Life Cycle Analysis report
Ace & Tate

Analysis of the eyeglasses Neil and Pierce

Table of contents

Definitions 5

Summary 6

General Statement 7
1 LCA Practitioner and commissioner 7
2 Time period covered and standards used 7
3 Verification 7

Goal of the Study 8
4 Reasons for carrying out the study 8
5 Its intended applications 8
6 The target audiences 8
1. Internal stakeholder 8
2. External stakeholders 8

Scope of the Study 9
7 Functional unit 10
8 System boundary 11
9 General description product system 12
Elaboration on Demo or Plano lens installed 13
Elaboration on Edging process 13
Elaboration on sun or optical lenses 13
Elaboration on production of acetate slab 13
1. End-of life 14
2. Omissions 14
3. Quantification of energy and material 17
4. Electricity production 24
10 Cut-off criteria 24

Life cycle inventory analysis 25
11 Data collection procedures 26
1. Own operation 26
2. Suppliers 26
12 Qualitative and quantitative description of unit processes 27
1. Neil frame production including lenses 27
1 Neil frame materials 27
2. Pierce frame production including lenses 29
1 Pierce frame materials 29
3. Transport (both Pierce and Neil) 31
4. Production (both Pierce and Neil) 31
5. Packaging (both Pierce and Neil) 33
6. Use phase (both Pierce and Neil) 34
7. End-of life (both Pierce and Neil) 34
13 Sources of published literature; 36
14 Calculation procedures 36
15 Validation of data 37
16 Completeness of environmental impacts and economic flows 37
17 Consistency and reproducibility 37

Life cycle impact assessment 38
18 LCIA procedures, calculations and impact categories 39
19 LCIA results relative to the LCI and the defined goal and scope 39

Life cycle interpretation 40
20 Results 41
1. Pareto analysis 44
1 Pareto interpretation Pierce 46

1) Production frame 46
2) Edging & mounting 46
3) Retail 46
2. Pareto Neil 46
1) Retail 46
2) Production frame Pierce 46
3) Transport of frames to edger 47
21 Sensitivity analysis 47
1. Sensitivity analysis Pierce 47
1 Sensitivity analysis on production of the Acetate frame 49
2 Sensitivity analysis on production of the Acetate slab 49
3 Sensitivity analysis on the end-of-life phase 49
2. Sensitivity analysis Neil 50
1 Sensitivity analysis on retail 50
2 Sensitivity analysis on the end-of-life phase 50
3 Production Acetate slab 51
4 Materials 51
5 Waste 51
22 Data quality assessment 52
1. Data sourced from suppliers 52
2. Materials 52

Critical review 53
23 Name and affiliation of reviewers 53
24 Critical review report 53

References 53

Definitions

In the report, terminology is used to specify a process or a material.
An explanation of these terms is stated in the definitions table below.

Frame	**Frame**	The material holding the lenses in front of a person's eyes
	Glasses	Also known as eyeglasses or spectacles, devices consisting of glass or hard plastic lenses mounted in a frame that holds them in front of a person's eyes, typically using a bridge over the nose, and arms that rest over the ears. In this document the term glasses is used to indicate the frame and the lenses
	Hardware	The metal components of a frame such as a core wire, hinges and screws
Lenses	**Lenses**	Transparent curved material for concentrating or dispersing light. Lenses are used to improve vision (prescription lenses) and / or for UV protection (sun lenses). In this document the term lenses is used to indicate the material mounted in the frame and relates to demo lenses, sun lenses, prescription lenses and plano lenses
	Demo lenses	Lenses made out of Polymethyl methacrylate (PMMA). These lenses are mounted in the frame after production and are used to maintain the shape of the frame during transport and on stock. These lenses are eventually replaced with prescription glasses.
	Plano lenses	Lenses made out of CR39 with UV filter and anti-reflection coating, without prescription. These lenses are used by customers that don't have a prescription. Plano lenses are also used for show models in stores.
	Sun lenses	Coloured lenses made out of CR39 with UV filter and anti-reflection coating, with or without prescription
	Prescription lenses	Lenses made out of CR39 with UV filter and anti-reflection coating, with prescription
	Edging	The shaping of a lens into the frame in the right position and in accordance with the prescription required by the customer
	Mounting	The assembly of the lenses into a frame
Packaging	**Consumer-packaging**	Materials used to protect the glasses when shipped to the end-consumer. Also, materials to clean the glasses. These include a case, a cleaning cloth and a tote bag.
	Packaging	The materials used to transport the components of the glasses without damaging them.

Summary

This document contains the method used and the results of the life cycle analysis (LCA) of Ace & Tate. An LCA describes the environmental impact of a product throughout its life cycle, including raw materials, production, transport, retail and waste treatment. The goal of the analysis is to understand and improve the environmental impact of the glasses and transparently communicate on this process to all the stakeholders of Ace & Tate.

For this LCA, Pierce and Neil were selected out of 200 styles, since they are both top sellers and have two components that run through the core of Ace & Tate's manufacturing process: metal and acetate. To calculate the environmental impact of Pierce and Neil, Ace & Tate and Sustainalize have developed an LCA tool. The goal of this tool is to gain an understanding of where the major impacts of Pierce and Neil are and to incrementally decrease the impact accordingly.

For Pierce, the production of the frame, which accounts for almost 50% of the greenhouse gas emissions, has by far the biggest environmental impact when it comes to CO_2 -eq. Edging & mounting and retail and consumer packaging attribute almost another 30%, which implies that these four life cycle stages equal 80% of the impact on CO_2 -eq.

For Neil, relatively the highest impact comes from retail, with almost 20%. Production of the frame, transport of the lens and frame to the edger, edging & mounting and consumer packaging of the final product contribute another 45%, which implies that these five stages in the life cycle equal approximately 65% of the impact on CO_2 -eq.

Indicators: **agricultural land occupation; climate change; fossil depletion; freshwater ecotoxicity; freshwater eutrophication; human toxicity; ionising radiation; marine ecotoxicity; marine eutrophication; metal depletion; natural land transformation; ozone depletion; particulate matter formation; photochemical oxidant formation; terrestrial acidification; terrestrial ecotoxicity; urban land occupation and; water depletion.**

GENERAL STATEMENT

1 LCA Practitioner and commissioner

This LCA has been commissioned by Ace & Tate and performed by Sustainalize.

Ace & Tate, the direct-to-consumer, omnichannel eyewear brand from Amsterdam, was founded in June 2013 by Mark de Lange from a simple idea that eyewear is not only a medical device but also a tool for self-expression. The Dutch brand changes the way people buy and think about eyewear, making the shopping experience seamless and fun. Ace & Tate now offers high-quality eyewear for men and women in eight different countries across Europe (the Netherlands, Belgium, Denmark, United Kingdom, Ireland, Austria, Sweden and Germany) and online in 26 countries and counting.

2 Time period covered and standards used

The study commenced in January 2019 and was finished in March 2019. It covers the sales and production data of 2018. This LCA report is in accordance with ISO 14040 and ISO 14044.

3 Verification

The study has been verified by Niels Jonker from EcoChain and fully complies to the ISO 14040 and 14044 norms, that ensure quality and transparency of the LCA.

GOAL OF THE STUDY

4 Reasons for carrying out the study

The goal of this study is to create understanding of the environmental impact of the Neil and Pierce glasses and to transparently report on this impact to Ace & Tate's stakeholders. Neil and Pierce were selected out of 200 styles. They are both top sellers and have two components that run through the core of Ace & Tate's manufacturing process: metal and acetate. The goal is to specifically focus on the processes Ace & Tate is able to influence and therefore the aim is to focus on the materials used, the production processes involved, the transport and the end-of-life phase of the glasses. When the understanding of the environmental impact is on the table, the company aims to incrementally decrease the impact and communicate the journey to its stakeholders throughout this iterative process.

5 Its intended applications

The outcome of the study is intended to be reported to Ace & Tate's stakeholders with the aim to decrease environmental impact in the coming years through research & development and supply chain partnerships. The analysis is not meant to be used in comparative assertions.

6 The target audiences

The target audience relates to both internal and external stakeholders.

1. Internal stakeholder

The internal stakeholders include all employees involved with the product, such as the Supply Chain team, Design team, the stores and the Customers Experience team. They will be informed to better understand the environmental impact of materials and processes and to be able to make decisions to improve overall performance. Furthermore, the rest of Ace & Tate's organisation as well as the Management Team is to be informed to better understand the impact of the product they work with and to create awareness. The information communicated will be (a summary of) this document containing also a partial impact assessment (LCIA) that contains most relevant/well known impact.

2. External stakeholders

The information is intended to be communicated to external stakeholders such as customers and all partners in the value chain since the overall performance can only be changed as a whole chain, not only by one company within the value chain.

Scope of the Study

This section of the report details the object of the analysis as well as the system boundary, specifying which elements of the life cycle inventory analysis are part of the product system.

7 Functional unit

The analysis covers two types of glasses. Included are the Pierce and Neil frames, lenses and packaging. The average total weight of the product (including consumer packaging and lenses) as shipped to consumer of the Pierce is 220,84 grams and of the Neil is 239,48 grams.

The glasses are visualised in Figures 1 and 2.

The analysis takes a cradle-to-gate approach with end-of-life phase inventory and does not consider the use phase. This is due to the uncertainty related to the use phase.

The environmental impact relating to the use phase of the glasses is mainly dependent on the type of cleaning (cloth, warm water and soap) the frequency of cleaning, esthetical preferences over time and how the user handles the product (which will determine how long a product can be used and at what frequency it can be used to fulfil its function as eyewear). The use of the product varies significantly per individual consumer and is, in accordance with

Figure 1: Pierce

Figure 2: Neil

the goal of the study, not part of the scope that focuses on materials and production. Furthermore, the goal of the study does not involve a comparative assertion on quality to other types of eyewear. A comparative assertion would require a detailed analysis on how (long) Ace & Tate glasses are used and how this usage would compare to other brands and materials but also to other ways to improve vision (e.g. contact lenses). Therefore, the declared units are:

1 The production and end-of-life waste-treatment of 1 pair of Pierce glasses including frame, lenses and packaging

2 The production and end-of-life waste-treatment of 1 pair of Neil glasses including frame, lenses and packaging

The declared units are consistent with the goal and scope to create an insight that supports Ace & Tate in understanding the environmental impact of its glasses and for the company to be able to communicate this impact to its stakeholders.

The declared units represent an average of all types of lenses and production routes possible per pair of glasses. The average is based on sales and route data covering the year 2018.

8 System boundary

The system boundary depicts the life cycle stages of the product that are part of the analysis. In the analysis for the Pierce and Neil this study takes into account the environmental impact related to the production of raw materials required to produce the product, the energy needed to produce the product, the transport required to distribute the product and the waste processing of the excess materials discarded during production.
Services, materials, and energy that are not directly connected to the glasses during its life cycle because they do not become the product, make the product, or directly carry the product through its life cycle are defined as non-attributable processes.

These include:
- Corporate activities and services (e.g., research and development, servers, home try on, construction of (new) stores, administrative functions, company sales and marketing)
- Transport of the product user to the retail location
- Transport of employees to and from work

The energy related to retail locations is included in the study as this is specifically part of the Ace & Tate sphere of influence. The system boundaries of Neil and Pierce are visualised in Figures 3 and 4.

9 General description product system

Both Neil and Pierce are produced in China. The materials required to produce the glasses are supplied locally. The transport to the production site and the materials required have been taken into account. When finalising production, the frames are mounted with either a demo-lens, a plano lens or a sun lens and packed for transport. The sun and plano lens will not be discarded later in the process. The demo-lens is replaced by an optical lens and discarded in full.

The glasses are then shipped to the Netherlands. The glasses that need optical lenses are shipped for edging and mounting to either Thailand, the Netherlands or a retail location.

