eco®

CARBON NEGATIVE EYEWEAR

# Carbon footprint report

2023

# Pioneering sustainable eyewear since 2009

Eco Eyewear is all for being positive, but not when it comes to the emission of $CO_2$. We're proud to announce that our mission of planting trees has led Eco to become one of the very first carbon negative eyewear brands in the world!

What does this mean, exactly? Unlike being carbon neutral, where one compensates for $CO_2$ emissions at a ratio of one to one, Eco is carbon negative. This means that our efforts in reducing carbon emissions by planting trees actually surpass neutrality. "Our" trees clean out more $CO_2$ than our eyewear production creates.

Eco has planted 3.3 million trees so far, offsetting a total of 154 million kilograms of $CO_2$!

CARBON NEGATIVE

PRODUCT FAMILIES

# Frames made from sustainable materials

## Biobased

Our biobased frames are crafted using castor seed oil, making them lightweight, comfortable — and sustainable.

## Recycled metal

Our recycled frames are made using 95% recycled metal. That's a serious saving on natural resources!

## Ocean plastic

All Eco Ocean frames are created from recycled and ocean based plastics. Join the wave of change!

# Report summary

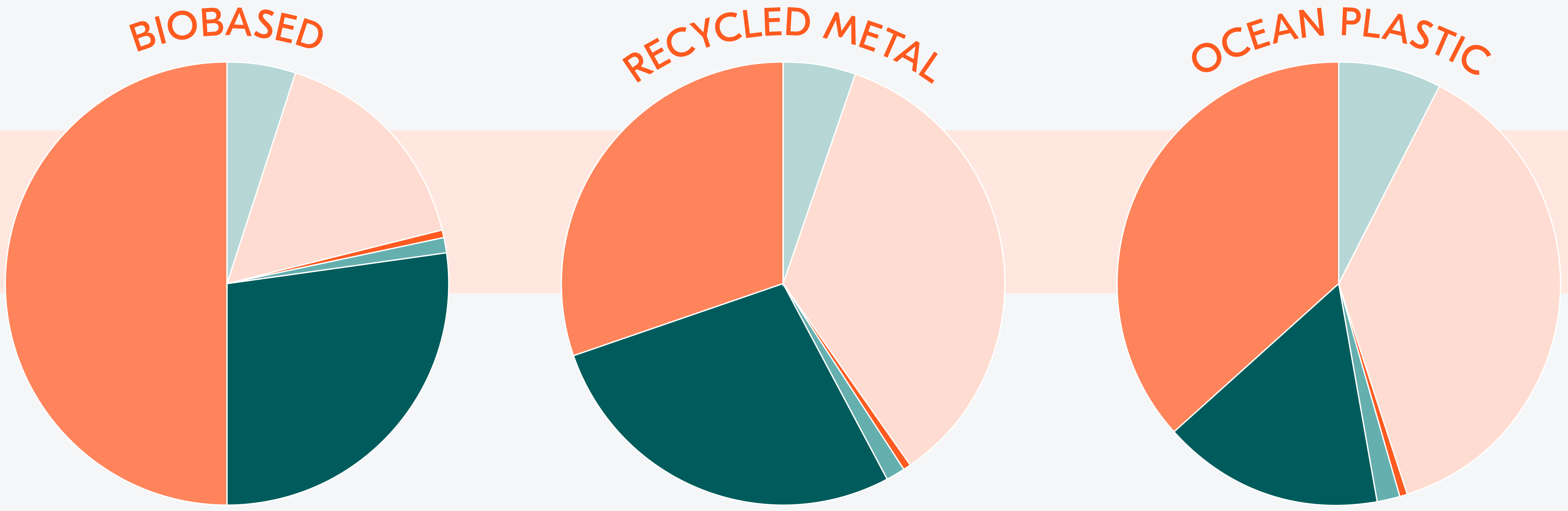
## Why?

With the aim of gaining **greater awareness** and **control** of our **environmental performance**, we decided to issue this study to evaluate the Carbon Footprint of our three product materials: Biobased, Recycled Metal and Ocean plastic.

## How?

The methodology has been performed in accordance with ISO 14067 and the ISO standards on LifeCycle Assessment (LCA) (ISO14040/14044)*.

## Results:



| | Total (neutral approach — kg CO$_2$ eq) | 1,703 | 1,447 | 1,296 |
|---|---|---|---|---|
| ■ | **End of life phase** | 5.0% | 5.5% | 7.5% |
| ■ | **Production phase** | 16.2% | 34.9% | 37.6% |
| ■ | **Logistics centers consumption** | 0.5% | 0.6% | 0.6% |
| ■ | **Distribution** | 1.1% | 1.3% | 1.5% |
| ■ | **Supply transportation** | 27.3% | 27.4% | 16.2% |
| ■ | **Raw materials** | 49.9% | 30.2% | 36.5% |

**The system boundaries include frame, lenses, glasses case, cleaning cloth and packaging raw material production, their transport to suppliers, semi-finished products production, packaging reel production, its transport to the Logistic centers, distribution of finished product through retail channel and end of life of the product and packaging.*

CARBON NEGATIVE

**154 MILLION KILOGRAMS OF CO2 OFFSET**

ONE FRAME ONE TREE

**3.3 MILLION TREES PLANTED SO FAR**

# Carbon Footprint report

# Index

# 1. Introduction

The goal of this LCA study is to evaluate the greenhouse gas emissions of three products by means of the Carbon Footprint calculation in order to support the environmental communication with customers.

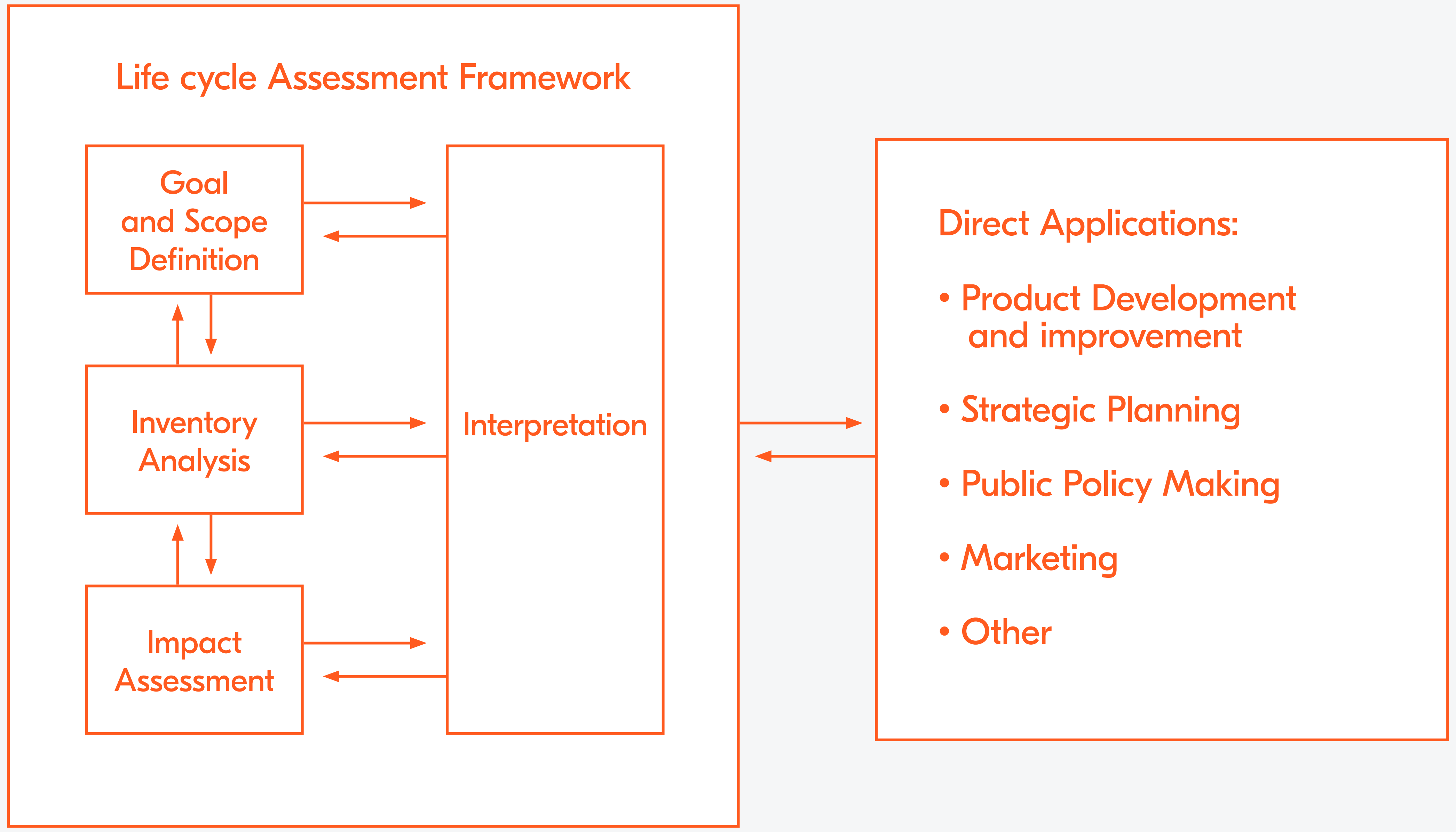
The Carbon Footprint (CF) is an environmental indicator with the scope to quantify the direct or indirect GHG emissions produced by a company, an organization, a product or an event, with the scope to measure how the anthropological activity impact climate change.

Climate change has implications for both human and natural systems and could lead to significant impacts on resource availability, economic activity and human wellbeing. In response, international, regional, national and local initiatives are being developed and implemented by public and private sectors to mitigate greenhouse gas (GHG) concentration in the Earth's atmosphere as well as to facilitate adaptation to climate change [1].

This Carbon Footprint study is performed in accordance with ISO 14067:2018, that specifies principles, requirements and guidelines for the quantification and reporting [1].

The methodology follows as well the international standards on Life Cycle Assessment (LCA) (ISO14040/14044) [2][3]. LCA is structured in four stages:

- Goal and Scope Definition: preliminary phase in which the aim of the study, the functional unit, the system boundaries, the type of data required and the assumptions are defined;
- Inventory Analysis (Life Cycle Inventory – LCI): quantification of all inputs and outputs of the analysed system;
- Impact Assessment (Life Cycle Impact Assessment – LCIA): phase that aggregates the results of the inventory, through the use of scientific models, in a specific number of potential environmental impacts;
- Interpretation: phase in which the results of the LCA are interpreted, in order to formulate conclusions and recommendations.



Life cycle Assessment Framework

Goal and Scope Definition

Inventory Analysis

Impact Assessment

Interpretation

Direct Applications:

- Product Development and improvement
- Strategic Planning
- Public Policy Making
- Marketing
- Other

*Figure 1-LCA phases according to ISO 14040-44 [2,3]*

# 1. Introduction

### Carbon Footprint study

The objects of this Carbon Footprint study are the three Eco materials: Biobased, Recycled metal and Ocean plastic. In this study represented by KASAI (Biobased), BONAIRE (Recycled metal), and SAND (Ocean plastic).

**Biobased**
KASAI

**Recycled metal**
BONAIRE

**Ocean plastic**
SAND

### 1.1 Products description

The objects of this Carbon Footprint study are three eyewear models: KASAI (Biobased), BONAIRE (Recycled metal), and SAND (Ocean plastic).

### 1.2 KASAI

The KASAI model belongs to the Eco Biobased family of Eco eyewear, its frame is made with castor seed oil and the metal used in temples is recycled stainless steel.

*Figure 2 - KASAI eyewear [5]*

### KASAI model components:

*Table 1 - KASAI components*

| Components | Material | Material composition | Component weight (g) |
|---|---|---|---|
| Front | Rilsan PA (G850) | 45% biobased - 55% fossil | 7.9 |
| Hinge | Nickel-silver alloy | - | 0.2 |
| Temple | Rilsan PA (G850) | 45% biobased - 55% fossil | 7.5 |
| Tip | TPE | - | 1.2 |
| Screw | Recycled Stain steel 301 | 100% recycled | 0.01 |
| Demo lenses | Recycled PMMA | 99% recycled - 1% virgin | 0.1 |
| | | Tot (g) | 16.91 |

# 1. Introduction

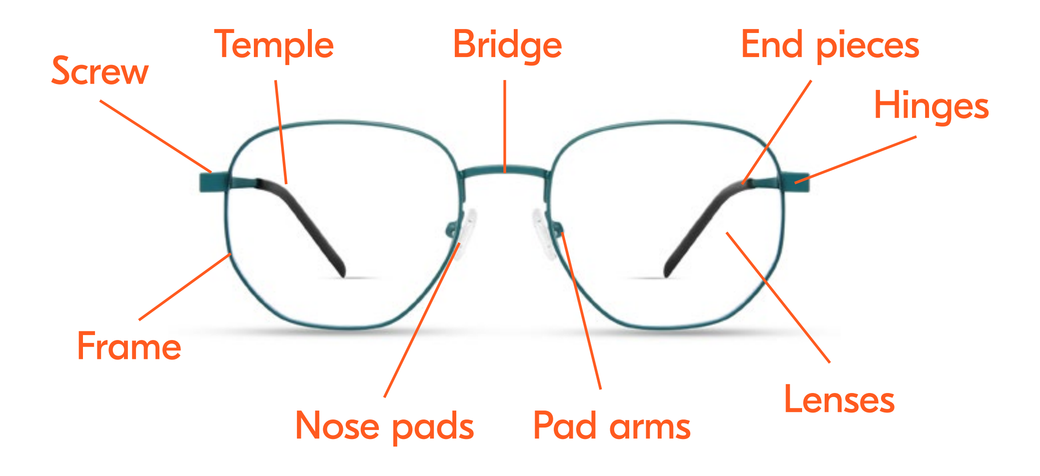


*Figure 3 - Eyewear components (https://www.framesbuy.com/trends/parts-of-glasses/)*

## KASAI production process flow:

- Injection moulding
- Rolling for polish
- Clean up process
- Coloring
- Dry
- Coating
- Dry
- Assemble
- Packing

*Figure 4 - KASAI eyewear production process flow*

### 1.2.1 BONAIRE

The BONAIRE model belongs to the Eco Recycled metal family of Eco eyewear, its frame is made from re-purposed metal materials.

*Figure 5 - BONAIRE eyewear [5]*

## BONAIRE model components:

*Table 2 - BONAIRE components*

| Components | Material | Material composition | Component weight (g) |
|---|---|---|---|
| Front | Recycled Stain steel 301 | 95% recycled — 5% virgin | 6.2 |
| Nose pade | Silicone | - | 0.3 |
| Temple | Recycled Stain steel 301 | 95% recycled — 5% virgin | 8.5 |
| Tip | Acetate | 100% recycled | 1.2 |
| Screw | Recycled Stain steel 301 | 100% recycled | 0.01 |
| Demo lenses | Recycled PMMA | 99% recycled - 1% virgin | 0.1 |
| | | Tot (g) | 16.31 |

## BONAIRE production process flow:

- Welding
- Plating
- Assemble
- Packing

*Figure 6 - BONAIRE production process flow*

# 1. Introduction

## 1.2.2 SAND

The SAND model belongs to the Eco Ocean plastic family of Eco eyewear, its frame is made from repurposed ocean plastic.

*Figure 7 - SAND eyewear*

### SAND model components:

*Table 3 - SAND components*

| Components | Material | Material composition | Component weight (g) |
|---|---|---|---|
| Front | Econyl | 100% recycled | 7.9 |
| Hinge | Nickel-silver alloy | - | 0.2 |
| Temple | Econyl | 100% recycled | 7.5 |
| Tip | TPE | - | 1.2 |
| Screw | Recycled Stain steel 301 | 100% recycled | 0.01 |
| Demo lenses | Recycled PMMA | 99% recycled - 1% virgin | 0.1 |
| | | **Tot (g)** | **16.91** |

### SAND production process flow:

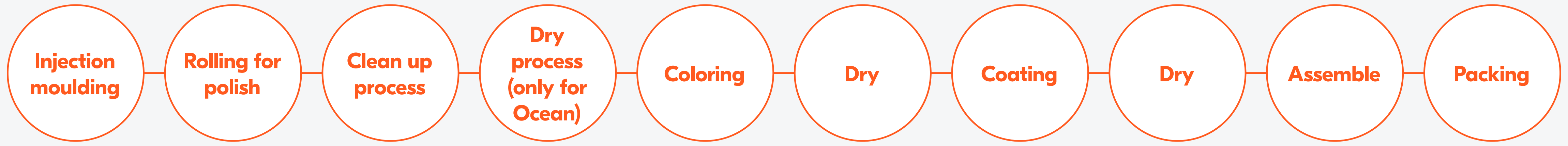


*Figure 8 - SAND production process flow*

# 2. Goal and Scope definition

This study aims to evaluate the Carbon Footprint of three eyewear models to support the environmental communication with customers. A third-party verification is also foreseen.

The present study has been conducted with SimaPro v9.4 software, in line with the ISO 14067 standard and the ISO 14040/14044 on LCA [6]. The ecoinvent v3.8 database has been used for this analysis [7].

## 2.1 LCA approach

Attributive LCA approach has been used in the study. The attributive approach is a type of modelling that considers relevant inputs and outputs to be ascribed to the functional unit in every process involved in the product life cycle.

## 2.2 Functional unit

The studied functional unit is a pair of glasses as delivered to the final consumer, including glasses case and cleaning cloth [8].

## 2.3 System boundaries

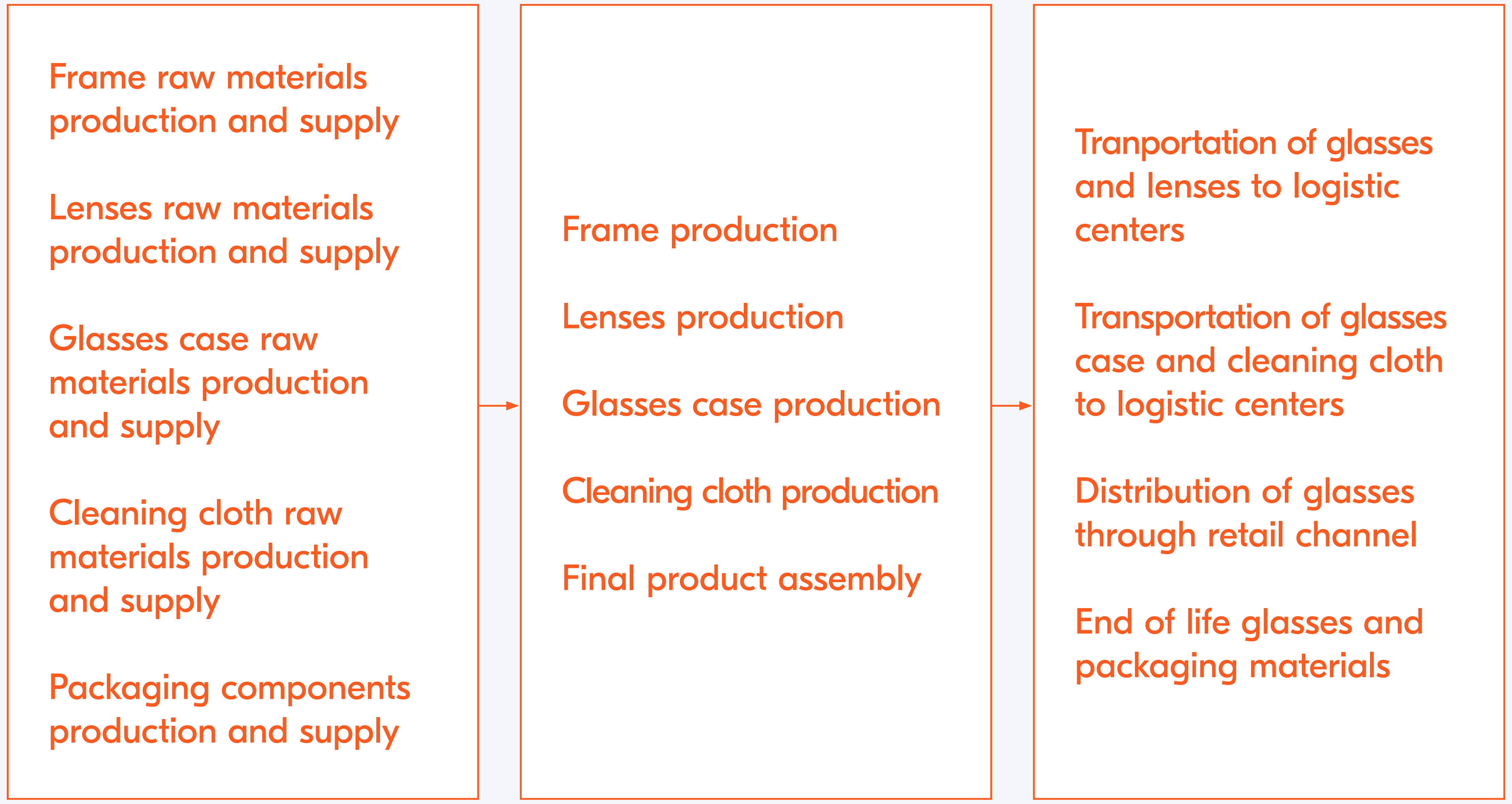
The system boundaries considered are from “cradle to grave”, comprising all production life cycle phases from the extraction of raw material to the end of life phase.

