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RECYCLING OF WASTE ACRYLIC TEXTILES

D6.5: Life Cycle Environmental Assessment Report for recycled acrylic textile and comparative analysis

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Abstract	LCA analysis of recycled acrylic textile considering inputs and outputs of each process, such as energy, water and chemicals

	consumption, gas emission, waste generation. The results from D6.1 will be compared and evaluated, to assess the overall environmental impact of recycling process.
Keywords	LCA analysis, comparative analysis LCA

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Acknowledgment

** REPORT: Document, report (excluding the periodic and final reports)*

DEM: Demonstrator, pilot, prototype, plan designs

DEC: Websites, patents filing, press & media actions, videos, etc.

OTHER: Software, technical diagram, etc

EXECUTIVE SUMMARY

This deliverable has been created in the context of the Work Package 6 (LCA and recommendations) of the H2020-funded project REACT (Grant No. 820869).

This Document is the second action taken to implement the comparative Life Cycle Assessment (LCA) for the recycling of acrylic textile used for awning and umbrella.

Within this context, the present LCA for the awning made of a mixture of recycled and virgin acrylic is considered as an innovative product and will be compared to the previously evaluated baseline, in order to assess the overall environment benefits coming from the recycling process developed in the project.

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ABBREVIATIONS

AIB	Association of Issuing Bodies
ADP	Abiotic Depletion Potential
BaP	Benzo[a]pyrene
CTUh	Comparative Toxic Unit for humans
CTUe	Comparative Toxic Unit for ecosystems
COD	Chemical Oxygen Demand
DCB	1,4-dichlorobenzene
DoA	Description of the Action
EoL	End of Life
EF	Environmental Footprint impact assessment method
EPD	Environmental Product Declaration
FU	Functional Unit
GA	Grant Agreement
GeR	Geographical representativeness
GWP	Global Warming Potential
HDPE	High-Density Polyethylene
HTOX	Human toxicity
IBC	Intermediate Bulk Container
ISO	International Organization for Standardization
KPI	Key Performance Indicators
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
LUC	Land Use Change
ND	Not Determined
NMVOC	Non-methane volatile organic compounds
NyA	Not yet Available
ODP	Ozone Depletion Potential
PAH	Polycyclic Aromatic Hydrocarbons
PAN	Polyacrylonitrile (fibre)
PEF	Product Environmental Footprint
PFC	Perfluorocarbons
PMB	Project Management Board
PMR	Project Management Report
POCP	Photochemical Ozone Creation Potential
Pt	Points (dimensionless unit)

SDS	Safety Data Sheet
TeR	Technological representativeness
TiR	Time-related representativeness
WP	Work Package

1 INTRODUCTION

Recycle is a common word used more and more but is still not tackled appropriately in the EU, while landfill and incineration rates remain high. One of the major problems is to have secondary raw material that is as much as possible “equal” to the virgin one because of contamination, treatments and deterioration that lower the product performance.

The **Recycling of Waste Acrylic Textiles (REACT) project addresses the management of waste acrylic textiles coming from outdoor awnings and furnishing.** A crucial issue is the analysis and removal of finishing substances that affect the secondary raw material purity and their management. Then a mechanical recycling process will be implemented to obtain second life fibre and fabrics, which performance will be tested for the best application.

A full process to remove hazardous materials on finishing of waste acrylic textile will be investigated and developed, together with a safe utilisation and disposal of removed substances.

The final goal is to perform a new process for hazardous chemicals removal from finished acrylic textiles, with innovative investigation and processing techniques ant to obtain a fully compatible recycled acrylic textile for reuse.

To maximise the impacts of the project results, recommendations for recycling process implementation, standards, design, and technology transfer will be produced. With this aim in mind, the sustainability of the whole process will be evaluated through the application of the Life Cycle Assessment (LCA) tool on a comparison between the innovation coming from the project and the state-of-the-art situation.

The present report represents the Project Deliverable D 6.1 and collects the results of the LCA carried out for the new recycled and virgin acrylic textiles. It documents the whole life cycle of the textile product made starting from acrylic pre-consumer scraps: the study boundaries are “from cradle to grave”. The core production process was taken into consideration, together with the upstream processes performed to obtain the primary and secondary raw materials and the downstream processes need for distributing, using, and disposing the product.

The results will be used as start of point in the Project Deliverable 6.5 to compare and assess the overall environmental impact of the innovative recycling process develop in the project.

The Life Cycle Assessment is a methodological approach for assessing products, processes, industrial systems, and the like. The reason underpinning its introduction in the REACT project is the fact that this tool enables comparing the environmental performance of two or more products throughout their whole life cycle. Indeed, a complete LCA analysis is usually "cradle-to-grave". This means that the whole product’s life cycle is considered, from the raw materials extraction to the end-of-life (EoL) stage, where all the materials are dismantled, disposed, or recycled. This type of life cycle analysis evaluates all stages of a product’s life from the perspective that they are interdependent, meaning that one operation leads to the next. It enables the estimation of the cumulative environmental impacts resulting from all stages in the product life cycle and, as a result, it allows selecting the path or process that is preferable from the environment point of view.

The LCA helps decision-makers to select the product, process, or technology that results in the least impact to the environment. This information can be used with other factors, such as cost and performance data to find optimal solutions. The LCA supports in identifying the shifting of environmental burdens from one media to another, from one impact indicator to another, and between different life cycle stages. The diagram illustrated in Figure 1 illustrates the main life cycle stages and environmental pressures considered in an LCA.