After edging, the glasses are all sent to the Netherlands where they are packed for final consumer usage in a case with a cloth.

After packaging the glasses are transported to retail locations or direct to consumers. For 16% of the sales, the glasses come with a complementary organic cotton tote bag.

7% of all glasses are returned by consumers. The glasses are then inspected and categorised by Ace & Tate:

Category 1
The glasses are unworn and in mint condition. They will be cleaned, polished and put back into stock.

Category 2
The glasses have a small defect. They will be cleaned, polished and put into Friends & Family stock (the employees of Ace & Tate have the possibility to buy the frames for a lower price to avoid waste).

Category 3
The glasses have a major defect. They will be stocked for research and development around recycling.

The frames that are resold are attributed with an extra 600 km of truck transport plus the impact of optical lenses.

In Figure 3 and 4 the system boundaries of the products are visualised.

ELABORATION ON DEMO OR PLANO LENS INSTALLED

When the frame is produced in China, a demo or plano lens will be installed in the frame. The demo lens will be removed in The Netherlands, at a retail location or in Thailand and will not be used again. It is therefore modelled as waste in the LCA and attributed with a waste incineration proxy from Ecoinvent (for an explanation on Ecoinvent, see chapter 6, page 28).

ELABORATION ON EDGING PROCESS

The mounting and edging of the lenses is done in Thailand, in the Netherlands or at a retail location. For the Neil, 52% is edged in the Netherlands, 17% in Thailand and the rest is not edged as plano or sun lenses are used. For the Pierce, 14% is edged in Thailand and 60% in the Netherlands. The remainder of the lenses is not edged and/or edged and mounted in stores.

ELABORATION ON SUN OR OPTICAL LENSES

The difference between the sun and the optical lenses is a small amount of pigment, for this small amount of pigment no detailed environmental impact data is available and this material is therefore not taken into account. The sun lenses are only available for the Neil frame and are installed at the production site in China and are directly available for retail and online sales.

ELABORATION ON PRODUCTION OF ACETATE SLAB

The production of the Pierce frame requires an extra step; the frame is cut from an acetate slab. The acetate granulate, for which supplier specific data is provided and used, is mixed with the plasticizer DEP (see table 14) and then rolled into slabs. For this study, energy usage, production waste and plasticisers usage are based on literature and Ecoinvent to calculate the impact of acetate slab production as no data was provided by the acetate slab producing company. The slab is then transported to a site in China, the exact distance has been used to calculate the impact of transporting the slab. The production site receiving the slab then cuts the frame from the slab.

1. End-of life

For the end-of life phase no detailed information is available on how consumers in the various countries discard the glasses at end-of-life. Therefore, the analysis for the end of-life-phase is modelled via a municipal waste collection scenario. An incineration scenario is used to assess the impact of the waste phase, this excludes energy generation due to the use of the cut-off model in Ecoinvent.

2. Omissions

The utilities data on the production of the acetate slab and the plasticiser usage is estimated based on literature and Ecoinvent. The weight of the slab, the percentage of production waste, and the distance from the acetate supplier to the producer has been used.

All processes within the system boundary were taken into account although not every supplier was able to provide all the required data. The missing data is modelled using Ecoinvent version 3.5 relating to the production of raw materials and the processing of these materials. All calculations on raw materials, transport, waste and energy are elaborated upon in chapter 6.

Figure 3 and 4 below show the boundaries of the two products and the processes taken into account. Pierce and Neil can be produced with various options in the production process. The weight and amounts used present an average relative to the produced amount.

Figure 3: System boundary Neil

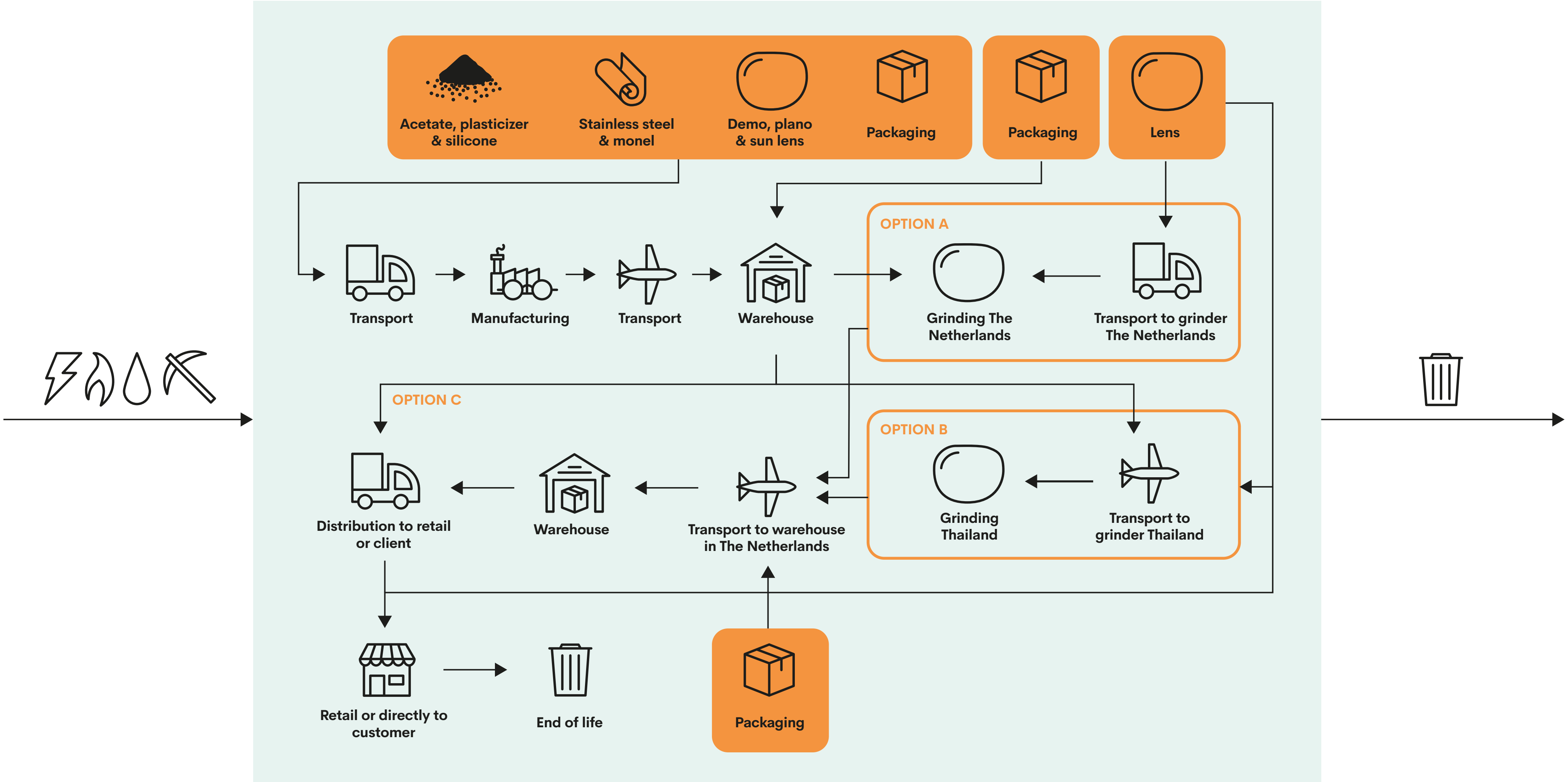
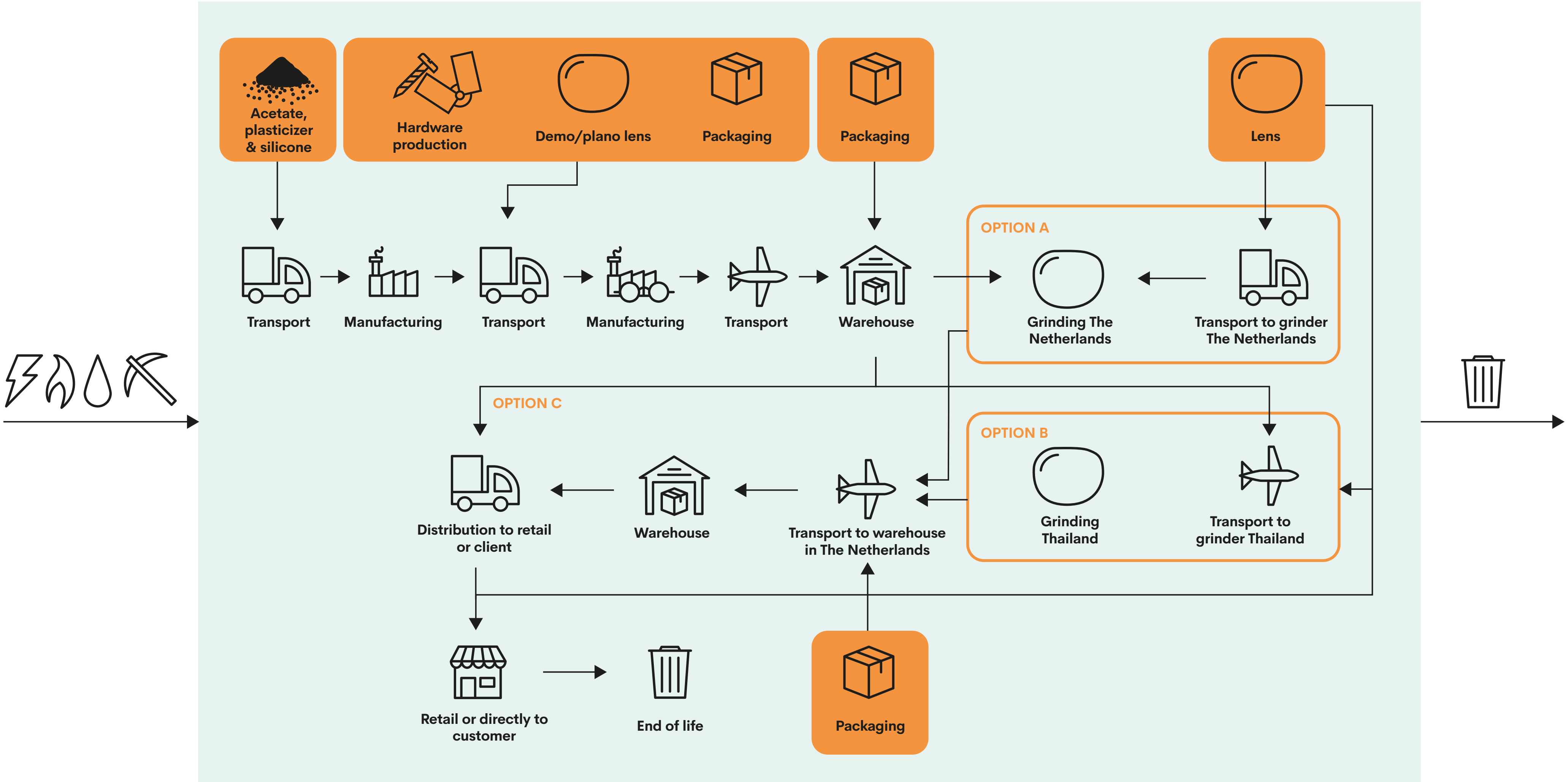


Figure 4: System boundary Pierce.



3. Quantification of energy and material

In the tables all energy and material input and output are stated in gross and nett weight. The difference between nett and gross is production waste, the rest material that is thrown away in the process. The emissions related to the treatment of production waste are attributed to the life cycle stage in which they occur. In tables 1 – 8 the amount of raw materials is stated, as well as the utilities needed for production and the transport required.