The system boundaries include frame, lenses, glasses case, cleaning cloth and packaging raw material production, their transport to suppliers, semi-finished products production, packaging reel production, its transport to the Logistic centers, distribution of finished product through retail channel and end of life of the product and packaging.

It was assumed that capital goods (e.g., machinery and buildings) do not provide a significant contribution to the life cycle evaluation, therefore they are not considered in the product system analysis.

The processes included within the system boundaries are shown in Figure 9.

# 2. Goal and Scope definition



Frame raw materials production and supply

Lenses raw materials production and supply

Glasses case raw materials production and supply

Cleaning cloth raw materials production and supply

Packaging components production and supply

Frame production

Lenses production

Glasses case production

Cleaning cloth production

Final product assembly

Tranportation of glasses and lenses to logistic centers

Transportation of glasses case and cleaning cloth to logistic centers

Distribution of glasses through retail channel

End of life glasses and packaging materials

*Figure 9 - System boundaries*

**2.4 Data quality**

Primary data provided by Modo have been used for glasses frame, lenses, glasses case and cleaning cloth raw materials and processing, packaging materials, electricity consumption, thermal energy consumption, total water consumption and total number of units shipped from the warehouse.
For all the other processes secondary data have been used, originating from the Ecoinvent v3.8 LCA database.

**2.5 Time boundaries**

Primary data refer to 2022. Secondary data originate from the ecoinvent v3.8 LCA database published in 2021 and available in the LCA software used for calculations, SimaPro 9.4.

**2.6 Geographic boundaries**

The glasses frame and lenses production site is located in Wenzhou City (China), while the glasses case and cleaning cloth production site is located in Shanghai (China). There are two logistic centers, the first one is located in Domegge di Cadore (Italy) and the other one is located in Creekside Parkway (OH-USA).

The products are sold and used in Europe and USA, the study refers to European and USA situation. End of life scenarios of product and packaging refer to European and USA data taken from the Eurostat database and OECD database.

**2.7 Allocation and cut-off rules**

No allocation rule has been adopted.

No allocation is applied for recyclable materials. As an input for recycled resources the recycling process is included. Recycled outputs are considered as an input of resources for the following steps. Data from database are obtained from the “ecoinvent 3.8, allocation, cut-off by classification” database.

# 2. Goal and Scope definition

### 2.8 Biogenic $CO_2$ emissions and removals

For $CO_2$ emissions originating from biogenic materials, the carbon neutrality approach has been adopted. With this approach, it is assumed that all $CO_2$ emissions absorbed by plants and derivative materials will be released back into the atmosphere during the end-of-life stage. Essentially, neither emissions nor trapping of $CO_2$ related to biological materials are evaluated, assuming a carbon net exchange equal to zero.

The amount of $CO_2$ taken up in biomass and the equivalent amount of $CO_2$ emissions from the biomass at the point of complete oxidation results in zero net $CO_2$ emissions integrated over time, except when biomass carbon is not converted into methane, non-methane volatile organic compounds (NMVOC) or other precursor gases.

Additionally, emissions and trapping of biogenic $CO_2$ have been calculated and reported as a separate indicator concerning only biogenic $CO_2$, as required by ISO 14067.

For those substance with higher relative contribution to biogenic $CO_2$ sequestration, balancing has been carried out to achieve neutrality as require by ISO 14067.

For the calculation of the biogenic $CO_2$ emissions, removals of $CO_2$ into biomass has been characterized in the LCIA as $-1$ kg $CO_2e$/kg $CO_2$ in the calculation of the CFP when entering the product system, while emissions of biogenic $CO_2$ has been characterized as $+1$ kg $CO_2e$/kg $CO_2$ of biogenic carbon in the calculation of the CFP.

### 2.9 Environmental impact assessment method

The life cycle impact assessment (LCIA) method adopted in this study is IPCC 2021 GWP 100a v1.01 method. The method quantifies greenhouse gases emissions, expressing the impact in the form of kilograms of $CO_2$ equivalent emitted.

Kilograms of $CO_2$ equivalent are calculated by multiplying the emissions of each greenhouse gas with its Global Warming Potential (GWP). The Global Warming Potential is a characterization factor, developed by the Intergovernmental Panel on Climate Change (IPCC), which expresses the contribution of a given greenhouse gas to global warming compared to carbon dioxide, whose GWP by definition is equal to 1 [9].

The IPCC method used for the calculation of the Carbon Footprint counts all the greenhouse gases required by ISO 14067 and in the IPCC AR6 report.

For atmospheric emissions of $CO_2$ from biogenic materials, the IPCC 2021 GWP 100 v1.01 method adopts the carbon neutrality approach. With this approach, it is assumed that all atmospheric emissions of GHG absorbed by plants and derived materials will be released into the air during the end-of-life phase. In practice, neither $CO_2$ removals nor $CO_2$ emissions from biological materials are assessed, assuming a net carbon sequestration equal to zero. It is important to note that the release of biogenic methane is assessed in this global warming indicator.

Since the ISO 14067 requires to calculate biogenic GHG emissions and removals and to express them separately, these emissions and removals were calculated and reported as a separate indicator for biogenic GHG only.

Environmental impacts related to other environmental impact categories were not considered in this study.

### 2.10 Disclaimer

The results presented in this report are elaborations of data collected and provided by Modo. The results are not necessarily intended to be comparable to those of studies performed by other companies and for other products.

# 3. Life Cycle Inventory

LCI is the phase of LCA involving the compilation and quantification of inputs and outputs for a product throughout its life cycle [1]. Input data include energy consumptions and materials incoming to the productive system (e.g. raw materials, water) while output data include emissions, scraps, waste, coproducts.

Data collection has been performed through questionnaires compiled by Modo and components suppliers. In addition, some data and clarifications were provided through documents and email exchange.

Primary data have been used for the fundamental aspects of the study, for all processes for which primary or representative data were not available, the LCA database ecoinvent v3.8, cut-off by classification, has been used. If necessary, ecoinvent processes have been modified to make them more representative. Raw materials not available in the ecoinvent database have been modelled from the information contained in scientific articles and documentations or by modifying existing ecoinvent processes of similar materials.

For electricity consumption in glasses frame, lenses, glasses case and cleaning cloth production,the electricity mix from China (ecoinvent v3.8) has been used, while for the Italian and USA logistic center, the electricity mixes from respectively Italy and USA (ecoinvent v3.8) have been used.

Supply and distribution distance and means of transport have been evaluated through Google maps and www.searates.com.

# 3. Life Cycle Inventory

## 3.1 Inventory Glasses case

The glasses case is the same for each glasses model, the glasses case components are shown in Table 4.

*Table 4 - KASAI components*

| Components | Material | Material composition | Component weight (g) |
|---|---|---|---|
| Cornstarch fibers | Cornstarch | - | 0.05 |
| Fabric | PET fiber | 100% recycled | 20.00 |
| Lining | PET fiber | 80% recycled-20% virgin | 20.00 |
| Paper | Paper | 100% recycled | 25.00 |
| Magnet | Alloy Fe-Co-Ni | - | 10.00 |
| Metal | Steel | 100% recycled | 5.00 |
| Cleaning cloth | PET fiber | 100% recycled | 3.00 |
| | | Tot (g) | 83.05 |

For the cutting process of cornstarch fibers, fabric, lining, paper and cleaning cloth was assumed 5% of scrap, the cornstarch fibers scrap destination is landfill, while for the other scraps the destination is incineration, as declared by the company. Raw materials not available in the ecoinvent database have been modelled from the information contained in scientific articles and documentation or by modifying existing ecoinvent processes of similar materials.

- Cornstarch fibers process has been modelled considering ecoinvent process: "Maize starch {GLO}| textile production, woven cotton | Cut-off, S".
- Recycled PET fibre:
  The ecoinvent process polyester fibre (Fibre, polyester {RoW}| polyester fibre production, finished | Cut-off, U) has been modified replacing virgin PET granules with recycled PET granules.
  Recycled PET granules has been modelled from the article data: "Life cycle environmental impacts of chemical recycling via pyrolysis of mixed plastic waste in comparison with mechanical recycling and energy recovery", considering mechanical polymer recycling [9].
  Table 5 represents the production of 1 ton of recycled PET granules.

*Table 5 - Recycled PET granules data*

| | Amount | Ecoinvent processes |
|---|---|---|
| Waste PET | 1.5 ton | Waste polyethylene terephthalate, for recycling, sorted {RoW}\| market for waste polyethylene terephthalate, for recycling, sorted \| Cut-off, S |
| Electricity | 1.89 GJ | Electricity, medium voltage {CN}\| market group for \| Cut-off, S |
| Transport (assumption) | 150.0 km | Transport, freight, lorry 16-32 metric ton, EURO4 {RoW}\| transport, freight, lorry 16-32 metric ton, EURO4 \| Cut-off, S |
| Scrap PET | 0.5 ton | Waste plastic, mixture {CH}\| treatment of, municipal incineration \| Cut-off, S |

- Recycled paper process has been modelled considering ecoinvent process: "Graphic paper, 100% recycled {RoW}| production | Cut-off, S".
- Magnet:
  Alloy iron-cobalt-nickel most frequently used is Fe:Ni:Co 55:28:17 [11]. Table 6 represents the production of 1 kg of magnet.

# 3. Life Cycle Inventory

*Table 6 - Magnet alloy data*

| | Amount | Ecoinvent processes |
|---|---|---|
| Fe-Ni | 83% | Ferronickel {GLO}\| market for ferronickel \| Cut-off, S |
| Co | 17% | Cobalt {GLO}\| market for \| Cut-off, S |
| Electricity | 15.6 kWh | Electricity, medium voltage {CN}\| market group for \| Cut-off, S |
| Transport (assumption) | 100 km | Transport, freight, lorry >32 metric ton, euro4 {RoW}\| market for transport, freight, lorry >32 metric ton, EURO4 \| Cut-off, S |

The electricity amount is an ecoinvent data coming from the process: "Permanent magnet, for electric motor {GLO}| production | Cut-off, U".

- Metal:
  This component was assumed as recycled stainless steel. The ecoinvent process (Steel, chromium steel 18/8 {RoW}| steel production, electric, chromium steel 18/8 | Cut-off, U) has been modified replacing virgin raw material with iron scrap and the various electric mix with the Chinese electric mix.

The following data represent the production of 1 kg of metal component:

*Table 7 - Metal data*

| | Amount | Ecoinvent processes |
|---|---|---|
| Recycled Stain Steel | 1.05 kg | |
| Processing | 1.05 kg | Metal working, average for chromium steel product manufacturing {RoW}\| processing \| Cut-off, S |
| Transport | 464 km | Transport, freight, lorry >32 metric ton, euro4 {RoW}\| market for transport, freight, lorry >32 metric ton, EURO4 \| Cut-off, S |
| Scrap | 0.05 kg | Scrap steel {RoW}\| treatment of scrap steel, municipal incineration \| Cut-off, S |

The cornstarch fiber supplier is placed in Hebei (China), for the magnet supply is assumed 100 km from supplier to producer plant and the other raw materials are placed in Wenzhou. For the raw materials whose location is known, the distance from supplier to producer plant was calculated using Google maps.

*Table 8 - Distance supplier - producer*

| | Distance supplier - producer |
|---|---|
| Hebei - Shanghai | 1171 km |
| Wenzhou - Shanghai | 464 km |

# 3. Life Cycle Inventory

The type of transport used to supply the raw materials is lorry>32 metric ton, it was assumed lorry euro 4. For the packaging is assumed the supplier-producer distance of 100 km, lorry 16-32 metric ton euro 4.

The following table represent the packaging amount for a single glasses case:

*Table 9 - Glasses case packaging type*

| Packaging type | Component weight (kg) for a glasses case | Ecoinvent process | Ecoinvent process |
|---|---|---|---|
| Primary | Cornstarch bag | 0.005 | Polylactide, granulate {GLO} \| market for \| Cut-off, S + Extrusion, plastic film {GLO}\| market for \| Cut-off, S |
| Secondary | Inner box | 0.05 | Corrugated board box {RoW}\| market for corrugated board box \| Cut-off, S |
| Tertiary | Outer box | 0.007 | Corrugated board box {RoW}\| market for corrugated board box \| Cut-off, S |

Company consumption to produce glasses case:

*Table 10 - Glasses case production consumption*

| | Amount | Ecoinvent processes |
|---|---|---|
| Recycled Stain Steel | 1.05 kg | |
| Processing | 1.05 kg | Metal working, average for chromium steel product manufacturing {RoW}\| processing \| Cut-off, S |
| Transport | 464 km | Transport, freight, lorry >32 metric ton, euro4 {RoW}\| market for transport, freight, lorry >32 metric ton, EURO4 \| Cut-off, S |
| Scrap | 0.05 kg | Scrap steel {RoW}\| treatment of scrap steel, municipal incineration \| Cut-off, S |

This consumption has been divided to total glasses case production 2022, for find the consumption for a single glasses case.

It was assumed that the water consumption and wastewater is the same quantity. The transport from production plant to logistic centers is divided in the European case and USA case, the percentage were estimated as the ratio of total number of KASAI/BONAIRE/SAND shipped from the warehouse 2022 to Italian or USA Logistic center and total number of KASAI/BONAIRE/SAND shipped from the warehouse 2022 to Italian and USA Logistic center.

# 3. Life Cycle Inventory

*Table 11 - Distance supplier-logistic centers*

| Case | Transport | | |
|---|---|---|---|
| European case | 65% airfreight | Shanghai airport – Aviano airport + road Aviano airport to Domegge di Cadore | 8852.09 km airfreight + 108 km lorry>32 metric ton euro 4 |
| | 35% seafreight | Shanghai port – Venice port + road Venice port to Domegge di Cadore | 15596.28 km seafreight + 135 km lorry>32 metric ton euro 4 |
| USA case | Seafreight | Shanghai port – New York seaport + road New York seaport – Creekside Pkwy | 20327.71 km seafreight + 859 km lorry>32 metric ton euro 4 |

The road distance has been calculated with Google maps while the airfreight and seafreight distance has been calculated with www.searates.com.

The disposal scenario for packaging and end of life of glasses case is divided in the European scenario and USA scenario, the percentage were estimated as the ratio of total number of KASAI/BONAIRE/SAND shipped from the warehouse 2022 to Italian or USA Logistic center and total number of KASAI/BONAIRE/SAND shipped from the warehouse 2022 to Italian and USA Logistic center.

## Packaging disposal contribution:

*Table 12 - Packaging disposal contribution*

| Scenario | | Contribution |
|---|---|---|
| European scenario | Primary packaging | 33.5% Composting |
| | | 29.13% Incineration |
| | | 37.37% Landfill |
| | Secondary and tertiary packaging | 82.3% Recycling |
| | | 9.6% Incineration |
| | | 8.1% Landfill |
| USA scenario | Primary packaging | 9.73% Composting |
| | | 11.96% Incineration |
| | | 78.31% Landfill |
| | Secondary and tertiary packaging | 23.3% Recycling |
| | | 10.2% Incineration |
| | | 66.5% Landfill |

# 3. Life Cycle Inventory

End of life glasses case disposal contribution:

*Table 13 - Glasses case end of life disposal contribution*

| Scenario | Contribution |
|---|---|
| European scenario | 37.4% Recycling |
| | 28.6% Landfill |
| | 34% Incineration |
| USA scenario | 23.3% Recycling |
| | 66.5% Landfill |
| | 10.2% Incineration |

European scenario contribution data come from Eurostat data 2020-2021 (Europe) [12], USA scenario contribution data come from OECD data 2020 (USA) [13].

### 3.2 Inventory KASAI

3.2.1 Inventory KASAI production

The KASAI glasses components are:

*Table 14 - KASAI glasses components*

| Components | Material | Material composition | Component weight (g) |
|---|---|---|---|
| Front | Rilsan PA (G850) | 45% biobased - 55% fossil | 7.9 |
| Hinge | Nickel-silver alloy | - | 0.2 |
| Temple | Rilsan PA (G850) | 45% biobased - 55% fossil | 7.5 |
| Tip | TPE | - | 1.2 |
| Screw | Recycled Stain steel 301 | 100% recycled | 0.01 |
| Demo lenses | Recycled PMMA | 99% recycled - 1% virgin | 0.1 |
| | | **Tot (g)** | **16.91** |

For the injection moulding process of Rilsan (polyamide-11 or nylon-11), for front and temple components, it was assumed 0.6% of scrap from ecoinvent data, the polyamide-11 scrap destination is assumed as 69.1% incineration and 30.9% landfill, data extrapolated from Asia OECD data 2020. Rilasan® Clear G850 Rnew® uses 45% biobased raw material and 55% fossil raw material. The producer of this material is Arkema, the Rilsan PA (G850) production process consists of [14]:

- Harvesting castor seed from castor plant;
- Grinding Castor seed to produce castor oil,
- Monomer synthesis from castor oil of amino-11 monomer;
- Polymerization of amino-11 to polyamide-11/nylon-11;
- Combination of 45% polyamide-11 biobased and 55% polyamide fossil.

# 3. Life Cycle Inventory

*Table 14 - KASAI glasses components*

Polyamide-11 biobased not available in the ecoinvent database has been modelled in the following way:

- Castor oil is not available in the ecoinvent database, this process has been modelled modifying existing ecoinvent process of "Soybean oil, crude {RoW}| soybean meal and crude oil production | Cut-off, U" replacing Soybean process (Soybean {RoW}| market for soybean | Cut-off, S) with Castor bean process (Castor bean {GLO}| market for castor bean | Cut-off, S) and modifying the amount of castor bean considering the efficiency value (one ton of castor seed yields about 300-500 kg oil, so the average value is 400 kg of oil), from the article: "Castor Oil: Properties, Uses, and Optimization of Processing Parameters in Commercial Production" (SAGE journals, 2016) [14].

- Polyamide-11 biobased has been modelled as represented in the following table for 1 kg of polyamide-11 biobased:

| | Amount | Ecoinvent process |
|---|---|---|
| Castor oil | 0.0155 kg | |
| Electricity | 162 MJ | Electricity, medium voltage {CN}\| market group for \| Cut-off, S |

Ricinoleic acid representing about 90% of the castor oil [15].
It was assumed the efficiency value of 50% to convert ricinoleic acid to amino-11 and the efficiency value of 95% to convert amino-11 to polyamide-11 (assumption molecular weight 15 000g/mol), with these data it was possible to calculate the amount of castor oil needed to produce 1 kg of polyamide.
The electricity consumption is a data from the report: "Bio-based products — from idea to market" (European Commission, 2018) [16].

- Rilsan PA (G850) has been modelled as represented in the following table for 1 kg of Rilsan:

*Table 16 - Rilsan data*

| | Amount | Ecoinvent process |
|---|---|---|
| PA-biobased | 45% | |
| PA-fossil | 55% | Nylon 6-6 {RoW}\| market for nylon 6-6 \| Cut-off, S |
| Transport (assumption) | 100 km | Transport, freight, lorry 16-32 metric ton, euro4 {RoW}\| market for transport, freight, lorry 16-32 metric ton, EURO4 \| Cut-off, S |

# 3. Life Cycle Inventory

For the FRONT and TEMPLE it is necessary to consider the production process (Injection moulding {RoW}| processing | Cut-off, S). Raw materials not available in the ecoinvent database have been modelled from the information contained in scientific articles and documentation or by modifying existing ecoinvent processes of similar materials.