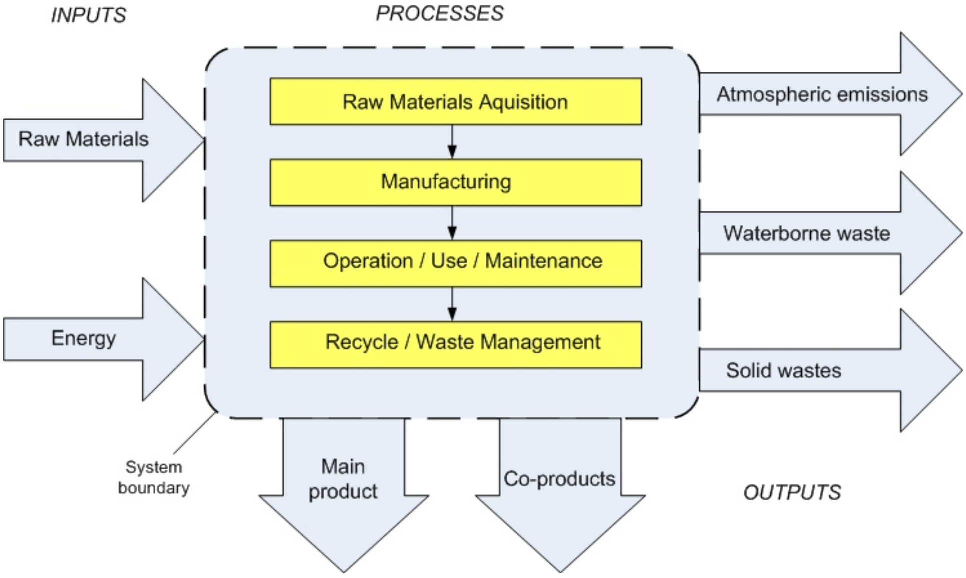


Figure 1 The main stages and typical inputs/outputs in an LCA.

As it is possible to see in the diagram above, any product or technology would require input of some raw materials and energy at all the stages: from the raw materials acquisition to the manufacturing step, the operation and the use phase, and finally the end-of-life. All the mentioned life cycle stages may produce atmospheric, waterborne or soil emissions, and solid wastes, simply because the efficiency in the material processing, as well as in the energy conversion, is never 100%. There are losses and by-products, which sometimes can be highly undesirable. The LCA helps to keep track of all useful and harmful outcomes and provides a guideline to life cycle mapping.

To reach these objectives, information on inputs and outputs of the entire process need to be collected and elaborated. The standardized LCA framework encompasses four phases, as shown in Figure 2 (ISO 2006a, b).

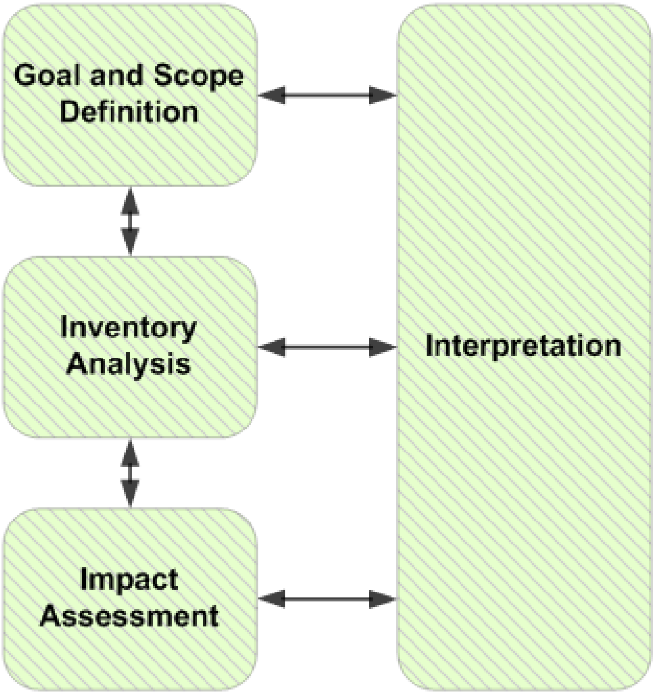


Figure 2 Stage of LCA (ISO 2006a).

Goal definition and scope: this is the first level of the study; the purpose, scope and main hypotheses considered are defined here. Firstly, the goal must be specified, as well as the set of decisions that will be made based on the results obtained. Secondly, the scope of the study is determined. The latter should be well defined to ensure that the extent, robustness, and detail of the study are compatible and consistent to address the stated goal. This action implies defining the system, its limits, quality of data, the main assumptions, and the study limitations. The definition of the functional unit is a key step. This is the unit of the product or service whose environmental impacts will be assessed and on which the comparison will be performed. Finally, the system boundaries are outlined. They determine which stages, processes and flows will be included in the study. See section 3.

Inventory analysis: this is a technical process of data collection aimed at quantifying and measuring all the inputs and the outputs of the system, as it is defined in the scope. The emissions released to the environment and the consumed resourced along the production life cycle are collected and calculated with reference to the functional unit. The main steps are: (1) data collection; (2) relevant and non-relevant element identification; (3) mass and energy balances, and (4) system burdens allocation. See section 4.

Impact assessment: during this phase, the data are translated into environmental impacts, through the application of one or more impact assessment methods. Briefly, it is the procedure to identify and characterize the potential effects produced in the environment by the system analysed. Suitable software will be used for this purpose (GaBi software[1]). The environmental pressures are characterized for several impact categories, e.g. global warming, acidification, eutrophication, resource depletion, human health, cumulative energy demand, etc. These impact categories and potential environments impact are described in section. See section 5.

Data interpretation: in this phase, the findings obtained are presented in a synthetic way, identifying, and examining the critical sources of impacts and the possible options to decrease them. The interpretation is useful to indicate the results consistency according to all the aspects defined during the goal and scope stage. The interpretation requires consistency checks, ensuring that there is complete information. See section 6.

The present study represents an application of the Life Cycle Assessment (LCA) methodology, in accordance with the ISO standard series (ISO, 2006a, b). The Life Cycle Impact Assessment is carried out by means of Environmental Footprint method (EC, 2013) as in its last update (Fazio et al., 2018), and by means of the CML method (Guinee et al., 2002) as in the 2016 update[2]. Further references for the methodology are the PEF method for the transition phase (Zampori and Pant, 2019), the LCA guidelines indicated by the Joint Research Centre (EC-JRC-IES, 2010) and the EPD International Programme (EPD International, 2019).