Table 1: Bill of material for Pierce

Product	Material	unit	Avg. Net weight	Avg. Gross weight	Avg. Waste
Pierce frame	Acetate slab production	gram	57,12	71,40	14,28
Pierce frame	Acetate slab to frame	gram	6,93	57,12	50,19
Pierce frame	Nickel silver (screws, hinges and core wire)	gram	6,64	9,16	2,52
Demo lens	PMMA (Pierce)	gram	4,50	10,12	5,62
CR 39 Optical lens	CR-39	gram	7,50	20,22	12,72
Plano lens	CR39	gram	7,06	20,22	13,16
Polybag (PE) packaging	Polyethylene	gram	2,20	Not available, no assumptions were made, net is gross	Not available, no assumptions were made, net is gross
White paper box + shipping box packaging	White paper box	gram	8,60	Not available, no assumptions were made, net is gross	Not available, no assumptions were made, net is gross
Cloth (Consumer packaging)	Recycled PET	gram	4,50	4,84	0,34
Shipping box (packaging)	FSC Kraft paper	gram	0,53	0,58	0,05
Case (Consumer packaging)	Water-based polyurethane	gram	13,87	15,07	1,20
Case (Consumer packaging)	FSC Kraft paper	gram	14,11	Not available, no assumptions were made, net is gross	Not available, no assumptions were made, net is gross
Case (Consumer packaging)	Recycled PET	gram	14,11	Not available, no assumptions were made, net is gross	Not available, no assumptions were made, net is gross
Case (Consumer packaging)	Glue	gram	3,29	Not available, no assumptions were made, net is gross	Not available, no assumptions were made, net is gross
Case (Consumer packaging)	Recycled polyester	gram	0,47	Not available, no assumptions were made, net is gross	Not available, no assumptions were made, net is gross

Case (Consumer packaging)	Cotton	gram	0,47	Not available, no assumptions were made, net is gross	Not available, no assumptions were made, net is gross
Case (Consumer packaging)	Oil paint	gram	0,71	Not available, no assumptions were made, net is gross	Not available, no assumptions were made, net is gross
Paper (warranty leaflet, Consumer packaging)	Paper	gram	6,60	Not available, no assumptions were made, net is gross	Not available, no assumptions were made, net is gross
Tote bag (Consumer packaging)	Organic Cotton	gram	48	Not available, no assumptions were made, net is gross	Not available, no assumptions were made, net is gross

Table 2: Bill of material for Neil

Product	Material	unit	Avg. Net weight	Avg. Gross weight	Avg. Waste
Neil frame	Stainless steel (frame)	gram	9,33	16,52	7,19
Neil frame	Acetate (tip)	gram	1,85	7,66	5,81
Neil frame	Stainless steel (windsor rim)	gram	0,79	0,95	0,16
Neil frame	Stainless steel (rim)	gram	3,40	3,40	0,00
Neil frame	Monel (bridge)	gram	0,68	1,57	0,89
Neil frame	Endpiece & temple (stainless steel)	gram	5,25	11,55	6,30
Neil frame	Silicone (nose pads)	gram	0,2	0,2	Not available, no assumptions were made, net is gross
Demo lens	PMMA	gram	4,41	8,90	4,49
Optical lens	CR-39	gram	7,50	20,22	12,72
Sun lens	CR-39	gram	7,50	20,22	12,72
Plano lens	CR39	gram	7,50	20,22	12,72

Polybag (PE) packaging	Polyethylene	gram	2,13	Not available, no assumptions were made, net is gross	Not available, no assumptions were made, net is gross
White paper box + shipping box packaging	White paper box	gram	8,60	Not available, no assumptions were made, net is gross	Not available, no assumptions were made, net is gross
Cloth (Consumer packaging)	Recycled PET	gram	4,50	4,84	0,34
Shipping box (packaging)	FSC Kraft paper	gram	0,53	0,58	0,05
Case (Consumer packaging)	Water-based polyurethane	gram	13,87	15,07	1,20
Case (Consumer packaging)	FSC Kraft paper	gram	14,11	Not available, no assumptions were made, net is gross	Not available, no assumptions were made, net is gross
Case (Consumer packaging)	Recycled PET	gram	14,11	Not available, no assumptions were made, net is gross	Not available, no assumptions were made, net is gross
Case (Consumer packaging)	Glue	gram	3,29	Not available, no assumptions were made, net is gross	Not available, no assumptions were made, net is gross
Case (Consumer packaging)	Recycled polyester	gram	0,47	Not available, no assumptions were made, net is gross	Not available, no assumptions were made, net is gross
Case (Consumer packaging)	Cotton	gram	0,47	Not available, no assumptions were made, net is gross	Not available, no assumptions were made, net is gross
Case (Consumer packaging)	Oil paint	gram	0,71	Not available, no assumptions were made, net is gross	Not available, no assumptions were made, net is gross
Paper (warranty leaflet, Consumer packaging)	Paper	gram	6,60	Not available, no assumptions were made, net is gross	Not available, no assumptions were made, net is gross
Tote bag (Consumer packaging)	Organic Cotton	gram	48	Not available, no assumptions were made, net is gross	Not available, no assumptions were made, net is gross

Table 3: Utility required to produce the Pierce frame

Product	Utilities for frame production	Unit	Amount
Pierce frame	Electricity (CN)	kWh	3,16

Table 4: Utility required to produce the Neil frame

Product	Utilities for frame production	Unit	Amount
Neil frame	Electricity (CN)	kWh	0,58
Neil frame	Water	Liter	7

Table 5: Utility data for production of the case, the cloth and retail per frame

Product	Utilities for frame production	Unit	Amount
Production Cloth	Electricity	kWh	0,006246292
Production Cloth	Natural gas	m3	2,90E-05
Production case	Electricity (CN)	kWh	0,166
Utilities (retail)	Electricity	kWh	1,43
Utilities (retail)	Gas	m3	0,11

Table 6. Utilities required by warehouse to pack the product (final assembly)

Product	Utilities for frame production	Unit	Amount
Frame (Neil or Pierce)	Electricity	kWh	0,174
Frame (Neil or Pierce)	Water	liter	0,015

Table 7: The Utilities required for the full process from blanc to finished lens, including mounting and edging.

Product	Utilities for frame production	Unit	Amount
Edging lenses In the Netherlands	Electricity	kWh	1,2026151
Edging lenses In the Netherlands	Gas	m3	0,0522596
Edging lenses In the Netherlands	Water	liter	0,0044329
Edging lenses Thailand	Electricity	MJ	14,34
Edging lenses Thailand	Water	liter	47,24
Edging lenses Thailand	LPG	MJ	0,062

Table 8: Transport distances used

Transport movement	Type of transport	km
Acetate to site (Pierce) (assumed distance)	Truck	75
Acetate from Hong Kong site to manufacturer Hong Kong(Pierce)	Truck	40,5
Hardware to manufacturer (Pierce) (assumed distance)	Truck	75
Demo lens to manufacturer (Pierce)	Truck	75
Plano lens to manufacturer (Pierce) (assumed distance)	Truck	75
Packaging to manufacturer (Pierce) (assumed distance)	Truck	75
Frame + packaging + demo lens from Pierce site to HK airport and AMS airport to a warehouse in the Netherlands (Pierce)	Truck	144,6
Frame + packaging + demo lens from Pierce production site Hong Kong to a warehouse in the Netherlands (Pierce) (assumed distance)	Airplane	9261
Frame + packaging + plano lens from Pierce production site to HK airport and AMS airport to a warehouse in the Netherlands (Pierce)	Truck	144,6
Frame + packaging + plano lens from Hongkong to a warehouse in the Netherlands (Pierce)	Airplane	9261
Metal Hong Kong to manufacturer Hong Kong (Neil)	Truck	75
Hardware to manufacturer (Neil) (assumed distance)	Truck	75
Demo lens to manufacturer (Neil) (assumed distance)	Truck	75
Packaging to manufacturer (Neil) (assumed distance)	Truck	75
Frame + packaging + demo lens from Neil production site Hong Kong to HK airport and AMS airport to a warehouse in the Netherlands (Neil)	Truck	155,6
Frame + packaging + demo lens from Hong Kong site to a warehouse in the Netherlands (Neil)	Airplane	9261

Frame + packaging + plano lens from Neil production site Hong Kong to HK airport and AMS airport to a warehouse in the Netherlands	Truck	155,6
Frame + packaging + plano lens from Hong Kong site to a warehouse in the Netherlands (Neil)	Airplane	9261
Frame + demo lens from the warehouse in the Netherlands (to edger In the Netherlands)	Truck	80
Frame + demo lens from the warehouse in the Netherlands (to edger Thailand) (Pierce is 14%, Neil is 17%)	Airplane	9178
Frame + demo lens from the warehouse in the Netherlands (to edger Thailand) (Pierce is 14%, Neil is 17%)	Truck	77
Lens from Senai, Malaysia, to edger In the Netherlands	Airplane	10130
Lens to edger Thailand (assumed distance)	Truck	75
Frame + lens from the Netherlands to a warehouse in the Netherlands	Truck	109
Frame + lens from Thailand to a warehouse in the Netherlands	Truck	77
Frame + lens from Thailand to a warehouse in the Netherlands	Airplane	9178
Raw materials cloth from China to manufacturer Siem Reap	Truck	130
Raw materials cloth from China to manufacturer Siem Reap	Ocean freight	4700
Raw materials cloth from China to manufacturer Siem Reap	Truck	525
Finished cloth from Siem Reap to a warehouse in the Netherlands option 1	Truck	524
Finished cloth from Siem Reap to a warehouse in the Netherlands option 1	Ocean freight	14365
Finished cloth from Siem Reap to a warehouse in the Netherlands option 1	Truck	1268
Finished cloth from Siem Reap to the warehouse in the Netherlands option 2 (22% of shipment)	Truck	315
Finished cloth from Siem Reap to a warehouse in the Netherlands option 2 (22% of shipment)	Airplane	9668
Finished cloth from Siem Reap to a warehouse in the Netherlands option 2 (22% of shipment)	Truck	96
Tote Bag (from India to the Netherlands)	Ocean freight	12818

Tote Bag (from the Netherlands to warehouse)	Truck	92
Case to a warehouse in the Netherlands	Truck	986
Case to a warehouse in the Netherlands	Ocean freight	19685
Case to a warehouse in the Netherlands	Truck	900
Average distance (return shipment is (+600)	Truck	300

4. Electricity production

As a proxy for electricity use production, Ecoinvent data is used as described in the life cycle inventory chapter 6, page 23/24.

10 Cut-off criteria

The end-of-waste state is determined by the economic cut-off method. The cut-off model is explained by Ecoinvent as:

“The underlying philosophy of this approach is that primary (first) production of materials is always allocated to the primary user of a material. If a material is recycled, the primary producer does not receive any credit for the provision of any recyclable materials. As a consequence, recyclable materials are available burden-free to recycling processes, and secondary (recycled) materials bear only the impacts of the recycling processes. For example, recycled paper only bears the impacts of waste paper collection and the recycling process of turning waste paper into recycled paper. It is free of any burdens of the forestry activities and processing required for the primary production of the paper.

Furthermore, producers of wastes do not receive any credit for recycling or reuse of products resulting out of any waste treatment. For example, heat from the incineration of municipal solid waste can be used to heat houses or offices, and therefore has a value. Nevertheless, the incineration is allocated completely to the treatment of the waste, and therefore the burdens lay with the waste producer. The heat comes burden-free.“

This means that when processes raise the value of materials, which is the case for certain recycling processes, the environmental impact of the recycling process is allocated to the life cycle of the reclaimed materials. In this analysis Ecoinvent cut-off processes, including waste treatment processes, are used. The end point of waste is therefore the point at which it is used to create a new product with a positive economic value. In the case of this study this means that the energy generated from the incineration of the waste, which has a positive value, is not attributed to a pair of glasses.

