Eyeglasses VS Contact Lenses

LIFE CYCLE ASSESSMENT _ AG2800

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GROUP 05

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Abstract

This report is intended for assessing the whole life cycle of three alternatives for vision correction. The focus of this comparative LCA study is on the eyeglasses, daily contact lenses and monthly contact lenses and its aim is to understand how much each of them has potential environmental impacts during its life cycle. Moreover, a clear interpretation of inventory analyses will be presented along with the impact assessment of these three products. SimaPro software was used for modeling of the processes in this report. The results show that eyeglasses have lower impacts than the contact lenses and also the maintenance liquid of contact lenses has a high impact on the environment.

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1 Goal and scope

The first step of an LCA is to define goal and scope of the study. This step should address the reason for carrying out the study, select the suitable LCA, the intended application and the intended audience.

1.1 Goal of the study

Visual impairment affects a lot of people in a wide range of age. There are different ways to cope with sight loss, such as using eyeglasses, contact lenses or Lasik eye surgery. Since this problem concerns so many people, it is of actual interest to investigate some solutions and, in particular the impact they have on the environment. The attention of our group has been focused on three alternatives: the use of eyeglasses, daily contact lenses or monthly contact lenses. The goal of the study is to get a comprehensive overview on this issue, in order to provide some indications to help people taking a more environmental-friendly decision. This LCA study is therefore accounting and comparative, and the intended application of our case study is to communicate the information and enhance or improve people knowledge about this topic. Finally the intended audience is composed by those customers who seek for a more environmental-friendly solution to cope with their visual impairment.

1.2 Functional unit

The functional unit is of utmost importance to make a relevant and precise LCA. The functional unit of this case study is "one year vision correction, provided by one pair of eyeglasses, compared to the corresponding number of pairs of contact lenses needed (365 daily or 12 monthly)".

1.3 System boundaries

In order to collect relevant data in a LCA study, system boundaries are needed. In our case we consider almost all the processes related to the production of eyeglasses and contact lenses: from extraction (cradle) and refining of raw materials to the final disposal (grave), passing through the shaping of the components, the transportation and the use phase.

Geographical boundaries. We place the use phase and the end of life of our products in Stockholm. We also consider where the materials and the sub-assemblies have been produced and the transportations related to them. For more details look at the following flowcharts (Figure 1, Figure 2, Figure 3).

Time horizon. The study can provide information required for future LCA about eyeglasses and contact lenses; our analysis should be valid at least for one decade and there should be no problems to use data from previous studies. We do not take into account the long term impacts, because, in the balance of daily life impacts, the contribution of eyeglasses or contact lenses is very small.

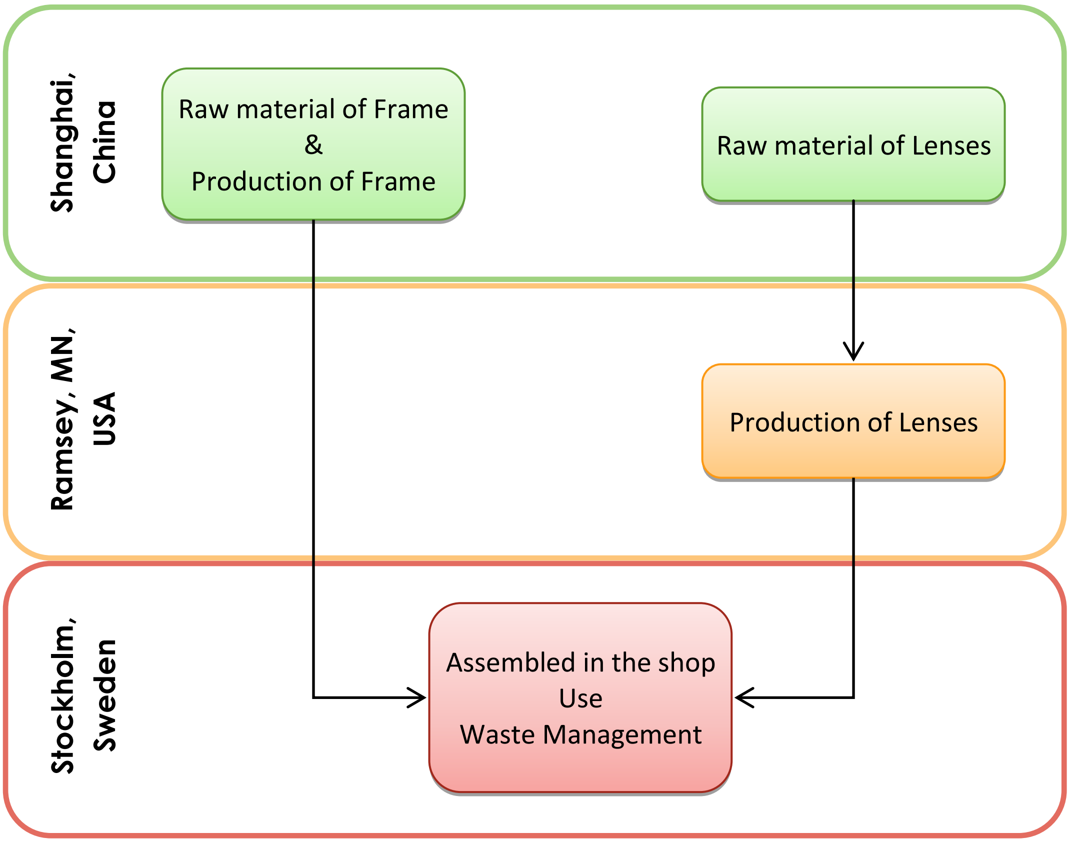

Figure 1. Geographical boundaries – Eyeglasses

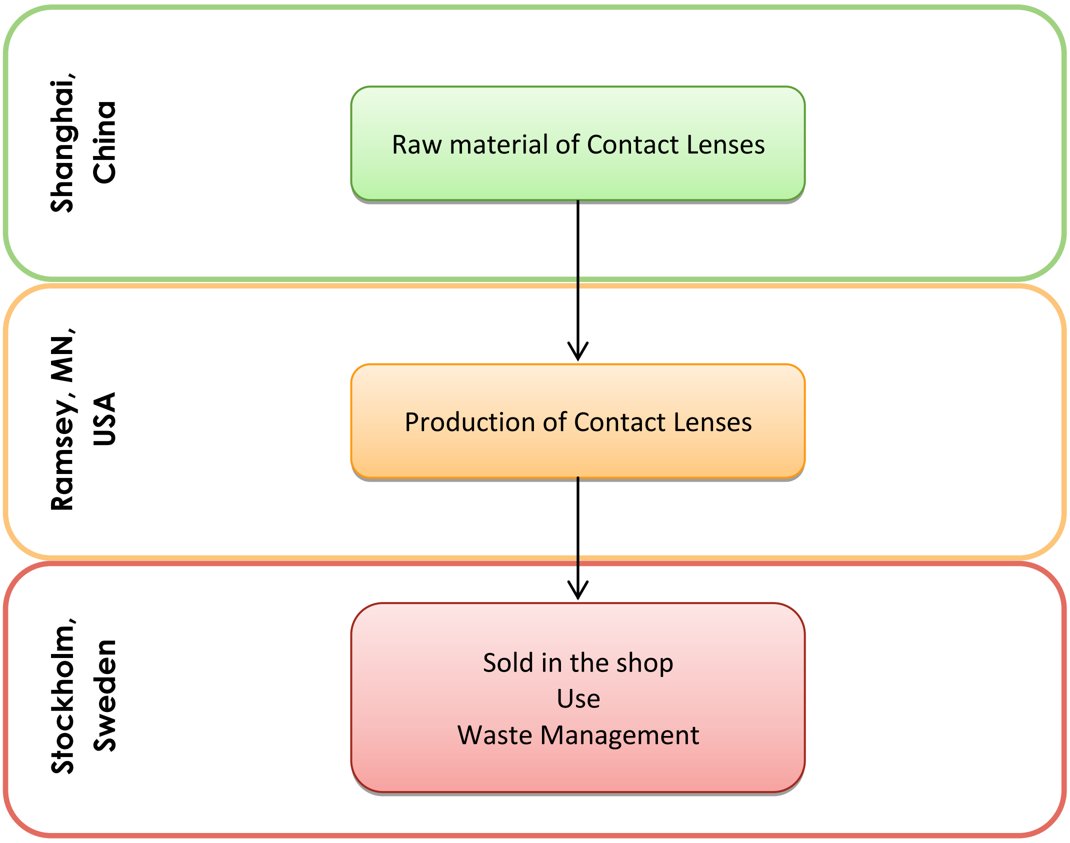

Figure 2. Geographical boundaries - Daily Contact Lenses

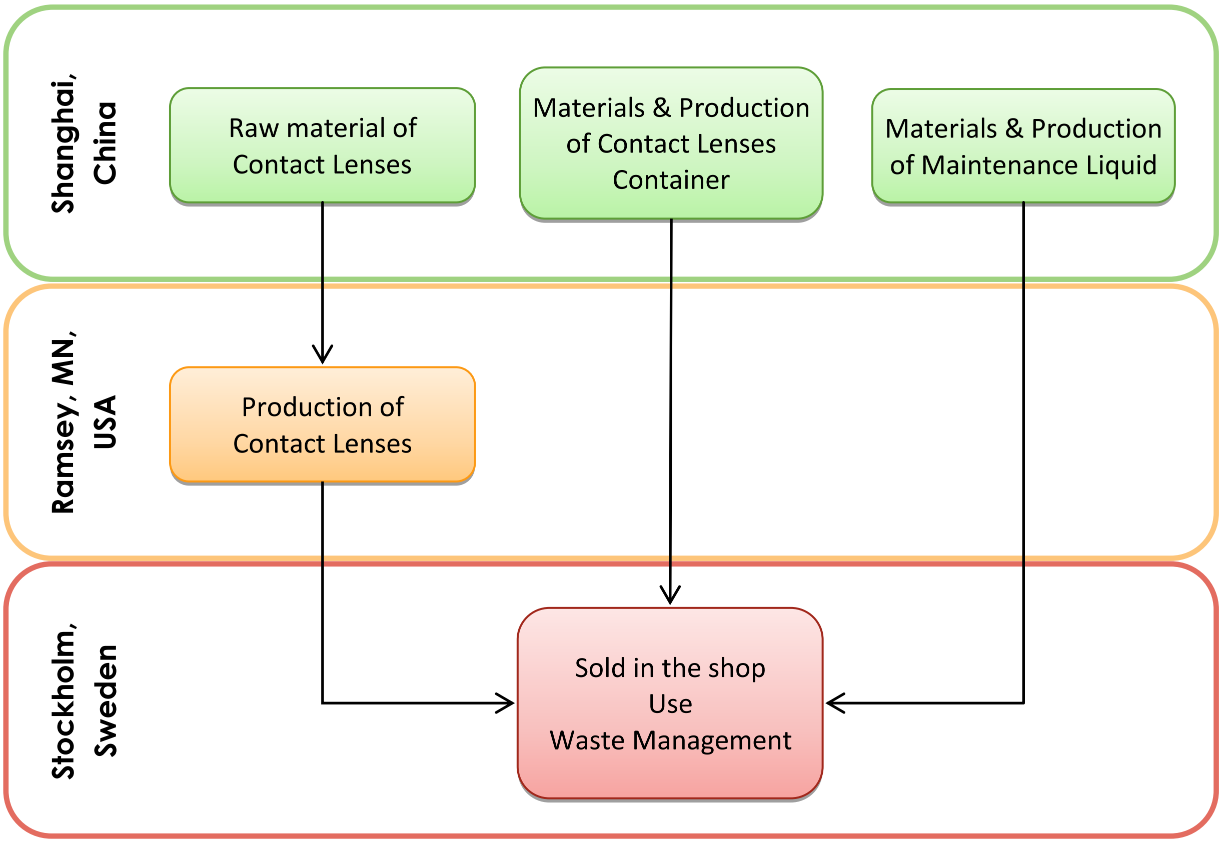

Figure 3. Geographical boundaries - Monthly Contact Lenses

Cut-off criteria. In our study we exclude some elements because of data gaps and not to make it too complex; most of these cut-off are driven by the shortage of time. First of all, we take into account just one specific pair of eyeglasses (with a metal frame) and two kinds of contact lenses (daily and monthly), disregarding the other solutions present on the market. We also don´t consider some components and processes related to our assemblies: the packaging of raw materials and eyeglasses, as well as the spectacle case; the processes of assembling the components (e.g. the assembling of the frame); the maintenance of eyeglasses; the process of wetting for the contact lenses (we just consider the water mass input flow, but not the energy needed; further details in §2.2.1); the impact of the shop where contact lenses and eyeglasses are sold, as well as the movements of customers; the waste treatment of the maintenance liquid.

Allocation procedure. Regarding contact lenses users, it´s reasonable to assume that they also use a pair of eyeglasses. This way an allocation problem comes up: we should include the contribution of eyeglasses to the use phase of contact lenses, but we have decided not to go through it. This choice has been driven by the lack of statistic data about the combined use of contact lenses and eyeglasses. Another allocation problem arises in the waste management scenario: we assume that a percentage of the plastic materials go to incineration in a combined heat and power (CHP) plant and, to allocate heat and electricity production, we refer to Hässelbyverket CHP-plant in Stockholm. (Fortum, 2011)

1.4 Assumptions and limitations

Working on our project we have run into a lot of data gaps and, therefore, we have been in the need of doing some assumptions and approximations. These have been done according to our background and referring to reasonable common knowledge.

We assume that all the plastic materials are made in China. The transportations are by freight on the sea and by truck on the land, because they represent the cheapest solution (for further details about transportation look at §2.2.2). We also assume a regular use of contact lenses and maintenance liquid, according to the prescription and disregarding the "average customer" misbehavior.

For data regarding energy and heat recovered from incineration, we refer to the average Swedish production (further details in §2.2.3).

One of the biggest limitations of our analysis comes from the processes database we have used. In fact most of the impact data refers to the European average or just to Switzerland, while, in the real product system, the processes are located in China and USA mainly. This may lead to not precise results.

1.5 Impact categories and impact assessment method

To assess the impact of our product systems we use the method "ReCiPe Midpoint (H) V1.05", as implemented in SimaPro 7.3.

In ReCiPe method, the first aim is to turn the long list of Life Cycle Inventory results into a limited number of indicator scores. These indicators show the comparative effects on an environmental impact category.

ReCiPe method uses environmental mechanisms as the source of its modeling. We can explain an environmental mechanism as the series of effects that can create a certain level of damage together to, for example, ecosystem or human health. There are two levels for indicators in ReCiPe:

- Eighteen Midpoint indicators
- Three Endpoint indicators

In midpoint indicators, because of the shorter cause-effect chain (shorter assessing time), the uncertainty is lower, while endpoint indicators have a higher grade of uncertainty. Furthermore, there are eighteen midpoint indicators that are harder to interpret because of their variety and their abstract meanings. Endpoint indicators, on the contrary, are just three and they have more understandable meaning. (ReCiPe, 2011)

"Each method (midpoint, endpoint) contains factors according to these three cultural perspectives:

- *Individualist*: short term, optimism that technology can avoid many problems in future.
- *Hierarchist*: consensus model, as often encountered in scientific models, this is often considered to be the default model.

- *Egalitarian*: long term based on precautionary principle thinking.”

These perspectives build a way for making proper choices according to the time horizon or some other limitations or properties. (Pré Consultant, 2011)

In our project we use a *Midpoint* method because of its lower uncertainty and a *Hierarchist* perspective because of the consensus it has in the scientific field.

In this study some impact categories are chosen because they appear to be the more relevant:

- *Climate change*: climate change may cause a wide variety of impacts on ecosystem and society. The emission of carbon dioxide, methane, chlorofluorocarbons (CFCs), nitrous oxide and other trace gasses contribute to this impact category.
- *Human toxicity*
- *Fresh water eco-toxicity*
- *Marine eco-toxicity*
- *Terrestrial acidification*: the main pollutants that may cause acidification are: SO_2, NO_x, HCl and NH_3.
- *Metal depletion*: metal depletion is an environmental impact which occurs by high rate of metal extraction from the environment.
- *Fossil depletion*: fossil depletion is an environmental impact that is due to the high rate of consumption of fossil fuel. (Baumann, et al., 2004)

1.6 Normalization and weighting

In the impact assessment, “normalization means that the impact of a studied product is related to the total environmental impact in a region so the relative contribution of the product can be determined” (Baumann, et al., 2004). In this report we use normalization which is defined in “ReCiPe Midpoint (H) V1.05 / World ReCiPe H/H”. We decide to refer to the global scenario because the system boundaries are defined in China, USA and Stockholm, Sweden. (ReCiPe, 2011)

Weighting is not considered our project. Actually weighting method is not proper for comparing LCA studies. (Baumann, et al., 2004)

2 Life cycle inventory analysis

After the definition of the goal and the scope of our analysis, we can create a flow model of the system. This includes all the processes involved in fulfilling the function chosen as functional unit. The model takes also into account all the considerations, the approximations, the cut-off and the system boundaries previously discussed.

2.1 Process flowchart

In the following pages the detailed flowcharts of each product system are presented. They were used to model the relative systems on the SimaPro software. The excluded processes are colored in grey.