- Nickel-silver alloy:
  A typical Ag-Ni alloy for hinge is Ag40Ni, its composition is: 40% Silver, 30% Copper, 28% Zinc and 2% Nickel, the Ag-Ni alloy process has been modelled as represented in the following table for 1 kg of alloy [17]:

*Table 17 - Hinge alloy data*

| | Amount | Ecoinvent process |
|---|---|---|
| Silver | 40% | Silver {GLO}\| market for \| Cut-off, S |
| Copper | 30% | Copper-rich materials {GLO}\| market for copper-rich materials \| Cut-off, S |
| Zinc | 28% | Zinc {GLO}\| market for \| Cut-off, S |
| Nickel | 2% | Nickel-rich materials {GLO}\| market for nickel-rich materials \| Cut-off, S |
| Processing | 1 kg | Metal working, average for metal product manufacturing {RoW}\| processing \| Cut-off, S |
| Transport (assumption) | 100 km | Transport, freight, lorry 16-32 metric ton, euro4 {RoW}\| market for transport, freight, lorry 16-32 metric ton, EURO4 \| Cut-off, S |

- TPE process has been modelled considering ecoinvent process: “Synthetic rubber {GLO}| market for | Cut-off, S”.
- Recycled Stain steel 301: The ecoinvent process steel production (Steel, chromium steel 18/8 {RoW}| steel production, electric, chromium steel 18/8 | Cut-off, U) has been modified replacing virgin raw material with iron scrap and the various electric mix with the Chinese electric mix. For the screw it will also be necessary to consider the processing to produce it (Wire drawing, steel {RoW}| processing | Cut-off, S).
- Recycled PMMA has been modelled considering the 99% of Recycled PMMA and 1% of virgin PMMA (Polymethyl methacrylate, sheet {GLO}| market for | Cut-off, S). Recycled PMMA has been modelled considering a carbon dioxide emission to air of 0.739 kg, data referring to emissions from chemical polymer recycling from article: “Life cycle environmental impacts of chemical re cycling via pyrolysis of mixed plastic waste in comparison with mechanical recycling and energy recovery”. The energy consumption associated with cutting PMMA sheets to obtain the lenses is neglected.

It was assumed for each components a transport lorry 16-32 metric ton euro 4 and a distance of 100 km from raw material supplier to glasses production plant. For the packaging is assumed the supplier-producer distance of 100 km, lorry 16-32 metric ton euro 4.

The following table represent the packaging amount for a single glasses frame:

*Table 18 - Glasses frame packaging data*

| Packaging type | Material-type | Component weight (kg) for a glasses frame | Ecoinvent process |
|---|---|---|---|
| Primary | box | 0.005 | Corrugated board box {RoW} \| market for corrugated board box \| Cut-off, S |

# 3. Life Cycle Inventory

Company consumption to produce KASAI glasses:

*Table 19 - Consumption to produce KASAI glasses*

| Consumption | Total consumption 2022 |
|---|---|
| Electricity (glasses frame production) | 892.07 kWh |
| Total KASAI glasses frame production 2022 | 4 163 pc |
| Electricity (lenses production) | 8 000 kWh |
| Total lenses production 2022 | 9 000 000 pc |

These consumptions have been divided to total glasses and lenses respectively production 2022, for find the consumption for a single frame and lens.

The transport from production plant to logistic centers is divided in the European case and USA case, the percentage were estimated as the ratio of total number of KASAI shipped from the warehouse 2022 to Italian or USA Logistic center and total number of KASAI shipped from the warehouse 2022 to Italian and USA Logistic center.

*Table 20 - Distance supplier-logistic centers*

| Case | Transport | | |
|---|---|---|---|
| European case | 65% airfreight | Wenzhou airport — Aviano airport + road Aviano airport to Domegge di Cadore | 8858.05 km airfreight + 108 km lorry>32 metric ton euro 4 |
| | 35% seafreight | Wenzhou port — Venice port + road Venice port to Domegge di Cadore | 15155.82 km seafreight + 135 km lorry>32 metric ton euro 4 |
| USA case | Seafreight | Wenzhou port — New York seaport + road New York seaport — Creekside Pkwy | 20572.72 km seafreight + 859 km lorry>32 metric ton euro 4 |

The road distance has been calculated with Google maps while the airfreight and seafreight distance has been calculated with www.searates.com.

The disposal scenario for packaging is divided in the European scenario (61%) and USA scenario (39%), the percentage were estimated as the ratio of total number of KASAI shipped from the warehouse 2022 to Italian or USA Logistic center and total number of KASAI shipped from the warehouse 2022 to Italian and USA Logistic center.

# 3. Life Cycle Inventory

Packaging disposal contribution:

*Table 21 — Glasses frame and lenses packaging disposal contribution*

| Scenario | Contribution |
|---|---|
| European scenario | 82.3% Recycling |
| | 9.6% Incineration |
| | 8.1% Landfill |
| USA scenario | 23.3% Recycling |
| | 10.2% Incineration |
| | 66.5% Landfill |

European scenario contribution data derived from Eurostat data 2020 (Europe), USA scenario contribution data derived from OECD data 2020 (USA).

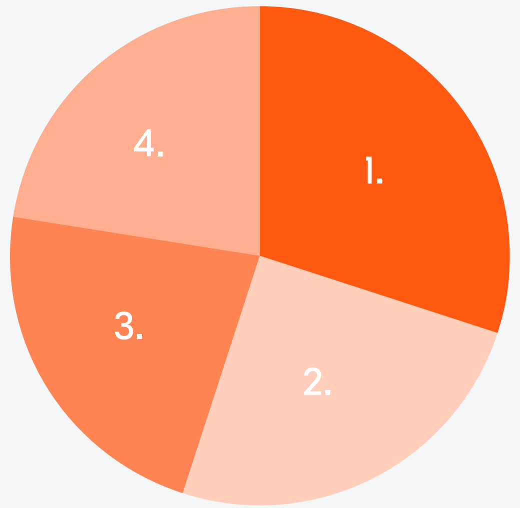
### 3.2.2 Inventory KASAI logistic centers

The distribution from logistic centers to customer is divided in the European case and USA case, the percentage has been estimated as the ratio of total number of KASAI shipped from the warehouse 2022 to Italian or USA Logistic center and total number of KASAI shipped from the warehouse 2022 to Italian and USA Logistic center.

*Table 22 - KASAI distribution data*

| | Amount KASAI units shipped | Distribution percentage |
|---|---|---|
| European case | 3020 pc | 61% |
| USA case | 1931 pc | 39% |

European case — sales distribution:



1. Italy 30%
2. Spain 25%
3. Germany 22,5%
4. France 22,5%

*Figure 11 - Sales distribution (EU)*

The Italy and Spain percentage value has been provided by the company, while the remaining amount has been allocated to Germany and France from Istat data on population distribution [18]. Distances have been calculated using Google maps considering the capital city of each state.

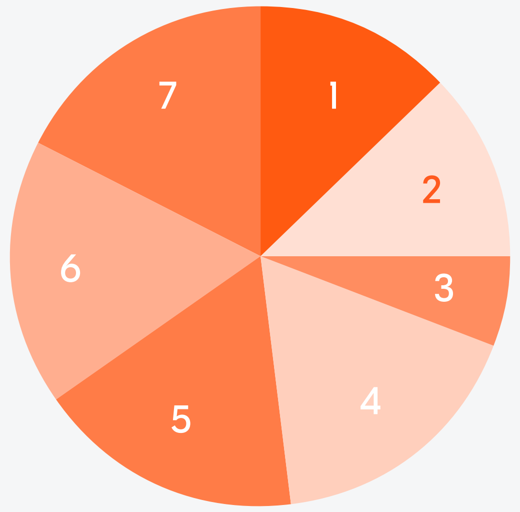
*Table 23 - Distribution European case*

# 3. Life Cycle Inventory

*Table 23 - Distribution European case*

| Distance | | |
|---|---|---|
| Italy | 640 km | From Domegge di Cadore to Rome |
| Spain | 1954 km | From Domegge di Cadore to Madrid |
| Germany | 934 km | From Domegge di Cadore to Berlin |
| France | 1061 km | From Domegge di Cadore to Paris |

## USA case — sales distribution:



1. Texas-Austin 13%
2. California-Sacramento 12%
3. Canada-Toronto 6%
4. New York-New York City 17,25%
5. Illinois-Chicago 17,25%
6. Pennsylvania-Philadelphia 17,25%
7. Ohio-Columbus 17,25%

*Table 24 - Distribution USA case*

| Distance | | |
|---|---|---|
| Texas | 1988 km | From Creekside Parkway to Austin |
| Canada | 706 km | From Creekside Parkway to Toronto |
| Illinois | 588 km | From Creekside Parkway to Chicago |
| Ohio | 21 km | From Creekside Parkway to Columbus |
| California | 3784 km | From Creekside Parkway to Sacramento |
| New York | 860 km | From Creekside Parkway to New York |
| Pennsylvania | 752 km | From Creekside Parkway to Philadelphia |

The Texas, California and Canada percentage value has been provided by the company, while the remaining amount has been allocated by population distribution [19].
The road distance has been calculated with Google maps. It was assumed for distribution a transport lorry 16-32 metric ton euro 4.

The electricity consumption in logistic centers has been divided in the European case and USA case considering the value in the table 25.

# 3. Life Cycle Inventory

*Table 25 - Logistic centers consumption data*

| | Amount | Ecoinvent process |
|---|---|---|
| Total electricity consumption 2022 (Logistic center- Italy) | 13 008 kWh | Electricity, medium voltage {IT}\| market for \| Cut-off, S |
| Total number of KASAI units shipped from Italian Logistic center | 3 020 pc | - |
| Total number of glasses units shipped from Italian Logistic center | 527 842pc | - |
| Total electricity consumption (Logistic center – USA) | 28 704 KWh | Electricity, medium voltage {US}\| market group for \| Cut-off, S |
| Total thermal energy consumption 2022 | 4 388 kWh | Heat, district or industrial, natural gas {RoW}\| heat production, natural gas, at boiler condensing modulating >100kW \| Cut-off, S |
| Total number of KASAI units shipped from USA Logistic center | 1 931 pc | - |
| Total number of glasses units shipped from USA Logistic center | 2 189 490 pc | - |

These consumptions have been divided to total glasses and lenses respectively production 2022, for find the consumption for a single frame and lens, for the consumption there is two case: Italian case and USA case. Italian case (61%) consider the process: "Electricity, medium voltage {IT}| market for | Cut-off, S" and USA case (39%) consider the processes: "Electricity, medium voltage {US}| market group for | Cut-off, S" and "Heat, district or industrial, natural gas {RoW}| heat production, natural gas, at boiler condensing modulating >100kW | Cut-off, S".

The total electricity and thermal energy consumption has been divided for the total number of glasses units shipped from the respective logistic centers. For the packaging is assumed the supplier-producer distance of 100 km, lorry 16-32 metric ton euro 4.

The following table represent the packaging amount for a pair of glasses:

*Table 26 - Product packaging data*

| Packaging type | Material-type | Component weight (kg) for a glasses case | Ecoinvent process |
|---|---|---|---|
| Primary | Cornstarch bag | 0.001 | Polylactide, granulate {GLO}\| market for \| Cut-off, S + Extrusion, plastic film {GLO}\| market for \| Cut-off, S |
| Secondary | Paper box | 0.001 | Kraft paper {RoW}\| market for kraft paper \| Cut-off, S |
| Tertiary | Cardboard box | 0.0015 | Corrugated board box {RoW}\| market for corrugated board box \| Cut-off, S |

The disposal scenario for packaging and end of life of KASAI glasses is divided into European scenario (61%) and USA scenario (39%).

# 3. Life Cycle Inventory

## Packaging disposal contribution:

*Table 27 - Packaging disposal contribution*

| Scenario | | Contribution |
|---|---|---|
| European scenario | Primary packaging | 33.5% Composting |
| | | 29.13% Incineration |
| | | 37.37% Landfill |
| | Secondary and tertiary packaging | 82.3% Recycling |
| | | 9.6% Incineration |
| | | 8.1% Landfill |
| USA scenario | Primary packaging | 9.73% Composting |
| | | 11.96% Incineration |
| | | 78.31% Landfill |
| | Secondary and tertiary packaging | 23.3% Recycling |
| | | 10.2% Incineration |
| | | 66.5% Landfill |

## End of life KASAI disposal contribution:

*Table 28 - Product end of life disposal contribution*

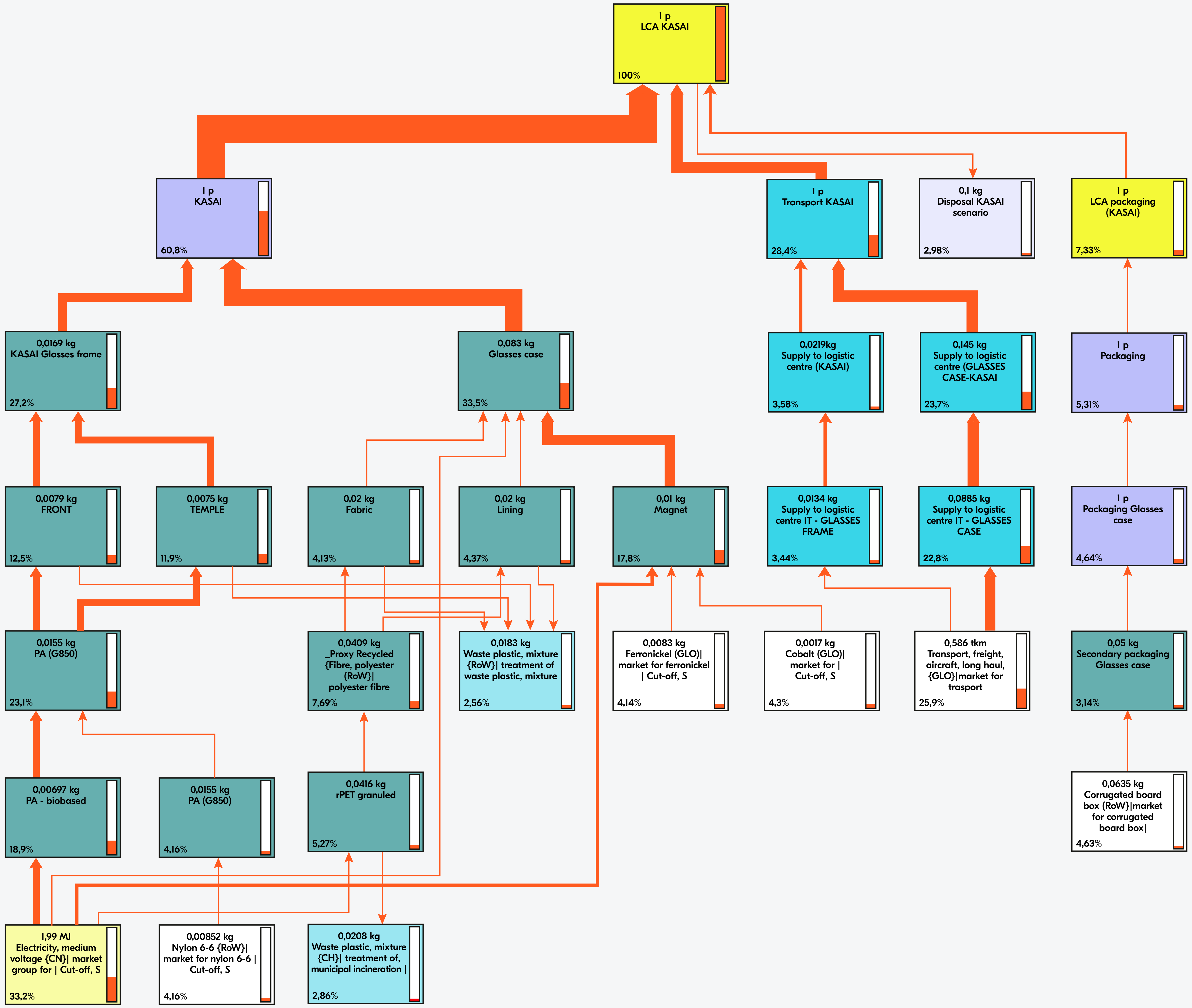
| Scenario | Contribution |
|---|---|
| European scenario | 37.4% Recycling |
| | 28.6% Landfill |
| | 34% Incineration |
| USA scenario | 23.3% Recycling |
| | 66.5% Landfill |
| | 10.2% Incineration |

European scenario contribution data derived from Eurostat data 2020-2021 (Europe), USA scenario contribution data derived from OECD data 2020 (USA).

# 3. Life Cycle Inventory

### 3.2.3 Inventory KASAI results

The figure shows the flowchart of the most significant processes relate to the calculation of KASAI product Carbon Footprint. The thickness of the arrows is proportional to the contribution of each process.



1 p
LCA KASAI
100%

1 p
KASAI
60,8%

1 p
Transport KASAI
28,4%

0,1 kg
Disposal KASAI scenario
2,98%

1 p
LCA packaging (KASAI)
7,33%

0,0169 kg
KASAI Glasses frame
27,2%

0,083 kg
Glasses case
33,5%

0,0219kg
Supply to logistic centre (KASAI)
3,58%

0,145 kg
Supply to logistic centre (GLASSES CASE-KASAI
23,7%

1 p
Packaging
5,31%

0,0079 kg
FRONT
12,5%

0,0075 kg
TEMPLE
11,9%

0,02 kg
Fabric
4,13%

0,02 kg
Lining
4,37%

0,01 kg
Magnet
17,8%

0,0134 kg
Supply to logistic centre IT - GLASSES FRAME
3,44%

0,0885 kg
Supply to logistic centre IT - GLASSES CASE
22,8%

1 p
Packaging Glasses case
4,64%

0,0155 kg
PA (G850)
23,1%

0,0409 kg
_Proxy Recycled {Fibre, polyester (RoW}| polyester fibre
7,69%

0,0183 kg
Waste plastic, mixture {RoW}| treatment of waste plastic, mixture
2,56%

0,0083 kg
Ferronickel (GLO)| market for ferronickel | Cut-off, S
4,14%

0,0017 kg
Cobalt (GLO)| market for | Cut-off, S
4,3%

0,586 tkm
Transport, freight, aircraft, long haul, {GLO}|market for trasport
25,9%

0,05 kg
Secondary packaging Glasses case
3,14%

0,00697 kg
PA - biobased
18,9%

0,0155 kg
PA (G850)
4,16%

0,0416 kg
rPET granuled
5,27%

0,0635 kg
Corrugated board box (RoW}|market for corrugated board box|
4,63%

1,99 MJ
Electricity, medium voltage {CN}| market group for | Cut-off, S
33,2%

0,00852 kg
Nylon 6-6 {RoW}| market for nylon 6-6 | Cut-off, S
4,16%

0,0208 kg
Waste plastic, mixture {CH}| treatment of, municipal incineration |
2,86%

*Figure 13 - Flow chart of KASAI eyewear, IPCC GWP 100a method (cut-off 2.5%)*

# 3. Life Cycle Inventory

Figure 13 shows the Life Cycle flow chart of a pair of KASAI glasses with glasses case and cleaning cloth. The higher contributions related to the GWP impact category for LCA of a pair of KASAI glasses with glasses case and cleaning cloth are due for 60.8% to KASAI production (frame, lenses and glasses case), particularly to Magnet production and PA production; for 22.8% to transportation from China supply to Italian logistic center, this high contribution will be due to airfreight, and for 7.3% to Packaging production and disposal. The inventories of the main greenhouse gases for the functional unit (a pair of KASAI glasses with glasses case and cleaning cloth) are reported in table 29.