Life cycle inventory analysis

This chapter entails the details of our data collection procedures, literature use, and calculation procedures. In this inventory analysis all environmental input (e.g. resources, energy and waste) was quantified and qualified into environmental impact through the use of LCA background data from Ecoinvent or LCIA's directly sourced from suppliers.

11 Data collection procedures

1. Own operation

Ace & Tate does not own or operate any assets related to the production of the frames. The emissions related to the operation of the retail locations are the only processes that generate an environmental impact which is attributable to Ace & Tate. The retail locations sell the glasses and are also responsible for mounting and edging 20% of all lenses (Same-Day-Service). The utilities used to mount and edge the lenses in store are part of the overall utilities data from their stores. All retail locations have been requested to send utility-relevant information for this assessment. If data was not, or only partially available, data has been extrapolated to a full year and/or extrapolated from other stores based on average utilities per m2 to create one average per frame.

2. Suppliers

All suppliers have been requested to send environmentally-relevant product information for this assessment. The information requested consisted of the following data-points:

- Is an LCA/EPD of your material available? If not;
- Can you provide us with information on the Bill of material?
    - Type of material
    - (gross and net) Weight of materials
    - Waste treatment involved
- Can you provide us with the utilities required to produce your product (type and amount)?
- Are there auxiliary materials needed to produce the product (type and amount)?
- Is there any emission occurring to air, water and soil (type and amount per product)?
- Can you provide us with details regarding transport (km)?

One supplier (an acetate producing chemical company) provided an LCIA, where other material producers provided details on the (intermediate) composition of materials and, where possible, the gross amount of materials. Processing sites provided data on energy, waste, emissions and transport.

Data was acquired for all life cycles stages except for the production of the acetate slab, an intermediate product.

12 Qualitative and quantitative description of unit processes

In this section each separate process within the life cycle is elaborated upon. This entails the reference used to assess the environmental impact for each process step within the system boundary and provides a brief description of the process step.

1. Neil frame production including lenses

The Neil is visualized below, in Figure 5. It is a stainless-steel frame containing either sun, optical or plano lenses (coated, not edged). The frame is completely produced in China.

1 NEIL FRAME MATERIALS

The Neil frame consists of mainly metal parts and a small acetate tip. The parts are cut on site in China and the 'eyes' of the frame are made out of a roll thread stainless steel. In the table below the reference data used to calculate the environmental impact required to produce the frame is stated.

Figure 5: Neil

Table 9: Material references used to calculate the environmental impact of the Neil frame

Material	References	Source	Motivation
Stainless steel	Steel, chromium steel 18/8, hot rolled//[RoW] steel production, chromium steel 18/8, hot rolled	Ecoinvent 3.5	Corresponds to metal used by site
Acetate (tip) Plasticizer DEP	Data provided by chemical supplier of acetate: PP200 Cellulose Acetate; Cellulose Acetate Propionate phthalic anhydride//[GLO] market for phthalic anhydride thermoforming, with calendaring//[RoW] thermoforming production, with calendaring	Ecoinvent 3.5 Acetate producing chemical company Ecoinvent 3.5	Directly sourced from supplier Proxy process based on content
Monel (bridge)	Nickel, 99.5%//[GLO] market for nickel, 99.5% copper//[GLO] market for copper metal working, average for copper product manufacturing//[GLO] market for metal working, average for copper product manufacturing The ratio is 65% copper and 35% Nickel	Ecoinvent 3.5	Proxy process based on content
Silicone (nose pad)	Polydimethylsiloxane//[GLO] market for polydimethylsiloxane thermoforming, with calendering//[RoW] thermoforming production, with calendaring	Ecoinvent 3.5	Proxy process based on content
Polybag (PE)	Packaging film, low density polyethylene//[GLO] market for packaging film, low density polyethylene	Ecoinvent 3.5	Corresponds to material used by site
Organic Cotton	Textile, knit cotton//[GLO] textile production, knit cotton, batch dyed Polymethyl methacrylate, sheet//[RoW] polymethyl methacrylate production, sheet	Ecoinvent 3.5	Corresponds to material used by site
Demo lens (optical)	Data provided by chemical supplier: Diallyl diglycol carbonate; Glycol Ester; $C_{12}H_{18}O_7$	Ecoinvent 3.5	Corresponds to material used by site
CR39 (sun/plano)	polymethyl methacrylate, sheet//[RoW] polymethyl methacrylate production, sheet	Ecoinvent 3.5	Proxy process based on content

2. Pierce frame production including lenses

The Pierce is visualized below, in Figure 6. It is an acetate frame with small steel hardware components containing either optical or plano lenses (coated, not edged). The frame is completely produced in China.

1 PIERCE FRAME MATERIALS

The Pierce frame consists mainly out of acetate and some small hardware components (screws, hinges and core wires). In the table below the reference data used to calculate the environmental impact required to produce the frame is stated.

Figure 6: Pierce

Table: 10 Material references used to calculate the environmental impact of the Pierce frame

Material	References	Source	Motivation
Nickel silver	Nickel, 99.5%//[GLO] market for nickel, 99.5% copper//[GLO] market for copper metal working, average for copper product manufacturing//[GLO] market for metal working, average for copper product manufacturing zinc//[GLO] market for zinc The ratio is 64% copper and 24% Zinc and 12% Nickel	Ecoinvent 3.5	Proxy process based on content
Acetate (slab) Plasticizer DEP	US: CA 398-30 CT - PP200 Cellulose Acetate; Cellulose Acetate Propionate CAP-482-20 RMG with 2016 acid con Exergy Fiber Ester Flake CA-394-60S no 7R with 2016 usages (Exergy) phthalic anhydride//[GLO] market for phthalic anhydride thermoforming, with calendering//[RoW] thermoforming production, with calendering	Ecoinvent 3.5 Acetate producing chemical company Ecoinvent 3.5	Directly sourced from supplier Proxy process based on content
Polybag (PE)	Packaging film, low density polyethylene//[GLO] market for packaging film, low density polyethylene	Ecoinvent 3.5	Corresponds to material used by site
Organic Cotton	Textile, knit cotton//[GLO] textile production, knit cotton, batch dyed	Ecoinvent 3.5	Corresponds to material used by site
Demo lens (optical)	Polymethyl methacrylate, sheet//[RoW] polymethyl methacrylate production, sheet	Ecoinvent 3.5	Corresponds to material used by site
CR39 (plano)	Data provided by chemical supplier: Diallyl diglycol carbonate; Glycol Ester; $C_{12}H_{18}O_7$ polymethyl methacrylate, sheet//[RoW] polymethyl methacrylate production, sheet	Ecoinvent 3.5	Proxy process based on content

3. Transport (both Pierce and Neil)

For all transport related emissions three Ecoinvent processes have been used. Table 11 states the references for these transports.

Table 11: References for transport used

Shipping method	Reference	Source	Motivation
Truck	Transport, freight, lorry, unspecified//[RoW] transport, freight, lorry, all sizes, EURO5 to generic market for transport, freight, lorry, unspecified	Ecoinvent 3.5	Corresponds to material used by site
Airplane	Transport, freight, aircraft//[RoW] transport, freight, aircraft, intercontinental	Ecoinvent 3.5	Corresponds to material used by site
Ocean freight	Transport, freight, sea, transoceanic ship//[GLO] transport, freight, sea, transoceanic ship	Ecoinvent 3.5	Corresponds to material used by site

4. Production (both Pierce and Neil)

The frames are handled in various sites and various countries, including China, Thailand, and the Netherlands and then sold throughout Europe. For the utilities used at the production sites that produce the frames cases and cloth, Chinese data is used. Thailand and the Netherlands data are used for the utilities used for the edging of the lenses, and the rest of the utilities relate to retail sites. In table 12 the references used are visualised.

Table 12: Utilities references used for production data and retail

Utility type	Reference	Source	Motivation
Electricity NL (retail, warehouse and mounting & edging)	Electricity, low voltage//[NL] market for electricity, low voltage	Ecoinvent 3.5	Corresponds to energy used by site
Electricity CN (production of frames and case)	Electricity, medium voltage//[CN] market group for electricity, medium voltage	Ecoinvent 3.5	Corresponds to energy used by site
Electricity TH (mounting and edging)	Electricity, medium voltage//[TH] market for electricity, medium voltage	Ecoinvent 3.5	Corresponds to energy used by site
Natural Gas NL (retail, warehouse and mounting & edging)	Heat, district or industrial, natural gas//[Europe without Switzerland] heat production, natural gas, at industrial furnace >100kW 35,17 MJ per m3 used to assess impact per m3 natural gas used	Ecoinvent 3.5 Wikipedia on heating values	Corresponds to energy used by site
Natural Gas CN (production of frames)	Heat, district or industrial, natural gas//[Europe without Switzerland] heat production, natural gas, at industrial furnace >100kW 38,98 MJ per m3 used to assess impact per m3 natural gas used	Ecoinvent 3.5 Wikipedia on heating values	Corresponds to energy used by site
Electricity KH (cloth)	Electricity, medium voltage//[KH] market for electricity, medium voltage	Ecoinvent 3.5	
LPG	Heat, central or small-scale, natural gas//[GLO] propane extraction, from liquefied petroleum gas	Ecoinvent 3.5	Corresponds to energy used by site
Water	Tap water//[GLO] market group for tap water	Ecoinvent 3.5	Corresponds to material used by site
Electricity BE (retail)	Electricity, low voltage//[BE] market for electricity, low voltage	Ecoinvent 3.5	Corresponds to energy used by site
Electricity SE (retail)	Electricity, low voltage//[SE] market for electricity, low voltage	Ecoinvent 3.5	Corresponds to energy used by site
Electricity DE (retail)	Electricity, low voltage//[DE] market for electricity, low voltage	Ecoinvent 3.5	Corresponds to energy used by site
Electricity DK (retail)	Electricity, low voltage//[DK] market for electricity, low voltage	Ecoinvent 3.5	Corresponds to energy used by site
Electricity AT (retail)	Electricity, low voltage//[AT] market for electricity, low voltage	Ecoinvent 3.5	Corresponds to energy used by site
Electricity IE (retail)	Electricity, low voltage//[IE] market for electricity, low voltage	Ecoinvent 3.5	Corresponds to energy used by site
Electricity UK (retail)	Electricity, low voltage//[GB] market for electricity, low voltage	Ecoinvent 3.5	Corresponds to energy used by site

5. Packaging (both Pierce and Neil)

The product is packed in various stages of the Life Cycle.
The packaging references used are listed in table 13.