For the present study, Centrocot mainly used specific data for modelling the production of the awnings' fabric (acrylic). Data were provided by Parà S.p.a., Ják Spinning KFT and Soft Chemicals s.r.l., partners involved the REACT Project. Data were processed, integrated, and analysed by means of the LCA software GaBi 9.5.1.46 (distributed by Thinkstep, a Sphera company) and its implemented database, i.e. GaBi Professional service pack 40 (Sphera, 2020) and ecoinvent 3.6 (Ecoinvent, 2019).

[1] http://www.gabi-software.com/international/index/

[2] https://www.universiteitleiden.nl/en/research/research-output/science/cml-ia-characterisation-factors

2 PROJECT, PARTNERS AND PRODUCTS

2.1 The REACT Project

REACT is a three-year research and innovation project approved by the European Commission under the Horizon 2020 program with convention No. 820869. As mentioned in the INTRODUCTION, the Project is focused on developing and evaluating the options for giving new life to outdoor acrylic fibre wastes. The aim of the project is the recycling of acrylic fibres from various textile sectors such as outdoor furniture and awnings.

The overall purpose of the REACT Project is to develop a method to remove undesirable substances (fluorocarbons, melamine and acrylic resins, anti-mould agents) from waste of acrylic fabrics with an environment friendly process to enhance their recycling, to improve sustainability, and to reduce environmental and health risk, as stated in Regulation (EC) No 1907/20061 (EC, 2006).

Therefore, the specific objectives of the proposal, to be reached within its 36 months duration, are:

- To remove those hazardous substances whose presence could adversely affect the quality of the secondary raw materials and prevent their recycling.
- To reach a removal rate of 90-95% of those substances.
- To treat up to 99% of all sewage impurities, obtained from removal steps, for safe utilisation or disposal of these substances.
- To obtain a final textile product with yarn coming from 100% recycled fibre, mixing regenerated fibres from card, winding opened thread and waste material collected fibre, each up to 33%.
- To re-use the acrylic textiles as raw material for other production cycles, also in combination with virgin fibres, to reach 30% of waste prevented from disposal (3.600 tonnes total) for the outdoor sector (awnings and furnishing).
- To produce recommendations on:
    - production chain implementation (management and recovery of production scraps)
    - design and manufacturing of materials to enhance recyclability
    - technology transfer (knowledge transfer to other products and applications)

Furthermore, the sustainability assessment on Project's results would encourage European fabric manufacturers to produce the least amount of waste, recovering hazardous chemicals, and using fewer harmful chemicals.

These objectives aim to be beneficial and highly impactful for the whole environment and thereby are expected to improve the quality of life for all European citizens with overall resonance and high potential on a global scale.

For further details: https://www.react-project.net

2.2 The partners in the LCA analysis

2.2.1 Parà S.p.A.

Parà Industrial Group is a family company founded in 1921, which for three generations has been producing textiles with outstanding aesthetic and technical qualities. With six manufacturing plants and significant market penetration, Parà Group is present in 3 specific business sectors: sun protection, indoor and outdoor furnishing accessories, and marine.

Parà Group has won a reputation on the market as a manufacturer of high-quality textiles, strictly "Made in Italy" with close monitoring of the entire production cycle, vertically integrated from the spinning to the weaving stages, from printing to dyeing, from coating through to finishing.

Parà is one of the largest European manufacturers of fabric for awnings and holds important positions in major markets such as Italy, where it is the undisputed leader with a market share of over 30%, and Germany where it is a supplier of the major operators in the sector.

The availability of goods in stock also includes the presence of reliable suppliers that pay attention not only to the quality of raw materials but also to the logistic organization (production planning, transports, communication). Parà has a R&D department that is always in touch with both suppliers of raw materials, for a continuous improvement of the quality products, and research institutes for a constant updating on new products and control methodologies to anticipate market needs regarding quality and product sustainability.

Participation in the Italian and European technical committees (Assotende and Esso European Solar Shading Organization) and CEN working groups (TC3 / WG5) allows Parà to be a reference point for its customers for updating on European standards active on sun protection devices.

The Parà Tempotest brand has become synonym of awning thanks to the high standards of product and service and to a persistent and continuous sponsorship and communication campaign of the brand transmitted through national radio and television networks. The fabrics for sun protection represent the core business, while the fabric for outdoor furniture represent a small percentage of the production made with acrylic yarn.

Thanks to its widespread sales network, Parà is continuously in contact with the manufacturers and distributors, therefore always updated on the needs of the final customers

2.2.2 Ják spinning

Ják Spinning was born in 2006 as the foreign branch of Filatura Prealpina di Mornico al Serio (Italy) with the objective to satisfy the continuous requests from its customers to increase the production of acrylic yarns.

Today, it is an independent production facility with more than 30 employees and several ring-spinning and twisting lines. Working h24, 7 days a week, it mainly works on acrylic fibres intended for awnings and outdoor furniture fabrics.

Ják Spinning is a textile manufacturing enterprise qualified in spinning activity covering the hole spinning cycle. It is specifically specialized in spinning of acrylic fibres used especially for awnings, also in cooperation with Parà. Among its facilities, it counts two complete spinning lines and a quality control laboratory.

2.2.3 Soft Chemicals s.r.l.

Based in Marnate (VA, Italy), Soft Chemicals specializes in textile auxiliaries and offers chemical solutions for fabric treatment for various applications, developing special skills in the treatment of textile fibres for clothing, interior, exterior design, and blackout curtains.

As supplier of auxiliary chemicals to the textile industry (preparation, dyeing, finishing, coating and garment treatments) it has an in-depth knowledge of the relevant chemistry and technology which allows technological improvements, costs saving and process controls of many aspects of the textile productive sector.