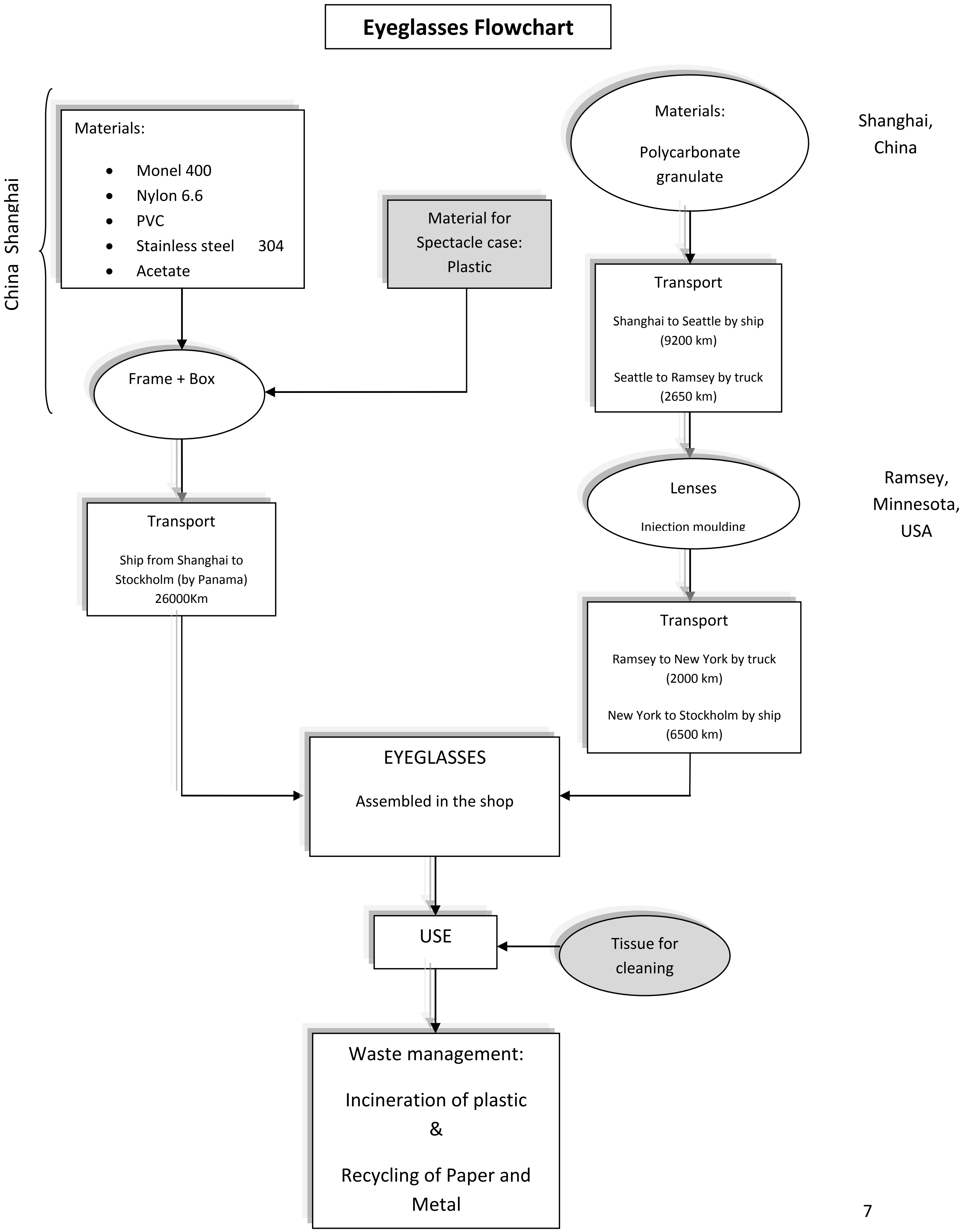

Figure 4. Eyeglasses Flowchart

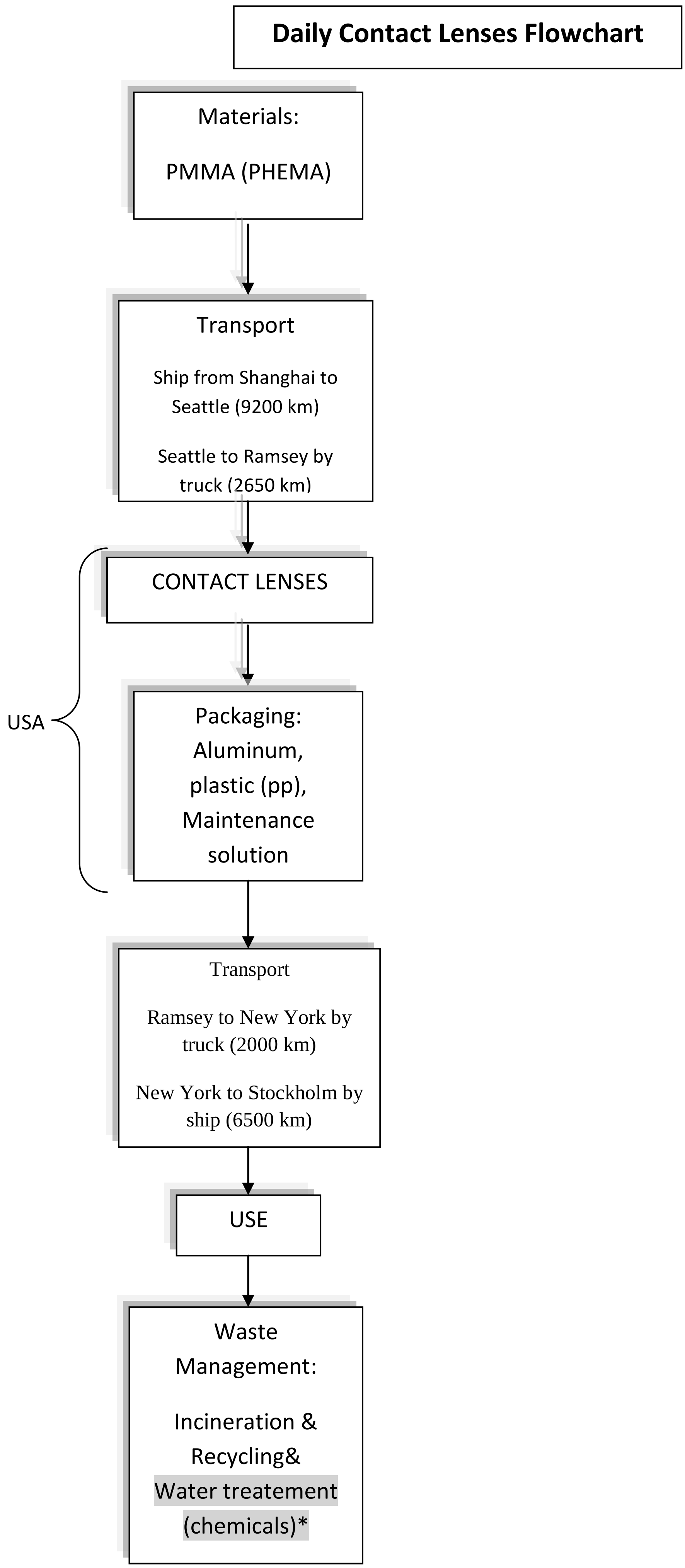

Figure 5. Daily Contact Lenses Flowchart

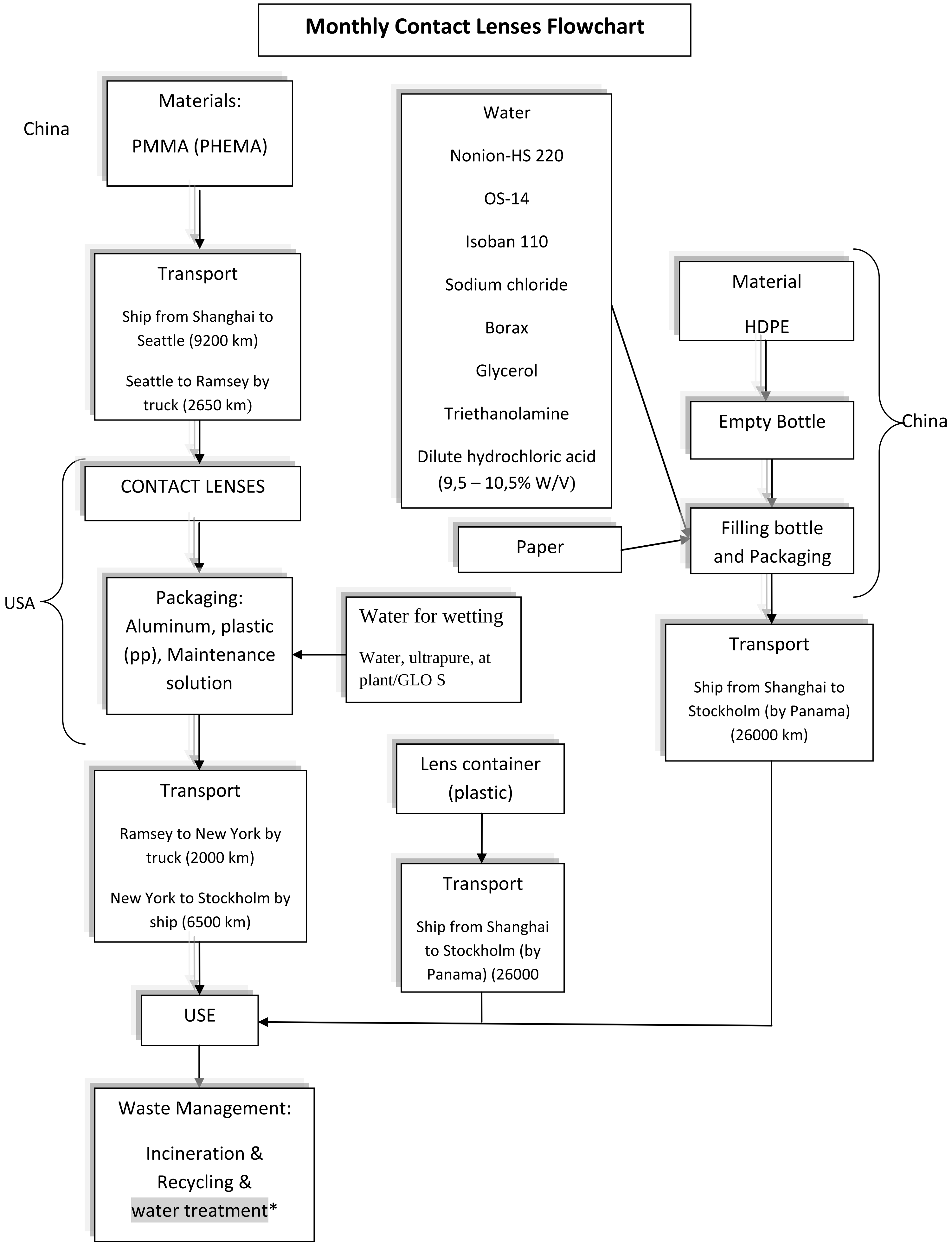

Figure 6. Monthly Contact Lenses Flowchart

2.2 Data

The main source of data for our analysis was provided by the database embedded in the software SimaPro 7.3.2. We used mainly the data from the Ecoinvent database ("Ecoinvent system processes", as implemented in SimaPro 7.3.2) and Industry Data 2.0 ("Industry data 2.0", as implemented in SimaPro 7.3.2). We also refer to LCA publications and websites, especially for statistics about the use of eyeglasses and contact lenses (Rastogi, 2010) and maintenance liquid (Morgan, et al., 2003).

Due to the lack of information about some materials, we made some reasonable approximations. For example, regarding contact lenses, instead of polyhydroxyethyl methacrylate (pHEMA) we considered polymethyl methacrylate (PMMA): these two polymers are different in properties, but they are made starting from very similar chemical products. Thereby the environmental load of their productive process should be comparable. We were self-confident about this assumption after looking at other LCA analysis about contact lenses, where PMMA is "approximated" to polyethylene (PE) (Morgan, et al., 2003).

2.2.1 Assemblies

To do the inventory of the eyeglasses we took a pair of eyeglasses with a metallic frame and we pulled them apart, then we directly weighted each component. The materials the frame is made of were chosen looking at the most used in this context (Morgan, et al., 2011). We considered the lenses to be made of polycarbonate and produced by one American company, *Vision-Ease Lens* (Vision-Ease Lens, 2011). The life time of one pair of glasses was estimated in 2,2 years (Rastogi, 2010). Since we used one year vision correction as a reference, a fraction of "0,46 eyeglasses per year" was considered. In Table 1 the inventory is presented in details.

Table 1. Eyeglasses inventory

Component	Material/Process	SimaPro	Amount	Data source	Description and comments
Frame					
Metallic structure	Monel 400	Iron-nickel-chromium alloy, at plant/RER S	8,5 g	"Ecoinvent system processes", as implemented in SimaPro 7.3.2	In the SimaPro model we use the alloy with the closest composition to the Monel 400 (Alloy Wire International, 2011)
	Wire extrusion	Wire drawing, steel/RER S		"Ecoinvent system processes", as implemented in SimaPro 7.3.2	
Wires to fix the lenses	Nylon 6,6	Nylon 66, at plant/RER S	0,1 g	"Ecoinvent system processes", as implemented in SimaPro 7.3.2	
	Wire extrusion	Extrusion, plastic film/RER S		"Ecoinvent system processes", as implemented in SimaPro 7.3.2	
Nose Pads	PVC	Polyvinylchloride, bulk polymerised, at plant/RER S	0,4 g	"Ecoinvent system processes", as implemented in SimaPro 7.3.2	

Component	Material/Process	SimaPro	Amount	Data source	Description and comments
	Injection moulding	Injection moulding/RER S		"Ecoinvent system processes", as implemented in SimaPro 7.3.2	
Temple tips	Acetate	Ethylene vinyl acetate copolymer, at plant/RER S	1 g	"Ecoinvent system processes", as implemented in SimaPro 7.3.2	
	Injection moulding	Injection moulding/RER S		"Ecoinvent system processes", as implemented in SimaPro 7.3.2	
Screws	Stainless steel 304	Chromium steel 18/8, at plant/RER S	1 g	"Ecoinvent system processes", as implemented in SimaPro 7.3.2	
	Wire extrusion	Wire drawing, steel/RER S		"Ecoinvent system processes", as implemented in SimaPro 7.3.2	
Lenses					
Lenses	Polycarbonate	Polycarbonate granulate (PC), production mix, at plant RER	35 g	"ELCD", as implemented in SimaPro 7.3.2	
	Injection moulding	Injection moulding/RER S		"Ecoinvent system processes", as implemented in SimaPro 7.3.2	

Contact lenses, both daily and monthly, are made of one particular hydrogel, the polyhydroxyethyl methacrylate (pHEMA): this material is a thermoset polymer that can be swollen with water to a high extent, becoming soft, flexible and very permeable to oxygen. They are shaped through injection moulding into a dry product that is wetted afterwards. In our model the process of wetting was implemented just as an input of water, disregarding all the other parameters (e.g. energy consumption) because of a data gap. We also included the packaging: the mass of plastic and aluminum were directly measured, while, regarding the paper box, we considered a box of 5 cm x 5 cm x 12 cm with grammage 240 g/m^2. The packaging take also into account the liquid needed to keep the lenses wet: we assumed that it has the same composition of the maintenance liquid. In the Table 2 the inventory for one lens is reported in detail.

Table 2. Daily contact lenses inventory

Component	Material/Process	SimaPro	Amount	Data source	Description and comments
Contact lens					
Lens	pHEMA	PMMA beads E	25 mg	"Industry data 2.0", as implemented in SimaPro 7.3.2	PMMA and pHEMA are made from similar chemicals, so their impact should be comparable

Component	Material/Process	SimaPro	Amount	Data source	Description and comments
	Injection moulding	Injection moulding/RER S		"Ecoinvent system processes", as implemented in SimaPro 7.3.2	
	Wetting	Water, ultrapure, at plant/GLO S	32 mg	"Ecoinvent system processes", as implemented in SimaPro 7.3.2	In SimaPro this process is modeled just as a mass input flow of water, disregarding the energy and the other impacts
Packaging					
Sealing foil	Aluminium	Aluminium sheet, primary prod., prod. mix, aluminium semi-finished sheet product RER S	0,2 g	"ELCD", as implemented in SimaPro 7.3.2	
Plastic container	PP	Polypropylene injection moulding E	1,12 g	"Industry data 2.0", as implemented in SimaPro 7.3.2	
Maintenance liquid	Assembly Table 5	Maintenance Liquid	0,783 g	–	
Paper box	Kraft paper	Packaging, corrugated board, mixed fibre, single wall, at plant/RER S	0,1167 g	"Ecoinvent system processes", as implemented in SimaPro 7.3.2	One box divided by 60 lenses

For monthly contact lenses (Table 3) we used the same inventory of the daily ones; we assumed that the eventual differences are negligible. In this case we also considered the container where to store the lenses when they are not used: it is made of high density polyethylene (HDPE) and its mass was directly measured (Table 4).