Table 13: Packaging material references used

Packaging material	Reference	Source	Motivation
Polyethylene	Packaging film, low density polyethylene//[GLO] market for packaging film, low density polyethylene	Ecoinvent 3.5	Corresponds to material used by site
Organic Cotton	Textile, knit cotton//[GLO] textile production, knit cotton, batch dyed	Ecoinvent 3.5	Corresponds to material used by site
Recycled PET	Polyethylene terephthalate, granulate, amorphous, recycled//[RoW] market for polyethylene terephthalate, granulate, amorphous, recycled thermoforming, with calendering//[RoW] thermoforming, with calendering polyethylene terephthalate, granulate, amorphous, recycled//[RoW] market for polyethylene terephthalate, granulate, amorphous, recycled	Ecoinvent 3.5	Corresponds to material used by site
Water-based polyurethane	Polyurethane, rigid foam//[RoW] market for polyurethane, rigid foam Kraft paper, unbleached//[RER] kraft paper production, unbleached	Ecoinvent 3.5	Corresponds to material used by site
FSC Kraft Paper	Thermoforming, with calendering//[RoW] thermoforming, with calendering polyethylene terephthalate, granulate, amorphous, recycled//[RoW] market for polyethylene terephthalate, granulate, amorphous, recycled	Ecoinvent 3.5	Corresponds to material used by site
Recycled polyester	polyethylene, high density, granulate, recycled//[RoW] market for polyethylene, high density, granulate, recycled	Ecoinvent 3.5	Corresponds to material used by site
Glue	Paraffin//[GLO] market for paraffin	Ecoinvent 3.5	Corresponds to material used by site
Cotton	Cotton fibre//[GLO] market for cotton fibre	Ecoinvent 3.5	Corresponds to material used by site
Oil paint	Alkyd paint, white, without solvent, in 60% solution state//[RoW] market for alkyd paint, white, without solvent, in 60% solution state	Ecoinvent 3.5	Corresponds to material used by site
Recycled paper	Graphic paper, 100% recycled//[GLO] market for graphic paper, 100% recycled	Ecoinvent 3.5	Corresponds to material used by site
Paper	Paper, woodfree, coated//[RER] market for paper, woodfree, coated	Ecoinvent 3.5	Corresponds to material used by site

6. Use phase (both Pierce and Neil)

This analysis takes a cradle to gate approach with end-of-life phase inventory and does not consider the use phase. This is due to the uncertainty related to the use phase. The use phase of the glasses is not directly influenced by Ace & Tate and is therefore not part of the scope. Furthermore, the goal of the study does not involve a comparative assertion on quality to other types of eyewear.

7. End-of life (both Pierce and Neil)

The end-of life phase is part of the study to better understand the environmental impact of the product when the consumer disposes of the product. This is important since the materials chosen when developing glasses impact the environment at end-of life. Different business models (take back system) or other materials can have a positive impact on the end-of life phase. Since the treatment of waste per country is beyond the control of Ace & Tate and no data is available specifically on the end-of life phase of the frame, the study uses European averages from Ecoinvent to assess the environmental impact related to waste processing (economic cut-off) of all materials used in production..

Production waste is allocated to the process step where the waste is created. The waste references below are used for both the end-of life phase as well as the production waste.

Table 14: Waste references used

Waste processing	Reference	Source	Motivation
Acetate [waste processing]	Waste plastic, mixture//[RoW] treatment of waste plastic, mixture, municipal incineration	Ecoinvent 3.5	Worst case option selected for waste treatment related to type of reference materials
Stainless steel [waste processing]	Scrap steel//[RoW] treatment of scrap steel, municipal incineration	Ecoinvent 3.5	Worst case option selected for waste treatment related to type of reference materials
PMMA [waste processing]	Waste polypropylene//[RoW] treatment of waste polypropylene, municipal incineration	Ecoinvent 3.5	Worst case option selected for waste treatment related to type of reference materials
CR39 [waste processing]	Waste polypropylene//[RoW] treatment of waste polypropylene, municipal incineration	Ecoinvent 3.5	Worst case option selected for waste treatment related to type of reference materials
Metal [waste processing]	Scrap steel//[RoW] treatment of scrap steel, municipal incineration	Ecoinvent 3.5	Worst case option selected for waste treatment related to type of reference materials
Monel [waste processing]	Scrap steel//[RoW] treatment of scrap steel, municipal incineration	Ecoinvent 3.5	Worst case option selected for waste treatment related to type of reference materials
Nickel silver [waste processing]	Scrap steel//[RoW] treatment of scrap steel, municipal incineration	Ecoinvent 3.5	Worst case option selected for waste treatment related to type of reference materials
DEP [waste processing]	Waste plastic, mixture//[RoW] treatment of waste plastic, mixture, municipal incineration	Ecoinvent 3.5	Worst case option selected for waste treatment related to type of reference materials
Polyethylene [waste processing]	Waste polyethylene//[RoW] treatment of waste polyethylene, municipal incineration	Ecoinvent 3.5	Worst case option selected for waste treatment related to type of reference materials
White paper box [waste processing]	Waste paperboard//[RoW] treatment of waste paperboard, municipal incineration	Ecoinvent 3.5	Worst case option selected for waste treatment related to type of reference materials
Recycled PET [waste processing]	Waste plastic, mixture//[RoW] treatment of waste plastic, mixture, municipal incineration	Ecoinvent 3.5	Worst case option selected for waste treatment related to type of reference materials
Water-based polyurethane [waste processing]	Waste polyurethane//[RoW] treatment of waste polyurethane, municipal incineration	Ecoinvent 3.5	Worst case option selected for waste treatment related to type of reference materials
FSC Kraft Paper [waste processing]	Waste paperboard//[RoW] treatment of waste paperboard, municipal incineration	Ecoinvent 3.5	Worst case option selected for waste treatment related to type of reference materials

Recycled polyester [waste processing]	Waste polyethylene terephtalate//[RoW] treatment of waste polyethylene terephtalate, municipal incineration	Ecoinvent 3.5	Worst case option selected for waste treatment related to type of reference materials
Glue [waste processing]	Waste plastic, mixture//[RoW] treatment of waste plastic, mixture, municipal incineration	Ecoinvent 3.5	Worst case option selected for waste treatment related to type of reference materials
Cotton [waste processing]	Biowaste//[GLO] treatment of biowaste, municipal incineration	Ecoinvent 3.5	Worst case option selected for waste treatment related to type of reference materials
Oil paint [waste processing]	Waste paint//[RoW] treatment of waste paint, municipal incineration	Ecoinvent 3.5	Worst case option selected for waste treatment related to type of reference materials
Recycled paper [waste processing]	Waste paperboard//[RoW] treatment of waste paperboard, municipal incineration	Ecoinvent 3.5	Worst case option selected for waste treatment related to type of reference materials
Paper [waste processing]	Waste paperboard//[RoW] treatment of waste paperboard, municipal incineration	Ecoinvent 3.5	Worst case option selected for waste treatment related to type of reference materials
Cotton [waste processing]	Waste textile, soiled//[RoW] treatment of waste textile, soiled, municipal incineration	Ecoinvent 3.5	Worst case option selected for waste treatment related to type of reference materials

13 Sources of published literature

For the analysis supplier specific data and Ecoinvent 3.5 data is used. Ecoinvent data is used to complete the inventory for materials, processes, transport, energy usage and waste processing.

14 Calculation procedures

To consistently calculate the environmental impact, the Ecoinvent v3.5 cut-off database is used. Ecoinvent v3.5 is the latest version of the Ecoinvent database that provides well documented process data for thousands of products. To be able to model all processes for which no supplier specific data is available, Ecoinvent was used in this study.
Data provided by suppliers on amounts of materials, waste, transport and energy use was directly used in the model.

Because the glasses are produced via various production routes as stated in the scope and boundary, various averages and calculations have been made in a separate Excel to assess the average inventory for the edging process, materials related to lenses and the transport related to these routes. Furthermore, not all retail locations have data on utilities usage therefore the data is extrapolated from those location with data to calculate an average utility use per frame.

15 Validation of data

In this LCA the data relating to the manufacturing of the product and the background processes for environmental impacts are recent and geographically representative, meaning that the production locations are within the region for which the relevant Ecoinvent environmental records have been selected. The dataset is up-to-date and representative for the current technology used in the processes involved in manufacturing the products.

16 Completeness of environmental impacts and economic flows

All environmental impact flows – from sources such as resources, energy, emissions and waste – were quantified and qualified in environmental effects. There is no presumption that relevant input or output has been omitted. All identified environmental impact has been translated into environmental impact categories. The LCA references were derived from reputable databases which ensure that all relevant environmental impact was categorised.

17 Consistency and reproducibility

The process descriptions and quantities in this study are quantitatively reproducible in accordance with the reference standards that have been used. The references of all sources, both primary and public sources and literature, have been documented in the chapter "References". Additionally, in order to guarantee the reproducibility, a project dossier has been composed. This project dossier contains a summary of all the data used this LCA.

Life cycle impact assessment

18 LCIA procedures, calculations and impact categories

In this chapter the results of the LCA calculations are presented and discussed. The environmental profile consists of 18 impact categories and a number of parameters. The LCA profile of both products is presented in the tables below. The impact categories are calculated in the following manner: all environmental emissions from the inventory are multiplied by the characterisation factors from the ReCiPe Hierarchy midpoint impact assessment method v1.13 (without long term), after which these values are added up to provide the total environmental impact per impact category. The ReCiPe model is a method for impact assessment in an LCA that translates emissions and resource extractions into a limited number of environmental impact scores. It has been chosen as it represents a broad, up to date range of environmental impact categories that are relevant to the products being assessed in this study. Calculations have been done using Ecoinvent and there are no reasons to expect any omissions in these calculations. These LCIA results are relative expressions and do not predict impacts on category endpoints, the exceeding of thresholds, safety margins or risks.

19 LCIA results relative to the LCI and the defined goal and scope

No limitations relative to the defined goal and scope have been identified and the LCIA can be used to achieve the goals formulated in the goal and scope.

Life cycle interpretation

20 Results

In the two tables below the LCIA results are shown per frame. The LCIA results are visualised as a weighted average per pair of glasses. The weighted average is based on the amount of sun, plano and optical lenses produced and the relative routes of transport.

Table 15: LCIA Pierce

Impact category	Unit	Acetate & hinges, screws and core wire	Packaging	Transport to production in China	Production in China	Transport lens and frame	Edging	Transport frame	(Consumer) packaging+ transport	Warehouse in the Netherlands	Transport to client/retail	Retail	End-of-life	Total
Agricultural land occupation: ALOP	m2a	7,65E-03	3,39E-02	1,03E-05	8,17E-02	1,16E-03	3,98E-02	2,09E-04	5,20E-01	8,88E-03	4,27E-05	8,09E-02	1,58E-04	**7,74E-01**
Climate change: GWP100	kg CO2-Eq.	4,44E-01	1,48E-02	1,26E-03	3,22E+00	4,47E-01	8,36E-01	0,051976	5,37E-01	1,11E-01	5,22E-03	7,71E-01	1,36E-01	**6,88E+00**
Fossil depletion: FDP	kg oil-Eq.	1,03E-01	7,69E-03	4,74E-04	7,18E-01	1,57E-01	2,84E-01	1,82E-02	1,59E-01	3,56E-02	1,97E-03	2,22E-01	2,52E-03	**1,81E+00**
Freshwater ecotoxicity: FETPinf	kg 1,4-DC.	5,60E-04	7,41E-06	8,92E-07	7,58E-04	2,00E-04	7,50E-04	2,38E-05	2,29E-03	1,36E-05	3,70E-06	1,19E-04	1,46E-04	**4,93E-03**
Freshwater eutrophication: FEP	kg P-Eq.	2,04E-04	9,35E-07	1,93E-08	8,31E-05	1,70E-06	6,11E-05	3,01E-07	4,91E-05	8,51E-06	8,01E-08	9,47E-05	2,01E-07	**5,10E-04**
Human toxicity: HTPinf	kg 1,4-DC.	4,03E-01	1,06E-03	2,82E-04	1,88E-01	8,19E-03	4,23E-02	1,21E-03	7,20E-02	5,22E-03	1,17E-03	4,49E-02	1,10E-02	**7,83E-01**
Ionising radiation: IRP_HE	kg U235-Eq.	4,04E-03	6,44E-04	8,33E-05	2,35E-02	2,84E-02	1,72E-02	3,31E-03	1,56E-02	3,78E-03	3,45E-04	7,49E-02	1,81E-04	**1,72E-01**
Marine ecotoxicity: METPinf	kg 1,4-DC.	3,72E-03	1,34E-05	4,90E-06	9,15E-04	2,09E-04	5,06E-04	4,34E-05	8,56E-04	5,40E-05	2,03E-05	4,28E-04	1,08E-04	**6,97E-03**
Marine eutrophication: MEP	kg N-Eq.	6,55E-05	5,59E-06	1,66E-07	3,83E-04	7,74E-05	7,18E-05	1,14E-05	8,45E-04	1,11E-05	6,88E-07	1,22E-04	9,78E-06	**1,67E-03**
Metal depletion: MDP	kg Fe-Eq.	2,88E-01	1,88E-04	1,67E-05	1,33E-02	8,90E-04	8,69E-03	1,56E-04	1,06E-02	1,69E-03	6,93E-05	1,54E-02	2,37E-04	**3,39E-01**
Natural land transformation: NLTP	m2	-1,34E-05	-5,38E-07	-1,23E-07	-2,11E-04	-4,75E-06	-2,44E-05	-9,42E-07	-3,01E-05	-3,69E-06	-5,12E-07	-2,89E-05	-4,67E-07	**-3,19E-04**
Ozone depletion: ODPinf	kg CFC-11.	1,69E-08	1,14E-09	2,33E-10	2,30E-08	8,20E-08	4,08E-08	9,37E-09	4,03E-08	5,98E-09	9,67E-10	5,20E-08	9,72E-10	**2,74E-07**
Particulate matter formation: PMFP	kg PM10-Eq.	1,42E-03	2,92E-05	2,33E-06	7,11E-03	5,91E-04	6,83E-04	1,04E-04	1,37E-03	8,20E-05	9,67E-06	8,02E-04	3,58E-05	**1,26E-02**
Photochemical oxidant formation: POFP	kg NMVOC	1,13E-03	6,56E-05	5,25E-06	1,04E-02	2,21E-03	1,38E-03	3,25E-04	2,15E-03	1,71E-04	2,18E-05	1,21E-03	1,29E-04	**2,02E-02**
Terrestrial acidification: TAP100	kg SO2-Eq.	5,29E-03	6,75E-05	4,02E-06	1,35E-02	1,67E-03	2,24E-03	3,04E-04	3,29E-03	3,06E-04	1,67E-05	3,52E-03	8,48E-05	**3,14E-02**
Terrestrial ecotoxicity: TETPinf	kg 1,4-DC.	2,71E-02	6,45E-06	6,22E-07	7,36E-05	1,44E-05	2,21E-05	2,08E-06	9,95E-03	2,00E-06	2,58E-06	2,45E-05	7,53E-06	**3,72E-02**
Urban land occupation: ULOP	m2a	1,62E-03	4,05E-04	9,02E-05	2,25E-02	1,02E-03	2,43E-03	1,92E-04	6,59E-03	4,18E-04	3,74E-04	3,65E-03	1,02E-04	**3,94E-02**
Water depletion: WDP	m3	5,63E-03	4,67E-04	1,76E-06	1,13E-02	3,54E-04	4,94E-03	4,74E-05	1,01E-01	5,07E-04	7,29E-06	4,21E-03	4,83E-04	**1,30E-01**