2.2.4 Centre Europeen des Textiles Innovants (CETI)

The Centre Europeen des Textiles Innovants (CETI) is a non-profit organization dedicated to conceiving, experiment and prototype innovative textile materials and products. CETI’s core business is to show proof of innovation by doing demonstrators on the technological platforms through private R&D projects and collaborative R&D projects. Presently the staff of CETI is 24 persons including a majority of senior engineers and experienced technicians. Since the creation of the CETI in 2012, one of its major strategic axes is sustainable development. The importance of this implication, for a more virtuous fashion or technical textiles, makes it possible to palliate the lack of natural resources and the use of toxic products. By reinventing the end-of-life of textile products, we feed the textile industry with a secondary raw material. Our duty is to preserve our resources and improve our processes to stay at the forefront of technology. Eco-design is also an important focus of our offer. By accompanying our customers from the upstream to the downstream, we enable them to find technical solutions for more responsible textile items. The sustainable development department supports industrials and retailers in their efforts to consider the end-of-life of their textile waste. Thanks to our industrial recycling line, we can prototype the products of the future. The DNA of CETI is the prototyping of innovation in textile processing, upcycling, and future apparel experience. The capacity to prototype quickly some products reduces the risk of failures and improve the speed of development. The CETI is covering the Technological Readiness Levels between 4 and 8. CETI is providing proof of innovation from the idea to the industrial transfer but also helping in successful introduction on the market thanks to its tools of innovation valorisation. The strategic axis of activity are:

- The performance of materials processed through extrusion, filament spinning, nonwovens processing, yarn spinning, weaving, and finishing.
- Digital transformation to serve products.
- Eco responsible development.

CETI is in charge to transform the fabrics that have been clean up from hazardous products into fibres and then to spin the fibres. To achieve this work CETI uses its pilot lines composed with a tearing line, a line for preparation of fibres to the spinning and an open-end spinning line. The yarn is then delivered to Para S.p.A. to be woven.

2.3 Description of the assessed product

The main features of the considered products are reported in Table 1**Errore. L'origine riferimento non è stata trovata.**.

Table 1 Overview of products' main features.

PRODUCT	DESCRIPTION
OUTDOOR AWNING, Recycled/virgin acrylic	Arm awning for outdoor. 70% recycled acrylic pre-consumer/30% virgin acrylic fabric. Greige acrylic. Coating with fluorocarbon (C6) and melamine resin. Fabric measures: 3.4 x 2.2 m, 290 g/m^2. Extruded aluminium structure: – Torsion bar: 35 mm x 35 mm – Roller: Ø 58 mm – Front bar: 47 mm x 35 mm – Retractable lateral arms: 2 m

3 GOAL AND SCOPE DEFINITION

3.1 Goal

The present LCA study represents the second part of the comparison of the environmental performance of an outdoor awning throughout its whole life cycle. The comparison is mainly focused on the material's sourcing for the awning fabric part. In the baseline situation, it is 100% virgin acrylic fabric, whereas in the present innovation case study it is 70% recycled (pre-consumer) acrylic fabric and finally treated with bio-based finishing chemicals.

The comparison is aimed at assessing the environmental benefits of acrylic textiles made with recycled acrylic fibres, following an LCA approach. Concisely, the analysis aims to:

- **assess the environmental performance of the treatment and recovery system of textiles, to understand if the benefits arising from the material and energy recovery are offsetting the burdens.**
- **to compare the REACT Project concept with the conventional acrylic textiles production and valorisation processes.**
- **to compare the acrylic recycled materials with equivalent virgin products in the market. Here, a key indicator will be considered the carbon dioxide emission reduction since it was taken as reference in the preliminary evaluation carried out for the Project's proposal**.

The main goal of this comparison is to evaluate how the environmental performance can change when the fabric is recycled, i.e., it is collected, treated, and used again in the awning production process. The analysis allows verifying the influence of the recycling steps from the environmental point of view.

This is the reason underpinning **the determining of the second term of comparison (the REACT innovation scenario),** which is the **goal of the present study**. This evaluation allows to identify the main environmental benefits and possible pressures and, consequently, the strengths and the impact hotspots. Additionally, it highlights the environmental improvements, taking into consideration all the aspects related to the product analysed, i.e., not only the fabric.

As a result, the innovation characterization, and its comparison with the baseline, should lead to define some valuable recommendations:

- On production chain implementation (management and recovery of production scraps).
- On design and manufacturing of materials to enhance recyclability.
- For technology transfer to other products and applications.

The results of the project will generate new references on production chain for the management of textile industrial waste, and references on back logistic, for the implementation of take-back and rental-services approaches. The production process is designed and set-up with the product specifications, but special modifications could be made to enhance waste recovery and sorting, to reach higher recycling rates. The outlined steps and the related solution adopted for waste management could be used by similar enterprises, or adapted to other sectors, with similar productive process, thanks to the editing of specific recommendations.

The outcomes of the project about finishing removal, hazardous substances treatment and disposal and about mechanical recycling process could generate data and recommendations about product and production chain design, about best sustainable finishing and generate suggestions for next productions.

To meet the listed goals of the analysis, the LCA will be conducted on the following products:

- Outdoor awning made in 100% virgin acrylic fabric (the previous study).
- Outdoor awning made in 70% recycled acrylic fabric (the present study).

3.2 Scope

According to the guidelines by the Joint Research Centre (Zampori & Pant, 2019; EC-JRC-IES, 2010), each aspect of the scope is described in the following sections.

3.2.1 Functional unit and Reference flow

The functional unit of the analysis qualitatively and quantitatively describes the functions and duration of the product. In the present study, the functional unit of this analysis is the following: **one outdoor awning preserved in good conditions for a whole service life.**

The functional unit also provides the definition of the function, the extent of the function, the expected level of quality and the lifetime of the product. In Table 2, this further information is detailed; together with the amount of materials needed (i.e. the **reference flow**).

Table 2 Functional unit definition.

