-05	✓
Ozone depletion	2.16E-08	kg CFC-11 eq	2.16E-02	kg CFC-11 eq/pers.y	9.98E-07	
Human toxicity, cancer effects	3.83E-09	CTUh	3.68E-05	CTUh/pers.y	1.04E-04	✓
Human toxicity, n-c effects	4.39E-09	CTUh	5.32E-04	CTUh/pers.y	8.25E-06	
Particulate matter	2.60E-05	kg PM2.5 eq	4.60E+00	kg PM2.5 eq/pers.y	5.65E-06	
Ionizing radiation HH	1.18E-02	kBq U235 eq	1.13E+03	kBq U235 eq/pers.y	1.05E-05	
Ionizing radiation E (interim)	3.65E-08	CTUe	n.a.			
Photochemical ozone formation	2.48E-04	kg NMVOC eq	3.16E+01	kg NMVOC eq/pers.y	7.84E-06	
Acidification	3.09E-04	molc H+ eq	4.72E+01	molc H+ eq/pers.y	6.55E-06	
Terrestrial eutrophication	6.94E-04	molc N eq	1.75E+02	molc N eq/pers.y	3.97E-06	
Freshwater eutrophication	1.55E-05	kg P eq	1.48E+00	kg P eq/pers.y	1.05E-05	
Marine eutrophication	6.96E-05	kg N eq	1.69E+01	kg N eq/pers.y	4.12E-06	
Freshwater ecotoxicity	4.85	CTUe	8.71E+03	CTUe/pers.y	5.57E-04	✓
Land use	0.286	kg C deficit	6.82E+05	kg C deficit/pers.y	4.19E-07	
Water resource depletion	2.97E-03	m3 water eq	8.11E+01	m3 water eq/pers.y	3.67E-05	✓
Fossil resource depletion	2.62E-07	kg Sb eq	1.00E-01	kg Sb eq/pers.y	2.62E-06	

[3] Climate change (HH), Ozone depletion, Human toxicity, cancer and non-cancer effects, Particulate matter, Ionizing radiation, Photochemical ozone formation, Water resource depletion

Table 22. Summary of results, using conversion factors to identify relevant indicators for shampoo

	Indicator (ILCD Midpoint)	Value	Units/FU	Conversion factor	Units	Reference	Converted value	Converted value units/FU	Important?
Human health	Climate change (HH)	0.154	kg CO2 eq	2.55E-07	DALY/kg CO2-eq	de Schryver et al.	3.92E-08	DALY	✓
	Ozone depletion	2.16E-08	kg CFC-11 eq	1.05E-03	DALY/kg CFC-11 eq	Goedkoop et al. 2001*	2.26E-11	DALY	
	Human toxicity, cancer effects	3.83E-09	CTUh	13	DALY/CTUh	Humbert et al. 2012	4.98E-08	DALY	✓
	Human toxicity, n-c effects	4.39E-09	CTUh	1.3	DALY/CTUh	Humbert et al. 2012	5.70E-09	DALY	✓
	Particulate matter	2.60E-05	kg PM2.5 eq	1.80E-03	DALY/kg PM2.5 eq	Humbert 2009	4.68E-08	DALY	✓
	Ionizing radiation (HH)	1.18E-02	kBq U235 eq	2.10E-08	DALY/kBq U235 eq	ILCD, IMPACT 2002+	2.48E-10	DALY	
	Photochemical ozone formation	2.48E-04	kg NMVOC eq	1.28E-06	DALY/kg NMVOC eq	Goedkoop et al. 2001*	3.17E-10	DALY	
	Water resource depletion (HH)	2.97E-03	m3 water eq	n/a	DALY/m3-eq	Pfister et al. 2009	1.41E-08	DALY	✓
Ecosystem quality	Climate change (EQ)	0.154	kg CO2 eq	0.266	PDF.m2.y/kg CO2-eq	de Schryver et al.	4.09E-02	PDF.m2.y	✓
	Ionizing radiation (EQ)	3.65E-08	CTUe	5.48E-04	PDF.m2.y/CTUe	Humbert et al. 2012	2.00E-11	PDF.m2.y	
	Acidification	3.09E-04	molc H+ eq	6.73E-03	PDF.m2.y/molc H+ eq	ILCD, IMPACT 2002+	2.08E-06	PDF.m2.y	
	Terrestrial eutrophication	6.94E-04	molc N eq	1.15	PDF.m2.y/molc N eq	ILCD, IMPACT 2002+	7.98E-04	PDF.m2.y	
	Freshwater eutrophication	1.55E-05	kg P eq	34.9	PDF.m2.y/kg P eq	Humbert et al. 2012	5.42E-04	PDF.m2.y	
	Marine eutrophication	6.96E-05	kg N eq	12.5	PDF.m2.y/kg N eq	Bulle et al. 2013	8.70E-04	PDF.m2.y	
	Freshwater ecotoxicity	4.85	CTUe	5.48E-04	PDF.m2.y/CTUe	Humbert et al. 2012	2.66E-03	PDF.m2.y	
	Land use	0.286	kg C deficit	3.35E-03	PDF.m2.y/kg C deficit	Ecoindicator99	9.58E-04	PDF.m2.y	
	Water resource depletion (EQ)	2.97E-03	m3 water eq	n/a	PDF.m2.y/m3-eq	Pfister et al. 2009	1.04E-02	PDF.m2.y	✓
	Fossil resource depletion	2.62E-07	kg Sb eq	1	kg Sb eq/kg Sb eq	n/a	2.62E-07	kg Sb eq	✓