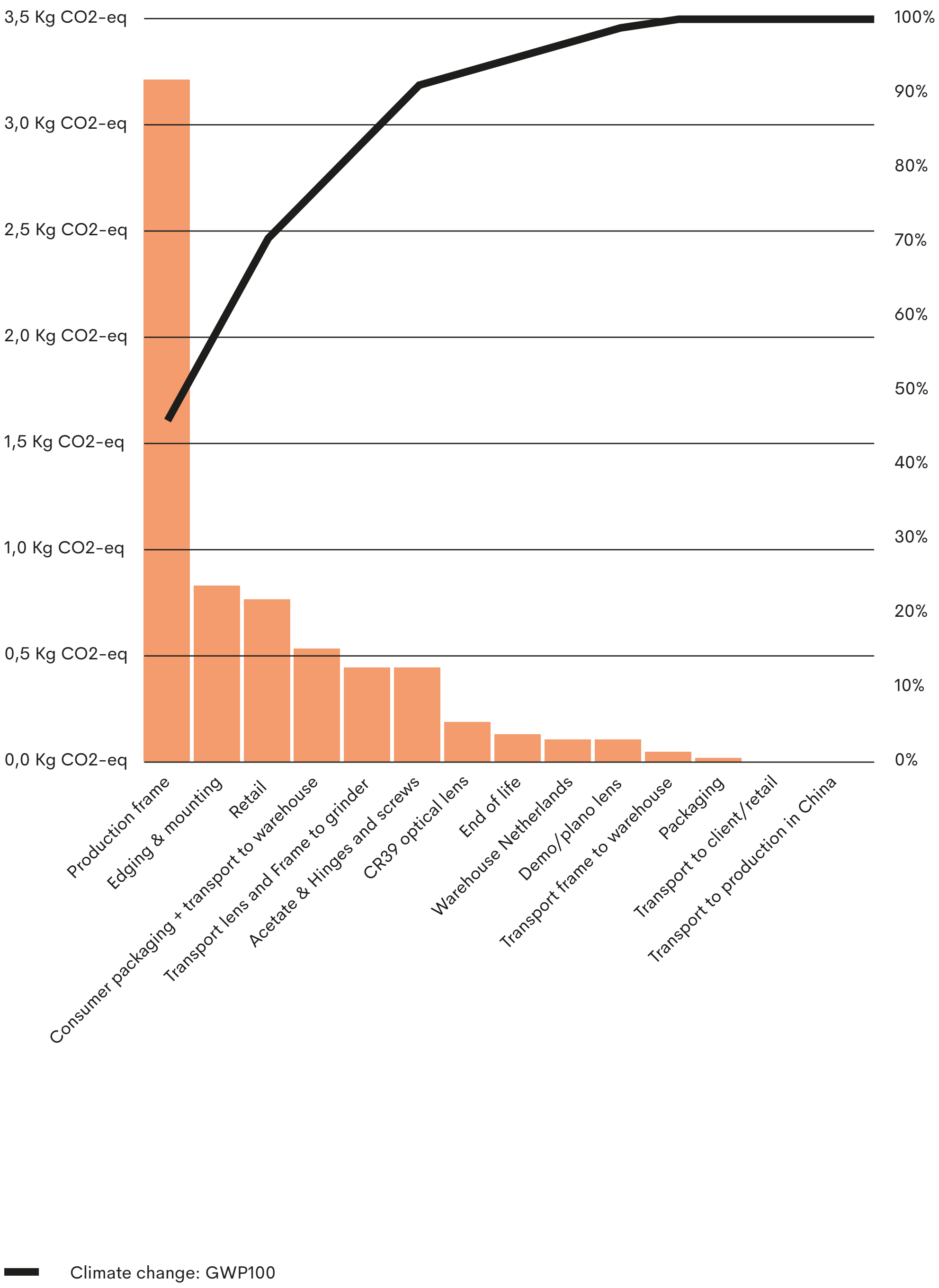
Table 16: LCIA Neil

Impact category	Unit	Metals & plastics for frame	Demo / plano lens	Transport to production in China	Production in China	CR39 optical lens	Transport lens and Frame	Edging	Transport frame	Transport frame	(Consumer) packaging+ transport	Warehouse in the Netherlands	Transport to client / retail	Retail	End-of-life	Total
Agricultural land occupation: ALOP	m2a	1,22E-02	1,04E-05	3,92E-06	1,59E-01	4,31E-05	1,36E-03	1,78E-02	2,36E-04	2,36E-04	5,20E-01	8,88E-03	4,94E-05	8,09E-02	1,63E-04	**8,34E-01**
Climate change: GWP100	kg CO2-Eq.	2,12E-01	5,03E-02	4,79E-04	5,83E-01	2,10E-01	5,34E-01	4,18E-01	6,26E-02	6,26E-02	5,37E-01	1,11E-01	6,03E-03	7,71E-01	1,43E-01	**3,65E+00**
Fossil depletion: FDP	kg oil-Eq.	5,42E-02	1,77E-02	1,80E-04	1,29E-01	7,21E-02	1,88E-01	1,42E-01	2,20E-02	2,20E-02	1,59E-01	3,56E-02	2,27E-03	2,22E-01	2,57E-03	**1,05E+00**
Freshwater ecotoxicity: FETPinf	kg 1,4-DC.	2,11E-04	1,01E-05	3,40E-07	1,32E-04	4,29E-05	2,39E-04	3,75E-04	2,86E-05	2,86E-05	2,29E-03	1,36E-05	4,28E-06	1,19E-04	1,43E-04	**3,62E-03**
Freshwater eutrophication: FEP	kg P-Eq.	5,95E-05	1,20E-06	7,35E-09	1,48E-05	4,88E-06	2,02E-06	3,06E-05	3,42E-07	3,42E-07	4,91E-05	8,51E-06	9,25E-08	9,47E-05	2,05E-07	**2,67E-04**
Human toxicity: HTPinf	kg 1,4-DC.	1,17E-01	7,58E-04	1,07E-04	3,45E-02	3,43E-03	9,79E-03	2,12E-02	1,42E-03	1,42E-03	7,20E-02	5,22E-03	1,35E-03	4,49E-02	1,20E-02	**3,25E-01**
Ionising radiation: IRP_HE	kg U235-Eq.	5,22E-03	6,36E-06	3,17E-05	4,01E-03	2,67E-05	3,38E-02	8,61E-03	3,99E-03	3,99E-03	1,56E-02	3,78E-03	3,99E-04	7,49E-02	1,88E-04	**1,51E-01**
Marine ecotoxicity: METPinf	kg 1,4-DC.	1,70E-03	1,33E-05	1,86E-06	1,64E-04	6,09E-05	2,49E-04	2,53E-04	4,85E-05	4,85E-05	8,56E-04	5,40E-05	2,35E-05	4,28E-04	1,29E-04	**3,99E-03**
Marine eutrophication: MEP	kg N-Eq.	3,56E-05	1,19E-05	6,31E-08	6,93E-05	4,86E-05	9,23E-05	3,59E-05	1,32E-05	1,32E-05	8,45E-04	1,11E-05	7,95E-07	1,22E-04	9,74E-06	**1,30E-03**
Metal depletion: MDP	kg Fe-Eq.	1,26E-01	1,99E-05	6,35E-06	2,41E-03	8,28E-05	1,06E-03	4,34E-03	1,78E-04	1,78E-04	1,06E-02	1,69E-03	8,01E-05	1,54E-02	2,47E-04	**1,63E-01**
Natural land transformation: NLTP	m2	-2,09E-05	-1,95E-08	-4,69E-08	-3,81E-05	-8,21E-08	-5,68E-06	-1,22E-05	-1,06E-06	-1,06E-06	-3,01E-05	-3,69E-06	-5,91E-07	-2,89E-05	-5,06E-07	**-1,42E-04**
Ozone depletion: ODPinf	kg CFC-11.	3,18E-07	3,87E-11	8,88E-11	4,41E-09	1,62E-10	9,79E-08	2,04E-08	1,13E-08	1,13E-08	4,03E-08	5,98E-09	1,12E-09	5,20E-08	9,88E-10	**5,54E-07**
Particulate matter formation: PMFP	kg PM10-Eq.	1,30E-03	5,60E-0	8,88E-07	1,28E-03	2,28E-04	7,05E-04	3,41E-04	1,18E-04	1,18E-04	1,37E-03	8,20E-05	1,12E-05	8,02E-04	3,62E-05	**6,36E-03**
Photochemical oxidant formation: POFP	kg NMVOC	8,90E-04	1,74E-04	2,00E-06	1,89E-03	7,11E-04	2,64E-03	6,90E-04	3,78E-04	3,78E-04	2,15E-03	1,71E-04	2,51E-05	1,21E-03	1,30E-04	**1,11E-02**
Terrestrial acidification: TAP100	kg SO2-Eq.	2,68E-03	1,94E-04	1,53E-06	2,45E-03	7,92E-04	2,00E-03	1,12E-03	3,43E-04	3,43E-04	3,29E-03	3,06E-04	1,92E-05	3,52E-03	8,53E-05	**1,69E-02**
Terrestrial ecotoxicity: TETPinf	kg 1,4-DC.	4,88E-03	1,91E-06	2,37E-07	1,23E-05	8,28E-06	1,72E-05	1,11E-05	2,44E-06	2,44E-06	9,95E-03	2,00E-06	2,98E-06	2,45E-05	9,05E-06	**1,49E-02**
Urban land occupation: ULOP	m2a	2,79E-03	4,94E-06	3,43E-05	4,07E-03	2,06E-05	1,22E-03	1,22E-03	2,20E-04	2,20E-04	6,59E-03	4,18E-04	4,32E-04	3,65E-03	1,18E-04	**2,12E-02**
Water depletion: WDP	m3	1,76E-03	1,79E-04	6,69E-07	1,53E-03	7,32E-04	4,22E-04	2,47E-03	5,59E-05	5,59E-05	1,01E-01	5,07E-04	8,43E-06	4,21E-03	4,99E-04	**1,14E-01**