*Table 29 - KASAI GHG inventory*

| Impact category | Unit | KASAI production | Transport | Energy consumption (Logistic centers-KASAI) | Disposal scenario | Packaging production and disposal | Total | GWP | % |
|---|---|---|---|---|---|---|---|---|---|
| $CO_2$ fossil | kg | 8.87E-01 | 4.77E-01 | 7.84E-03 | 3.59E-02 | 8.00E-02 | 1.49E+00 | 1.49E+00 | 87.35% |
| $CO_2$ land transformation | kg | 1.08E-03 | 4.74E-05 | 1.96E-06 | 1.34E-06 | 5.49E-04 | 1.68E-03 | 1.68E-03 | 0.10% |
| CH4 land transformation | kg | 7.94E-08 | 1.23E-08 | 1.99E-10 | 5.77E-10 | 2.17E-07 | 3.09E-07 | 9.22E-06 | 0.00% |
| CH4 biogenic | kg | 2.07E-04 | 1.70E-06 | 2.64E-06 | 4.55E-04 | 1.25E-03 | 1.92E-03 | 5.21E-02 | 3.06% |
| $CO_2$ to soil or biomass stock | kg | 3.48E-05 | 1.73E-06 | 3.55E-08 | 6.96E-08 | 8.96E-06 | 4.56E-05 | -4.56E-05 | 0.00% |
| CH4 fossil | kg | 4.21E-03 | 2.02E-04 | 2.05E-05 | 6.56E-05 | 2.43E-04 | 4.74E-03 | 1.41E-01 | 8.29% |
| N2O | kg | 3.66E-05 | 3.08E-06 | 3.48E-07 | 1.81E-06 | 1.08E-05 | 5.27E-05 | 1.44E-02 | 0.84% |
| SF6 | kg | 2.20E-07 | 2.00E-09 | 2.45E-09 | 6.53E-11 | 6.11E-09 | 2.30E-07 | 5.81E-03 | 0.34% |
| NF3 | kg | 8.08E-18 | 4.73E-19 | 1.04E-18 | 2.57E-19 | 2.70E-18 | 1.26E-17 | 2.18E-13 | 0.00% |
| Other GHG gases | kg | 1.63E-05 | 4.63E-06 | 5.55E-07 | 5.32E-08 | 6.96E-06 | 2.85E-05 | 2.79E-04 | 0.02% |
| **Total** | **kg** | **8.93E-01** | **4.77E-01** | **7.87E-03** | **3.64E-02** | **8.20E-02** | **1.50E+00** | **1.70E+00** | **-** |

# 3. Life Cycle Inventory

Where KASAI production includes glasses, lenses, glasses case and cleaning cloth production, Transport include transportation from supplier to logistic centers and KASAI distribution, Energy consumption include logistic centers consumption, Disposal scenario include the end of life product scenario.

*Table 30 - KASAI $CO_2$ biogenic*

| GAS | kg $CO_2$ biogenic |
|---|---|
| $CO_2$ biogenic emissions | 0,145 |
| $CO_2$ biogenic uptake | 0,109 |

### 3.3 Inventory BONAIRE

#### 3.3.1 Inventory BONAIRE production

**BONAIRE model components:**

*Table 31 - BONAIRE components*

| Components | Material | Material composition | Component weight (g) |
|---|---|---|---|
| Front | Recycled Stain steel 301 | 95% recycled-5% virgin | 6.2 |
| Nose pade | Silicone | - | 0.3 |
| Temple | Recycled Stain steel 301 | 95% recycled — 5% virgin | 8.5 |
| Tip | Acetate | 100% recycled | 1.2 |
| Screw | Recycled Stain steel 301 | 100% recycled | 0.01 |
| Demo lenses | Recycled PMMA | 99% recycled - 1% virgin | 0.1 |
| - | | Tot (g) | 16.31 |

Raw materials not available in the ecoinvent database have been modelled from the information contained in scientific articles and documentation or by modifying existing ecoinvent processes of similar materials:

- Recycled Stain steel 301 and screw have been modelled as in KASAI model. For the FRONT and TEMPLE it is necessary to consider the process that produces them (Metal working, average for chromium steel product manufacturing {RoW}| processing | Cut-off, S)
- Silicone has been modelled considering the ecoinvent process: "Silicone product {RoW}| market for silicone product | Cut-off, S".
- Acetate has been modelled considering a carbon dioxide emission to air of 0.739 kg, data referring to emissions from chemical polymer recycling from article: "Life cycle environmental impacts of chemical recycling via pyrolysis of mixed plastic waste in comprison with mechanical recycling and energy recovery".
- Recycled PMMA has been modelled considering the 99% of Recycled PMMA and 1% of virgin PMMA (Polymethyl methacrylate, sheet {GLO}| market for | Cut-off, S). Recycled PMMA has been modelled considering a carbon dioxide emission to air of 0.739 kg, data referring to emissions from chemical polymer recycling from article: "Life cycle environmental impacts of chemical recycling via pyrolysis of mixed plastic waste in comparison with mechanical recycling and energy recovery". The energy consumption associated with cutting PMMA sheets to obtain the lenses is neglected.

It was assumed for each components a transport lorry 16-32 metric ton euro 4 and a distance of 100 km from raw material supplier to glasses production plant.

# 3. Life Cycle Inventory

For the packaging is assumed the supplier-producer distance of 100 km, lorry 16-32 metric ton euro 4. The following table represent the packaging amount for a single glasses frame:

*Table 32 - Glasses frame and lenses packaging*

| Packaging type | Material-type | Component weight (kg) for a glasses frame | Ecoinvent process |
|---|---|---|---|
| Primary | box | 0.005 | Corrugated board box {RoW}\| market for corrugated board box \| Cut-off, S |

## Company consumption to produce glasses BONAIRE:

*Table 33 - Consumption to produce BONAIRE glasses*

| Consumption | Total consumption 2022 |
|---|---|
| Electricity (glasses frame production) | 622.5 kWh |
| Total BONAIRE glasses frame production 2022 | 2905 pc |
| Electricity (lenses production) | 8 000 kWh |
| **Total lenses production 2022** | **9 000 000 pc** |

These consumptions have been divided to total glasses and lenses respectively production 2022, for find the consumption for a single frame and lens.

The transport from production plant to logistic centers is divided in the European case and USA case, the percentage were estimated as the ratio of total number of BONAIRE shipped from the warehouse 2022 to Italian or USA Logistic center and total number of BONAIRE shipped from the warehouse 2022 to Italian and USA Logistic center.

*Table 11 - Distance supplier-logistic centers*

| Case | Transport | | |
|---|---|---|---|
| European case | 65% airfreight | Wenzhou airport – Aviano airport + road Aviano airport to Domegge di Cadore | 8858.05 km airfreight + 108 km lorry>32 metric ton euro 4 |
| | 35% seafreight | Wenzhou port – Venice port + road Venice port to Domegge di Cadore | 15155.82 km seafreight + 135 km lorry>32 metric ton euro 4 |
| USA case | Seafreight | Wenzhou port – New York seaport + road New York seaport – Creekside Pkwy | 20572.72 km seafreight + 859 km lorry>32 metric ton euro 4 |

The road distance has been calculated with Google maps, while the airfreight and seafreight distance has been calculated with www.searates.com.
The disposal scenario for packaging is divided in the European scenario (51.24%) and USA scenario (48.76%), the percentage were estimated as the ratio of total number of BONAIRE shipped from the warehouse 2022 to Italian or USA Logistic center and total number of BONAIRE shipped from the warehouse 2022 to Italian and USA Logistic center.

# 3. Life Cycle Inventory

Packaging disposal contribution:

*Table 35 - Packaging disposal contribution*

| Scenario | Contribution |
|---|---|
| European scenario | 82.3% Recycling |
| | 9.6% Incineration |
| | 8.1% Landfill |
| USA scenario | 23.3% Recycling |
| | 10.2% Incineration |
| | 66.5% Landfill |

European scenario contribution data derived from Eurostat data 2020 (Europe), USA scenario contribution data derived from OECD data 2020 (USA).

### 3.3.2 Inventory BONAIRE logistic centers

The distribution from logistic centers to customer is divided in the European case and USA case, the percentage were estimated as the ratio of total number of BONAIRE shipped from the warehouse 2022 to Italian or USA Logistic center and total number of BONAIRE shipped from the warehouse 2022 to Italian and USA Logistic center.

*Table 36 - BONAIRE distribution data*

| | Amount BONAIRE units shipped | Distribution percentage |
|---|---|---|
| European case | 2801 pc | 51.24% |
| USA case | 2665 pc | 48.76% |

The European and USA case are the same used for the KASAI model.
The electricity consumption in logistic centers has been divided in the European case and USA case considering the value in the table 36.

| | Amount | Ecoinvent processes |
|---|---|---|
| Total electricity consumption 2022 (Logistic center- Italy) | 13 008 kWh | Electricity, medium voltage {IT}\| market for \| Cut-off, S |
| Total number of BONAIRE units shipped from Italian Logistic center | 2 801 pc | - |
| Total electricity consumption (Logistic center — USA) | 28 704 KWh | Electricity, medium voltage {US}\| market group for \| Cut-off, S |
| Total thermal energy consumption 2022 | 4 388 kWh | Heat, district or industrial, natural gas {RoW}\| heat production, natural gas, at boiler condensing modulating >100kW \| Cut-off, S |
| **Total number of BONAIRE units shipped from USA Logistic center** | 2 665 pc | - |

These consumptions have been divided to total glasses and lenses respectively production 2022, for find the consumption for a single frame and lens, for the consumption there is two case: Italian case and USA case. Italian case (51.24%) consider the process: “Electricity, medium voltage {IT}| market for | Cut-off, S” and USA case (48.76%) consider the processes: “Electricity, medium voltage {US}| market group for | Cut-off, S” and “Heat, district or industrial, natural gas {RoW}| heat production, natural gas, at boiler condensing modulating >100kW | Cut-off, S”.

# 3. Life Cycle Inventory

The total electricity and thermal consumption has been divided for the total number of glasses units shipped from the respective logistic center.

The packaging is the same used for KASAI model, with the same assumptions. The disposal scenario for packaging and end of life of BONAIRE glasses is divided in the European scenario (51.24%) and USA scenario (48.76%). Packaging disposal and end of life glasses contribution are the same used for the KASAI model.

### 3.3.3 Inventory BONAIRE results

Figure 14 shows the flowchart of the most significant processes relate to the calculation of BONAIRE product Carbon Footprint. The thickness of the arrows is proportional to the contribution of each process.

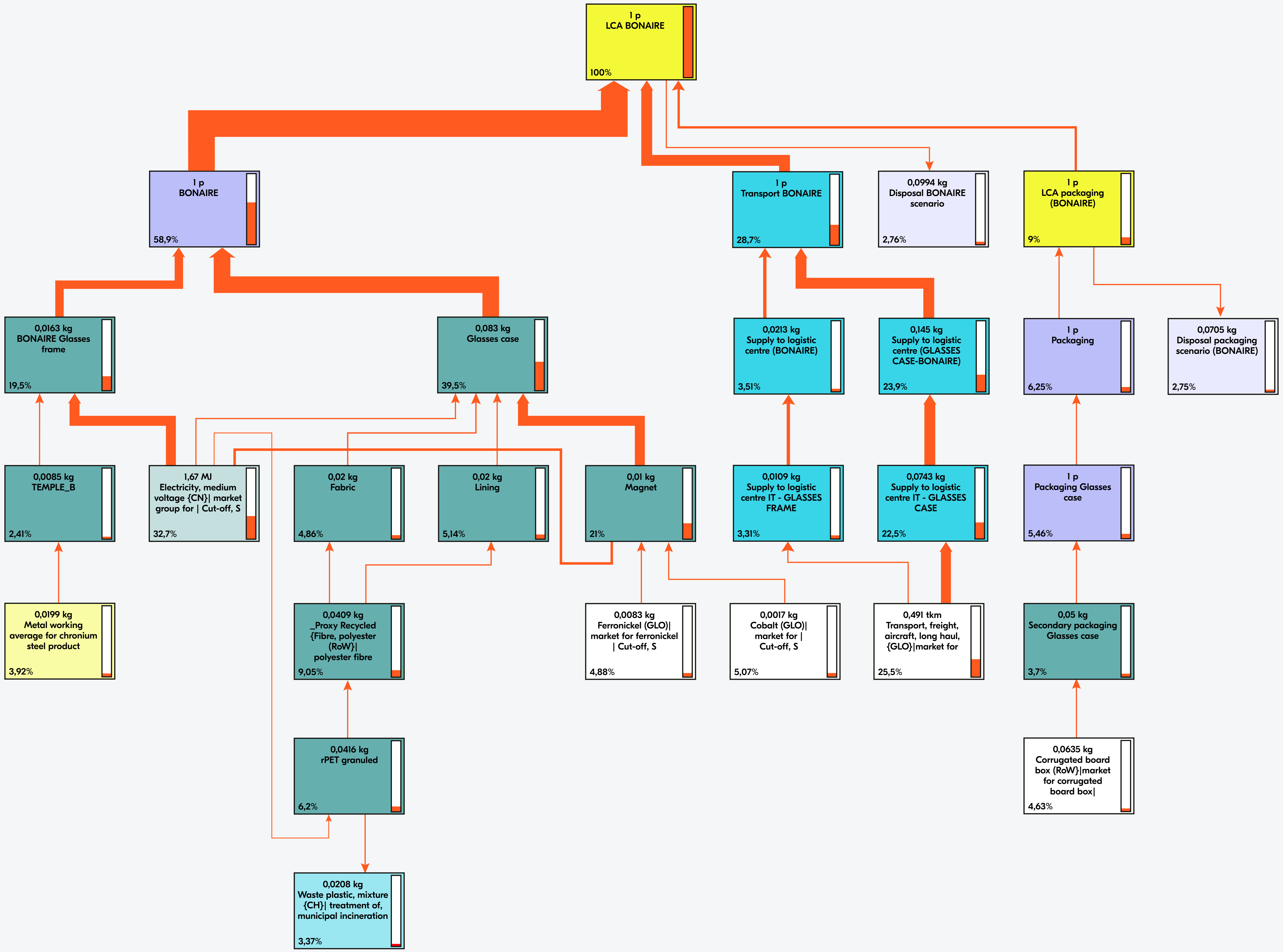


*Figure 14 - Flow chart of BONAIRE eyewear, IPCC GWP 100a method (cut-off 2.5%)*

# 3. Life Cycle Inventory

Figure 14 show Life Cycle flow chart of a pair of BONAIRE glasses with glasses case and cleaning cloth. The higher contributions related to the GWP impact category for LCA of a pair of BONAIRE glasses with glasses case and cleaning cloth are due for 58.9% to BONAIRE production (frame, lenses and glasses case), particularly to Magnet production and electricity consumption; for 22.5% to transportation from China supply to Italian logistic center, this high contribution will be due to airfreight, and for 9.0% to Packaging production and disposal. The inventories of the main greenhouse gases for the functional unit (a pair of KASAI glasses with glasses case and cleaning cloth) are reported in table 38.

*Table 38 - BONAIRE eyewear GHG inventory*

| Impact category | Unit | BONAIRE production | Transport | Energy consumption (Logistic centers-BONAIRE) | Disposal scenario | Packaging production and disposal | Total | GWP | % |
|---|---|---|---|---|---|---|---|---|---|
| $CO_2$ fossil | kg | 7.37E-01 | 4.09E-01 | 7.62E-03 | 2.46E-02 | 7.98E-02 | 1.26E+00 | 1.26E+00 | 86.97% |
| $CO_2$ land transformation | kg | 8.66E-04 | 4.55E-05 | 2.13E-06 | 1.32E-06 | 5.49E-04 | 1.46E-03 | 1.46E-03 | 0.10% |
| CH4 land transformation | kg | 7.75E-08 | 1.21E-08 | 1.83E-10 | 6.02E-10 | 2.17E-07 | 3.07E-07 | 9.15E-06 | 0.00% |
| CH4 biogenic | kg | 2.40E-04 | 1.51E-06 | 2.24E-06 | 4.93E-04 | 1.45E-03 | 2.19E-03 | 5.94E-02 | 4.11% |
| $CO_2$ to soil or biomass stock | kg | 3.37E-05 | 1.57E-06 | 3.43E-08 | 6.56E-08 | 8.97E-06 | 4.43E-05 | -4.43E-05 | 0.00% |
| CH4 fossil | kg | 3.26E-03 | 1.75E-04 | 1.96E-05 | 5.33E-05 | 2.44E-04 | 3.75E-03 | 1.12E-01 | 7.73% |
| N2O | kg | 2.31E-05 | 2.93E-06 | 3.26E-07 | 1.34E-06 | 1.08E-05 | 3.85E-05 | 1.05E-02 | 0.73% |
| SF6 | kg | 1.89E-07 | 1.80E-09 | 2.34E-09 | 6.07E-11 | 6.12E-09 | 1.99E-07 | 5.01E-03 | 0.35% |
| NF3 | kg | 6.30E-18 | 4.41E-19 | 8.86E-19 | 2.70E-19 | 2.72E-18 | 1.06E-17 | 1.85E-13 | 0.00% |
| Other GHG gases | kg | 1.66E-05 | 4.02E-06 | 4.95E-07 | 4.42E-08 | 6.96E-06 | 2.81E-05 | 2.61E-04 | 0.02% |
| **Total** | **kg** | **7.42E-01** | **4.09E-01** | **7.65E-03** | **2.51E-02** | **8.21E-02** | **1.27E+00** | **1.45E+00** | **-** |

# 3. Life Cycle Inventory

Where BONAIRE production includes glasses, lenses, glasses case and cleaning cloth production, Transport include transportation from supplier to logistic centers and BONAIRE distribution, Energy consumption include logistic centers consumption, Disposal scenario include the end of life product scenario.

*Table 39 - BONAIRE $CO_2$ biogenic*

| GAS | kg $CO_2$ biogenic |
|---|---|
| $CO_2$ biogenic emissions | 0,139 |
| $CO_2$ biogenic uptake | 0,105 |

## 3.4 Inventory SAND

### 3.4.1 Inventory SAND production

**SAND model components:**

*Table 40 - SAND components*

| Components | Material | Material composition | Component weight (g) |
|---|---|---|---|
| Front | Econyl | 100% recycled | 7.9 |
| Hinge | Nickel-silver alloy | - | 0.2 |
| Temple | Econyl | 100% recycled | 7.5 |
| Tip | TPE | - | 1.2 |
| Screw | Recycled Stain steel 301 | 100% recycled | 0.01 |
| Demo lenses | Recycled PMMA | 99% recycled - 1% virgin | 0.1 |
| - | | Tot (g) | 16.91 |

Econyl® nylon is produced by Aquafil, it's a nylon waste (such as fishing nets, fabric scraps, carpet flooring and industrial plastic) is recovered and converted into new yarn, which has the same qualitative characteristics as traditional nylon [20]. The Econyl production process consists:

- Depolymerization econyl caprolactam production (input: waste post-consumer);
- Polymerization;
- Econyl yarn production.

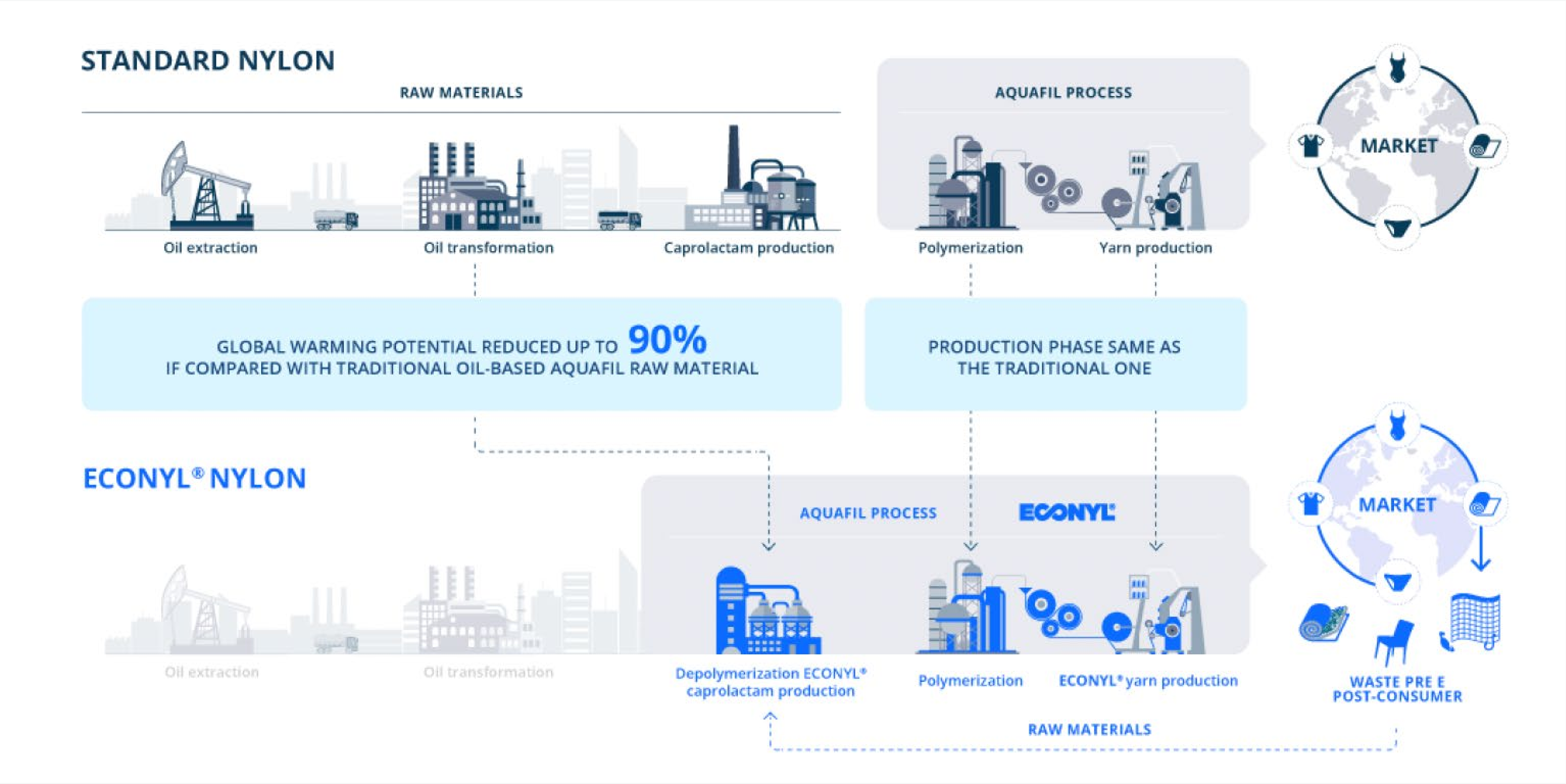


*Figure 15 - Econyl production process [21]*

# 3. Life Cycle Inventory

Raw materials not available in the ecoinvent database have been modelled from the information contained in scientific articles and documentation or by modifying existing ecoinvent processes of similar materials.