Table 3. Monthly contact lenses inventory

Component	Material/Process	SimaPro	Amount	Data source	Description and comments
Contact lens					
Lens	pHEMA	PMMA beads E	25 mg	"Industry data 2.0", as implemented in SimaPro 7.3.2	PMMA and pHEMA are made from similar chemicals, so their impact should be comparable
	Injection moulding	Injection moulding/RER S		"Ecoinvent system processes", as implemented in SimaPro 7.3.2	
	Wetting	Water, ultrapure, at plant/GLO S	32 mg	"Ecoinvent system processes", as implemented in SimaPro 7.3.2	In SimaPro this process is modeled just as a mass input flow of water, disregarding the energy and the other impacts
Packaging					
Sealing foil	Aluminium	Aluminium sheet, primary prod., prod. mix, aluminium semi-finished sheet	0,2 g	"ELCD", as implemented in SimaPro 7.3.2	

Component	Material/Process	SimaPro	Amount	Data source	Description and comments
		product RER S			
Plastic container	PP	Polypropylene injection moulding E	1,12 g	"Industry data 2.0", as implemented in SimaPro 7.3.2	
Maintenance liquid	Assembly Table 5	Maintenance Liquid	0,783 g	–	
Paper box	Kraft paper	Packaging, corrugated board, mixed fibre, single wall, at plant/RER S	0,1167 g	"Ecoinvent system processes", as implemented in SimaPro 7.3.2	Smaller box, divided by 24 lenses

Table 4. Contact lenses container inventory

Component	Material/Process	SimaPro	Amount	Data source	Description and comments
Contact lenses container					
Container	HDPE	Polyethylene, HDPE, granulate, at plant/RER S	11 g	"Ecoinvent system processes", as implemented in SimaPro 7.3.2	
	Injection moulding	Injection moulding/RER S	11 g	"Ecoinvent system processes", as implemented in SimaPro 7.3.2	

For what concern the maintenance liquids for contact lenses, we referred to a patent composition (Nakagawa, et al., 1996). Due to some lack in the SimaPro database of chemicals, we made some small approximations and simplifications. Also for this assembly we took into account the packaging, whose materials and mass were directly determined. One bottle of maintenance liquid last one month, so 12 bottles per year are needed. Table 5 shows all the details.

Table 5. Maintenance liquid inventory

Component	Material/Process	SimaPro	Amount	Data source	Description and comments
Maintenance liquid					
Solvent	Water	Water, ultrapure, at plant/GLO S	85 g	"Ecoinvent system processes", as implemented in SimaPro 7.3.2	
Chemical components (solutes)	Nonion HS-220 ®	Ethylene glycol diethyl ether, at plant/RER S	2 g	"Ecoinvent system processes", as implemented in SimaPro 7.3.2	

Component	Material/Process	SimaPro	Amount	Data source	Description and comments
	OS-14 ®	Alkylbenzene sulfonate, linear, petrochemical, at plant/RER S	1 g	"Ecoinvent system processes", as implemented in SimaPro 7.3.2	
	Isoban 110 ®	Maleic anhydride, at plant/RER S	0,5 g	"Ecoinvent system processes", as implemented in SimaPro 7.3.2	
	Sodium chloride	Sodium chloride, powder, at plant/RER S	1 g	"Ecoinvent system processes", as implemented in SimaPro 7.3.2	
	Borax	Borax, anhydrous, powder, at plant/RER S	0,5 g	"Ecoinvent system processes", as implemented in SimaPro 7.3.2	
	Glycerol	Glycerine, from epichlorohydrin, at plant/RER S	10 g	"Ecoinvent system processes", as implemented in SimaPro 7.3.2	
	Triethanolamine	Triethanolamine, at plant/RER S	0,5 g	"Ecoinvent system processes", as implemented in SimaPro 7.3.2	
	Dilute hydrochloric acid (9,5 – 10,5% W/V)	Hydrochloric acid, 30% in H2O, at plant/RER S	0,2 g	"Ecoinvent system processes", as implemented in SimaPro 7.3.2	
Packaging					
Plastic bottle	HDPE	Polyethylene, HDPE, granulate, at plant/RER S	20 g	"Ecoinvent system processes", as implemented in SimaPro 7.3.2	
	Blow moulding	Blow moulding/RER S		"Ecoinvent system processes", as implemented in SimaPro 7.3.2	
Paper box	Kraft paper	Packaging, corrugated board, mixed fibre, single wall, at plant/RER S	7 g	"Ecoinvent system processes", as implemented in SimaPro 7.3.2	

2.2.2 Transportations

To assess the impact arising from the transport phase, we referred to the geographical boundaries set in the goal and scope. In particular, we placed the production of raw materials and eyeglasses metal frame in China (Shanghai). This choice was driven by our background knowledge about materials. The eyeglasses lenses, manufactured by the company we have chosen, are produced in a plant in Ramsey, Minnesota USA (Vision-Ease Lens, 2011). We also assumed that the contact lenses are produced in the same industrial district. The distances travelled have been estimated considering the busiest goods ports and using the software Google Earth. They are just an approximation of the real route the goods follow (Figure 7).

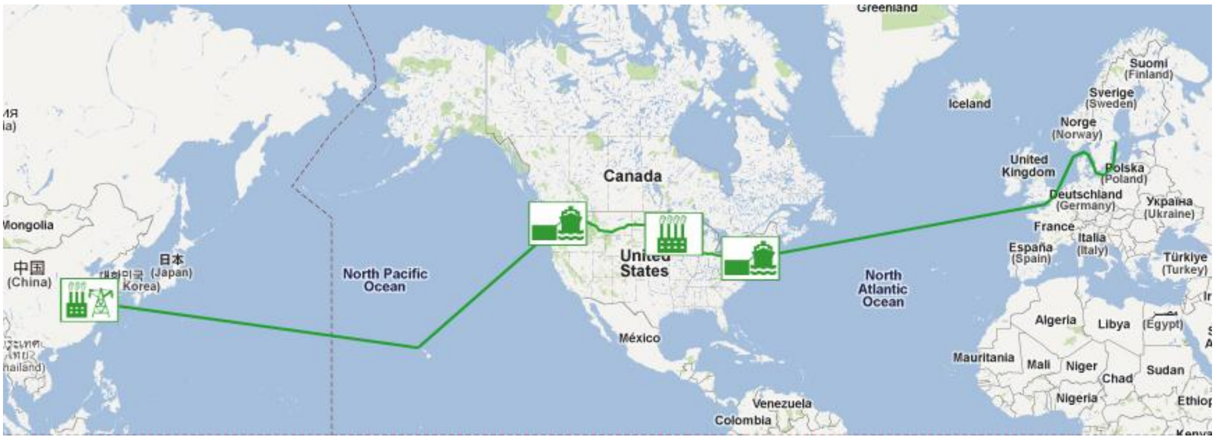

Figure 7. Estimated route

The transportations on water are by freight, while those on road are by truck. The goods that go directly from Shanghai to Stockholm are transported by freight, following a sea route passing through Panama. The details about transportation are reported on the Table 6.

Table 6. Transportations

Component	Transport	SimaPro	Distance	Data source
Eyeglasses				
Frame	from Shanghai to Stockholm (by Panama) by freight	Transport, transoceanic freight ship/OCE S	26000 km	“Ecoinvent system processes”, as implemented in SimaPro 7.3.2
Polycarbonate for lenses	from Shanghai to Seattle by freight	Transport, transoceanic freight ship/OCE S	9200 km	“Ecoinvent system processes”, as implemented in SimaPro 7.3.2
	from Seattle to Ramsey (MN, USA) by truck	Transport, lorry >16t, fleet average/RER S	2650 km	“Ecoinvent system processes”, as implemented in SimaPro 7.3.2
Lenses	from Ramsey (MN, USA) to New York by truck	Transport, lorry >16t, fleet average/RER S	2000 km	“Ecoinvent system processes”, as implemented in SimaPro 7.3.2
	from New York to Stockholm by freight	Transport, transoceanic freight ship/OCE S	6500 km	“Ecoinvent system processes”, as implemented in SimaPro 7.3.2
Contact lenses				
pHEMA for lenses	from Shanghai to Seattle by freight	Transport, transoceanic freight ship/OCE S	9200 km	“Ecoinvent system processes”, as implemented in SimaPro 7.3.2
	from Seattle to Ramsey (MN, USA) by truck	Transport, lorry >16t, fleet average/RER S	2650 km	“Ecoinvent system processes”, as implemented in SimaPro 7.3.2
Contact lenses	from Ramsey (MN, USA) to New York by truck	Transport, lorry >16t, fleet average/RER S	2000 km	“Ecoinvent system processes”, as implemented in SimaPro 7.3.2

Component	Transport	SimaPro	Distance	Data source
	from New York to Stockholm by freight	Transport, transoceanic freight ship/OCE S	6500 km	"Ecoinvent system processes", as implemented in SimaPro 7.3.2
Contact lenses container				
Container	from Shanghai to Stockholm (by Panama) by freight	Transport, transoceanic freight ship/OCE S	26000 km	"Ecoinvent system processes", as implemented in SimaPro 7.3.2
Maintenance liquid				
Bottle of maintenance liquid	from Shanghai to Stockholm (by Panama) by freight	Transport, transoceanic freight ship/OCE S	26000 km	"Ecoinvent system processes", as implemented in SimaPro 7.3.2

2.2.3 Waste management

The end of life of the products we have considered in our analysis is set in Stockholm. We have assumed two different waste scenarios: one for eyeglasses and one for contact lenses. In our hypothesis eyeglasses go to the not recycled fraction of domestic waste and, afterwards, to incineration. Contact lenses, together with their packaging, as well as the packaging of the maintenance liquid, are instead partially recycled and partially incinerated. In waste scenarios we haven't taken into account the landfill and the waste water treatment.

According to Swedish statistics, in 2009 the recycling fraction of paper packaging was 74%, while for plastic packaging it was 31% (Svantesson, 2011). We used these percentages to model the waste scenario and we created two processes for recycling on SimaPro, one for paper and one for plastics (Table 7).

Table 7. Recycling processes

Name	Default material/Waste type	Avoided products
5 - Recycling cardboard/RER S	Cardboard 1,03 kg	Core board, at plant/RER S 1 kg
5 - Recycling mixed plastics/RER S	Plastic 1 kg	Polyethylene, HDPE, granulate, at plant/RER S 0,4 kg
		Polyvinylchloride, bulk polymerised, at plant/RER S 0,15 kg
		Polyethylene terephthalate, granulate, amorphous, at plant/RER S 0,4 kg

To assess the avoided burden, we considered the heat and the electricity produced with incineration of plastic and we supposed them to replace an equivalent fraction of energy produced according to the Swedish energy mix ("Electricity, medium voltage, production SE, at grid/SE S" and " Heat, biowaste, at waste incineration plant, allocation price/CH S" from "Ecoinvent system processes", as implemented in SimaPro 7.3.2). Therefore we started estimating the average feedstock energy: we computed the average of the gross heat of combustion of some relevant polymers (Walters, et al., 2000):

Polymer	Heat of combustion (MJ/kg)
Polycarbonate (PC)	31,5
Polyethylene (PE)	47,74
Polymethyl methacrylate (PMMA)	26,7
Polypropylene (PP)	45,8
Average	**38**

The average efficiency of combined heat and power (CHP) plants in Stockholm is about 86% (Ottinger, 2005) so the energy produced from 1 kg of plastics may be estimated as:

$$38 \cdot 0{,}86 = 32{,}68\ MJ/kg$$

This energy is produced in the form of both heat and electricity. To solve this allocation problem we referred to Hässelbyverket CHP-plant in Stockholm (Fortum, 2011): in one year they produce 900 GWh (75%) of heat and 300 GWh (25%) of electricity. So for 1 kg of plastics we have the following avoided burdens:

	Percentage	Energy produced (MJ/kg)	Avoided production of
Heat	75%	**24,51**	Heat, biowaste, at waste incineration plant, allocation price/CH S
Electricity	25%	**8,17**	Electricity, medium voltage, production SE, at grid/SE S
Total	100%	32,68	

We then implemented these result in a customized incineration process ("5 - Disposal, plastics, mixture, 15.3% water, to municipal incineration/CH S").

3 Life cycle interpretation

Life cycle interpretation refers to the LCI and the LCIA carried on in the previous section. Analyzing the results, we can draw some conclusion on the overall impact of the products considered, in a life cycle perspective.

3.1 Results

The results of the comparative and accounting LCA for eyeglasses, daily and monthly contact lenses are mainly based on data from SimaPro. The analysis was carried on with an iterative approach: after looking at the preliminary normalization results, we focus on the impact categories with the higher relevance on the global scale.

The seven impact categories considered in this case are: climate change, human toxicity, terrestrial acidification, fresh water eco-toxicity, marine eco-toxicity, metal depletion and fossil depletion.

Climate change. The potential impact on climate change for eyeglasses is mostly from the polycarbonate granulate (PC) used to manufacture the lenses, as it is shown in the Figure 8.

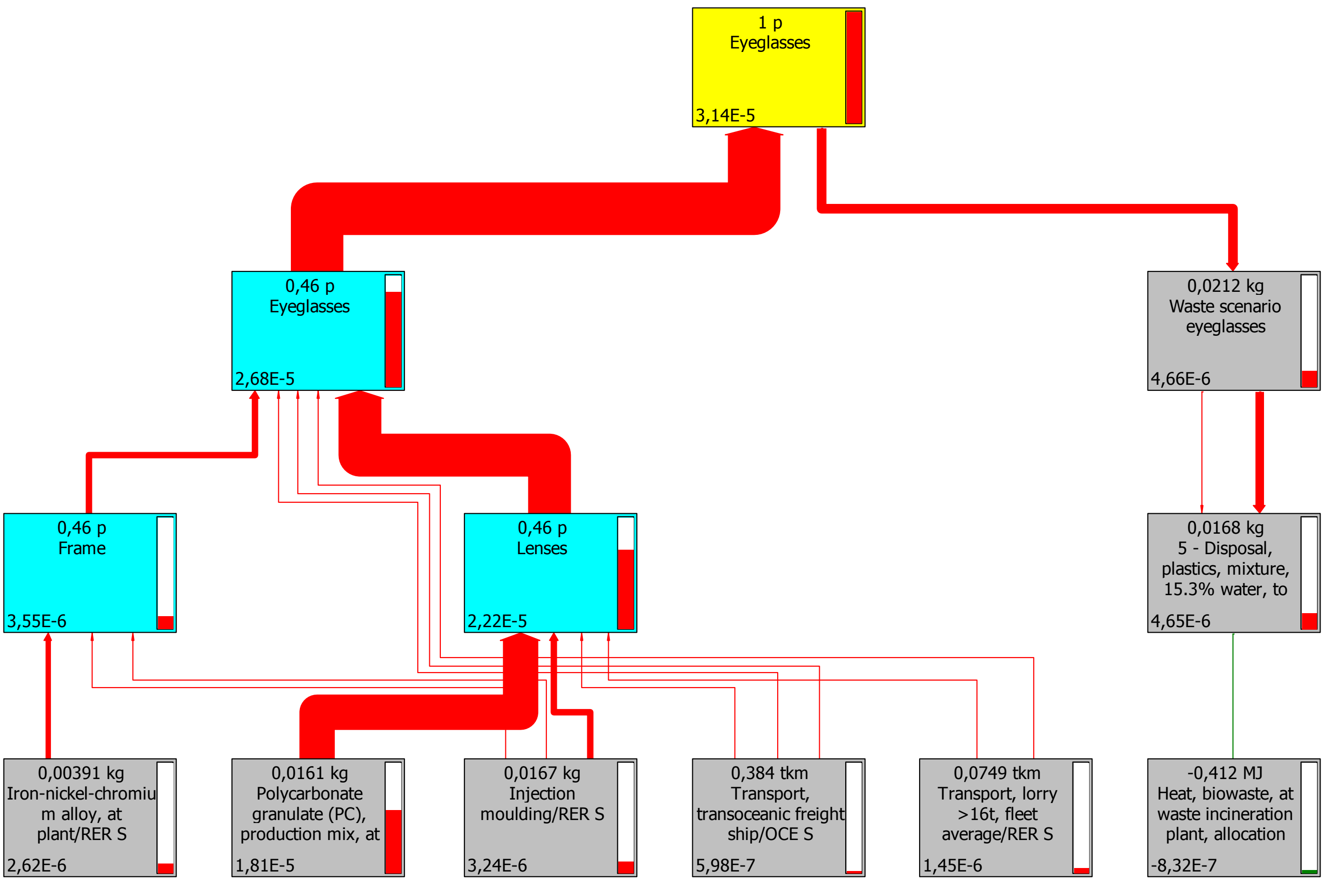

Figure 8. Normalization of climate change for life cycle of eyeglasses (adapted from SimaPro)

Another polymer, polypropylene (PP), is the main component responsible for climate change regarding daily contact lenses (Figure 9). This impact comes from the packaging.