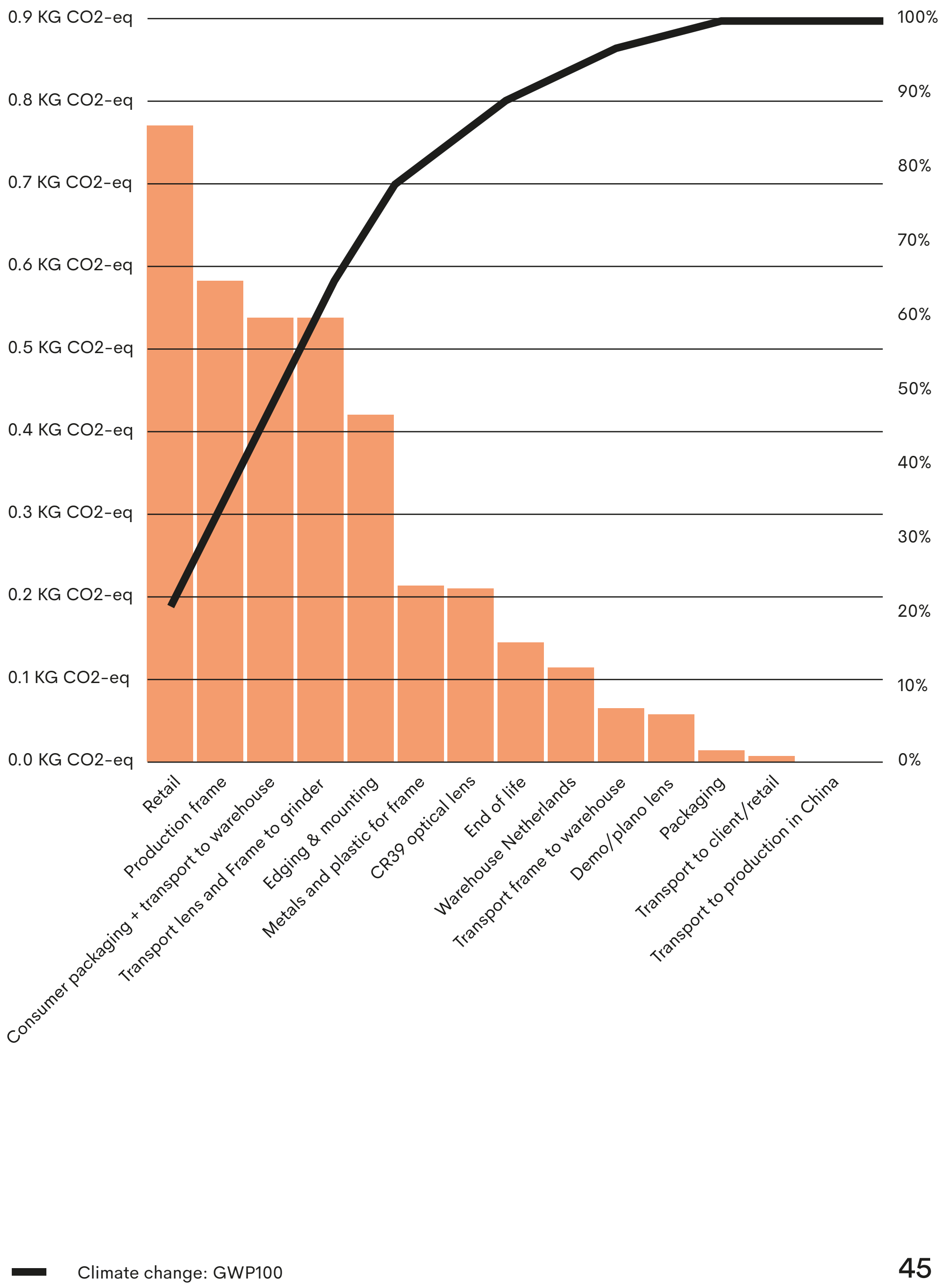
1. Pareto analysis

The two pareto (gravity) analyses in Graph 1 and Graph 2 visualise the most impactful stages in the life cycle on the impact category Global Warming Potential (GWP, in CO2 -eq.) for both the Neil and Pierce.

Graph 1: Pareto analysis Pierce



Graph 2: Pareto analysis Neil



1 PARETO INTERPRETATION PIERCE

The graph visualises the relatively high impact of the production of the Pierce.

Production of the frame attributes almost 50% to the impact. Edging & mounting and retail and consumer packaging attribute almost another 30%, which implies that these four life cycle stages equal 80% of the impact on CO2 -eq.

1) Production frame

The production of the frame in China relates to the energy required to produce the frame from the acetate slab. According to data derived from the site, 3,16 kWh was used by the main factory producing for Ace & Tate. The relatively high CO2 intensity of the Chinese energy mix in Ecoinvent is the main contributor to the impact on CO2 -eq. This life cycle step is further analysed in section 8.2 in a sensitivity analysis to understand the impact of the value on the total amount of CO2 -eq.

2) Edging & mounting

The edging is an energy intensive process with 4 kWh used in Thailand for the full process from blanc to finished lenses, including mounting and edging. As 17% of Neil products and 14% of Pierce products is edged in Thailand, only part of the full 4 kWh is attributed.

3) Retail

The retail locations itself have a relatively high impact but the impact of retail on the life cycle of the product is not high in general. Therefore, a sensitivity analysis was carried out. The main source of impact is the kWh usage in retail stores in Germany, which is at 0,63 kWh per pair of glasses, totalling into 1,43 kWh per pair of glasses.

2 PARETO NEIL

The graph for Neil visualises the relatively high impact of Retail, almost 20%. Production of the frame, transport of the lens and frame to edger, edging and mounting and consumer packaging of the final product attribute almost another 45%, which implies that these five stages in the life cycle equal approximately 65% of the impact on CO2 -eq.

1) Retail

The retail is energy intensive. As explained with the Pierce, the main driver is the kWh usage in Germany which is 0,63 kWh per pair of glasses totalling into 1,43 kWh per pair of glasses.

2) Production frame Pierce

The production of the frame in China relates to the energy required to produce the Neil frame from the stainless-steel sheet. According to data derived from the site 0,58 kWh is used. The relatively high CO2 intensity of the Chinese energy mix in Ecoinvent is the main contributor to the impact on CO2 -eq.

3) Transport of frames to edger

Some of the frames are transported from China via the Netherlands to Thailand by airplane. The relative high impact of this mode of transportation and the route via the Netherlands impacts the total amount of CO2-eq.

21 Sensitivity analysis

A sensitivity analysis aims to determine the influence of variations in assumptions, methods and data on the results. Mainly, the sensitivity of the most significant issues identified is checked. The purpose is to compare the results obtained using given assumptions, methods or data with the results obtained using altered assumptions, methods or data.

In sensitivity analyses, typically the influence of varying the results on the assumptions and data by some range (e.g. a range of 25%) is checked. Both results are then compared. Sensitivity can be expressed as the percentage of change or as the absolute deviation of the results. On this basis, significant changes in the results (e.g. larger than 10%) can be identified.

1. Sensitivity analysis Pierce

For the Pierce frame, three sensitivity analyses have been conducted. The first analysis has been on the production of the acetate frame. This is the single largest impact and indicates overall sensitivity in data. The second analysis has been on the production of the acetate slab, as limited data was available on the production process. The third sensitivity analysis carried out was on the end-of life, as this is based on waste treatment by incineration only.

1 SENSITIVITY ANALYSIS ON PRODUCTION OF THE ACETATE FRAME

Graph 3 visualises the sensitivity analysis of the impact of 20% increase and decrease in GWP (Global Warming Potential) for the production of the acetate Pierce frame on the total LCIA. The impact of this life cycle step on the total outcome, visualised in the pareto analysis, explains why a sensitivity analysis is done. The amount of kWh used to produce a frame, impacts the outcome of the study. A sensitivity analysis supports in understanding the significance of the amount of kWh on the total result. Furthermore, it provides an insight on the impact of other life cycles stages on the outcome since this is the largest impact.

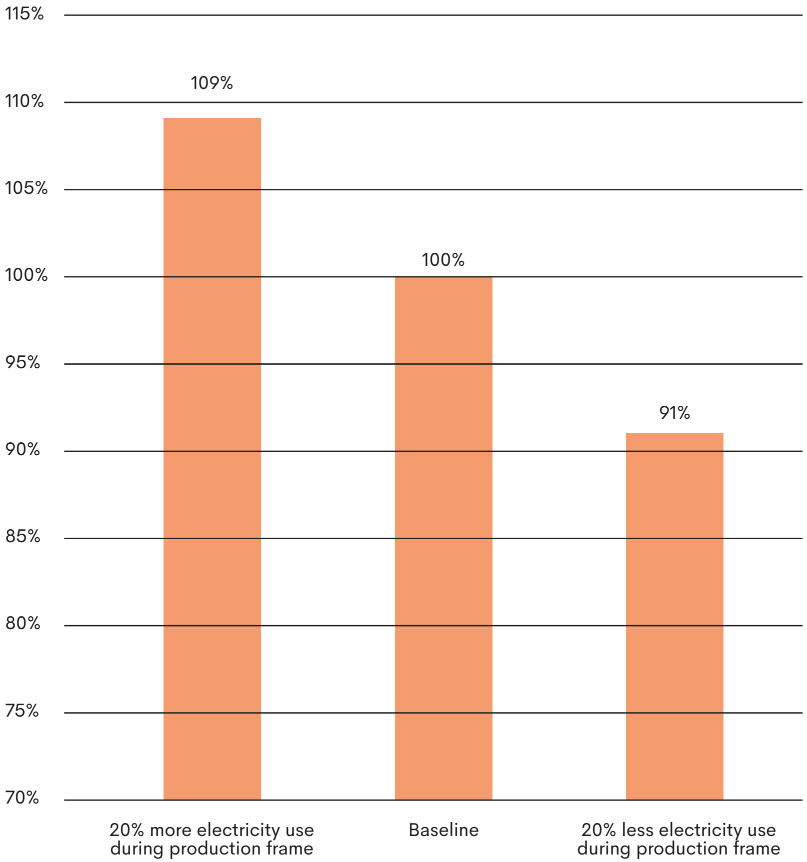
This sensitivity analysis shows an impact of 9% on the outcome. This is a relative high impact but not larger than 10%. Any other life cycle stage will therefore, with a similar sensitivity analysis of 20% increase and decrease, have a smaller impact on the final results.