- Econyl has been modelled considering a carbon dioxide emission to air of 1.40 kg, data referring to emission GWP from Econyl® nylon EPD (Environmental product declaration for Econyl® nylon textile filament yarns) [21]. For the FRONT and TEMPLE it is necessary to consider the production process (Injection moulding {RoW}| processing | Cut-off, S).
- Nickel-silver alloy has been modelled as in the table 17.
- TPE has been modelled considering ecoinvent process: “Synthetic rubber {GLO}| market for | Cut-off, S”.
- Recycled Stain steel 301 has been modelled as in KASAI model.
- Recycled PMMA has been modelled considering the 99% of Recycled PMMA and 1% of virgin PMMA (Polymethyl methacrylate, sheet {GLO}| market for | Cut-off, S). Recycled PMMA has been modelled considering a carbon dioxide emission to air of 0.739 kg, data referring to emissions from chemical polymer recycling from article: “Life cycle environmental impacts of chemical re cycling via pyrolysis of mixed plastic waste in comparison with mechanical recycling and energy recovery”. The energy consumption associated with cutting PMMA sheets to obtain the lenses is neglected.

It was assumed for each components a transport lorry 16-32 metric ton euro 4 and a distance of 100 km from raw material supplier to glasses production plant. For the packaging is assumed the supplier-producer distance of 100 km, lorry 16-32 metric ton euro 4.

The following table represent the packaging amount for a single glasses frame:

*Table 41 - Glasses packaging data*

| Packaging type | Material-type | Component weight (kg) for a glasses frame | Ecoinvent process |
|---|---|---|---|
| Primary | box | 0.005 | Corrugated board box {RoW}\| market for corrugated board box \| Cut-off, S |

The following table represent the packaging amount for a single glasses frame:

*Table 41 - Glasses packaging data*

| Consumption | Total consumption 2022 |
|---|---|
| Electricity (glasses frame production) | 81.9 kWh |
| Total SAND glasses frame production 2022 | 390 pc |
| Electricity (lenses production) | 8 000 kWh |
| **Total lenses production 2022** | **9 000 000 pc** |

These consumptions have been divided to total glasses and lenses respectively production 2022, for find the consumption for a single frame and lens.

The transport from production plant to logistic centers is divided in the European case and USA case, the percentage were estimated as the ratio of total number of SAND shipped from the warehouse 2022 to Italian or USA Logistic center and total number of SAND shipped from the warehouse 2022 to Italian and USA Logistic center.

# 3. Life Cycle Inventory

*Table 43 - Distance supplier - logistic centers*

| Case | Transport | | |
|---|---|---|---|
| European case | 65% airfreight | Wenzhou airport — Aviano airport + road Aviano airport to Domegge di Cadore | 8858.05 km airfreight + 108 km lorry>32 metric ton euro 4 |
| | 35% seafreight | Wenzhou port — Venice port + road Venice port to Domegge di Cadore | 15155.82 km seafreight + 135 km lorry>32 metric ton euro 4 |
| USA case | Seafreight | Wenzhou port — New York seaport + road New York seaport — Creekside Pkwy | 20572.72 km seafreight + 859 km lorry>32 metric ton euro 4 |

The road distance has been calculated with Google maps, while the airfreight and seafreight distance has been calculated with www.searates.com.
The disposal scenario for packaging is divided in the European scenario (24.07%) and USA scenario (75.93%), the percentage were estimated as the ratio of total number of SAND shipped from the warehouse 2022 to Italian or USA Logistic center and total number of SAND shipped from the warehouse 2022 to Italian and USA Logistic center.

Packaging disposal contribution:

*Table 44 - Packaging disposal contribution*

| Scenario | Contribution |
|---|---|
| European scenario | 82.3% Recycling |
| | 9.6% Incineration |
| | 8.1% Landfill |
| USA scenario | 23.3% Recycling |
| | 10.2% Incineration |
| | 66.5% Landfill |

European scenario contribution data derived from Eurostat data 2020 (Europe), USA scenario contribution data derived from OECD data 2020 (USA).

### 3.4.2 Inventory SAND logistic centers

The distribution from logistic centers to customer is divided in the European case and USA case, the percentage were estimated as the ratio of total number of SAND shipped from the warehouse 2022 to Italian or USA Logistic center and total number of SAND shipped from the warehouse 2022 to Italian and USA Logistic center.

# 3. Life Cycle Inventory

*Table 45 - Distribution data*

| | Amount SAND units shipped | Distribution percentage |
|---|---|---|
| European case | 58 pc | 24.07% |
| USA case | 183 pc | 75.93% |

The European and USA case are the same used for the KASAI model.
The electricity consumption in logistic centers has been divided in the European case and USA case considering the value in the table 45.

*Table 46 - Logistic centers consumption*

| | Amount | Ecoinvent processes |
|---|---|---|
| Total electricity consumption 2022 (Logistic center- Italy) | 13 008 kWh | Electricity, medium voltage {IT}\| market for \| Cut-off, S |
| Total number of sand units shipped from Italian Logistic center | 58 pc | - |
| Total electricity consumption (Logistic center – USA) | 28 704 KWh | Electricity, medium voltage {US}\| market group for \| Cut-off, S |
| Total thermal energy consumption 2022 | 4 388 kWh | Heat, district or industrial, natural gas {RoW}\| heat production, natural gas, at boiler condensing modulating >100kW \| Cut-off, S |
| **Total number of SAND units shipped from USA Logistic center** | 183 pc | - |

These consumptions have been divided to total glasses and lenses respectively production 2022, for find the consumption for a single frame and lens, for the consumption there is two case: Italian case and USA case. Italian case (24.07%) consider the process: “Electricity, medium voltage {IT}| market for | Cut-off, S” and USA case (75.93%) consider the processes: “Electricity, medium voltage {US}| market group for | Cut-off, S” and “Heat, district or industrial, natural gas {RoW}| heat production, natural gas, at boiler condensing modulating >100kW | Cut-off, S”.

The total electricity and thermal consumption has been divided for the total number of glasses units shipped from the respective logistic center.

The packaging is the same used for KASAI model, with the same assumptions.

The disposal scenario for packaging and end of life of SAND glasses is divided in the European scenario (24.07%) and USA scenario (75.93%). Packaging disposal and end of life glasses contribution are the same used for the KASAI model.

# 3. Life Cycle Inventory

### 3.4.3 Inventory SAND results

The figure shows the flowchart of the most significant processes relate to the calculation of SAND product Carbon Footprint. The thickness of the arrows is proportional to the contribution of each process.

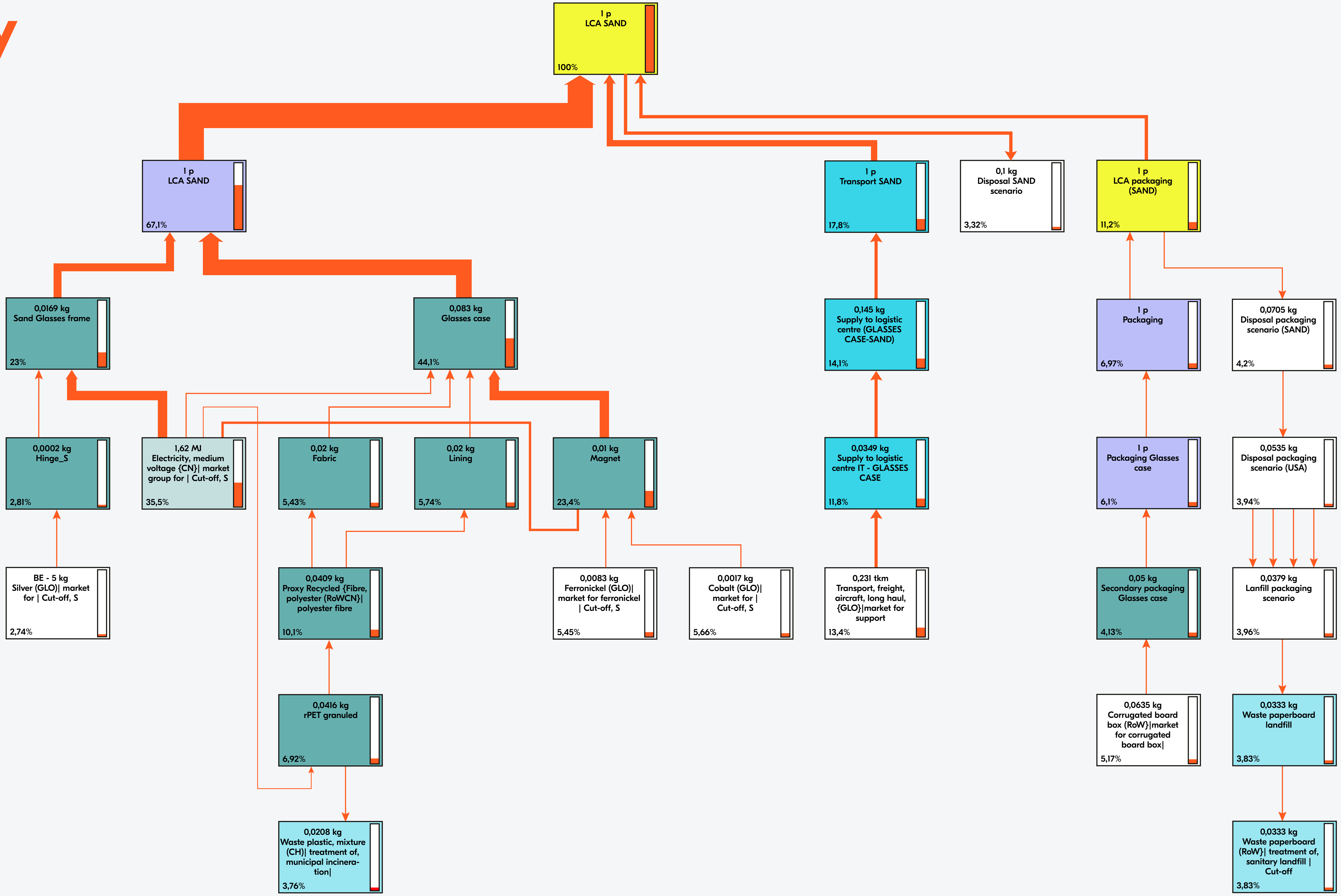


*Figure 16 - Flow chart of SAND eyewear, IPCC GWP 100a method (cut-off 2.5%)*

# 3. Life Cycle Inventory

Figure 16 show Life Cycle flow chart of a pair of SAND glasses with glasses case and cleaning cloth. The higher contributions related to the GWP impact category for LCA of a pair of BONAIRE glasses with glasses case and cleaning cloth are due for 67.1% to SAND production (frame, lenses and glasses case), particularly to Magnet production and electricity consumption; for 11.8% to Glasses case transportation from China supply to Italian logistic center, this high contribution will be due to air-freight, and for 11.2% to Packaging production and disposal.
The inventories of the main greenhouse gases for the functional unit (a pair of KASAI glasses with glasses case and cleaning cloth) are reported in table 47.

*Table 38 - BONAIRE eyewear GHG inventory*

| Impact category | Unit | SAND production | Transport | Energy consumption (Logistic centers-SAND) | Disposal scenario | Packaging production and disposal | Total | GWP | % |
|---|---|---|---|---|---|---|---|---|---|
| $CO_2$ fossil | kg | 7.56E-01 | 2.26E-01 | 7.01E-03 | 2.37E-02 | 7.94E-02 | 1.09E+00 | 1.09E+00 | 84.33% |
| $CO_2$ land transformation | kg | 8.94E-04 | 4.10E-05 | 2.59E-06 | 1.36E-06 | 5.50E-04 | 1.49E-03 | 1.49E-03 | 0.11% |
| CH4 land transformation | kg | 7.32E-08 | 1.17E-08 | 1.39E-10 | 5.41E-10 | 2.17E-07 | 3.02E-07 | 9.01E-06 | 0.00% |
| CH4 biogenic | kg | 1.85E-04 | 1.00E-06 | 1.15E-06 | 6.01E-04 | 2.00E-03 | 2.79E-03 | 7.58E-02 | 5.85% |
| $CO_2$ to soil or biomass stock | kg | 3.45E-05 | 1.12E-06 | 3.08E-08 | 7.68E-08 | 9.00E-06 | 4.48E-05 | -4.48E-05 | -0.003% |
| CH4 fossil | kg | 3.23E-03 | 1.04E-04 | 1.71E-05 | 8.57E-05 | 2.46E-04 | 3.68E-03 | 1.10E-01 | 8.46% |
| N2O | kg | 2.50E-05 | 2.56E-06 | 2.62E-07 | 1.23E-06 | 1.08E-05 | 3.99E-05 | 1.09E-02 | 0.84% |
| SF6 | kg | 1.90E-07 | 1.25E-09 | 2.03E-09 | 7.11E-11 | 6.14E-09 | 2.00E-07 | 5.04E-03 | 0.39% |
| NF3 | kg | 6.28E-18 | 3.58E-19 | 4.50E-19 | 3.19E-19 | 2.78E-18 | 1.02E-17 | 1.77E-13 | 0.00% |
| Other GHG gases | kg | 1.56E-05 | 2.37E-06 | 3.27E-07 | 4.45E-08 | 6.97E-06 | 2.53E-05 | 2.35E-04 | 0.02% |
| **Total** | **kg** | **7.61E-01** | **2.27E-01** | **7.03E-03** | **2.44E-02** | **8.22E-02** | **1.10E+00** | **1.30E+00** | **-** |

# 3. Life Cycle Inventory

Where SAND production includes glasses, lenses, glasses case and cleaning cloth production, Transport include transportation from supplier to logistic centers and SAND distribution, Energy consumption include logistic centers consumption, Disposal scenario include the end of life product scenario.

*Table 48 - SAND $CO_2$ biogenic*

| GAS | kg $CO_2$ biogenic |
|---|---|
| $CO_2$ biogenic emissions | 0,136 |
| $CO_2$ biogenic uptake | 0,105 |

# 4. Life Cycle Impact Assessment

The impact assessment phase of LCA is aimed at evaluating the significance of potential environmental impacts using the LCI results. In general, this process involves associating inventory data with specific environmental impact categories and category indicators, thereby attempting to understand these impacts [2], for example the global warming, through impact indicator and equivalence factors.

IPCC 2021 GWP 100a v1.01 method has been used for the environmental impact assessment, the method assesses the contributions of all greenhouse gases specified in the ISO 14067 standard, including carbon dioxide, methane gas, nitrogen oxide, sulfur hexafloride, nitrogen trifloride, and expresses them in a single result expressed in kg of equivalent carbon dioxide.

The IPCC 2021 GWP 100a v1.01 method calculates the various impact categories that ISO 14067:2018 requires to be reported separately, namely:

- Fossil GHG emissions and removals;
- Biogenic GHG emissions and removals;
- GHG emissions and removals occurring as a result of dLUC (direct land use change);
- Aircraft GHG emissions.

For $CO_2$ emissions originating from biogenic materials, the carbon neutrality approach has been adopted. With this approach, it is assumed that all $CO_2$ emissions absorbed by plants and derivative materials will be released back into the atmosphere during the end-of-life stage. Essentially, neither emissions nor trapping of $CO_2$ related to biological materials are evaluated, assuming a carbon net exchange equal to zero.

The calculation of the contribution of biogenic $CO_2$ to GWP has been modified to consider that the amount of $CO_2$ sequestered by raw materials is still re-emitted during end of life over the 100 years period considered in the calculation of the GWP indicator.

# 4. Life Cycle Impact Assessment

## 4.1 KASAI

*Table 49 - GWP results for KASAI sold*

| Impact category | Unit | Total | KASAI production | Packaging production | Transport | Energy consumption | GWP | % |
|---|---|---|---|---|---|---|---|---|
| GWP100 - fossil | kg $CO_2$-eq | 1.21E+00 | 1.03E+00 | 8.50E-02 | 4.33E-02 | 8.61E-03 | 3.83E-02 | 5.35E-03 |
| GWP100 - biogenic | kg $CO_2$-eq | 5.21E-02 | 5.62E-03 | 4.83E-03 | 1.04E-05 | 7.17E-05 | 1.24E-02 | 2.92E-02 |
| GWP100 - land transformation | kg $CO_2$-eq | 1.67E-03 | 1.09E-03 | 5.54E-04 | 2.34E-05 | 1.97E-06 | 1.36E-06 | 1.31E-06 |
| GWP100 - aircraft | kg $CO_2$-eq | 4.41E-01 | 0.00E+00 | 0.00E+00 | 4.41E-01 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| GWP100- total (neutral approach) | kg $CO_2$-eq | 1.70E+00 | 1.04E+00 | 9.04E-02 | 4.84E-01 | 8.69E-03 | 5.07E-02 | 3.45E-02 |

| Impact category | Unit | Total | KASAI production | Packaging production | Transport | Energy consumption | GWP | % |
|---|---|---|---|---|---|---|---|---|
| GWP100-$CO_2$ biogenic emissions | kg $CO_2$-eq | 1.45E-01 | 4.04E-02 | 3.05E-02 | 8.78E-04 | 9.29E-04 | 1.22E-02 | 6.04E-02 |
| GWP100-$CO_2$ biogenic uptake | kg $CO_2$-eq | -1.09E-01 | -3.97E-02 | -6.83E-02 | -7.87E-04 | -4.68E-04 | -1.93E-05 | -1.73E-05 |

** carbon footprint value*

# 4. Life Cycle Impact Assessment

KASAI production includes frame, lenses, glasses case and cleaning cloth production, transport include transportation from suppliers to production plants, from production plants to logistic centers and distribution.

For IPCC GWP 100a v1.01 indicator, GWP100-total, KASAI production has the highest impacts to the total life cycle, followed transport and packaging production.