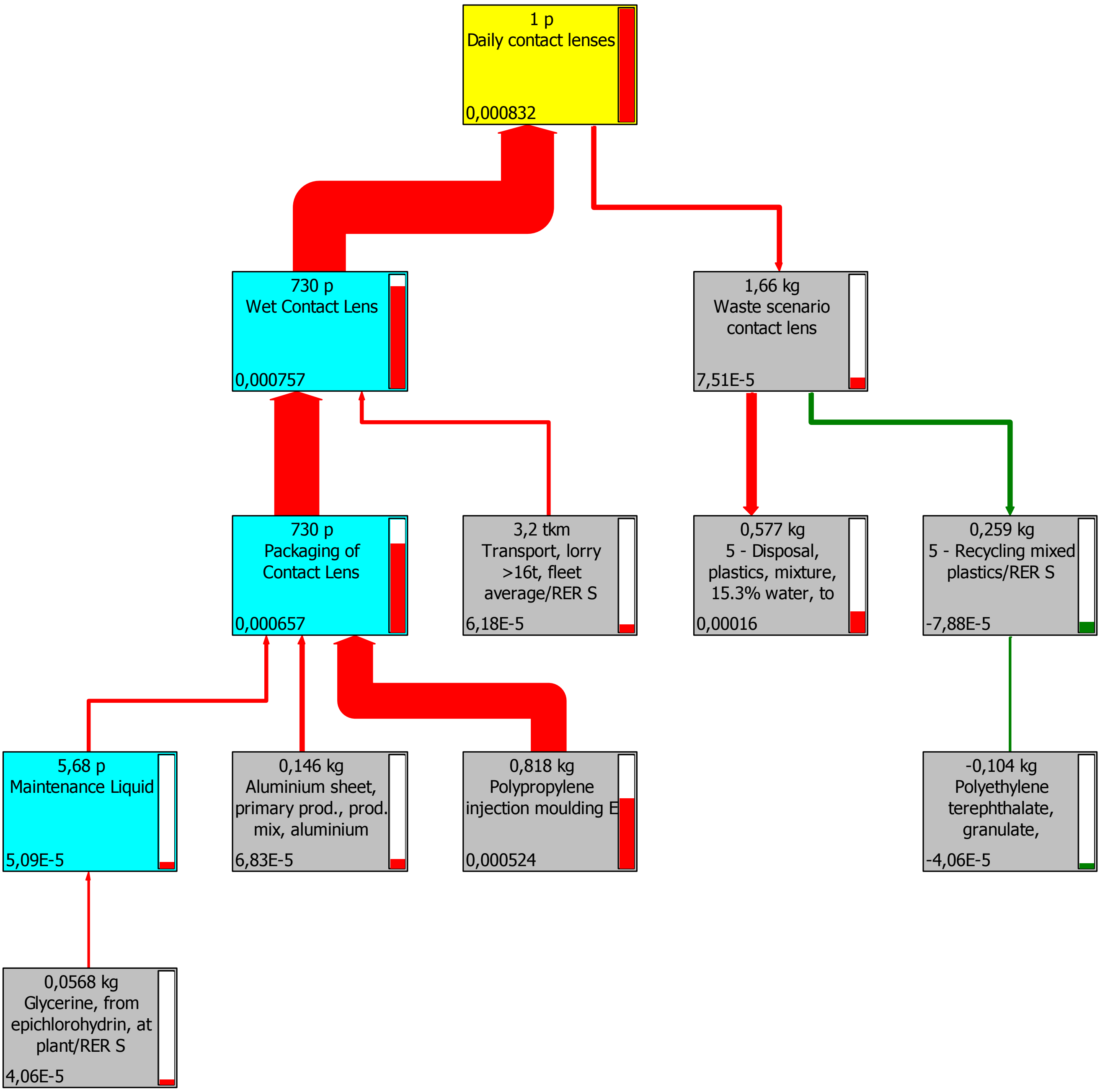

Figure 9. Normalization of climate change for life cycle of daily contact lenses (adapted from SimaPro)

Looking at the monthly contact lenses, the presence of the maintenance liquid gives rise to a relevant impact from the high density polyethylene (HDPE) of the bottle and from the glycerine contained in the chemical formulation (Figure 10).

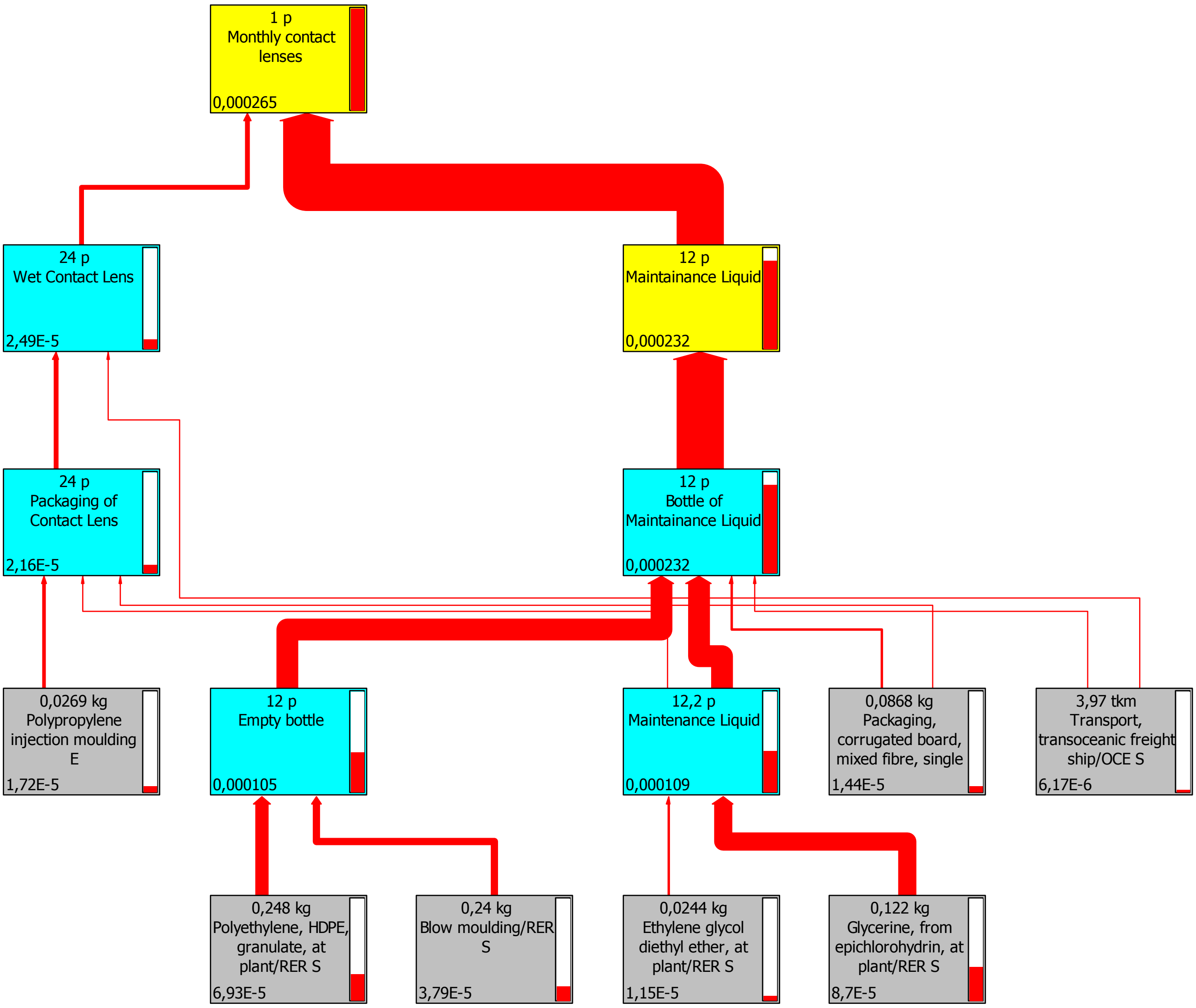

Figure 10. Normalization of climate change for life cycle of monthly contact lenses (adapted from SimaPro)

Human toxicity. The iron-nickel-chromium alloy in the frame of eyeglasses is the main component which causes human toxicity (Figure 13[1]). Human toxicity in daily contact lenses is originated from the glycerine required for the maintenance liquid in the packaging; this is completely recovered through incineration (Figure 14). For monthly contact lenses human toxicity comes again from the bottle of maintenance liquid (blow molding of the bottle and glycerine in the chemical composition, Figure 15).

Terrestrial acidification. The iron-nickel-chromium alloy of the frame, followed by the polycarbonate of the lenses, are the main reasons for terrestrial acidification in eyeglasses (Figure 16). Terrestrial acidification caused by daily contact lenses is originated from the polypropylene of the packaging (Figure 17). For monthly contact lenses there are three main sources that cause terrestrial acidification respectively named: polyethylene (HDPE) and blow molding for the empty bottle assembly and glycerine for the maintenance liquid (Figure 18).

[1] Figures 10 to 27 are reported in the appendix

Fresh water eco-toxicity. The iron-nickel-chromium alloy is again the most important reason for freshwater eco-toxicity in eyeglasses (Figure 19). Glycerine for maintenance liquid is responsible for fresh water eco-toxicity for daily contact lenses (Figure 20). Glycerine for maintenance liquid and blow molding are the two main sources that cause fresh water eco-toxicity in monthly contact lenses (Figure 21).

Marine eco-toxicity. The iron-nickel-chromium alloy is still the most relevant contribution to marine eco-toxicity in eyeglasses (Figure 22). Glycerine for maintenance liquid is the reason for marine eco-toxicity in daily contact lenses (Figure 23). Marine eco-toxicity originated by monthly contact lenses comes from glycerine for maintenance liquid and from blow molding of the plastic bottle (Figure 24).

Metal depletion. The iron-nickel-chromium alloy is the main reason for metal depletion in eyeglasses (Figure 25). Glycerine for maintenance liquid, transportation by lorry (metal used to build the track) and aluminum sheet for packaging are responsible for the metal depletion in daily contact lenses (Figure 26). Metal depletion regarding monthly contact lenses mainly comes from the glycerine needed for maintenance liquid (Figure 27).

Fossil depletion. Polycarbonate granulate for the lenses is the main source of fossil depletion in eyeglasses (Figure 28). Polypropylene for packaging is responsible for fossil depletion impact of daily contact lenses (Figure 29), while for monthly contact lenses fossil depletion is caused both by glycerine for maintenance liquid, as well as polyethylene used for the empty bottle (Figure 30).

Looking at the overall impact for each assembly, few components have a relevant impact for almost all the categories chosen. The metal alloy is the largest source for all the impact of the eyeglasses: the elements it is made of are toxic metals, like nickel and chromium. The only exception is represented by the climate change: in this case the polycarbonate of the lenses plays the lion share, mainly because of its fossil origin and its high feedstock energy.

Coming to contact lenses, glycerine result to be responsible in almost every kind of impact: this may arise from the use of chlorine in its production. The packaging of contact lenses is of great importance, too. Its plastic components cause relevant impact in almost all the categories considered, especially for what concern the climate change.

The characterization comparison clearly demonstrates that eyeglasses have a smaller impact in all the impact categories chosen for this case study, except from human toxicity and metal depletion. Considering contact lenses, daily contact lenses have the largest impact on climate change, terrestrial acidification and fossil depletion. For the others (human toxicity, freshwater eco-toxicity, marine eco-toxicity and metal depletion) monthly contact lenses show a more important impact (Figure 11).

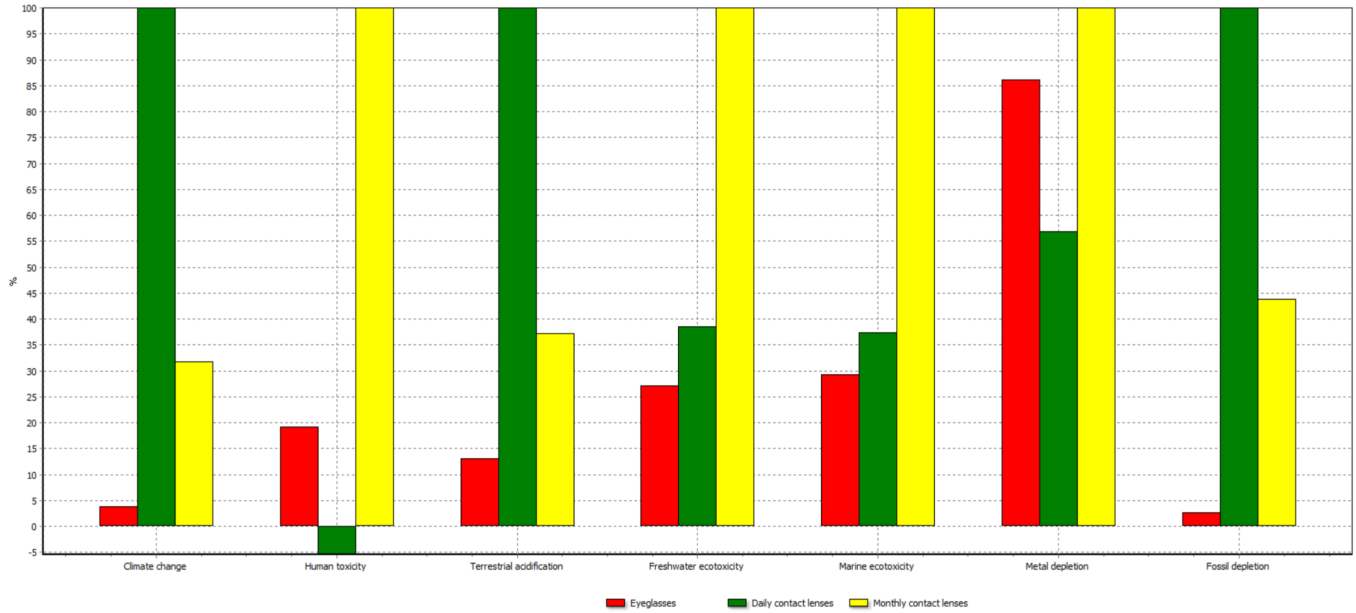

Figure 11. Comparing eyeglasses, daily contact lenses and monthly contact lenses by characterization

The impact assessed with the characterization method are showed, in the above graph, in percentage, based on the highest impact. The actual numerical values (per functional unit) for each category are presented in Table 8.

Table 8. Comparing eyeglasses, daily contact lenses and monthly contact lenses by characterization

Impact Category	Unit	Eyeglasses	Daily contact lenses	Monthly contact lenses
Climate Change	kg CO2 eq	0,217	5,74	1,82
Human Toxicity	kg CFC-11 eq	0,112	-0,0316	0,583
Terrestrial acidificatiom	kg SO2 eq	0,00239	0,0183	0,00681
freshwater ecotoxicity	kg 1,4-DB eq	0,00297	0,00422	0,011
Marine ecotoxicity	kg 1,4- DB eq	0,00317	0,00404	0,0108
Metal depletion	kg Fe eq	0,0556	0,0367	0,0646
Fossil depletion	kg oil eq	0,0568	2,16	0,946

The normalization of the results (Figure 12) give us a general idea of which are the more relevant impacts in the global context. Compared to the total emissions, those which cause climate change are relatively small. Also the contribution to metal depletion is considerably narrowed down. The larger impacts, in the broader context, are relative to human toxicity, freshwater and marine eco-toxicity for monthly contact lenses: they arise from the relatively large quantity of maintenance liquid needed for this product.

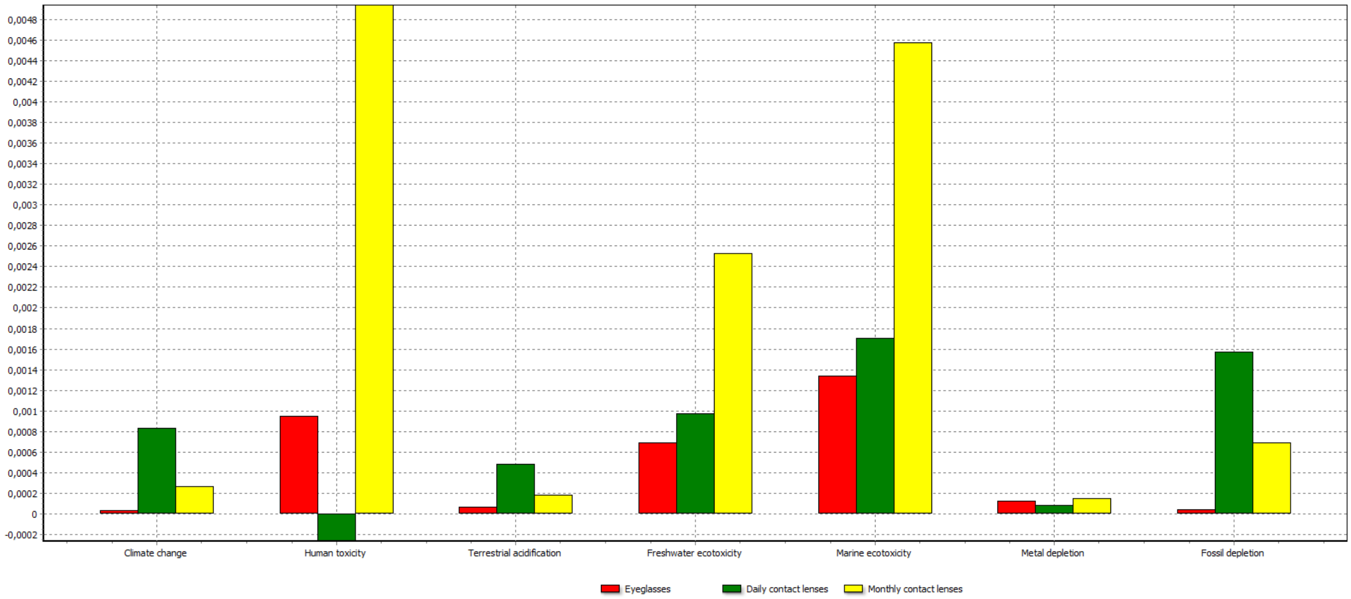

Figure 12. Comparing eyeglasses, daily contact lenses and monthly contact lenses by Normalization

Looking closer at the numerical values (Table 9), the results show how the impact coming from these products is really small, compared to the whole impact of everyday life.