FEATURE	DESCRIPTION
What	To provide an awning product to meet the consumer's specific needs.
How much	An arm awning for outdoor.
How well	70% recycled (pre-consumer) acrylic fabric/30% % virgin acrylic fabric. Greige fabric with a water-repellent finishing. Extruded aluminium structure. Maintained in good conditions.
How long	8 years of guaranteed service life (based on the fabric warranty)
Reference flow	**1 awning for outdoor composed by:** – **Acrylic fabric final amount: 2.169 kg** – **Aluminium for the structure final amount: 16.83 kg**

3.2.2 System boundaries

The system boundaries specify the unit processes that will be considered in the studied analysis. The system boundaries are defined through the stages of the products' life cycle. It is essential to define where to stop tracking energy and material uses of upstream processes, otherwise the analysis would be endless, and the environmental impacts would be altered in the several processes studied. These boundaries shall be adapted to the potential accuracy that could be obtained from the available data.

The present LCA study is cradle-to-grave, and it considers the whole life cycle of the outdoor awning, from its production to its use phase (i.e. its service life and maintenance), and to the end-of-life. This choice allows evaluating all the possible aspects linked to design and recycling process, including the variation in the service life and maintenance, and to give support in the decision-making process.

The system can be divided into three parts: (i) one **UPSTREAM**, characterized by background processes, i.e. those which, although falling within the boundaries, are not directly controlled by the companies; (ii) a main one (**CORE**), characterized by the processes performed by the companies; and (iii) a **DOWNSTREAM**, including the assembly and distribution, the use, and the end-of-life of the product. The transfer of waste to landfills or incineration is accounted in the downstream too.

In Table 3, it is reported a short description of the life cycle phases considered in this study according to their occurrence in the system: upstream, core and downstream activities. Starting from this scheme, the whole system was modelled in the GaBi software, reproducing the different passages that characterize it (see section 4.12).

Table 3 Description of process phases for upstream processes, the awning production, distribution, use and EoL.

OCCURRENCE	PROCESS UNIT	DESCRIPTION	INPUT	OUTPUT
Upstream	**Polymer production from virgin raw material (acrylic)**	Synthesis and transport of the material to spinning plant	Chemicals Energy Water	Acrylic polymer Air and water emission Waste
	Production of recycled material (acrylic)	Waste collection Chemical removal Tearing Carding	Chemicals Energy Water	Acrylic polymer Air and water emission Waste
	Manufacturing of chemical reagents	Synthesis of the chemical reagents used	Chemicals Energy Water	Chemicals Air and water emission Waste
	Production of the awning structure	Material production Metal extrusion Transport of the material to the assembly location	Mineral/metals Energy Water	Metal structure Air and water emission Waste
Core	**Spinning**	Extrusion of the virgin polymer Carding + Open-end spinning of recycled fibres	PAN fibres Teared recycled textile material Chemicals Energy Water	Mixed acrylic yarn (70/30) Air and water emission Waste
	Production of chemicals	Synthesis of chemical agents	Reagents Water Energy	Chemical agents for fabric manufacturing
	Manufacturing of the awning fabric	Warping, weaving, and finishing	Rec/Virg Acrylic yarn Chemicals Energy Water	Acrylic fabric Air and water Emission Waste
Downstream	**Awning assembly**	Awning assembling	Metal structure Fabric	Awning (ready for distribution)
	Awning distribution	Transport from factory to retailer/distribution centre Transport from retailer/distribution centre to the final customer	Transport means Fuels	Awning (at the final customer's place)
	Awning use	Washing (once a year).	Detergent Water	Awning (at the end of its service life)

OCCURRENCE	PROCESS UNIT	DESCRIPTION	INPUT	OUTPUT
	Awning EoL	Fabric and structure are disassembled and transported to the final disposal.	Landfill Incineration plant Recycling (metal only)	Energy from fabric incineration Secondary material (metal)

3.2.3 Environmental impact indicators

The Environmental Impact Indicator (or Category) is the class of resource use or environmental impact to which the resource use and emission profile data are related. The impact category is the quantifiable representation of type of environmental impact. A so-called "life cycle impact assessment method" can gather one or more environmental indicators, thus providing a wide range of evaluated types of impacts.

In the present study, the impact indicators adopted are the ones recommended by European Commission when conducting a Product Environmental Footprint (EC, 2013). The version selected is the most updated one (Fazio et al., 2018). The indicators were used as in the version implemented into the GaBi software, where the method is named EF 3.0 (Environmental Footprint 3.0). The general description of each indicator is briefly reported in Table 1.

Table 4 Environmental Impact Categories as in the EF v.3 LCIA method.

IMPACT CATEGORY	INDICATOR	UNIT	DESCRIPTION
Climate Change	Radiative forcing as Global Warming Potential (GWP100)	kg CO_2 eq	Capacity of a greenhouse gas to influence changes in the global average surface-air temperature and subsequent change in various climate parameters and their effects, such as storm frequency and intensity, rainfall intensity and frequency of flooding, etc. The values adopted for the Global Warming Potentials with time horizon 100 years (GWP-100) includes the carbon feedbacks for different substances.
Ozone Depletion	Ozone Depletion Potential (ODP)	kg CFC-11 eq	Degradation of stratospheric ozone due to emissions of ozone-depleting substances, for example long-lived chlorine and bromine containing gases (e.g. CFCs, HCFCs, Halons).
Human Toxicity, Cancer Effects*	Comparative Toxic Unit for humans (CTUh)	CTUh	Adverse health effects on human beings caused by the intake of toxic substances through inhalation of air or food/water ingestion, insofar as they are related to cancer.
Human Toxicity, Non-Cancer Effects*	Comparative Toxic Unit for humans (CTUh)	CTUh	Adverse health effects on human beings caused by the intake of toxic substances through inhalation of air or food/water ingestion, insofar as they are related to non-cancer effects that are not caused by particulate matter/respiratory inorganics or ionising radiation.