2 SENSITIVITY ANALYSIS ON PRODUCTION OF THE ACETATE SLAB

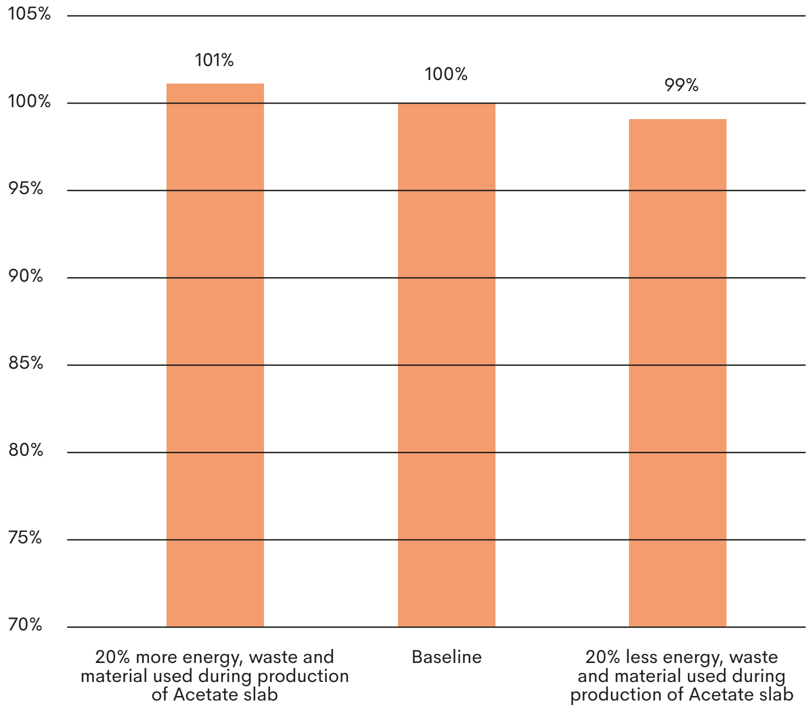
Since limited data was available on the production of the acetate slab, Graph 4 visualises the impact of a 20% increase and decrease in materials, utilities usage and waste.

The impact of a 20% increase and decrease is limited and impact the results with 1%.

Graph 3: Sensitivity analysis Pierce production acetate frame



Graph 4: Sensitivity analysis Pierce production Acetate slab



3 SENSITIVITY ANALYSIS ON THE END-OF-LIFE PHASE

As the end-of-life phase was based on an incineration scenario, sensitivity analysis is done to understand the impact of a 20% increase and or decrease related to the emissions from waste treatment.

The impact of waste treatment is limited with 0,4% impact on the final results.

2. Sensitivity analysis Neil

For the Neil two sensitivity analyses are carried out. The first analysis is on the production of the frame, which has the single largest impact. The second analysis is on the end-of-life, as the end-of-life is based on waste treatment by incineration only.

1 SENSITIVITY ANALYSIS ON RETAIL

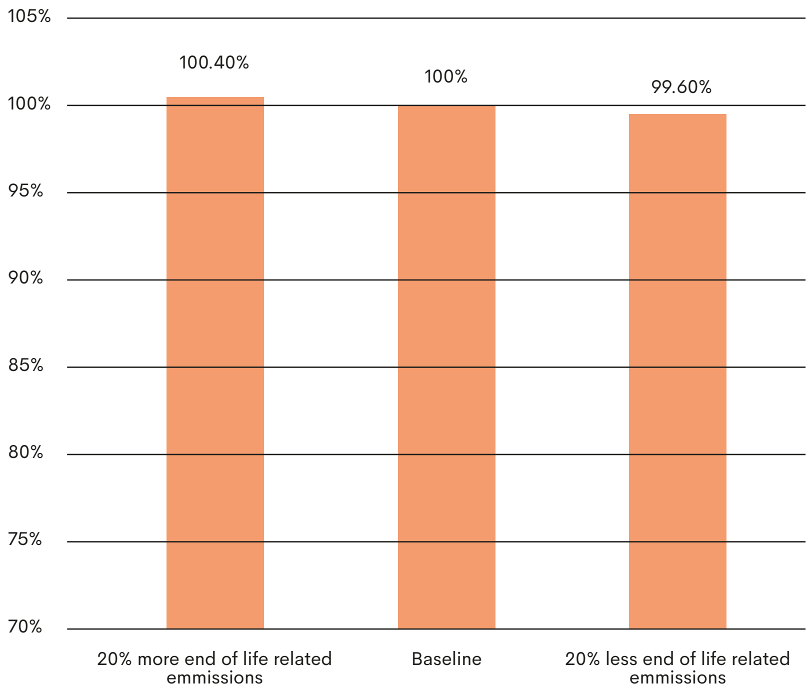
Graph 6 visualises a sensitivity analysis for the Neil. It shows the sensitivity of 20% decrease and increase of retail CO2-eq. on the total LCIA. This life cycle step is used as it has the single biggest impact.

This sensitivity analysis shows an impact of 6% on the total. This is a relative high impact, but not exceeding 10%. Any other life cycle stage will therefore, with a similar sensitivity analysis of 20% increase and decrease, have a smaller impact on the final results. Graph 6 therefore provides an overall insight into the sensitivity of all data in the model.

2 SENSITIVITY ANALYSIS ON THE END-OF-LIFE PHASE

As the end-of-life phase was based on an incineration scenario, a sensitivity analysis was done to understand the impact of a 20% increase and or decrease related to the emissions from waste treatment.
The impact of waste treatment is limited with 1% impact on the final results. Assumptions and limitations.

Graph 5: Sensitivity analysis end-of-life Pierce materials



3. Production Acetate slab

No data was available for the production of the acetate slab and data had to be estimated via Ecoinvent.

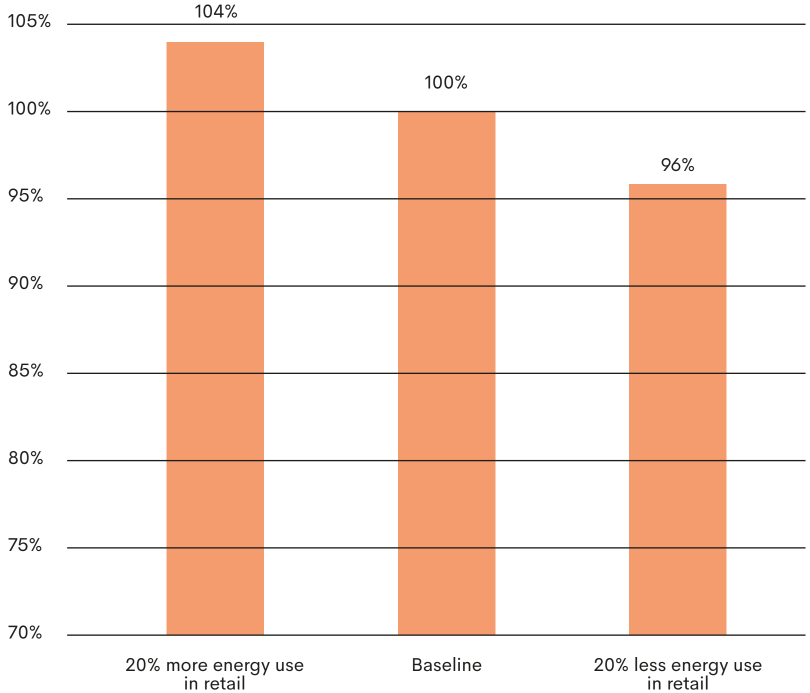
4. Materials

Not all supply chain partners have been able to provide a detailed LCA of the materials they provided. Getting this information would enable Ace & Tate to better understand the environmental impact related to the production of materials

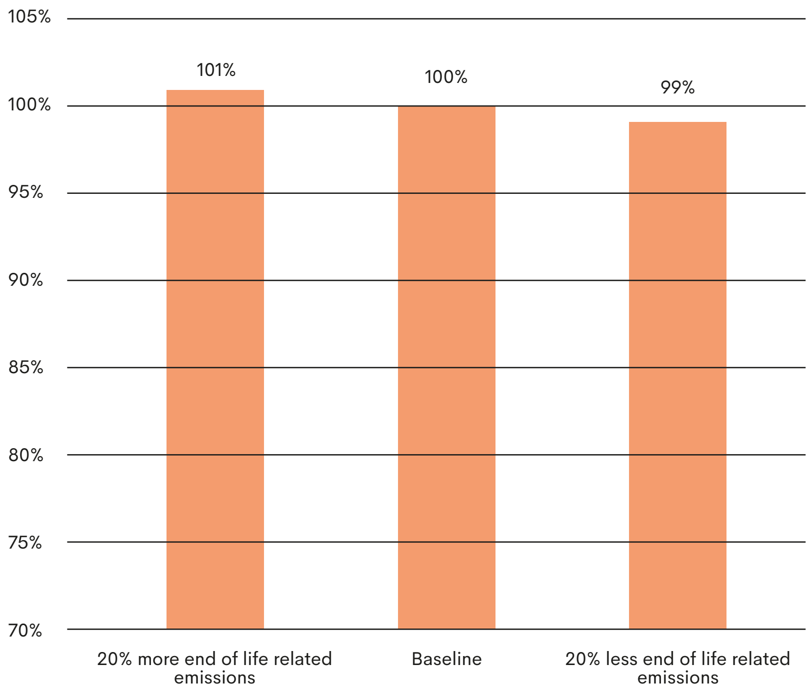
5. Waste

How production waste and product waste is treated is difficult to assess. Since the amount of waste generated throughout production is significant, Ace & Tate could focus on resource efficiency potential within their supply chain to decrease environmental burden.

Graph 6: Sensitivity analysis Neil for retail energy use



Graph 7: Sensitivity analysis Neil for end-of-life phase



22 Data quality assessment

1. Data sourced from suppliers

The data sourced from suppliers was up-to date and supplier specific. Making it both geographical and in time representative. This mainly relates to the weights of materials used, transport distances between companies and utilities usages the data gathered is consistent.

2. Materials

Data from Ecoinvent is used per life cycle inventory step. Ideally the data is iteratively phased out by actual material specific data.

Critical review

23. Name and affiliation of reviewers

Niels Jonker - EcoChain

24. Critical review report

"The LCA study under review has been performed thoroughly and accurately. Sufficient work has been put into the gathering of actual foreground data. For other data, LCA databases were used. A proper database (Ecoinvent) was selected for this. In possible future studies, the reliance on databases may become lower as more details on the actual data are gathered. Details of the life cycle and the choice of reference data to model the life cycle have been clearly described. An appropriate impact assessment method (Recipe) was selected for the calculations. Sufficient interpretation of the results was done to check the validity of the results and fulfil the scope of the study.

Therefore, my conclusion is that the LCA report fully complies with the ISO 14044 norm, which ensures quality and transparency of the LCA."

References

Mark A.J. Huijbregts, Zoran J.N. Steinmann, Pieter M.F. Elshout, Gea Stam, Francesca Verones, Marisa Vieira, Michiel Zijp, Anne Hollander, Rosalie van Zelm. ReCiPe2016: a harmonized life cycle impact assessment method at midpoint and endpoint level. International Journal of LCA, DOI 10.1007/s11367-016-1246-y.

Wernet, G., Bauer, C., Steubing, B., Reinhard, J., Moreno-Ruiz, E., and Weidema, B., 2016. The Ecoinvent database version 3 (part I): overview and methodology. The International Journal of Life Cycle Assessment, [online] 21(9), pp.1218–1230. Available at: http://link.springer.com/10.1007/s11367-016-1087-8>

Wikipedia contributors, 'Verbrandingswarmte', Wikipedia, The Free Encyclopedia, 10 januari 2019, 15:07 (UTC), <https://nl.wikipedia.org/w/index.php?title=Verbrandingswarmte&oldid=52970057> [accessed 10 januari 2019]

Wikipedia contributors, 'Heat of combustion', Wikipedia, The Free Encyclopedia, 15 March 2019, 16:44 UTC, <https://en.wikipedia.org/w/index.php?title=Heat_of_combustion&oldid=887909070> [accessed 27 March 2019]