*Table 50 - GWP result KASAI production and transport*

| | | KASAI PRODUCTION | | TRANSPORT | |
|---|---|---|---|---|---|
| **Impact category** | **Unit** | **KASAI frame and lenses production** | **KASAI glasses case and cleaning cloth production** | **Supply to logistic centers** | **Distribution to customer** |
| GWP100 - fossil | kg $CO_2$-eq | 0.462474 | 0.56582 | 2.38E-02 | 1.95E-02 |
| GWP100 - biogenic | kg $CO_2$-eq | 0.000784 | 0.004837 | 4.96E-06 | 5.44E-06 |
| GWP100 - land transformation | kg $CO_2$-eq | 0.000316 | 0.00077 | 1.53E-05 | 8.09E-06 |
| GWP100 - aircraft | kg $CO_2$-eq | 0,00E+00 | 0,00E+00 | 4.41E-01 | 0.00E+00 |
| GWP100- total (neutral approach) | kg $CO_2$-eq | 4.64E-01 | 5.71E-01 | 4.64E-01 | 1.95E-02 |

# 4. Life Cycle Impact Assessment

| | | KASAI PRODUCTION | | TRANSPORT | |
|---|---|---|---|---|---|
| **Impact category** | **Unit** | **KASAI frame and lenses production** | **KASAI glasses case and cleaning cloth production** | **Supply to logistic centers** | **Distribution to customer** |
| GWP100-$CO_2$ biogenic emissions | kg $CO_2$-eq | 8.27E-03 | 3.21E-02 | 7.47E-04 | 1.31E-04 |
| GWP100-$CO_2$ biogenic uptake | kg $CO_2$-eq | -7.79E-03 | -3.19E-02 | -6.64E-04 | -1.23E-04 |

Particularly, the highest impacts are due to KASAI production process (frame and glasses case) and to airfreight used for the supply.

# 4. Life Cycle Impact Assessment

## 4.2 BONAIRE

*Table 51 - GWP results for BONAIRE sold*

| Impact category | Unit | Total | BONAIRE | Packaging production | Transport | Energy consumption | GWP | % |
|---|---|---|---|---|---|---|---|---|
| GWP100 - fossil | kg $CO_2$-eq | 1.02E+00 | 8.45E-01 | 8.50E-02 | 4.66E-02 | 8.36E-03 | 2.65E-02 | 5.21E-03 |
| GWP100 - biogenic | kg $CO_2$-eq | 5.94E-02 | 6.54E-03 | 4.83E-03 | 1.11E-05 | 6.10E-05 | 1.34E-02 | 3.46E-02 |
| GWP100 - land transformation | kg $CO_2$-eq | 1.45E-03 | 8.68E-04 | 5.54E-04 | 2.55E-05 | 2.13E-06 | 1.34E-06 | 1.43E-06 |
| GWP100 - aircraft | kg $CO_2$-eq | 3.69E-01 | 0.00E+00 | 0.00E+00 | 3.69E-01 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| GWP100- total (neutral approach) | kg $CO_2$-eq | 1.45E+00 | 8.53E-01 | 9.04E-02 | 4.15E-01 | 8.42E-03 | 4.00E-02 | 3.98E-02 |

| Impact category | Unit | Total | BONAIRE | Packaging production | Transport | Energy consumption | GWP | % |
|---|---|---|---|---|---|---|---|---|
| GWP100-$CO_2$ biogenic emissions | kg $CO_2$-eq | 1.39E-01 | 3.51E-02 | 3.05E-02 | 7.78E-04 | 8.23E-04 | 1.17E-02 | 6.05E-02 |
| GWP100-$CO_2$ biogenic uptake | kg $CO_2$-eq | -1.05E-01 | -3.57E-02 | -6.83E-02 | -7.02E-04 | -4.31E-04 | -1.68E-05 | -1.85E-05 |

** carbon footprint value*

For IPCC GWP 100a v1.01 indicator, GWP100-total, BONAIRE production has the highest impacts to the total life cycle, followed transport and packaging production.

# 4. Life Cycle Impact Assessment

*Table 52 - GWP result BONAIRE production and transport*

| | | BONAIRE PRODUCTION | | TRANSPORT | |
|---|---|---|---|---|---|
| **Impact category** | **Unit** | **BONAIRE frame and lenses production** | **BONAIRE glasses case and cleaning cloth production** | **Supply to logistic centers** | **Distribution to customer** |
| GWP100 - fossil | kg $CO_2$-eq | 2.80E-01 | 5.66E-01 | 2.71E-02 | 1.95E-02 |
| GWP100 - biogenic | kg $CO_2$-eq | 1.70E-03 | 4.84E-03 | 5.66E-06 | 5.40E-06 |
| GWP100 - land transformation | kg $CO_2$-eq | 9.80E-05 | 7.70E-04 | 1.74E-05 | 8.13E-06 |
| GWP100 - aircraft | kg $CO_2$-eq | 0,00E+00 | 0,00E+00 | 3.69E-01 | 0,00E+00 |
| GWP100- total (neutral approach) | kg $CO_2$-eq | 2.81E-01 | 5.71E-01 | 3.96E-01 | 1.95E-02 |

| | | BONAIRE PRODUCTION | | TRANSPORT | |
|---|---|---|---|---|---|
| **Impact category** | **Unit** | **BONAIRE frame and lenses production** | **BONAIRE glasses case and cleaning cloth production** | **Supply to logistic centers** | **Distribution to customer** |
| GWP100-$CO_2$ biogenic emissions | kg $CO_2$-eq | 3.00E-03 | 3.21E-02 | 6.49E-04 | 1,29E-04 |
| GWP100-$CO_2$ biogenic uptake | kg $CO_2$-eq | -3.77E-03 | -3.19E-02 | -5.80E-04 | -1,22E-04 |

Particularly, the highest impacts are due to BONAIRE production process (glasses case) and to airfreight used for the supply.

# 4. Life Cycle Impact Assessment

## 4.3 SAND

*Table 53 - GWP results for SAND sold*

| Impact category | Unit | Total | SAND | Packaging production | Transport | Energy consumption | GWP | % |
|---|---|---|---|---|---|---|---|---|
| GWP100 - fossil | kg $CO_2$-eq | 1,04E+00 | 8,64E-01 | 8,50E-02 | 5,65E-02 | 7,64E-03 | 2,66E-02 | 4,83E-03 |
| GWP100 - biogenic | kg $CO_2$-eq | 7,58E-02 | 5,04E-03 | 4,83E-03 | 1,31E-05 | 3,14E-05 | 1,64E-02 | 4,95E-02 |
| GWP100 - land transformation | kg $CO_2$-eq | 1,49E-03 | 8,96E-04 | 5,54E-04 | 3,17E-05 | 2,59E-06 | 1,38E-06 | 1,77E-06 |
| GWP100 - aircraft | kg $CO_2$-eq | 1,74E-01 | 0,00E+00 | 0,00E+00 | 1,74E-01 | 0,00E+00 | 0,00E+00 | 0,00E+00 |
| GWP100- total (neutral approach) | kg $CO_2$-eq | 1,30E+00 | 8,70E-01 | 9,04E-02 | 2,30E-01 | 7,68E-03 | 4,30E-02 | 5,44E-02 |

| Impact category | Unit | Total | SAND | Packaging production | Transport | Energy consumption | GWP | % |
|---|---|---|---|---|---|---|---|---|
| GWP100-$CO_2$ biogenic emissions | kg $CO_2$-eq | 1.36E-01 | 3.41E-02 | 3.05E-02 | 5.10E-04 | 5.28E-04 | 9.95E-03 | 6.05E-02 |
| GWP100-$CO_2$ biogenic uptake | kg $CO_2$-eq | -1.05E-01 | -3.60E-02 | -6.83E-02 | -4.75E-04 | -3.29E-04 | -1.78E-05 | -2.21E-05 |

** carbon footprint value*

SAND production includes frame, lenses, glasses case and cleaning cloth production, transport include transportation from suppliers to production plants, from production plants to logistic centers and distribution.

For IPCC GWP 100a v1.01 indicator, GWP100-total, SAND production has the highest impacts to the total life cycle, followed transport and packaging production.

# 4. Life Cycle Impact Assessment

*Table 54 - GWP result SAND production and transport*

| | | SAND PRODUCTION | | TRANSPORT | |
|---|---|---|---|---|---|
| **Impact category** | **Unit** | **SAND frame and lenses production** | **SAND glasses case and cleaning cloth production** | **Supply to logistic centers** | **Distribution to customer** |
| GWP100 - fossil | kg $CO_2$-eq | 2.98E-01 | 5.66E-01 | 3.66E-02 | 1.98E-02 |
| GWP100 - biogenic | kg $CO_2$-eq | 2.02E-04 | 4.84E-03 | 7.70E-06 | 5.41E-06 |
| GWP100 - land transformation | kg $CO_2$-eq | 1.26E-04 | 7.70E-04 | 2.33E-05 | 8.44E-06 |
| GWP100 - aircraft | kg $CO_2$-eq | 0,00E+00 | 0,00E+00 | 1.74E-01 | 0,00E+00 |
| GWP100- total (neutral approach) | kg $CO_2$-eq | 2.99E-01 | 5.71E-01 | 2.11E-01 | 2.77E-02 |

| | | SAND PRODUCTION | | TRANSPORT | |
|---|---|---|---|---|---|
| **Impact category** | **Unit** | **SAND frame and lenses production** | **SAND glasses case and cleaning cloth production** | **Supply to logistic centers** | **Distribution to customer** |
| GWP100-$CO_2$ biogenic emissions | kg $CO_2$-eq | 2.04E-03 | 3.21E-02 | 3.83E-04 | 1.27E-04 |
| GWP100-$CO_2$ biogenic uptake | kg $CO_2$-eq | -4.02E-03 | -3.19E-02 | -3.54E-04 | -1.21E-04 |

Particularly, the highest impacts are due to SAND production process (glasses case) and to airfreight used for the supply.

# 5. Interpretation

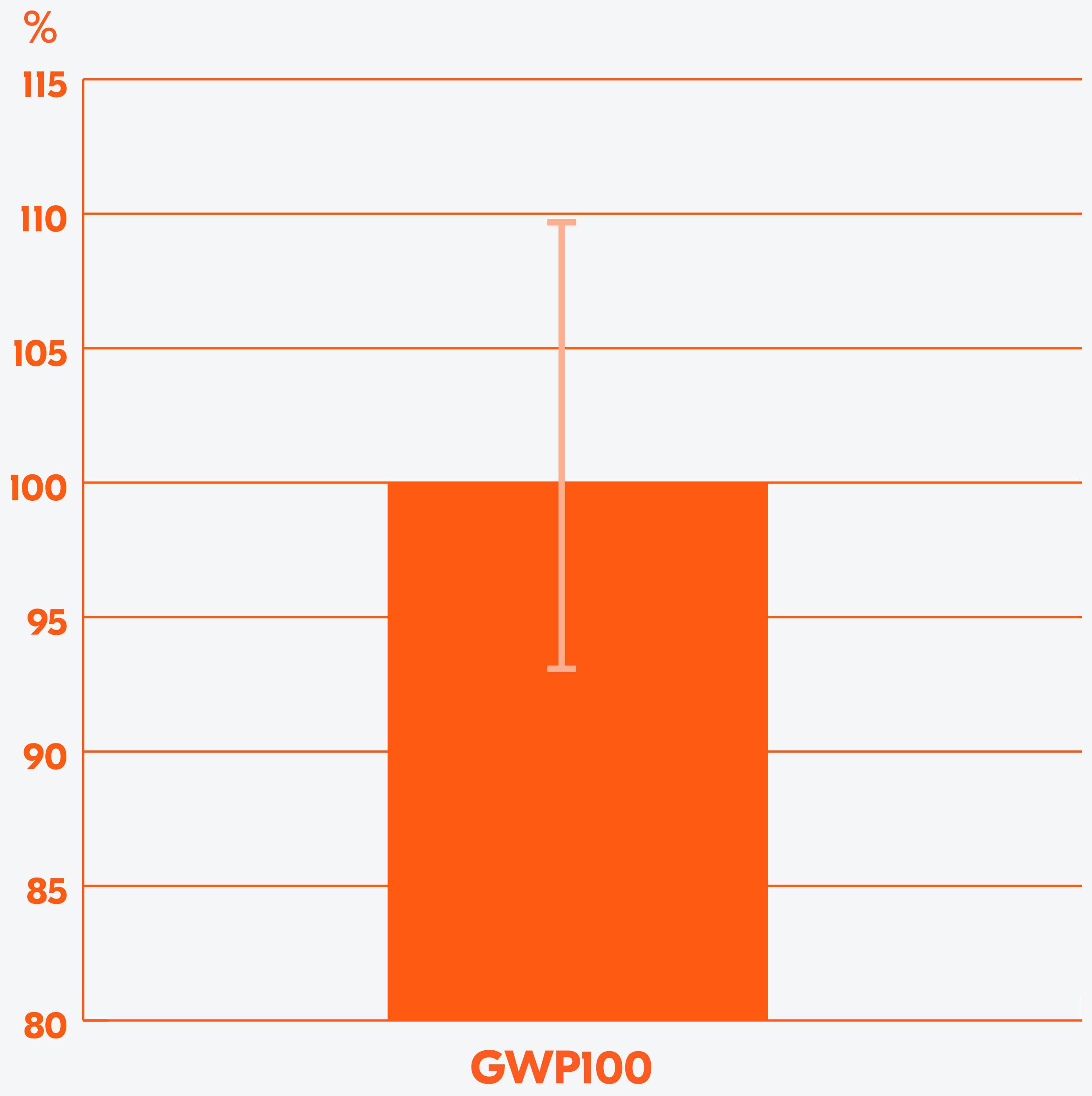
## 5.1 Uncertainty analysis

The uncertainty analysis related to the calculation of the carbon footprint of three Modo products has been carried out [22]. The uncertainty of the LCA model input data have been evaluated using the pedigree matrix as the evaluation method.

A Monte Carlo analysis was conducted and it is relative to a 95% confidence interval. To calculate the uncertainty, a lognormal probability distribution (in line with the ecoinvent database process) has been assigned to the data entered into the model. The uncertainty value considered refers to the average between the upper uncertainty interval and lower uncertainty interval obtained as a result of Monte Carlo analysis. Monte Carlo analysis was conducted for 1000 iterations.

# 5. Interpretation

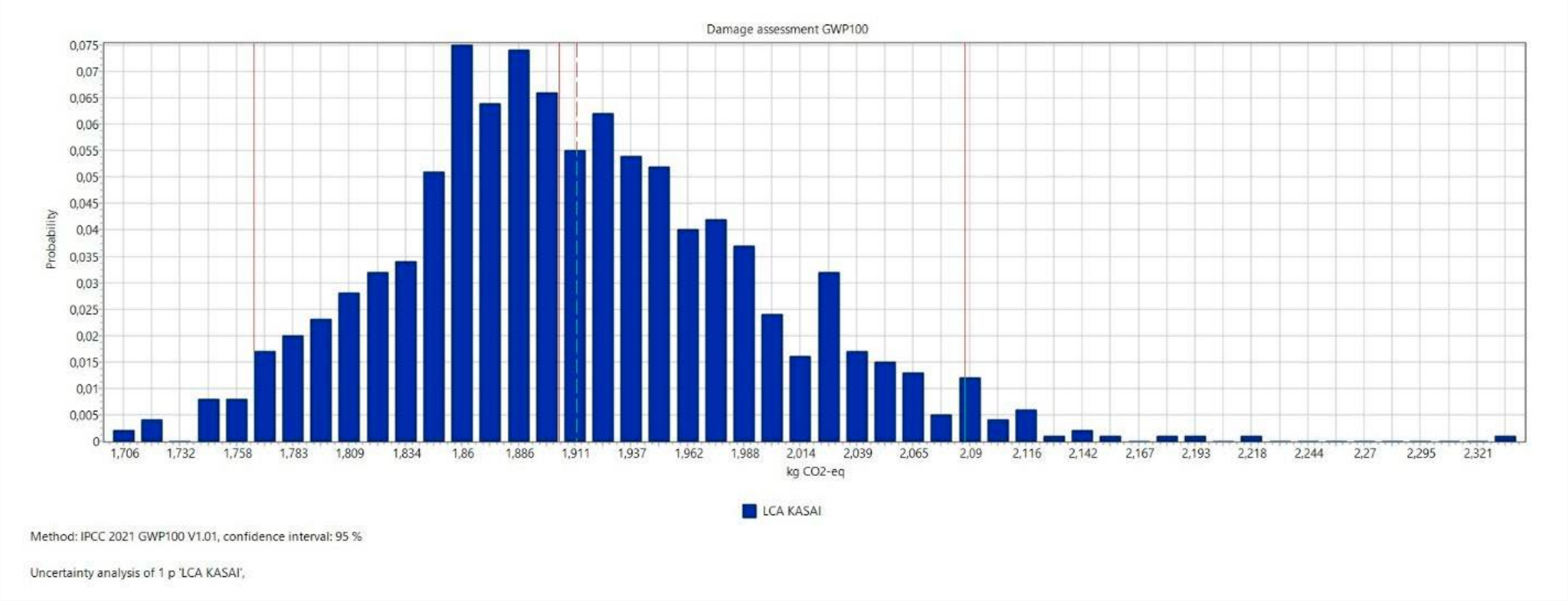
### 5.1.1 KASAI



Uncertainty analysis of 1 p ‘LCA KASAI’,
Method: IPCC 2021 GWP100 V1.01, confidence interval: 95 %

*Figure 17 - Uncertainty analysis KASAI model*

The overall uncertainty of the Carbon Footprint calculation for the KASAI model is found to be equal to +/- 8.5%.



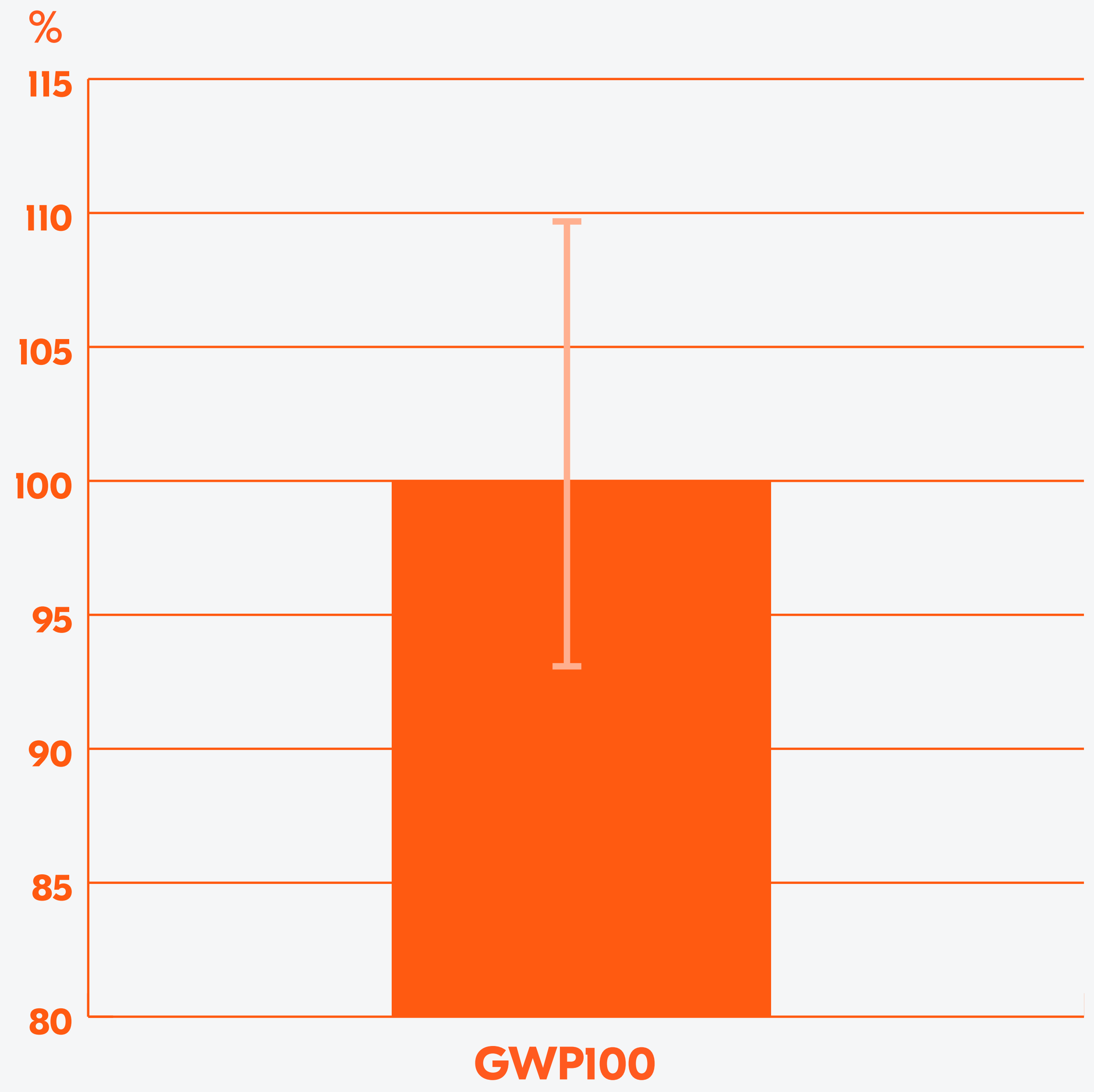
Method: IPCC 2021 GWP100 V1.01, confidence interval: 95 %

Uncertainty analysis of 1 p 'LCA KASAI',

*Figure 18 - Probability distribution of the results of the Carbon Footprint calculation of the KASAI model, obtained by running a Monte Carlo analysis with 1000 iterations and a 95% confidence interval*

# 5. Interpretation

### 5.1.2 BONAIRE



Uncertainty analysis of 1 p ‘LCA BONAIRE’,
Method: IPCC 2021 GWP100 V1.01, confidence interval: 95 %

*Figure 19 - Uncertainty analysis BONAIRE model*

The overall uncertainty of the Carbon Footprint calculation for the BONAIRE model is found to be equal to +/- 8.4%.