Impact category	Indicator	Unit	Description
Respiratory Inorganics/ Particulate matter	Human health effects associated with exposure to particulate matter	Disease incidences	The indicator assesses damage to human health from outdoor and indoor emissions of primary and secondary $PM_{2.5}$, in urban and rural areas. The impact category is characterising is the change in mortality due to PM emissions.
Ionizing Radiation	Human exposure efficiency relative to U-235	kg ^{235}U eq	Adverse health effects on human health caused by radioactive releases.
Photochemical Ozone Formation	Tropospheric ozone concentration increase	kg NMVOC eq	Formation of ozone at the ground level of the troposphere caused by photochemical oxidation of Volatile Organic Compounds (VOCs) and carbon monoxide (CO) in the presence of nitrogen oxides (NOx) and sunlight. High concentrations of ground-level tropospheric ozone damage vegetation, human respiratory tracts, and manmade materials through reaction with organic materials.
Acidification	Accumulated Exceedance (AE)	moli H^+ eq	The indicator addresses impact due to acidifying substances in the environment. Emissions of NO_x, NH_3 and SO_x lead to releases of hydrogen ions (H^+) when the gases are mineralised. The protons contribute to the acidification of soils and water when they are released in areas where the buffering capacity is low, resulting in forest decline and lake acidification.
Terrestrial Eutrophication	Accumulated Exceedance (AE)	moli N eq	Nutrients (mainly nitrogen) from sewage outfalls and fertilised farmland accelerate the growth of algae and other vegetation in water. The degradation of organic material consumes oxygen resulting in oxygen deficiency.
Freshwater Eutrophication	Fraction of nutrients reaching freshwater end compartment (P)	kg P eq	Nutrients (mainly phosphorus) from sewage outfalls and fertilised farmland accelerate the growth of algae and other vegetation in the freshwater. The degradation of organic material consumes oxygen resulting in oxygen deficiency and, in some cases, fish death.
Marine Eutrophication	Fraction of nutrients reaching marine end	kg N eq	Nutrients (mainly nitrogen) from sewage outfalls and fertilised farmland accelerate the growth of algae and other vegetation in seawater. The degradation of organic material

IMPACT CATEGORY	INDICATOR	UNIT	DESCRIPTION
	compartment (N)		consumes oxygen resulting in oxygen deficiency and, in some cases, fish death.
Freshwater Ecotoxicity	Comparative Toxic Unit for ecosystems (CTUe)	CTUe	Toxic impacts on freshwater ecosystems, which damage individual species and change the structure and function of the ecosystem.
Land Use	Soil quality index	Dimensionless, aggregated index (pt)	Use (occupation) and conversion (transformation) of land area by activities such as agriculture, roads, housing, mining, etc. The category considers different indicators for several soil properties (erosion, mechanical and physicochemical filtration, groundwater replenishment). These indicators have been pooled and re-scaled, to obtain a dimensionless soil quality index, accounting for the different properties evaluated by the original model.
Water Use	User deprivation potential	m^3 world eq. deprived	Deprivation-weighted water consumption. The indicator assesses the impact in terms of quantity of water deprived. Characterisation factors are recommended for blue water (i.e. the freshwater: surface and groundwater) consumption only, where consumption is defined as the difference between withdrawal and release of water.
Resource Use, mineral and metals	Abiotic resource depletion (ADP ultimate reserves)	kg Sb eq	Use of natural resources, either renewable or non-renewable, biotic, or abiotic.
Resource Use, energy carriers	Abiotic resource depletion, fossil fuels (ADP-fossil)	MJ	Use of fossil fuels. Uranium is included in the list of energy carriers.

*excluding “long-term emissions” (those occurring beyond 100 years

Additionally, the CML-IA LCIA method (Guinée et al., 2002) has been used to assess the environmental performance as well. The most recent version of the method was taken, i.e. CML-IA 2016, as in the version implemented into the GaBi software, where the method is named CML2001-Jan 2016. The indicators are presented in Table 5. Even if some impact categories have a name similar to those of the EF method, the underpinning model are different and cannot be compared.

Table 5 Environmental Impact Categories as in the CML 2016 LCIA method.

IMPACT CATEGORY	UNIT
Global Warming Potential (GWP 100 years)	kg CO_2 eq
Ozone Layer Depletion Potential (ODP steady state)	kg R11 eq.
Human Toxicity (HTP inf)	kg 1,4-dichlorobenzene eq.
Photochemical Ozone Creation Potential (POCP)	kg Ethene eq.
Acidification Potential	kg SO_2 eq.
Eutrophication Potential	kg PO_4^{3-} eq.
Marine Aquatic Ecotoxicity Pot. (MAETP inf.)	kg 1,4-dichlorobenzene eq.
Freshwater Aquatic Ecotoxicity (FAETP inf)	kg 1,4-dichlorobenzene eq.
Terrestrial Ecotoxicity (TETP inf)	kg 1,4-dichlorobenzene eq.
Abiotic Depletion (ADP elements)	kg Sb eq
Abiotic Depletion (ADP fossil)	MJ

3.2.4 Assumptions and limitations

In section 4.11, the overall data quality is analysed, whereas all the assumptions related to the study are indicated in the list below:

- **Metal structure:** as no primary data were available for this part of the awning, and no further indications were given within the Project's proposal, an assumption concerning the type and weight of the structure was made. The choice related to the aluminium material was deemed appropriated as most of retailers for outdoor awnings claim an aluminium structure for the "arm". On the same basis, also the weight related to this structure was defined. For most of products sold via internet and having the fabric size as in the F.U. of the study, the average weight is 19 kg. This includes the fabric, the structure and product packaging. Given that no information was reported concerning the packaging, this part was not considered, as deemed less significant (in terms of weight) compared to the metal structure and the fabric. Knowing the weight of the fabric from Parà primary data (see section 3.2.1), this amount was subtracted from the total weight (i.e. 19 kg) to get the kilograms related to the aluminium structure only.
- **Water emissions:** due to the absence of a possible match with existing flows in the database, some water emissions were excluded from the model. Details are reported in section 4.
- **Awning service life:** for this parameter, the warranty related to the fabric was taken a reference. Parà's warranty for the acrylic fabric is valid for 8 years and this number was assumed as awning service life. From a web search, it emerged that the lifespan of an outdoor awning could be from 5 to 15 years, depending on many factors, so the 8 years assumption was deemed a good average.
- **Awning washing**: Parà recommends to handwash the fabric, when needed. For instance, it may happen that the light fabric gets dirty in case of rain dust or if positioned in particularly polluted urban areas. In general, cleaning does not occur very frequently, also because in addition to the expense, it is not always easy to do. To take into consideration this activity during the service life, a cleaning step once a year was assumed.