Table 9. Comparing eyeglasses, daily contact lenses and monthly contact lenses by Normalization

Impact Category	Unit	Eyeglasses	Daily contact lenses	Monthly contact lenses
Climate Change	kg CO2 eq	3,14 E-5	0,000832	0,000265
Human Toxicity	kg CFC-11 eq	0,000946	-0,000268	0,00494
Terrestrial acidificatiom	kg SO2 eq	6,25E-05	0,000478	0,000178
freshwater ecotoxicity	kg 1,4-DB eq	0,000686	0,000973	0,00253
Marine ecotoxicity	kg 1,4- DB eq	0,00134	0,00171	0,00458
Metal depletion	kg Fe eq	0,000125	8,25E-05	0,000145
Fossil depletion	kg oil eq	4,14E-05	0,00157	0,000689

The results show that monthly contact lenses have generally a larger impact than the daily ones; this is consistent with other studies carried on this topic (Morgan, et al., 2003) and provide a validation to the model we build up.

It's also important to notice that daily contact lenses have a negative value of the human toxicity index just because the choice we did in modeling the waste scenario. With a worse treat management, that is easy to find out of the Stockholm context, surely the result would have been different.

3.2 Conclusions and recommendations

Assessing the more environmental-friendly option for vision correction was the goal of this study. By analyzing three options (eyeglasses, daily contact lenses and monthly contact lenses) we tried to give a comprehensive overview on this concern.

Despite approximations and cut-off necessarily made, the results of the analysis are consistent with our expectations: we suspected from the beginning that the impact of contact lenses should have been higher, because they are disposable products, with a short life time, and they involve quite a relevant packaging. The only surprise arises from the maintenance liquid, which has an impact higher than expected and gives a large contribution to the burdens coming from monthly contact lenses.

The comparative accounting LCA, carried on with SimaPro, shows that the eyeglasses have the lowest impact during the whole life cycle, with respect to the other two options. We draw these conclusions looking at the environmental impact categories we chose: eyeglasses perform better for all the indicators, except from two, human toxicity and metal depletion. For both, the more relevant contribution comes from the metal alloy used in the frame because it contains metal elements, such as nickel and chromium, which are toxic. On the other hand, the burden associated with the climate change indicator is much lower, as well as the fossil depletion.

For what concern daily contact lenses, the highest impact comes from climate change, terrestrial acidification and fossil depletion. This is mainly due to the packaging: each pair of lenses of 100 mg comes with almost 4 g of plastic packaging that is thrown away every day. On the other hand, they don´t need any kind of maintenance and so no chemical product for cleaning and preserving, with the correspondent impact, is involved in their life cycle.

Finally, monthly contact lenses are largely responsible for human toxicity, freshwater eco-toxicity and marine eco-toxicity. This is due to the maintenance liquid and, in particular to the glycerine contained. This chemical is not hazardous itself, but those impacts probably arise from its productive process, but further research are required to say the last word about this issue.

Without having performed a weighting procedure, it’s hard to state a final and sure conclusion about which is the more eco-friendly product. In spite of this, eyeglasses perform better in the majority of the indicators, so we can say, with some confidence, that they are the greenest choice. Such a conclusion is strengthened by the large difference in the climate change impact: this is one of the biggest issues discussed by politics and society nowadays, and it’s one of the indicators that people mostly pay attention to. On the other hand, one of the biggest limitations of our study comes from the fact that we investigated just one specific model of eyeglasses. Widening the perspective to include different models, made of different materials, the results may change: it would be interesting to assess how much a plastic frame would affect the results (increasing the contribution to climate change? to which extent?).

It’s important to underline that we did not consider the “price factor”, neither the “fashion factor”: these parameter, as well as the people (mis)behavior in the maintenance, are difficult to be taken into account because they are aleatory data, difficult to estimate.

Considering the limitations of our analysis, it would be of great interest to go deeper into this matter, including some of the cut-off within the system boundaries and looking at a wider context. Anyway LCA proved to be a powerful tool and showed how thinking in a life cycle perspective allows obtaining comprehensive and meaningful results.

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5 Appendix

In this appendix we report the Figures 10 to 27, which the Results section refers to.

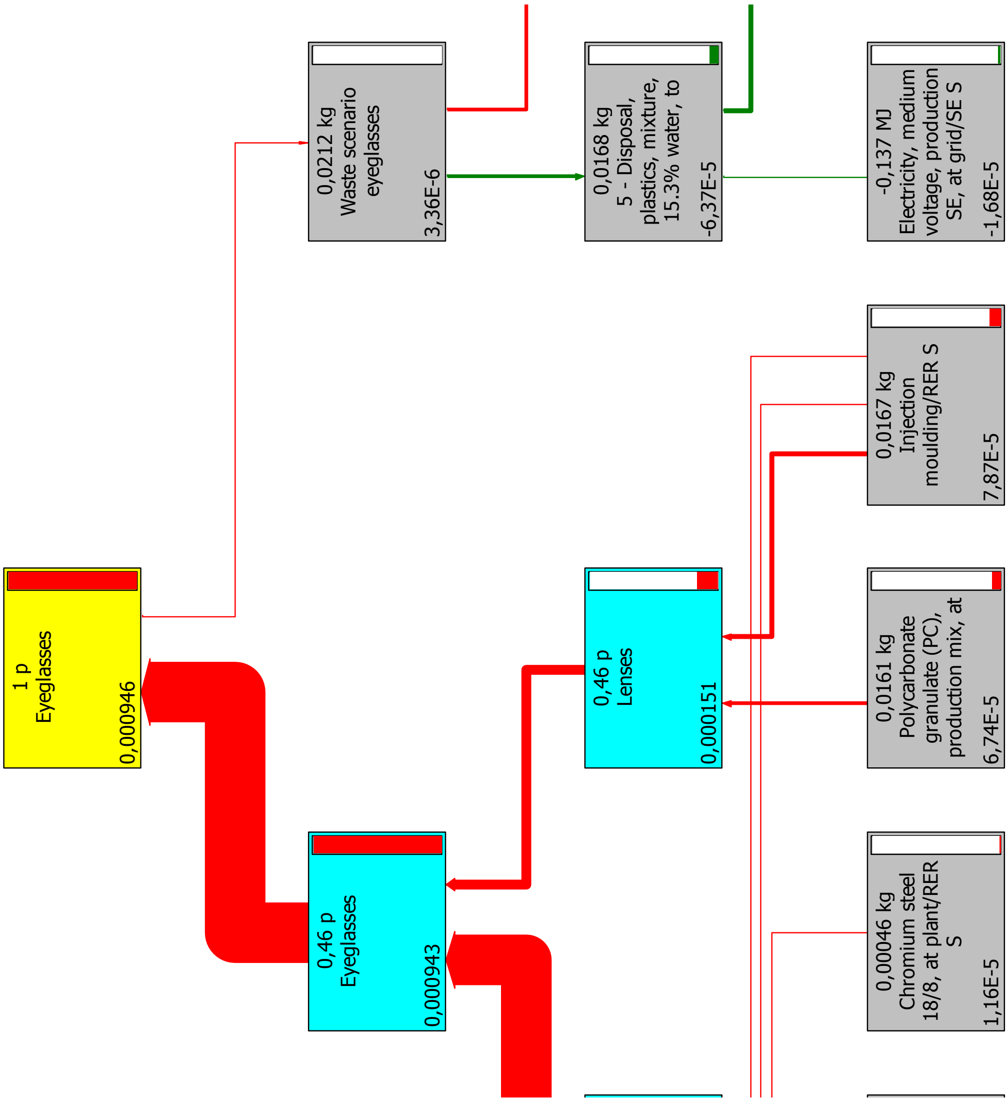

Figure 13. Normalization of human toxicity for life cycle of eyeglasses

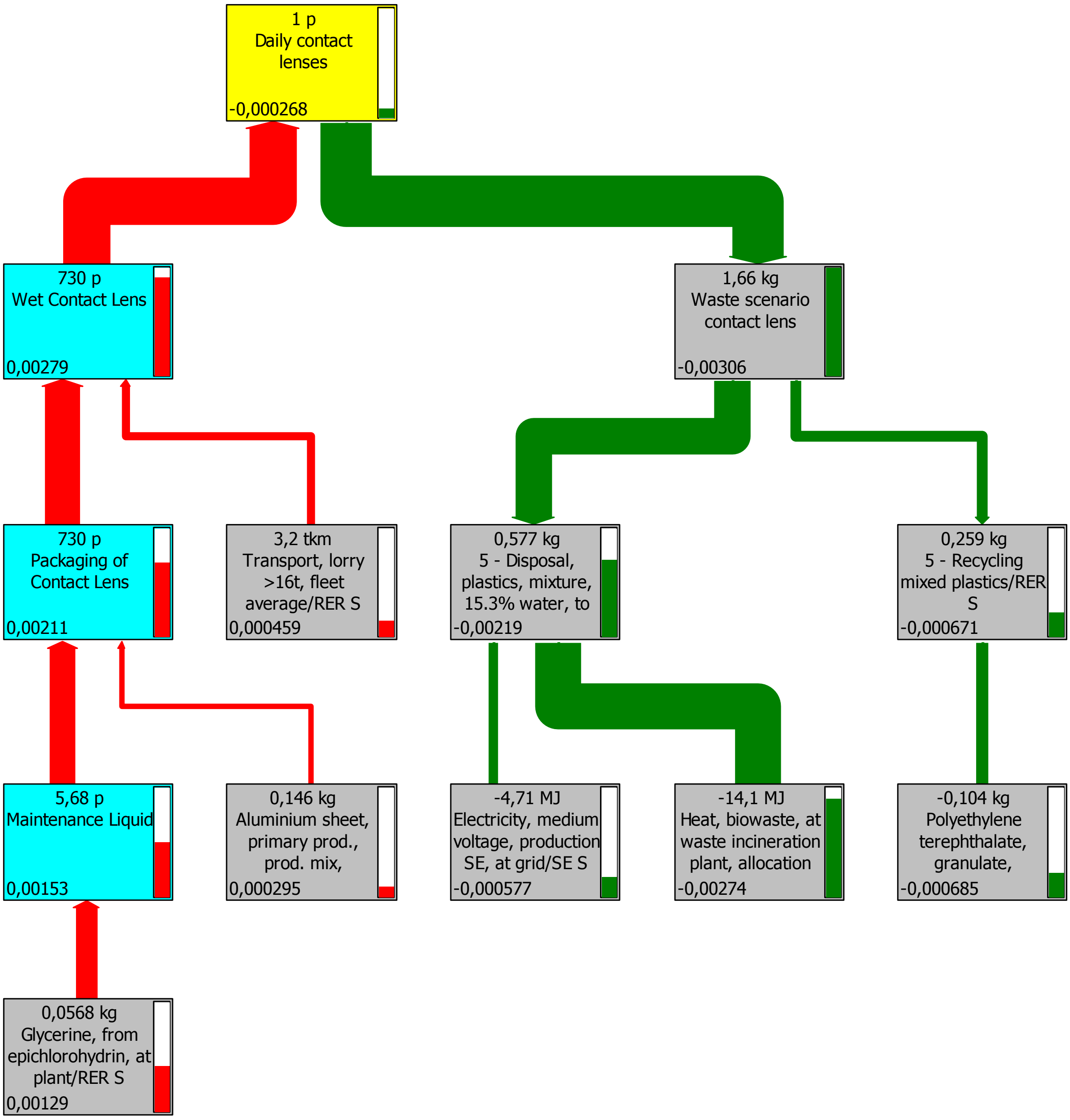

Figure 14. Normalization of human toxicity for life cycle of daily contact lenses

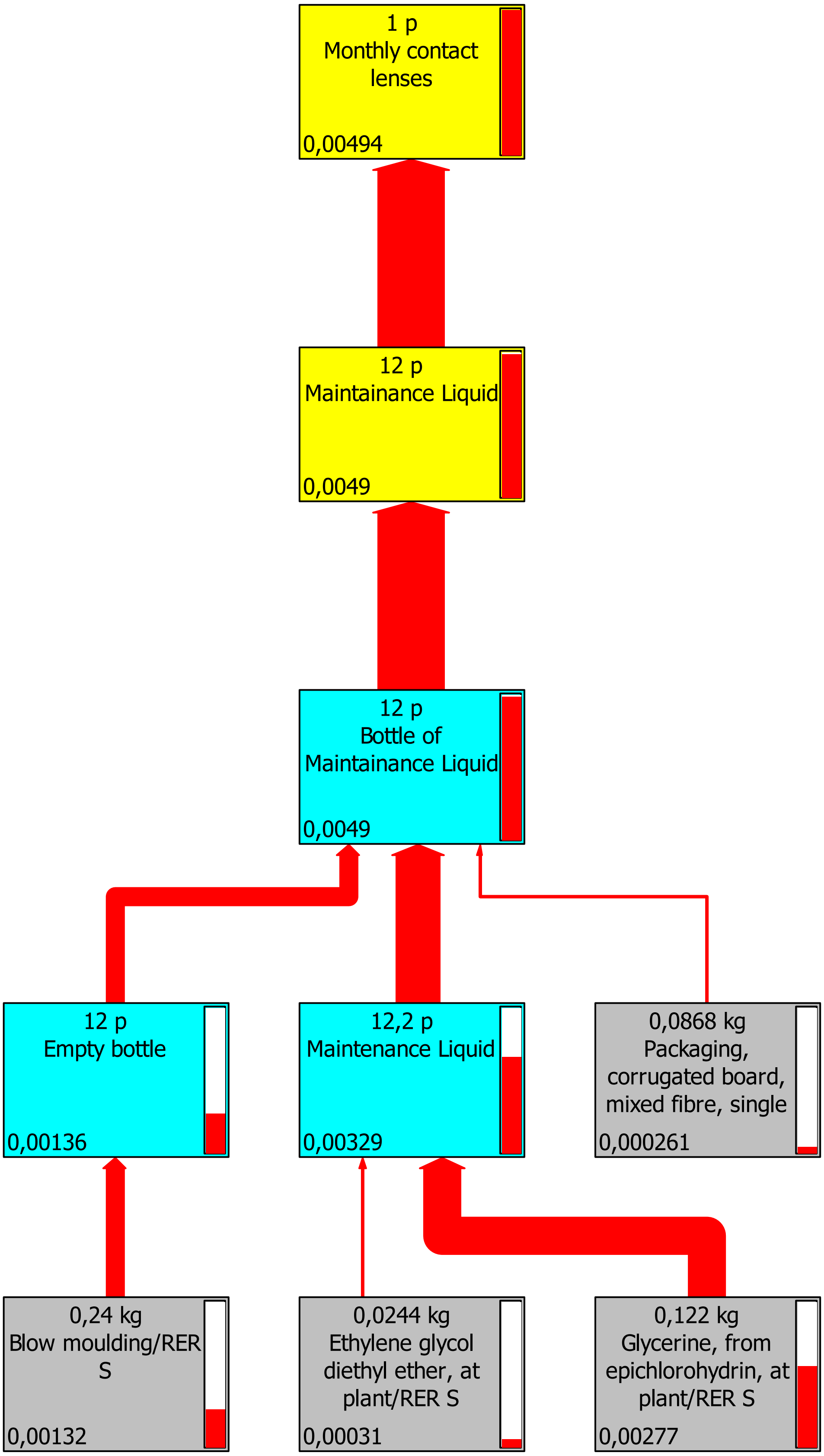

Figure 15. Normalization of human toxicity for life cycle of monthly contact lenses

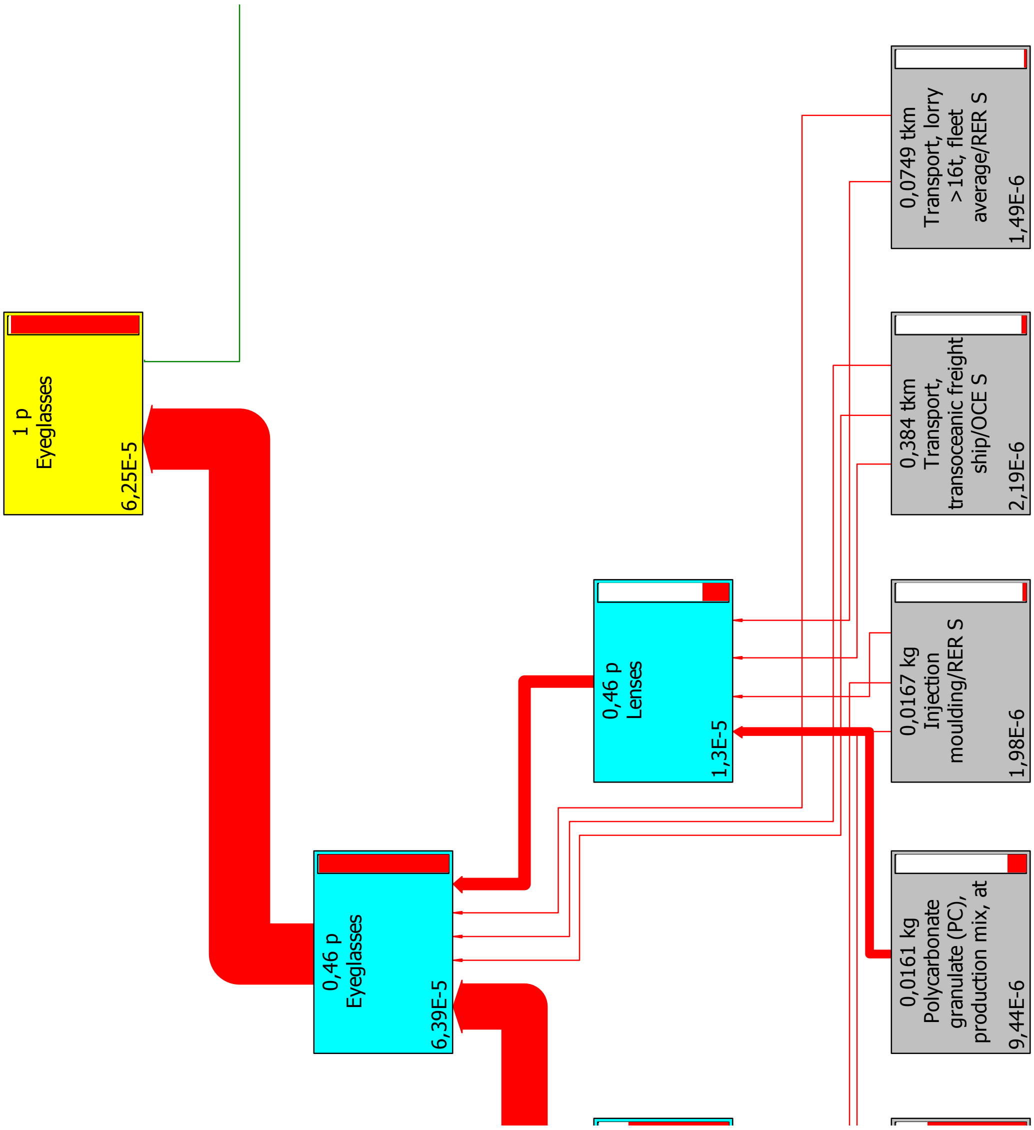

Figure 16. Normalization of terrestrial acidification for life cycle of eyeglasses