*Goedkoop et al. 2001, Jolliet et al. 2003, Humbert et al. 2012

6. Interpretation

The following study illustrates how the PEFCR can be used to perform a screening environmental footprint of a shampoo. The results and sensitivity analysis allowed us to evaluate relevant parameters that need to be refined in order to increase the quality of the guidance in the PEFCR. Important points identified are the following:

- The use stage shower water **temperature and quantity** are determined to have a relevant impact on results. Since these values are based on consumer habits, and it is difficult to provide data on this subject, sensitivity analyses around these parameters should be recommended.
- The **use stage energy mix** is also found to have a relevant impact on results. It is difficult to obtain publicly available data concerning the water heating energy mix and assumptions were made based on the EU-28 heating mix. More effort should be invested in refining and improving the quality of this data.
- **Wastewater treatment efficiency** is found to have a relevant impact on freshwater ecotoxicity results. The PEFCR should investigate the possibility of recommending ingredient-specific and/or WWT technology-specific recommendations for the % removal rate.

6.1 Environmental hotspots

The Use stage is identified as being an environmental hot spot for the shampoo use, due to the energy used to heat the water. Furthermore, the energy mix has a high uncertainty, as there is no publicly available data for the European energy mix to heat water, and certain assumptions were made in order to model this aspect.

6.2 Most relevant processes and life cycle stages

The life cycle stages identified as being the most relevant are the **use stage**, for almost all indicators except Freshwater ecotoxicity and Mineral, fossil and renewable resource depletion. For Freshwater ecotoxicity, and to a lesser extent Human toxicity (both cancer and non-cancer effects) the **product end-of-life** stage is the most relevant. **Ingredients production** and **distribution and storage** stages also have non negligible impacts for relevant impact categories, such as Human toxicity (both cancer and non-cancer effects), Particulate matter, Mineral, fossil and renewable resource depletion.

The processes identified as being the most relevant are those for the energy mix to heat the water such as the **heat** and **natural gas** ecoinvent processes as well as the **tap water** process in itself. Important modelling parameters influencing the impact of these processes is the energy mix (i.e. % natural gas, % fuel oil, etc.) as well as the water quantity and temperature. For Freshwater ecotoxicity, **sodium laureth sulfate** and **cocamidopropyl betaine**, are the most relevant processes (emissions). For Water resource depletion it is the **tap water** use during the use stage. For ingredients production, the processes **sodium laureth sulfate** and **cocamidopropyl betaine** are the most relevant; relevant modelling parameters affecting the impact of these processes are the wastewater treatment connectivity rate and wastewater treatment % removal. For distribution and storage **truck transport** is the most relevant process.

6.3 Most relevant impact categories

Preliminary indications of the most relevant impact categories, in order of significance are:

- Climate change
- Water resource depletion
- Mineral and fossil resource depletion
- Freshwater ecotoxicity (subject to the availability of appropriate methodology and data)

7. Conclusions

The most relevant life cycle stage is the **use stage**; it dominates results for the indicators Climate change, Ozone depletion, Photochemical ozone formation, Land use and Water resource depletion, and has a significant contribution to all other indicators except freshwater ecotoxicity, which is dominated by product end-of-life. The life cycle stages ingredients production, as well as distribution and storage both contribute for several indicators. The manufacturing stage contributes for Ionizing radiation and Freshwater eutrophication. The stages packaging production and end-of-life, relative to the other life cycle stages, do not have a large contribution to the overall results.

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