- **Chemical agents**: when dealing with chemicals, data gaps occurred for some of the reagents in the database used as source for secondary data. In these cases, proxy substances were retrieved from the ones available, based on an expert judgement that considered the function of the reagents and their molecular structure.
- **Intermediate Bulk Container (IBC)**: for this type of packaging related to chemicals, a 1000 L plastic tank (HDPE, extruded) weighting 14.5 kg was assumed.
- **Iron tank:** for this type of packaging related to chemicals, a 200 kg steel tank weighting 15.6 kg was assumed.
- **Calorific values and efficiency rates**: when dealing with the incineration process within the end-of-life scenario of the outdoor awning, the low heating value and the efficiency rate are requested. With no primary data available and given the difficulties in finding this information, the values adopted were the ones indicated in the datasets used to model the process. For the aluminium incineration, the efficiency rate was not clearly reported but the documentation related to the dataset states that it is a country-specific parameter taken into account.

Additionally, an issue related to an environmental indicator is reported here, as it could result in a limitation. The CML indicator "**Photochemical Ozone Creation Potential" (POCP)**, gives negative results (i.e. credits) for truck transports. As stated in the GaBi website[3]: *the negative POCP in the trucks is caused by the division of the NO_x emissions into the two single emissions NO_2 and NO during the upgrade from GaBi 4 to GaBi 5/6. The NO has a negative effect on the POCP since it reduces the close to ground ozone formation. There is a discussion in the scientific LCA community about this taking place since the message "We drive a truck and clean the air'" is questionable*.

[3] http://www.gabi-software.com/international/support/gabi-faq/

4 LIFE CYCLE INVENTORY

The LCA is a compilation of the inputs and the outputs of a considered product system, and the evaluation of the potential environmental impacts throughout its life cycle, including all stages from raw material extraction through processing, production, distribution, storage, use stage and end-of-life treatment of the product (from cradle to grave).

In this chapter, the data collection from the partners of the REACT Project will be described, together with secondary sources and the data gap filling procedures. Data are elaborated to obtain an inventory related to the awning life cycle. The same methodology will be applied on recycling process.

The Life Cycle Inventory (LCI) analysis includes the collection of the data and the calculation procedures to quantify the inputs and outputs related to a product system. Generally, the inventory analysis process is iterative. As data are collected and the practitioner becomes more familiar with the system, new requirements and limitations can be identified and can involve changes of the procedures of data collection, so that the objectives of the study are still satisfied.

As mentioned above, in this phase of the project, the LCA analysis focuses only on virgin acrylic fabric. This is the starting point for the comparative analysis between the "cradle to grave" process of virgin fabric, with the methodology of circular economy developed and which is the main project objective.

The collection of data for virgin acrylic fabric concentrated on the activity of 3 partners involved (i.e., Parà, Soft Chemicals and Ják spinning), which include the manufacturing of the finishing product, the production of the acrylic yarn and production of the final acrylic fabric. The remaining input and output data necessary to complete the LCI were retrieved from LCA databases, such as for example the production of the chemical reagents necessary for the finishing agents or the production of the acrylic polymer.

To facilitate the partners with the data collection, a questionnaire was prepared (Figure 3, Figure 4) with the necessary information in order to make the collection and the subsequent study of the data obtained quick and efficient. The questionnaire was divided into two categories: input and output; each of these was further subdivided to differentiate inputs as energy or chemicals and outputs as emissions to soil or water or air.

Data collection - BASELINE					
Company name					
Process type (the process taken into consideration in the case study)					
Location (of the production plant/plants referring to the process above)					
Country					
Year	2018	Or the most recent year available.			
Total production of...	amount	unit			
Product 1			Please, insert the type of product and the total amount produced in 2018 (or the selected year) to which all data reported are		
Product 2			Please, insert the type of product and the total amount produced in 2018 (or the selected year) to which all data reported are		
Product 3			Please, insert the type of product and the total amount produced in 2018 (or the selected year) to which all data reported are		
INPUT					
energy inputs	amount	unit (for units other than the ones indicated, please highlight the change or the conversion)			note
natural gas		m^3			
electricity (from the grid)		kWh			It should be important to have the details about the energy mix from the grid.
electricity from "on site" sources (e.g. photovoltaic panels, waste combustion, other)		kWh			
heat from "on site" sources (e.g. waste combustion, other)		MJ			
material inputs	amount	unit (for units other than the ones indicated, please highlight the change or the conversion)	input origin (supplier location)	transport mean (type, euro, weight)	note
water		kg			Please, indicate the source (from nature, from well, from water grid, etc)
other material input (please, specify)		kg			
other material input (please, specify)					
other material input (please, specify)					
chemical inputs	amount	unit (for units other than the ones indicated, please highlight the change or the conversion)	input origin (supplier location)	transport mean (type, euro, weight)	note
chemical 1 (please specify name and composition as much as possible)		kg			
chemical 2 (please specify name and composition as much as possible)		kg			
chemical 3 (please specify name and composition as much as possible)		kg			
		kg			
packaging	amount	unit (for units other than the ones indicated, please highlight the change or the conversion)	input origin (supplier location)	transport mean (type, euro, weight)	note
packaging (material input 1)		kg			
packaging (material input 2)		kg			
packaging (chemical input 1)		kg			
packaging (chemical input 2)		kg			

Figure 3 Data collection sheet - Inputs.