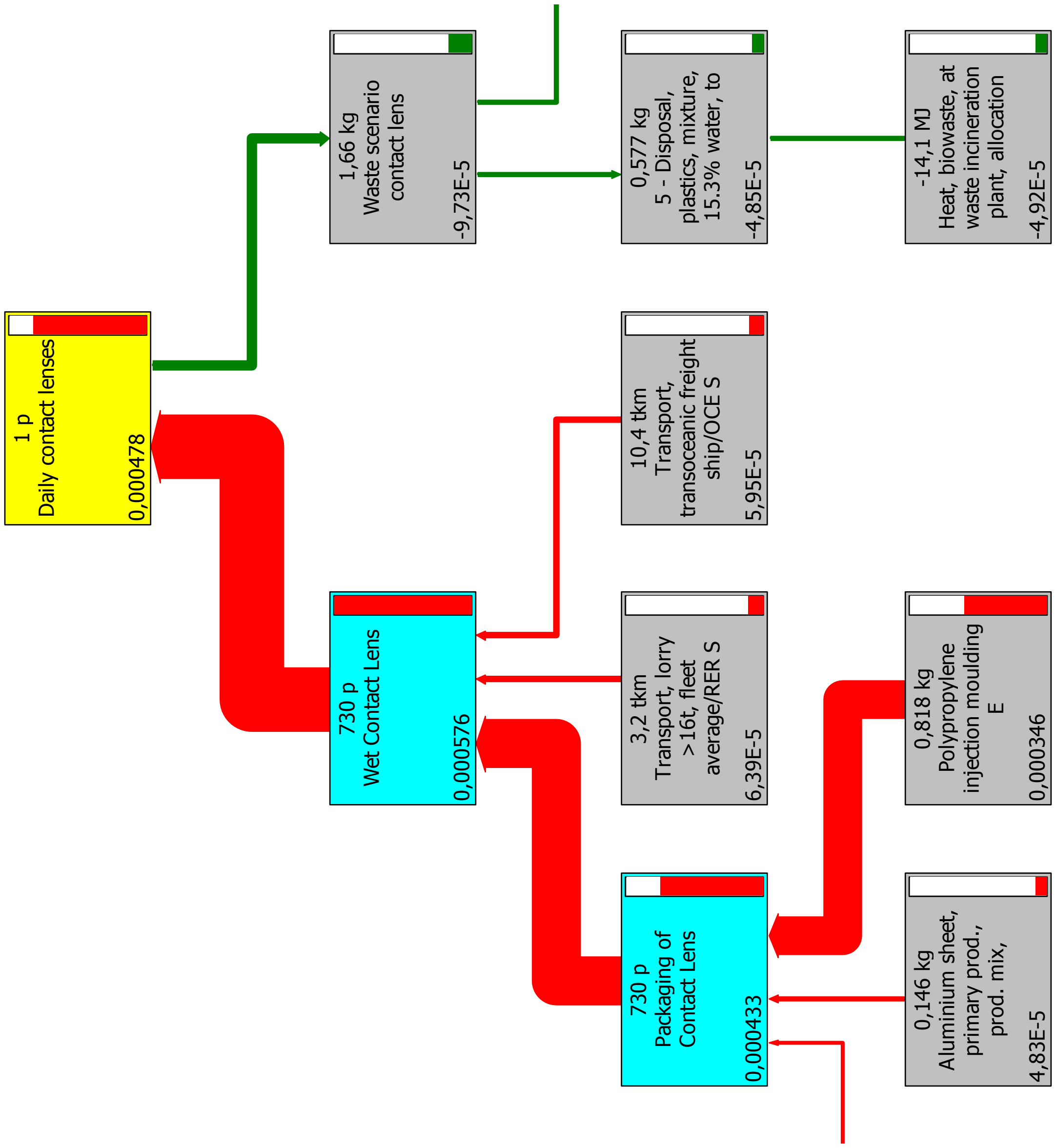

Figure 17. Normalization of terrestrial acidification for life cycle of daily contact lenses

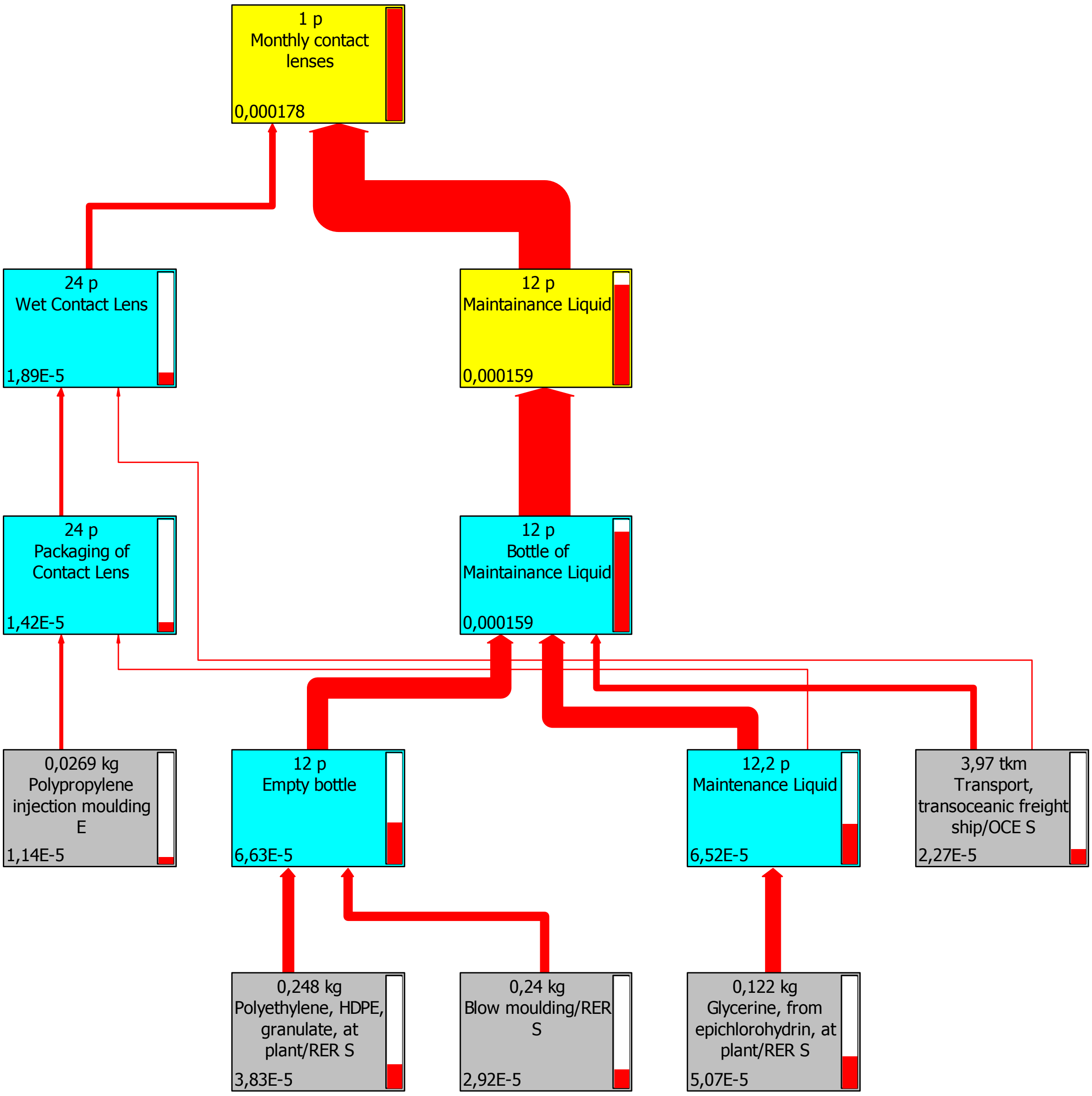

Figure 18. Normalization of terrestrial acidification for life cycle of monthly contact lenses

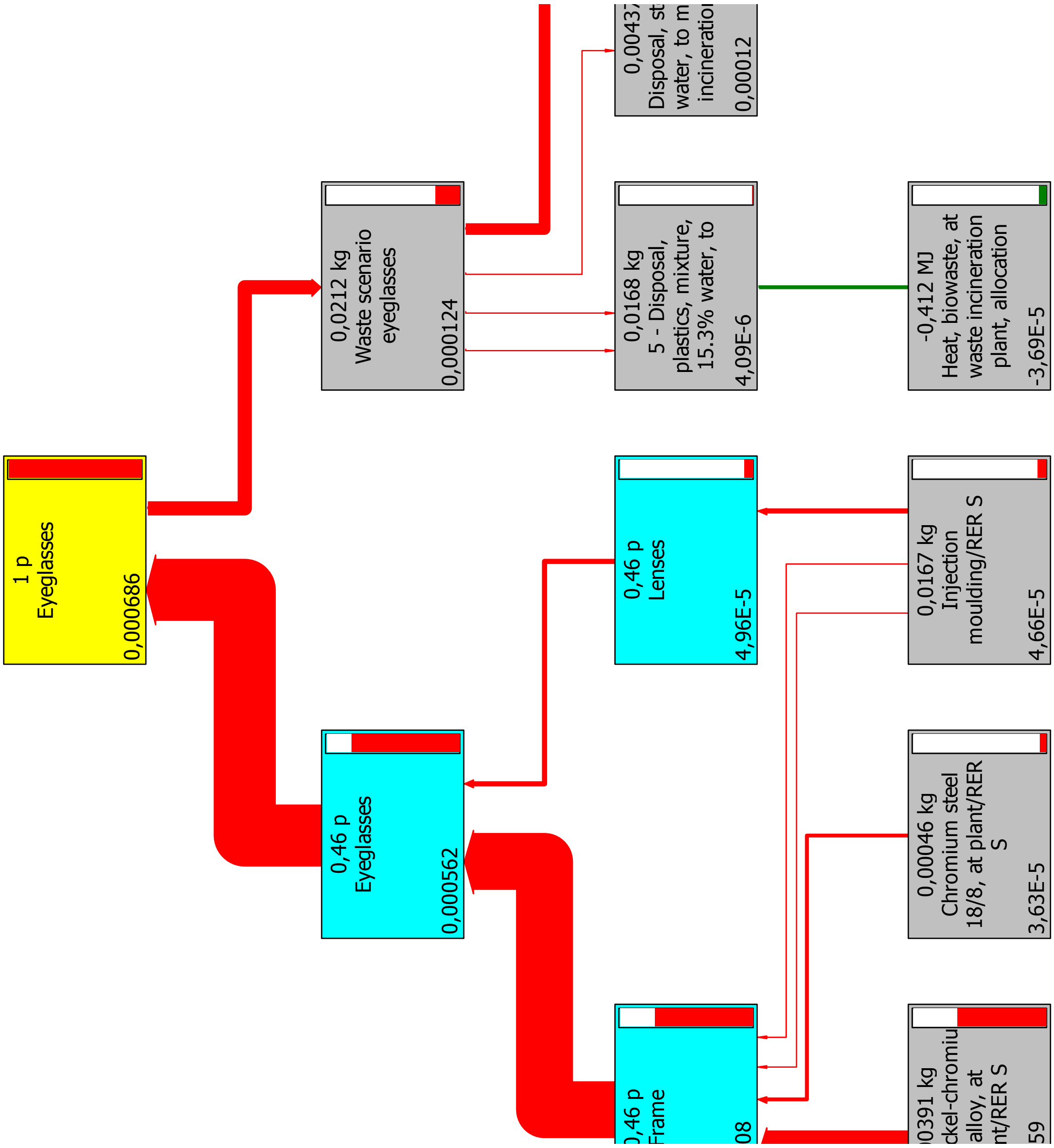

Figure 19. Normalization of fresh water eco-toxicity for life cycle of eyeglasses

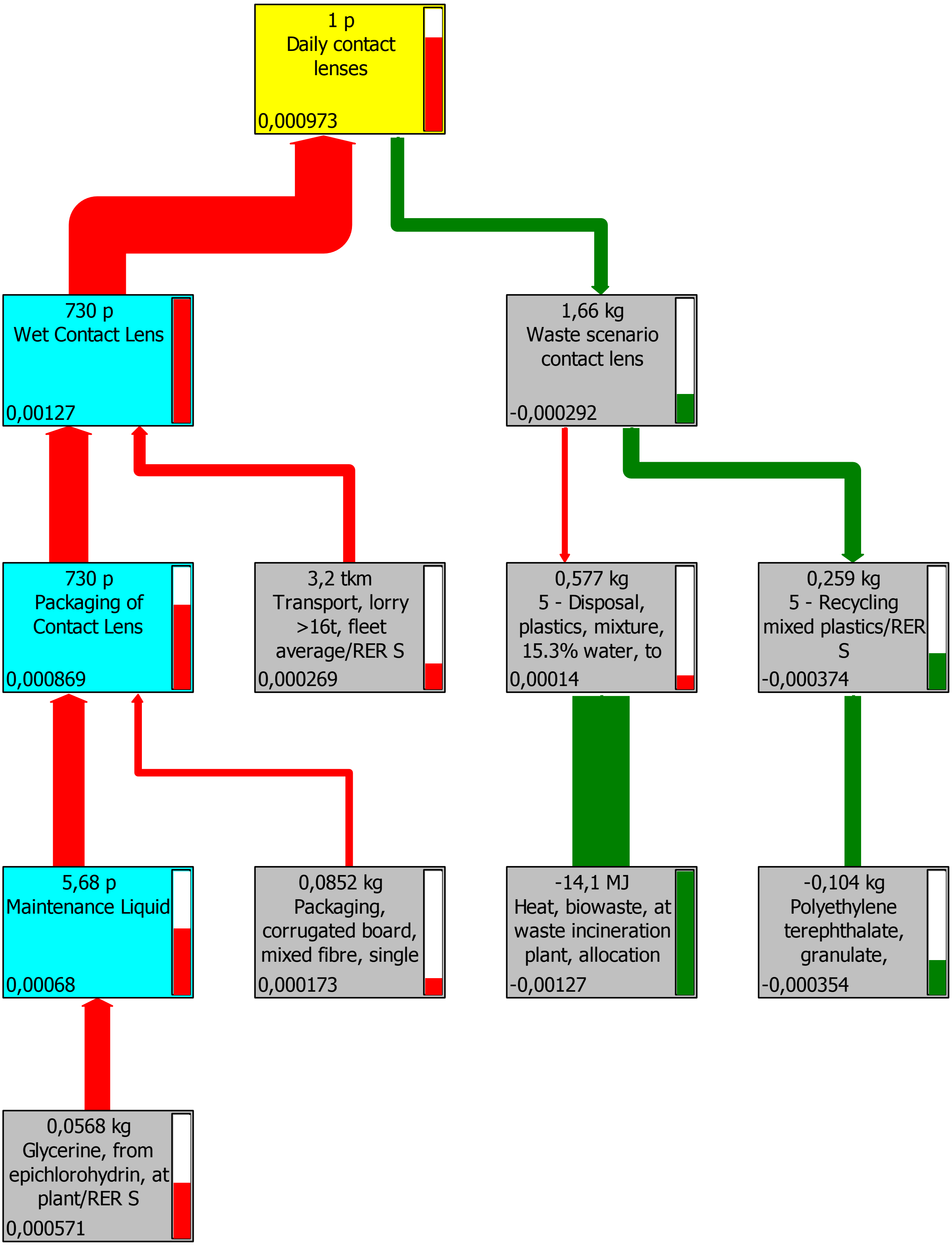

Figure 20. Normalization of fresh water eco-toxicity for life cycle of daily contact lenses