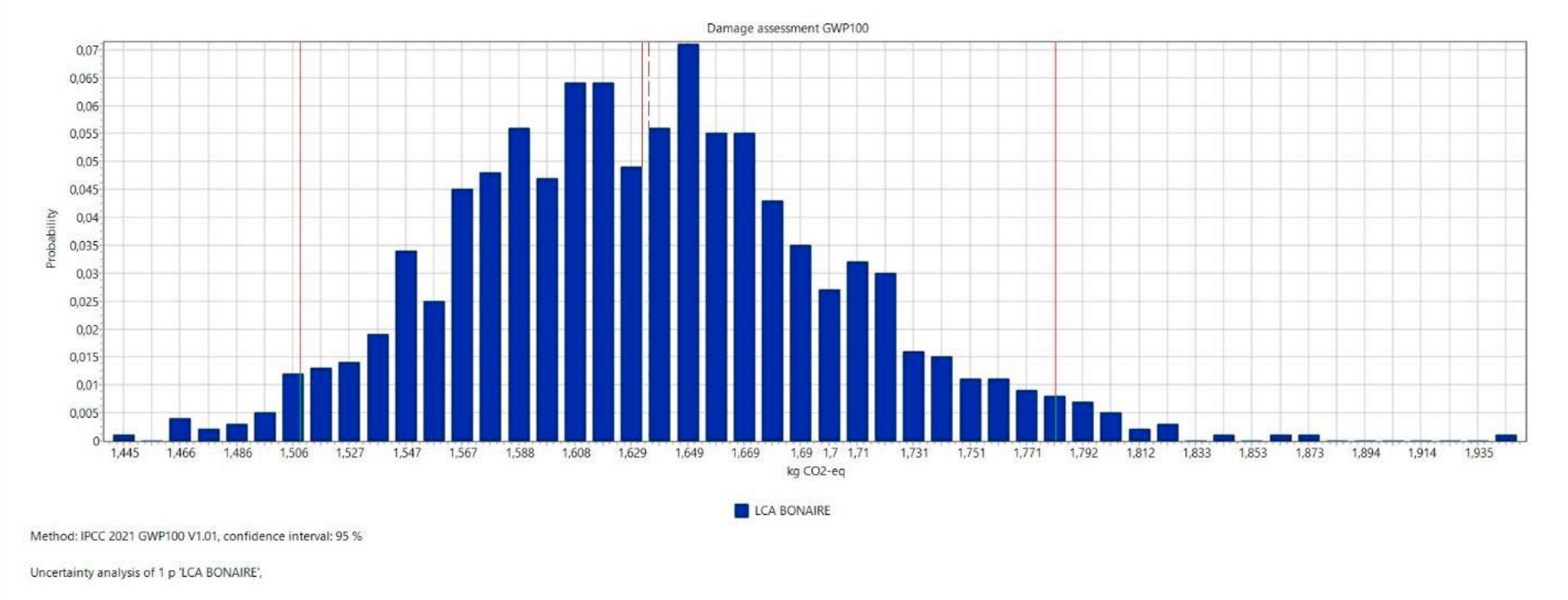
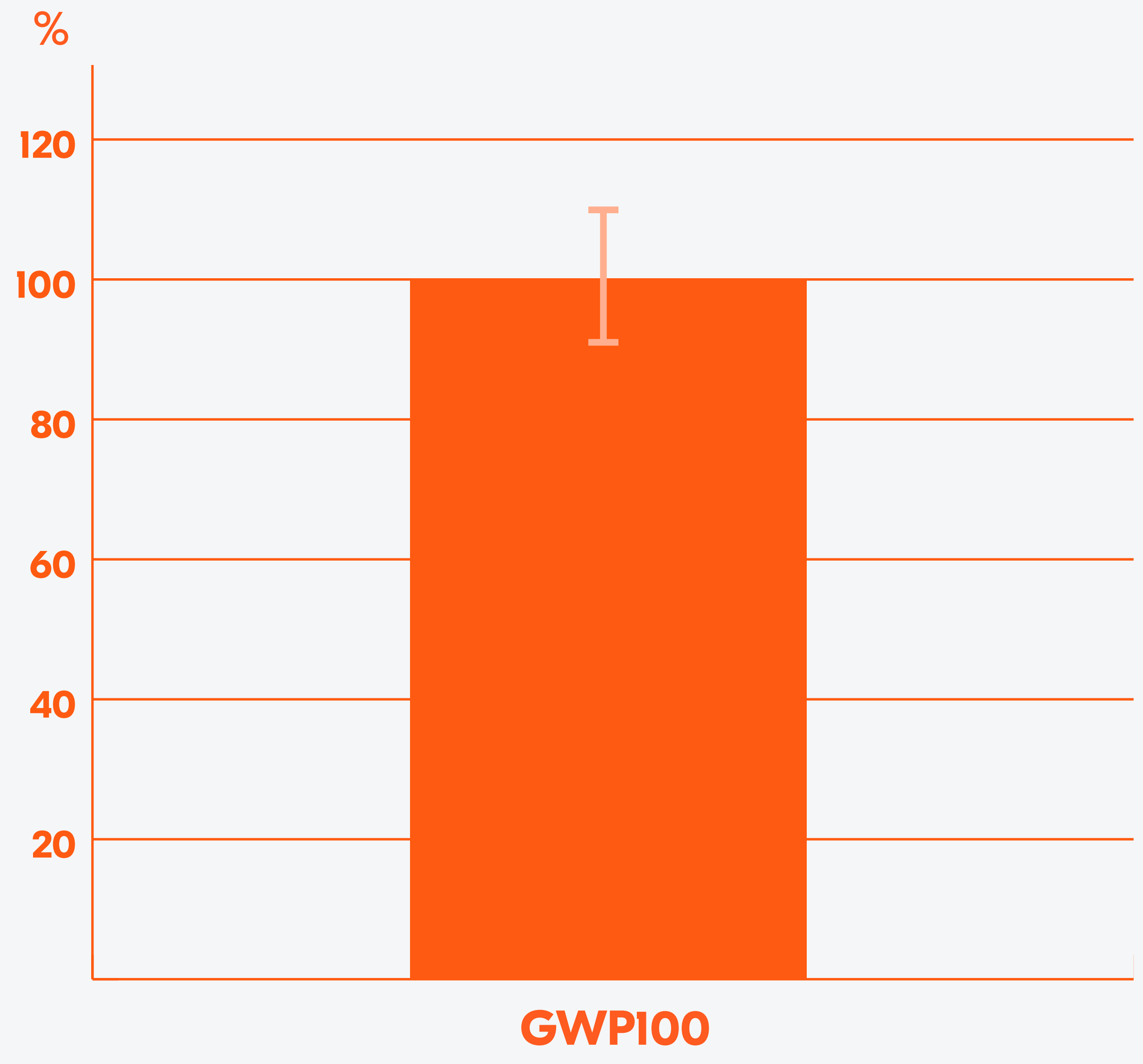


*Figure 20 - Probability distribution of the results of the Carbon Footprint calculation of the BONAIRE model, obtained by running a Monte Carlo analysis with 1000 iterations and a 95% confidence interval*

# 5. Interpretation

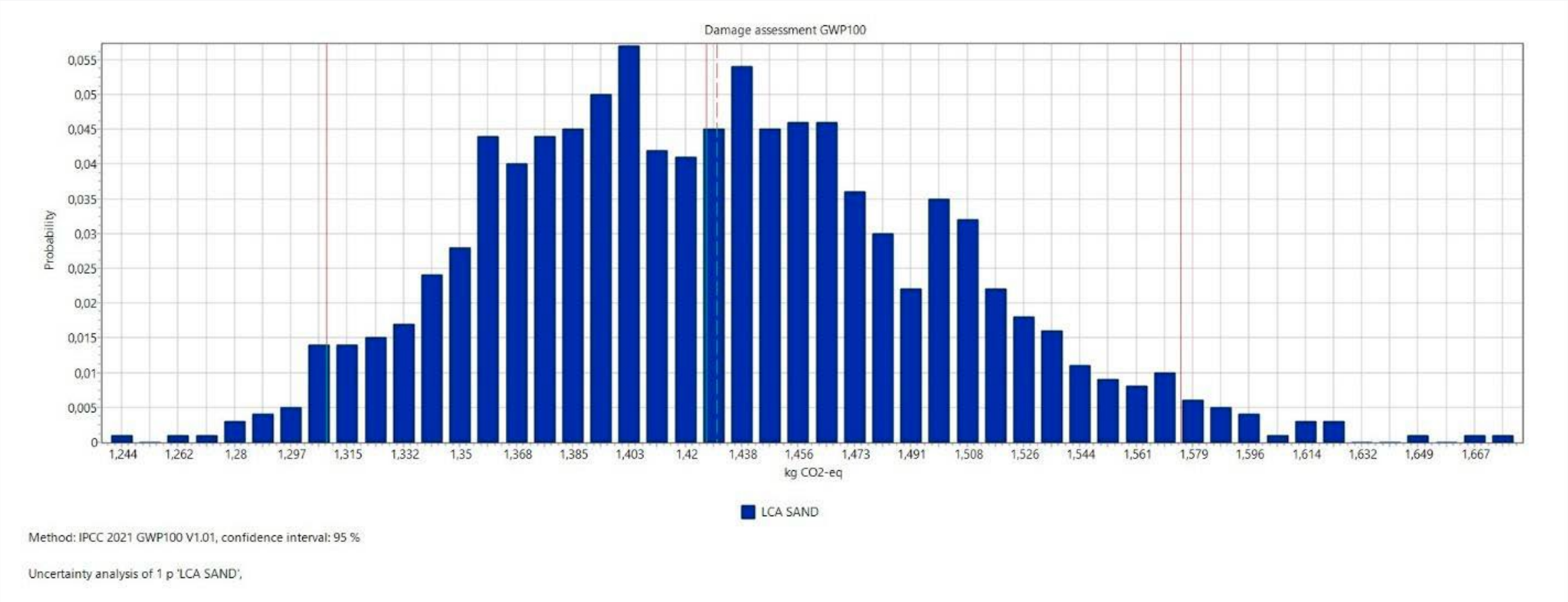
## 5.1.3 SAND



Uncertainty analysis of 1 p 'LCA SAND',
Method: IPCC 2021 GWP100 V1.01, confidence interval: 95 %

*Figure 21 - Uncertainty analysis SAND model*

The overall uncertainty of the Carbon Footprint calculation for the SAND model is found to be equal to +/- 9.3%.



Method: IPCC 2021 GWP100 V1.01, confidence interval: 95 %

Uncertainty analysis of 1 p 'LCA SAND',

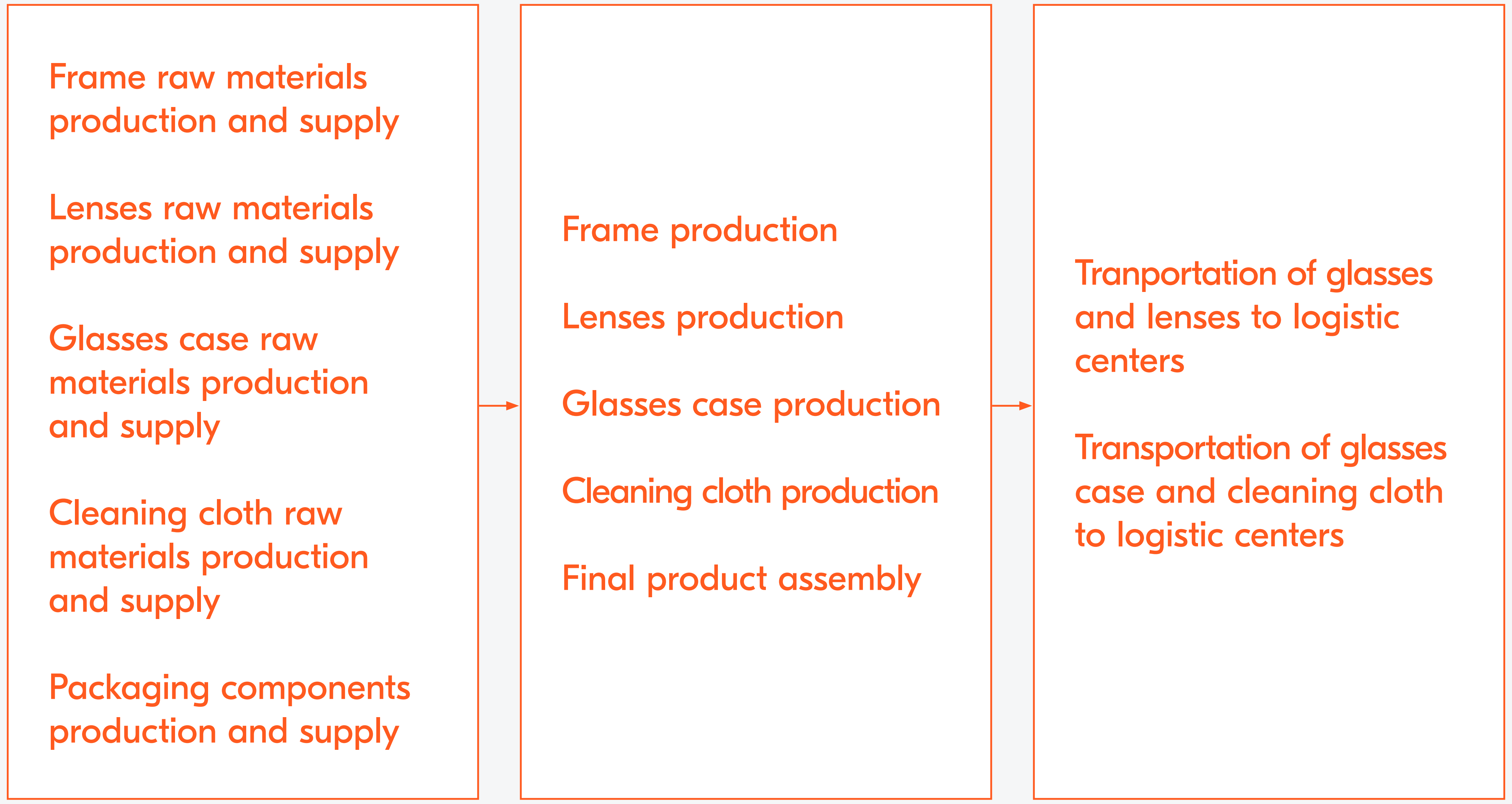
*Figure 22 - Probability distribution of the results of the Carbon Footprint calculation of the SAND model, obtained by running a Monte Carlo analysis with 1000 iterations and a 95% confidence interval*

# 5. Interpretation

## 5.2 Sensitivity analysis

A sensitivity analysis evaluates the influence of the most important assumptions on the results. This type of analysis allows us to understand how different assumptions affect the results. In this study the system boundaries have been varied in the sensitivity analysis, considering a “from cradle to gate” approach, i.e. considering all the production life cycle phase from the extraction of raw materials to the packaging of the final product. The system boundaries include frame, lenses, glasses case, cleaning cloth and packaging raw material production, semi-finished products production, packaging reel production and transport from supplier to logistic centers.

The processes included within the system boundaries are shown in Figure 23.



Frame raw materials production and supply

Lenses raw materials production and supply

Glasses case raw materials production and supply

Cleaning cloth raw materials production and supply

Packaging components production and supply

Frame production

Lenses production

Glasses case production

Cleaning cloth production

Final product assembly

Tranportation of glasses and lenses to logistic centers

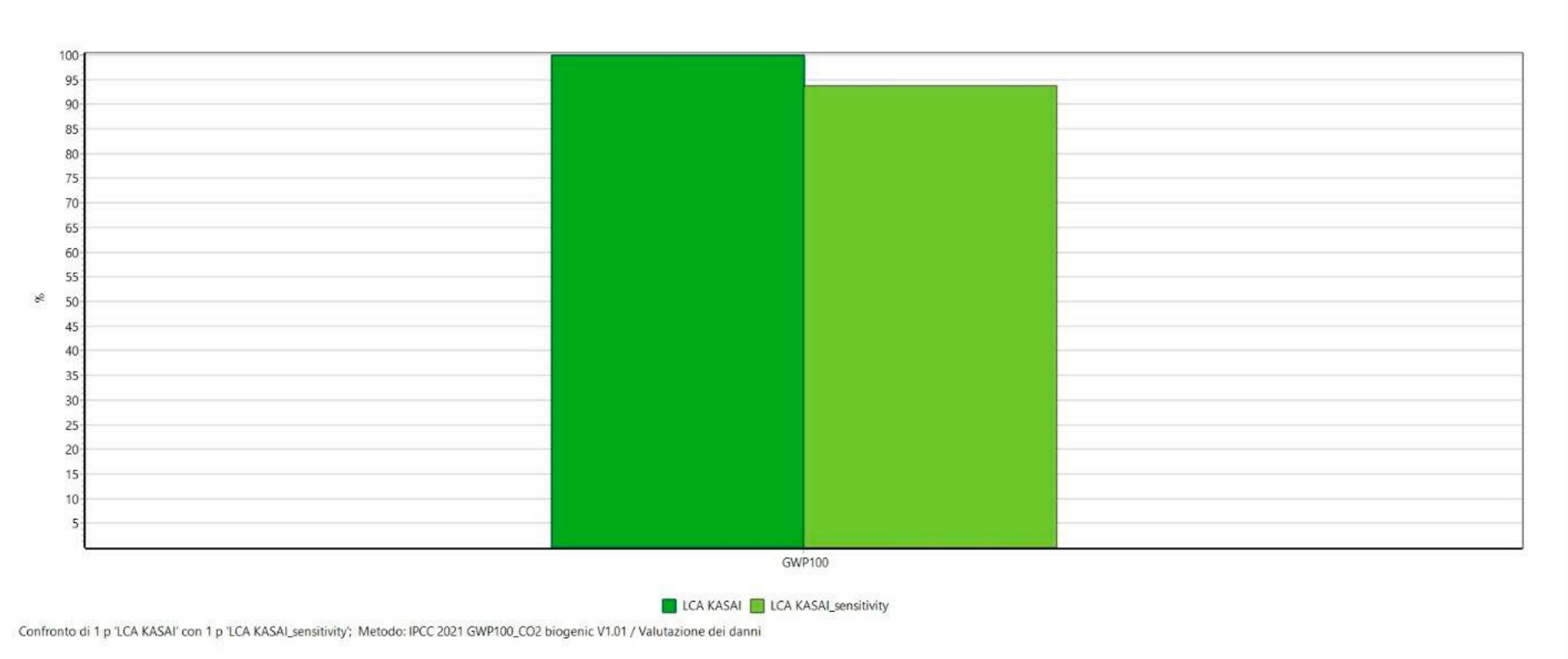
Transportation of glasses case and cleaning cloth to logistic centers

*Figure 23 - System boundaries “from cradle to gate”*

A comparison was made between the two case with different system boundaries for each glasses.

# 5. Interpretation

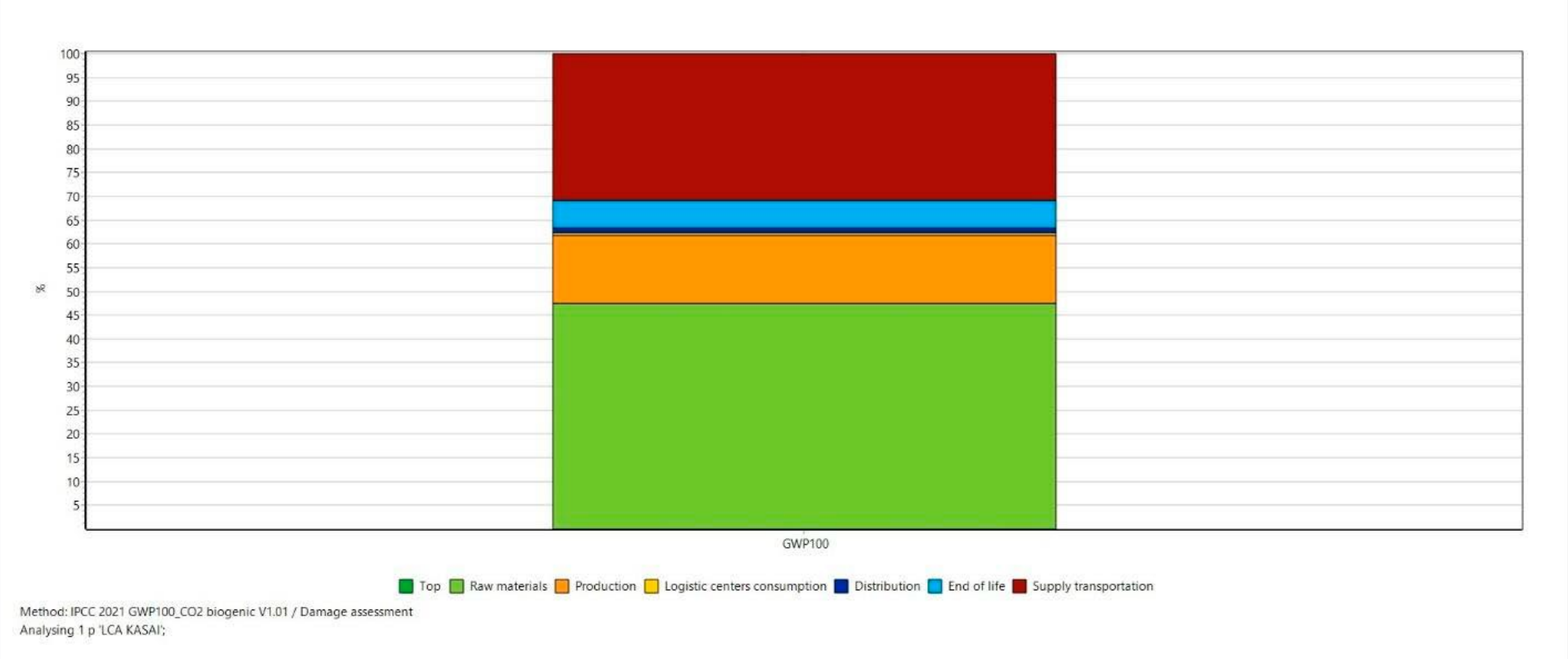
### 5.2.1 KASAI



Confronto di 1 p 'LCA KASAI' con 1 p 'LCA KASAI_sensitivity'; Metodo: IPCC 2021 GWP100_CO2 biogenic V1.01 / Valutazione dei danni

*Figure 24 - Sensitivity analysis KASAI eyewear*

Not considering distribution and end of life phases results in a 6.15 % reduction in impacts for the Carbon Footprint.



Method: IPCC 2021 GWP100_CO2 biogenic V1.01 / Damage assessment
Analysing 1 p 'LCA KASAI';

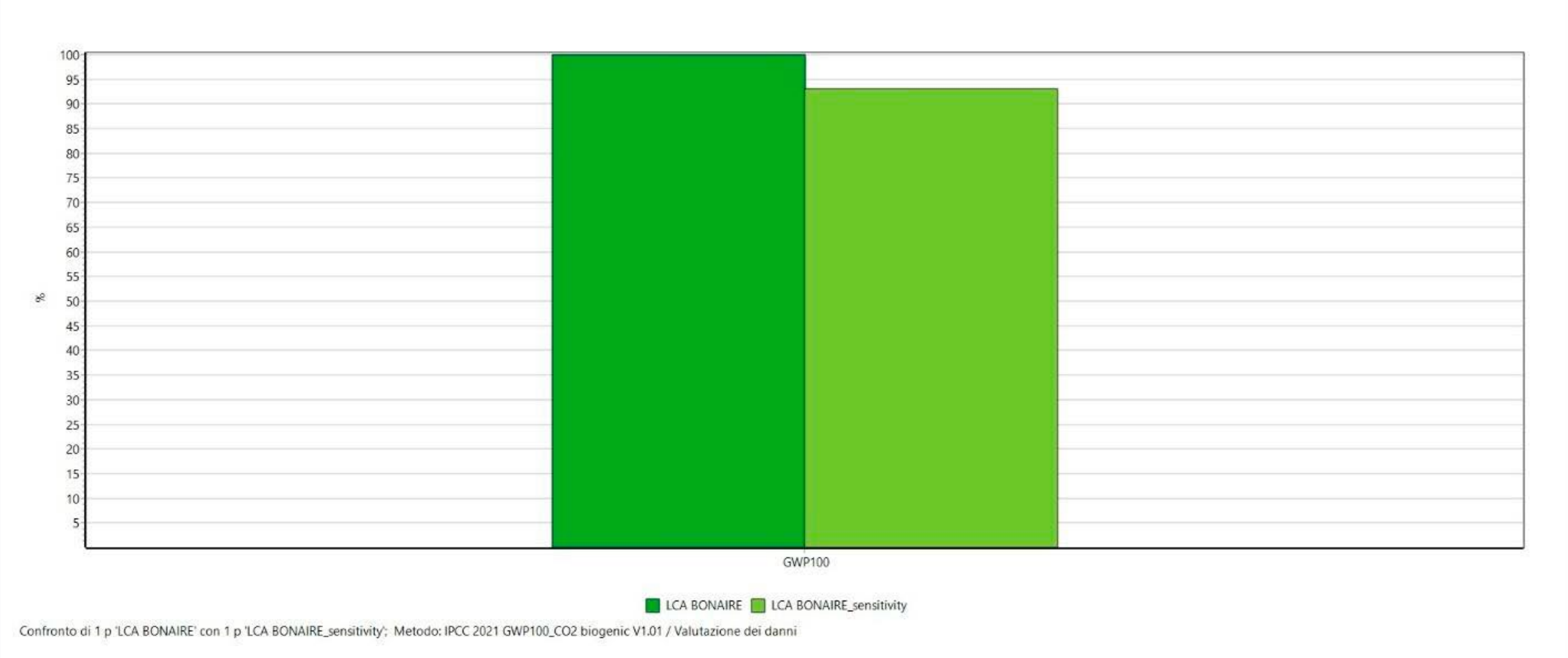
*Figure 25 - Sensitivity analysis KASAI eyewear (phases contribution)*

An analysis has been also carried out with the aim of identifying contributions related to the various stages of the life cycle.

Raw materials contribute 49.9%, supply transportation for 27.3%, production phase for 16.2%, End of life phase for 5.0%, distribution for 1.1% and Logistic centers consumption for 0.5%.

# 5. Interpretation

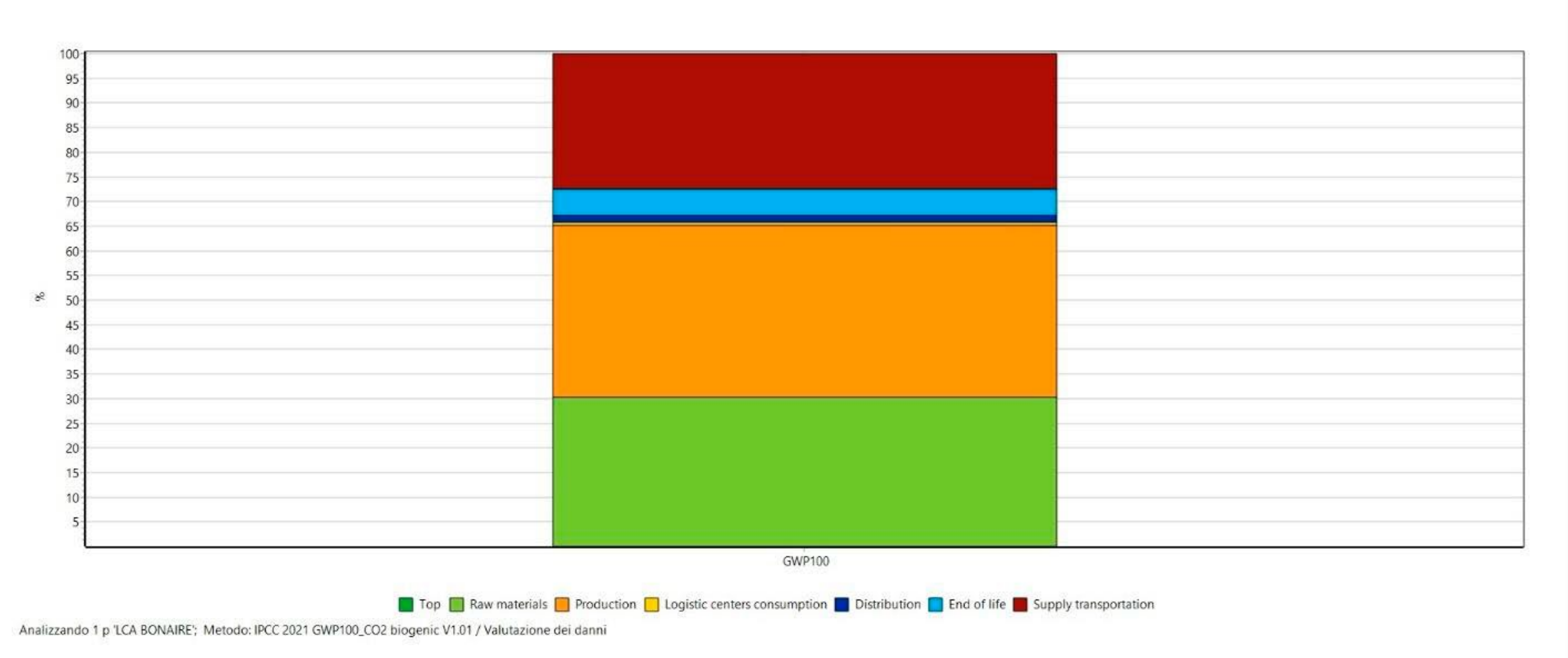
### 5.2.2 BONAIRE



Confronto di 1 p 'LCA BONAIRE' con 1 p 'LCA BONAIRE_sensitivity'; Metodo: IPCC 2021 GWP100_CO2 biogenic V1.01 / Valutazione dei danni

*Figure 26- Sensitivity analysis BONAIRE eyewear*

Not considering distribution and end of life phases results in a 6.86 % reduction in impacts for the Carbon Footprint.



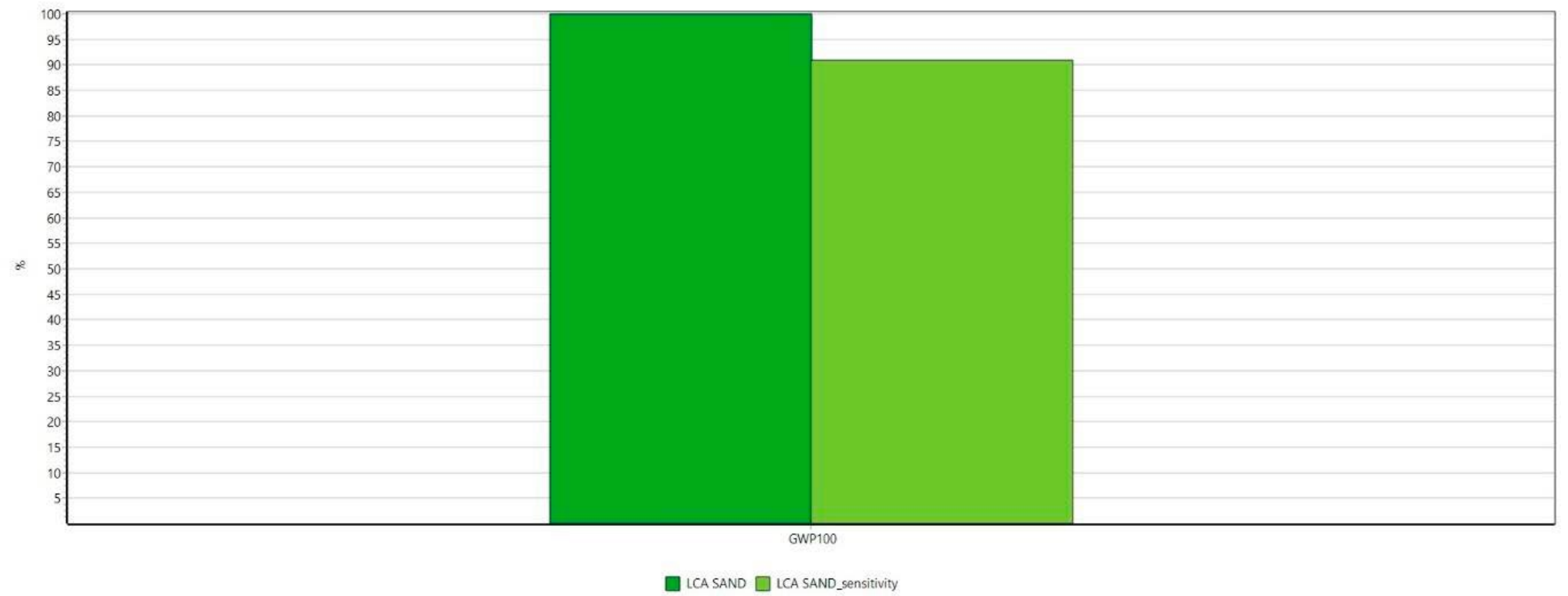
Analizzando 1 p 'LCA BONAIRE'; Metodo: IPCC 2021 GWP100_CO2 biogenic V1.01 / Valutazione dei danni

*Figure 27 - Sensitivity analysis BONAIRE eyewear (phases contribution)*

Production phase contribute 34.9%, supply transportation for 27.4%, raw materials for 30.2%, End of life phase for 5.5%, distribution for 1.3% and Logistic centers consumption for 0.6%.

# 5. Interpretation

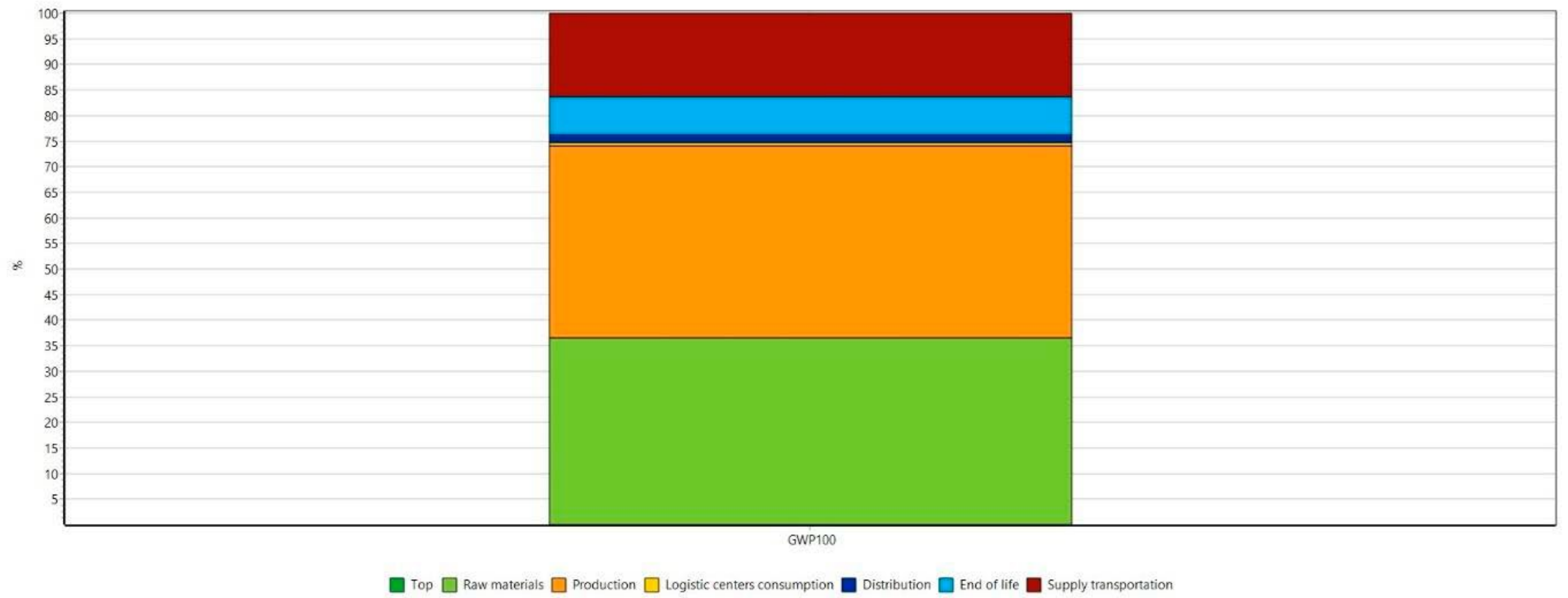
### 5.2.3 SAND



Confronto di 1 p 'LCA SAND' con 1 p 'LCA SAND_sensitivity'; Metodo: IPCC 2021 GWP100_CO2 biogenic V1.01 / Valutazione dei danni

*Figure 28 - Sensitivity analysis SAND eyewear*

Not considering distribution and end of life phases results in a 9.05 % reduction in impacts for the Carbon Footprint.



Analizzando 1 p 'LCA SAND'; Metodo: IPCC 2021 GWP100_CO2 biogenic V1.01 / Valutazione dei danni

*Figure 29 - Sensitivity analysis SAND eyewear (phases contribution)*

Raw materials contribute 36.5%, production phase for 37.6%, supply transportation for 16.2%, End of life phase for 7.5%, distribution for 1.5% and Logistic centers consumption for 0.6%.

# 6. Conclusion

This study aims to evaluate the Carbon Footprint of three eyewear models in order to support the environmental communication with customers.

Primary data refer to 2022. The company has applied the carbon footprint calculation to three eyewear models (KASAI, BONAIRE and SAND) as an assessment of its carbon footprint, with the aim of gaining greater awareness and control of its environmental performance.

The system boundaries include frame, lenses, glasses case, cleaning cloth and packaging raw material production, their transport to suppliers, semi-finished products production, packaging reel production, its transport to the Logistic centers, distribution of finished product through retail channel and end of life of the product and packaging.

The results of the impacts are summarized in the following tables:

*Table 55 - GWP summary by eyewear model for the reference year 2022*

| | KASAI | BONAIRE | SAND |
|---|---|---|---|
| GWP100 – fossil (kg $CO_2$eq) | 1.209 | 1.017 | 1,045 |
| GWP100 – biogenic (kg $CO_2$ eq) | 0.052 | 0.059 | 0,076 |
| GWP100 - land transformation (kg $CO_2$ eq) | 0.002 | 0.001 | 0,001 |
| GWP100 – aircraft (kg $CO_2$ eq) | 0.441 | 0.369 | 0,174 |
| GWP100- total (neutral approach – kg $CO_2$ eq) | 1.703 | 1.447 | 1,296 |

For all three products, the largest contributions are due to glasses case production, particularly to magnet production, transport, particularly to supply to the logistic centers (airfreight) and primary glasses case production.

As required by ISO 14067, emissions and removals of $CO_2$ of biogenic origin have been calculated separately and result in a net emission of 0.036 kg $CO_2$ biogenic for KASAI model, 0.034 kg $CO_2$ biogenic for BONAIRE model and 0.031 kg $CO_2$ biogenic for SAND model.
The methodology has been performed in accordance with ISO 14067 and the ISO standards on Life Cycle Assessment (LCA) (ISO14040/14044).

The overall uncertainty of the Carbon Footprint calculation for the KASAI model is found to be equal to +/- 8.5%, for the BONAIRE model is found to be equal to +/- 8.4% and for the SAND model is found to be equal to +/- 9.3%.

The results obtained are not necessarily intended to be comparable with those of studies performed by other companies and for other products.

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