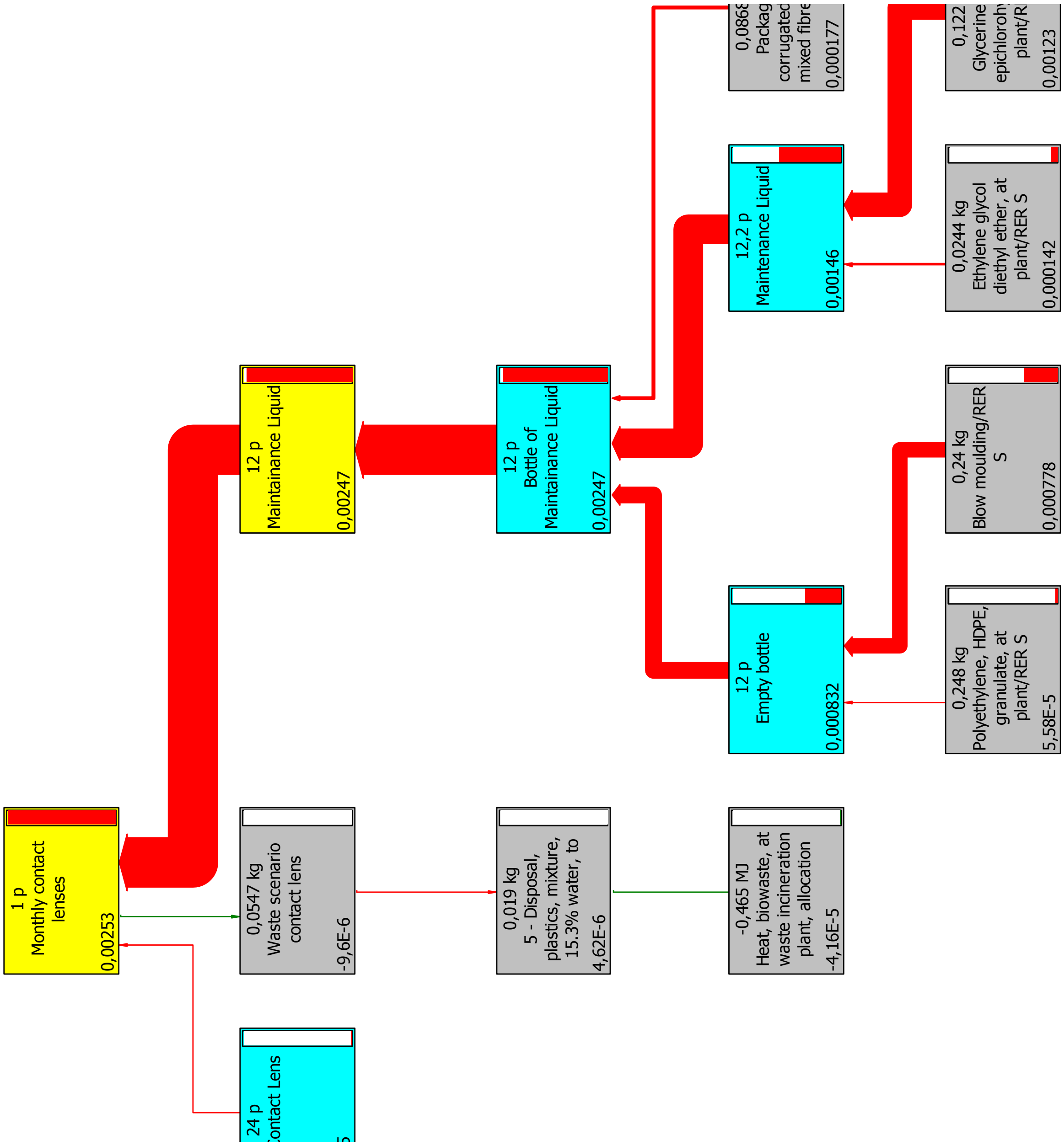

Figure 21. Normalization of fresh water eco-toxicity for life cycle of monthly contact lenses

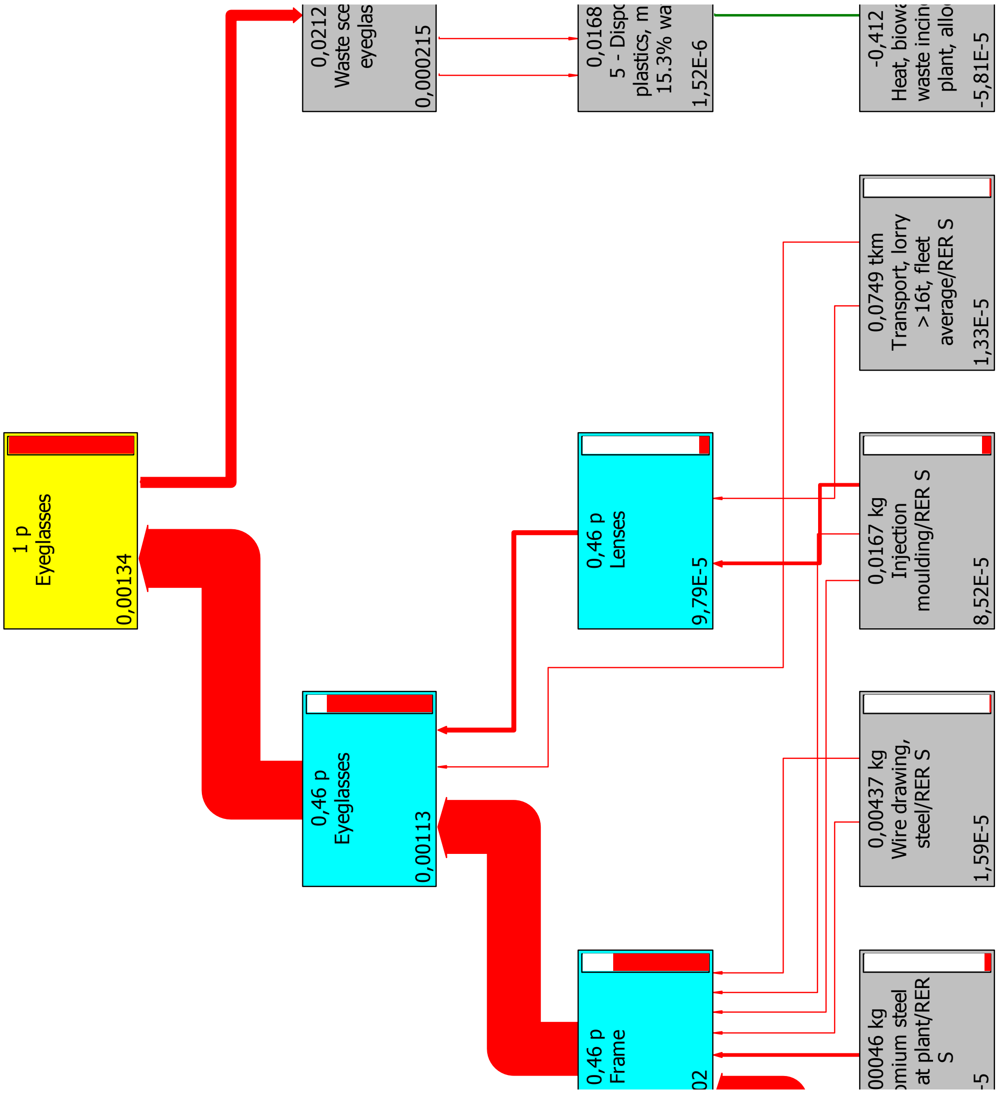

Figure 22. Normalization of marine eco-toxicity for life cycle of eyeglasses

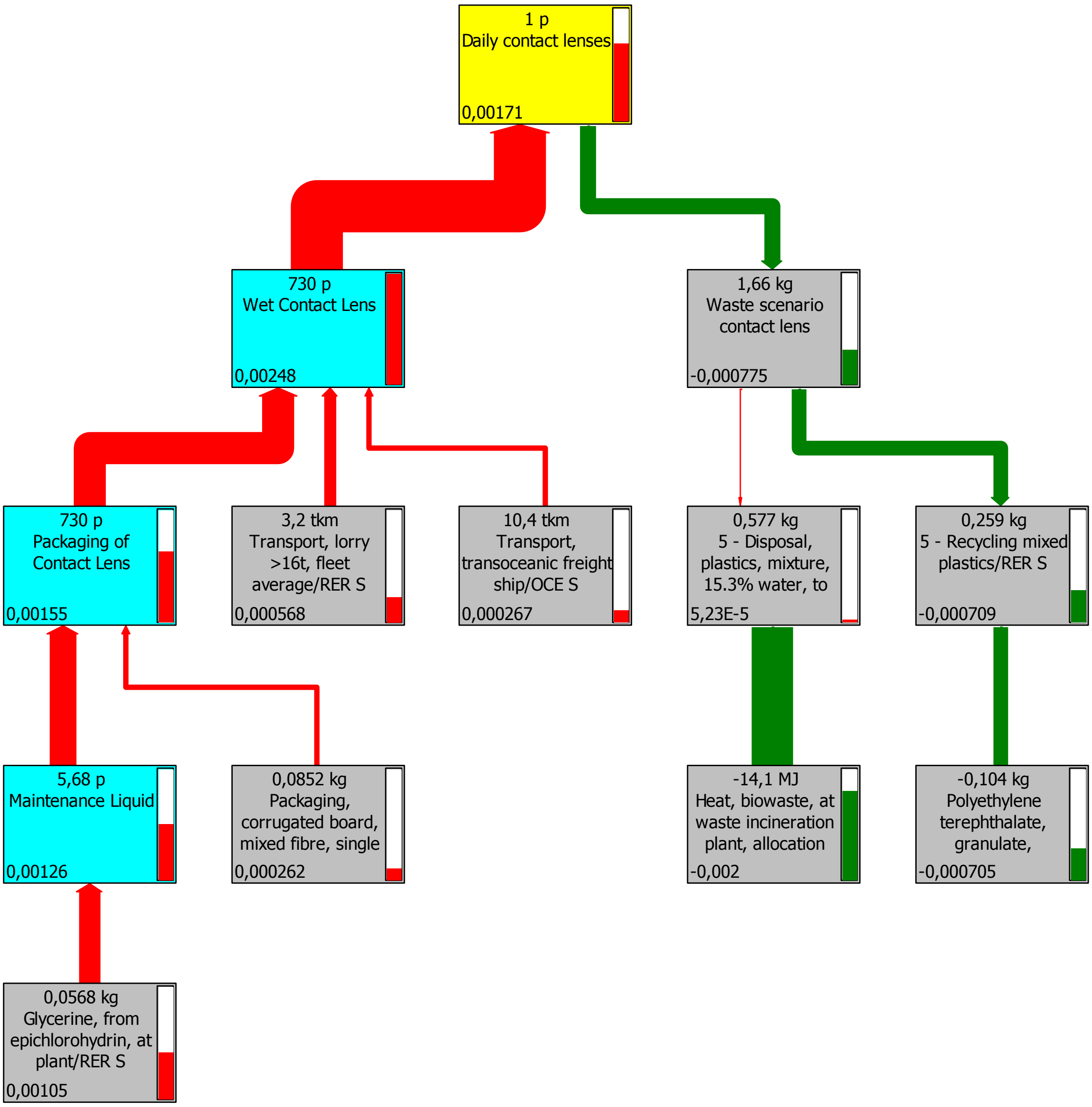

Figure 23. Normalization of marine eco-toxicity for life cycle of daily contact lenses

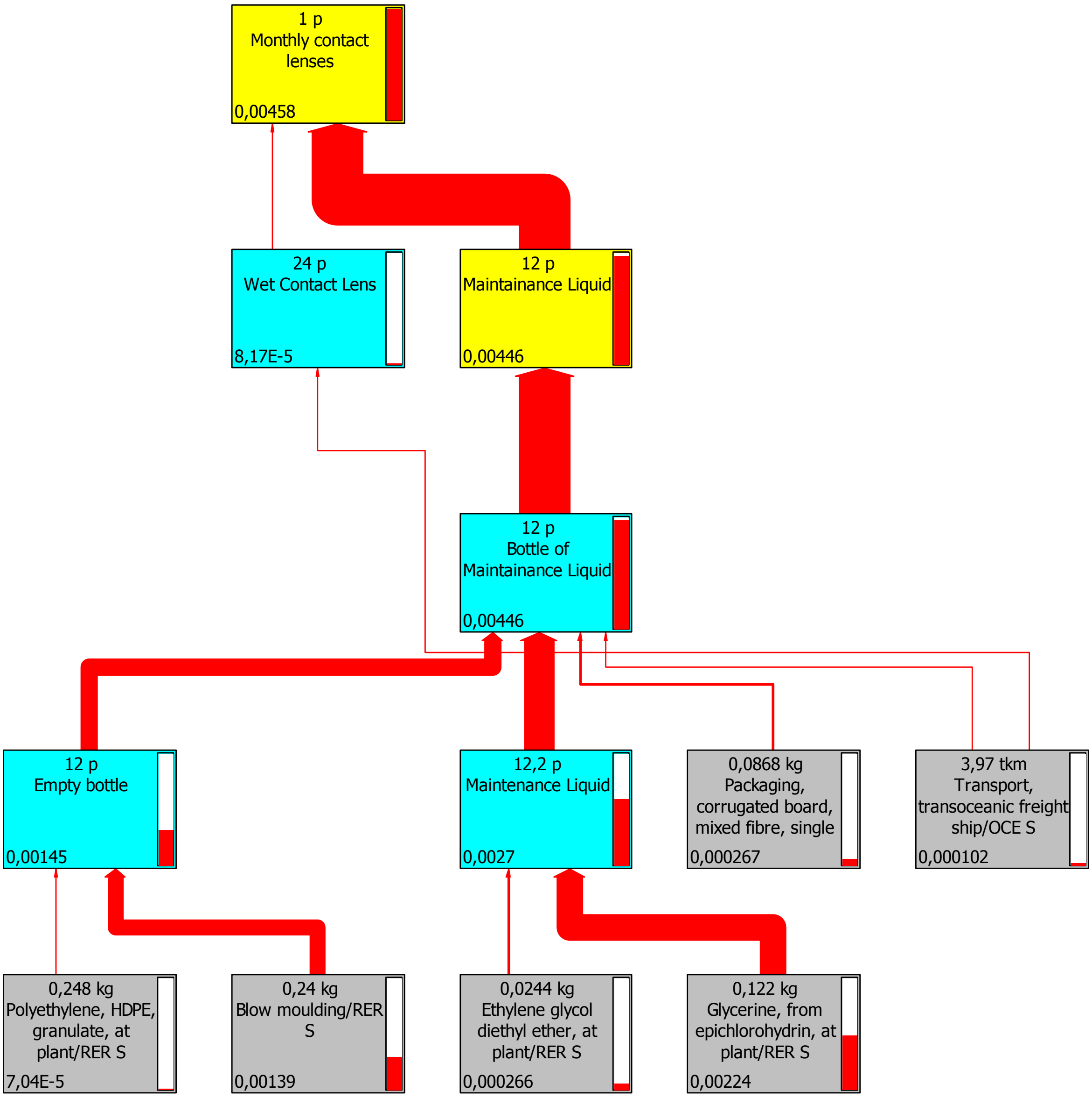

Figure 24. Normalization of marine eco-toxicity for life cycle of monthly contact lenses

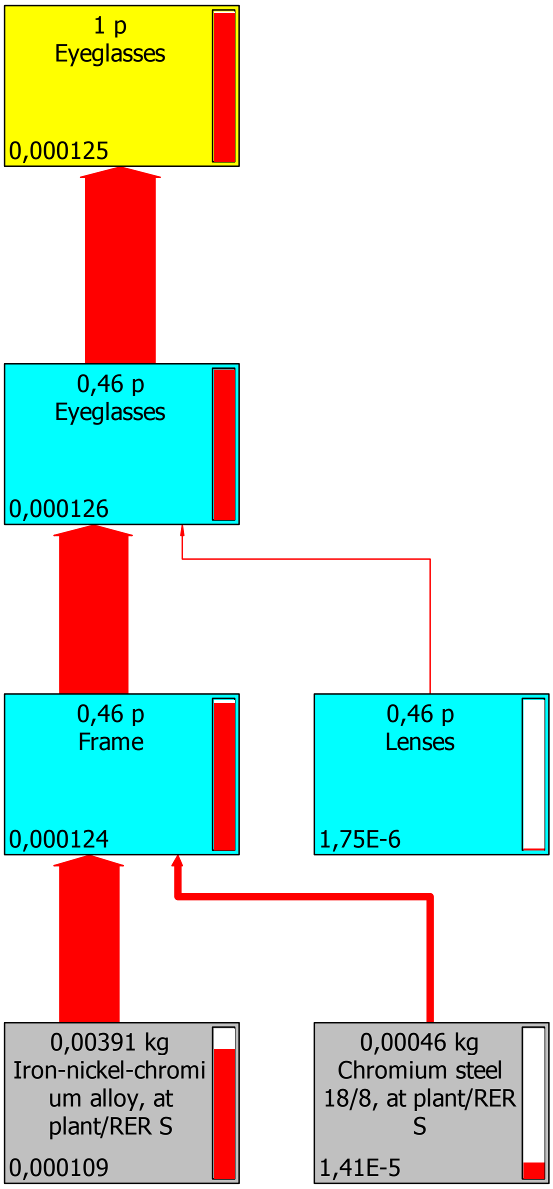

Figure 25. Normalization of metal depletion for life cycle of eyeglasses

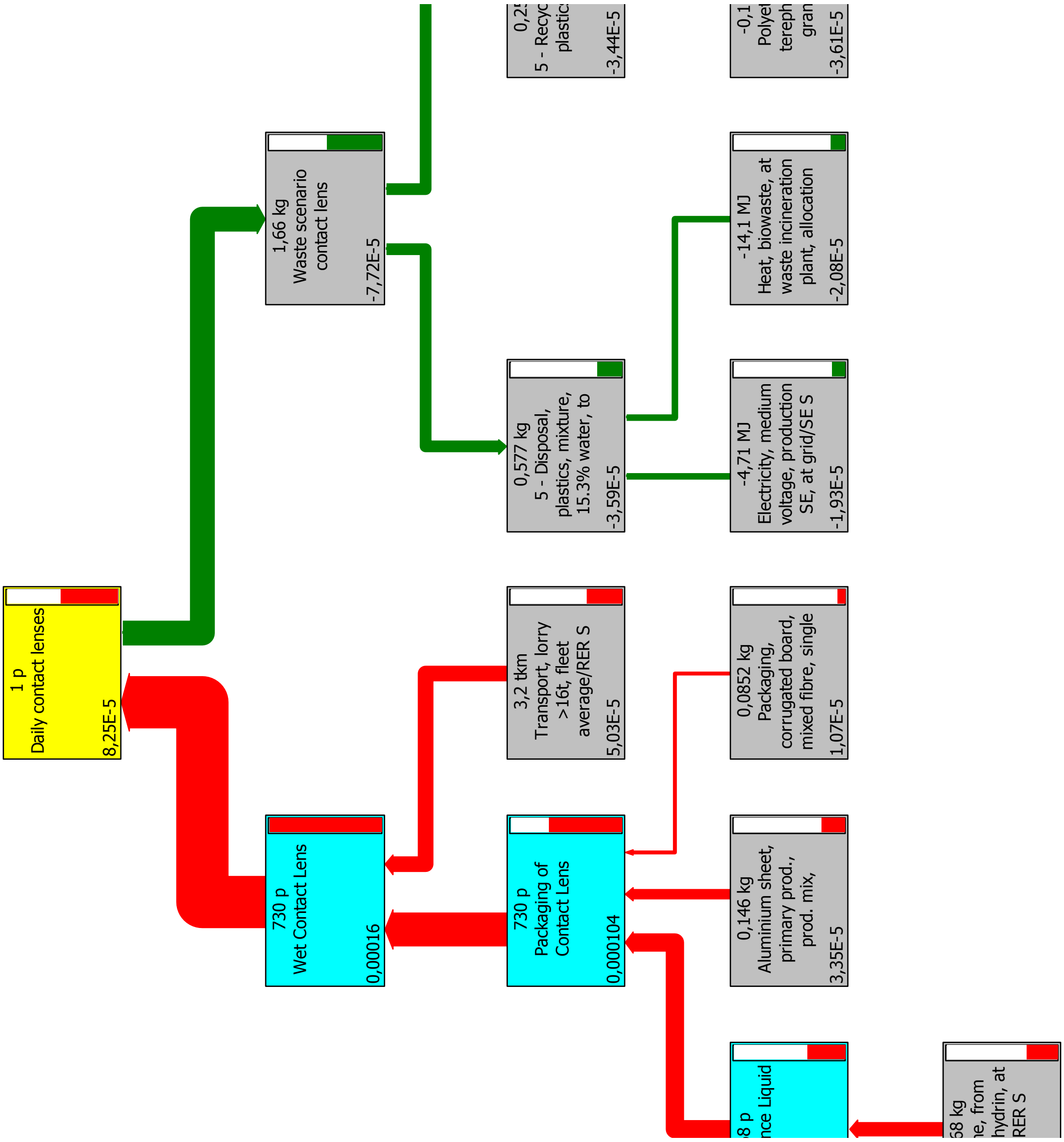

Figure 26. Normalization of metal depletion for life cycle of daily contact lenses

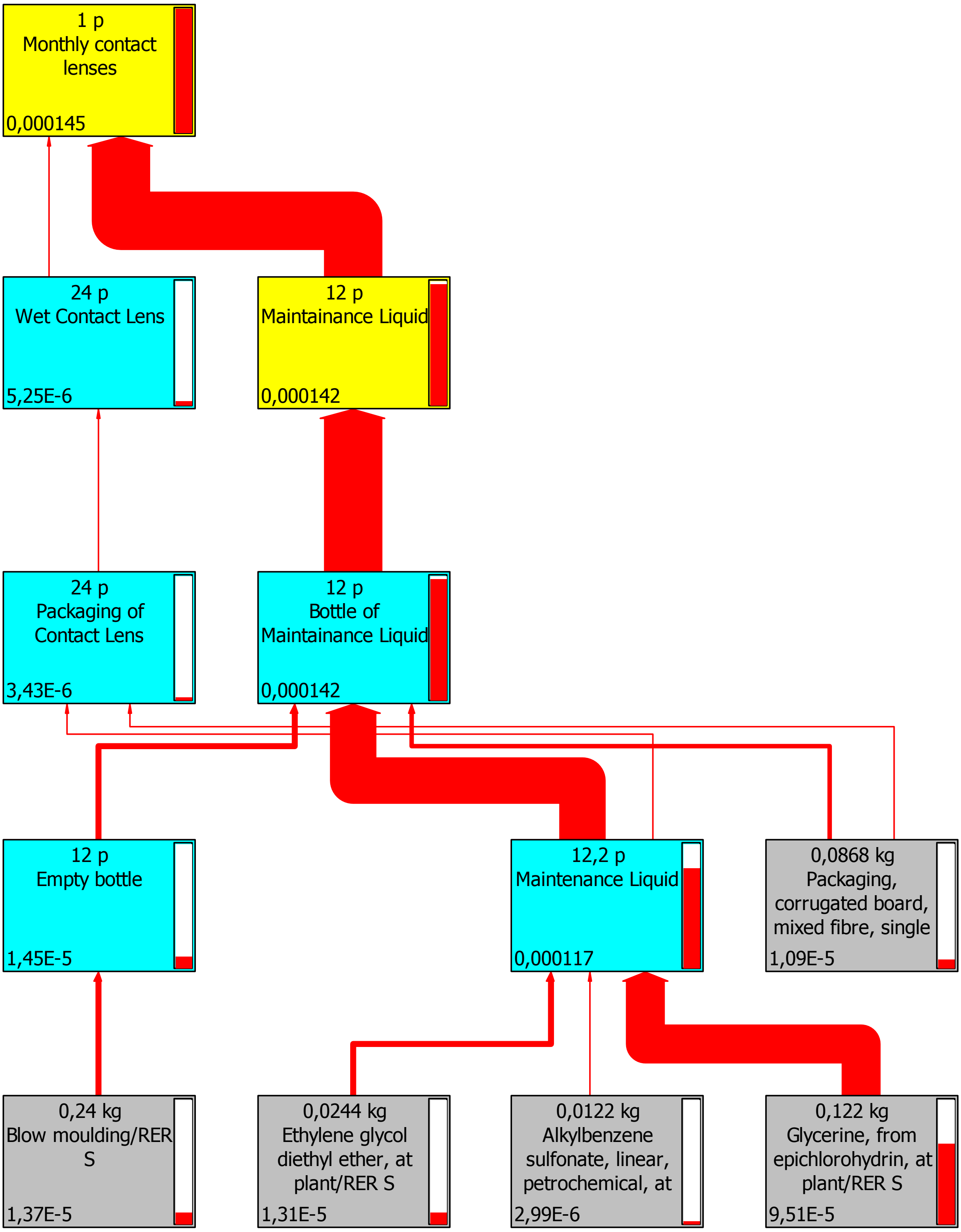

Figure 27. Normalization of metal depletion for life cycle of monthly contact lenses

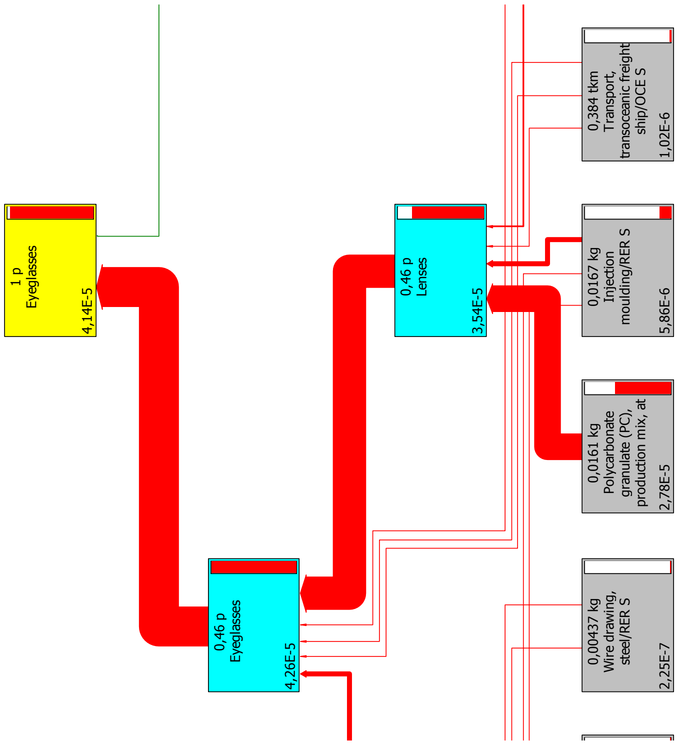

Figure 28. Normalization of fossil depletion for life cycle of eyeglasses

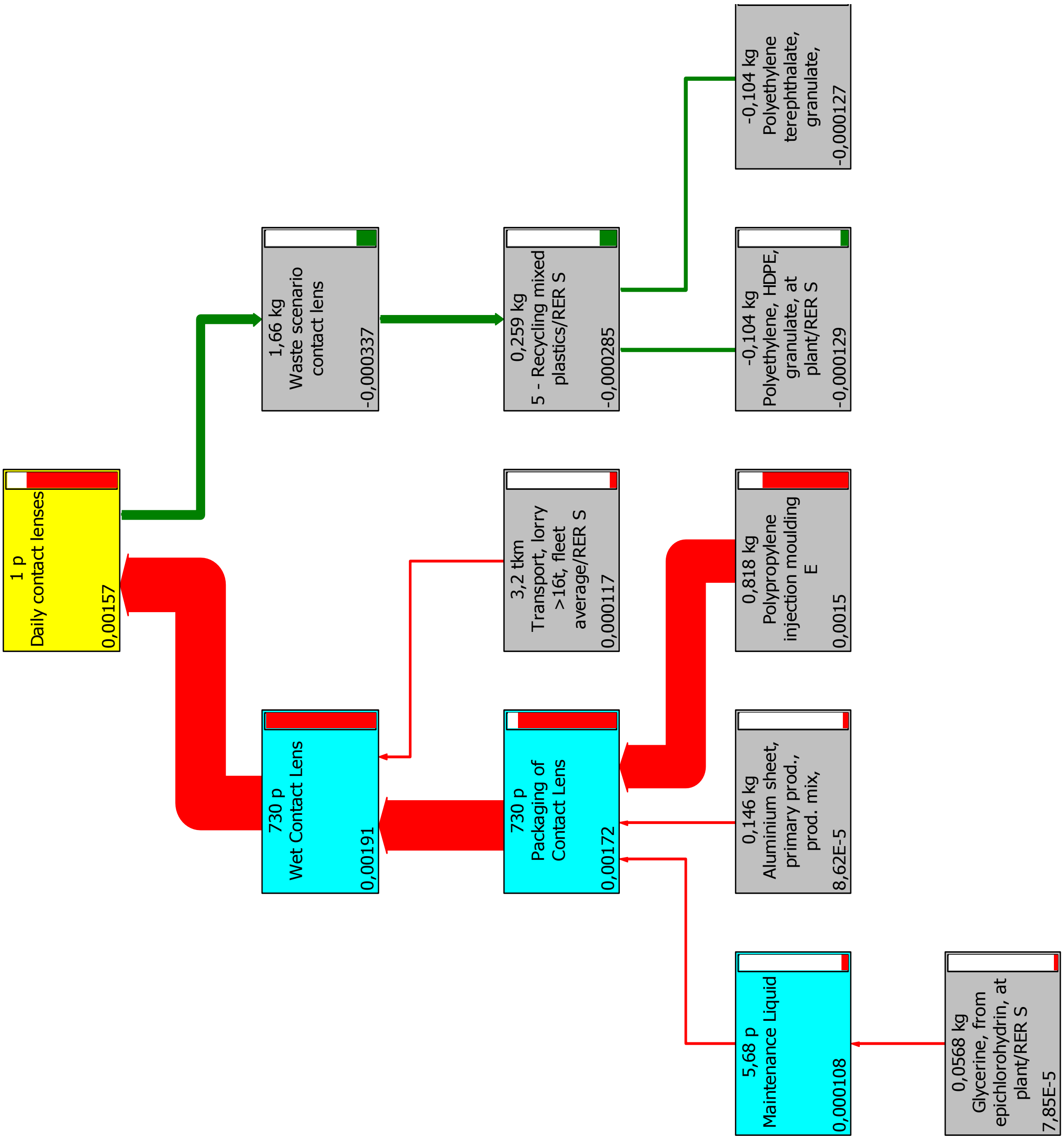

Figure 29. Normalization of fossil depletion for life cycle of daily contact lenses

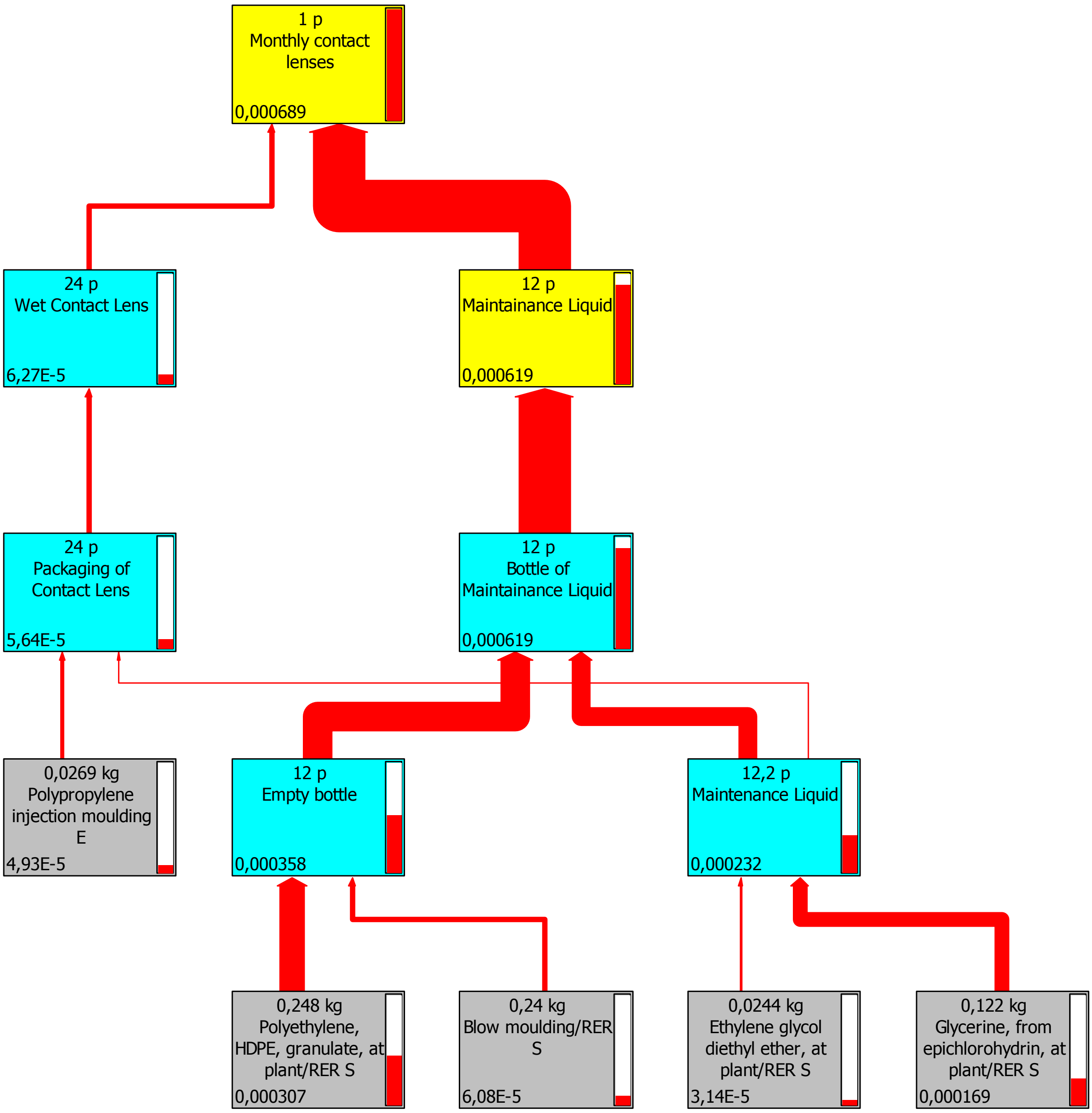

Figure 30. Normalization of fossil depletion for life cycle of monthly contact lenses