OUTPUT					
Product(s)	amount	unit (for units other than the ones indicated, please highlight the change or the conversion)			note
Product (total amount produced)	-	0			Cells in columns B and C are directly linked to cells B10, B11, B12 and C10, C11,C12
Product (total amount produced)	-	0			in case of multiple products from the plants
...	-	0			in case of multiple products from the plants
chemicals waste	amount	unit (for units other than the ones indicated, please highlight the change or the conversion)	output destination (location)	transport mean (type, euro, weight)	note
					If internally recycled, please specify how and by mean of what type of process
other material waste	amount	unit (for units other than the ones indicated, please highlight the change or the conversion)	output destination (location)	transport mean (type, euro, weight)	note
		kg			If internally recycled, please specify how and by mean of what type of process
		kg			
		kg			
emissions to air	amount	unit (for units other than the ones indicated, please highlight the change or the conversion)			note
		kg			known emissions to air coming from the process
		kg			
emissions to water	amount	unit (for units other than the ones indicated, please highlight the change or the conversion)			note
		kg			known emissions to water coming from the process
		kg			
		kg			
emissions to soil	amount	unit (for units other than the ones indicated, please highlight the change or the conversion)			note
		kg			known emissions to soil coming from the process
		kg			

Figure 4 Data collection sheet - Outputs.

In the present study, the inventory data refer to the annual production of Ják Spinning, Soft Chemicals and Parà, and were collected in relation to:

- Inputs:
  - Water consumption
  - Energy consumption
  - Raw material consumption

    - Chemicals
- Outputs:
    - Products and co-products
    - Wastewater
    - Emission to air and to water
    - Waste
- Transport.

Following the instructions reported in the PEF method as recommended for the transition phase (Zampori & Pant, 2019), the capital goods such as infrastructures and equipment were excluded from the study since no data were available about the material composition of the machineries and no previous evidence that they could be relevant was retrieved.

4.1 General modelling choices

The reasoning and calculations underpinning modelling aspects common to all the system's parts are illustrated below.

Starting from the water used by the companies for their activities, the dataset "*EU-28: Process water*" from GaBi Professional sp40 was considered, if no primary information were available. This dataset models the treatment from groundwater (ion-exchange) and was used to represent a generic treatment applied to withdrawn water before using it.

Considering grid energy consumption, each company was asked to report the energy supplier, demonstrated by a Guarantee of Origin if present, and the presence of any energy systems *in situ*, to model an energy mix as realistic as possible. In accordance with the PEF requirements (Zampori & Pant, 2019), as regards the energy mix, when no 100% tracking system is in place, residual mix should be considered. Soft Chemicals stated that 100% energy consumed derives from the photovoltaics panels *in situ*, so this source was used for the company. The second option was followed for Parà and CETI. Therefore, the report created by the Association of Issuing Bodies was consulted (AIB, 2022). The data registered for Italy and Belgium in table 2 of the document have been integrated into the model and reported in Table 6 (reference year 2021).

Table 6 Energy Residual Mix for Italy.

ENERGY SOURCE	ITALY (%)	FRANCE (%)
Renewables	10.81%	8.03%
Coal	12.75%	0.87%
Natural gas	63.60%	7.53%
Oil	4.43%	0.44%
Lignite	0.19%	0%
Nuclear	6.42%	82.7%
Fossil unspecified	1.8%	0.43%

Regarding the items "Renewables" and "Fossil unspecified", the documentation available in the report was consulted. The detail is shown in Table 7. Having no precise information, it has been assumed that the items "Renewables" and "Fossil unspecified" correspond to biogas and "coal gases", respectively. In order to identify a suitable fossil source, a sensitivity analysis was carried out on the impacts (in CO_2 eq) calculated for 2018, to identify the hypothesis allowing to be consistent as much as possible in the impacts of the energy mix with those reported in the document drawn up by the Association of Issuing Bodies (see section 6.2.1).

Table 7 Details about the fractions coming from renewables and fossil unspecified.

	ITALY (%)	FRANCE (%)
RENEWABLES		
Hydro	2.48%	2.04%
Photovoltaics	5.24 %	1.85%
Wind	0.76%	3.12%
Biomass	2.33%	1%
Geothermal	0.00%	0.02%
Other renewables (biogas)	0.00%	0%
FOSSILS UNSPECIFIED		
Coal gases	4.98%	0.43%

To model the combustion of natural gas in the processes, the thermal energy generation process of the GaBi Professional database sp.40 (Thermal energy from natural gas process) was inserted, converting the quantity of natural gas reported in the inventory into energy (MJ). To do this, an average calorific value was adopted, according to the data found on the World Nuclear Association website[4].

Another characteristic of the study common to all phases concerns chemicals. To determine the production process of chemical products, it was decided to take the composition from the safety data sheets (SDS) and to recreate it in the model. Section 3 of the SDS generally provides information on the composition of the chemical. The information usually reported includes the name and / or commercial name and other identifying elements (such as CAS number, registration number etc.) of substances, ingredients, or impurities which:

- contribute to the overall hazard classification; or
- are present in concentrations above certain risk levels; or
- are subject to occupational exposure limits.

In addition, for mixtures, the concentration or concentration range of the constituent is indicated. Chemical suppliers can choose whether to list the complete composition of the substance or mixture by reporting all the constituents or components, even those that are not dangerous. The choice of use of the data from the SDS constitutes a first approximation. Other criteria chosen for the modelling of chemical products are:

- Where there are concentration ranges, it was decided to take the higher value, thus placing itself in the most significant case.
- Where there was a percentage of water, it was added with the EU-28 process: Process water (GaBi Professional sp.40) to reach 100%.

[4] https://www.world-nuclear.org/information-library/facts-and-figures/heat-values-of-various-fuels.aspx

- For the chemical compounds reported in the data collection questionnaires for which generic data were not available, assumptions were made motivated by chemical analogy and synthesis methodologies.

Common assumptions for all transports in the system are the following: in the absence of specific data relating to the transport and the means with which it is carried out, an average distance of 100 km (i.e. local supply chain) and an average vehicle was assumed (*GLO process: Truck, euro 4, 20-26 t gross weigh*t, GaBi Professional database sp.40). In the case of multiple suppliers for the same input, the greater distance was used to model the transport, associating it with the entire quantity of the product (that is, adding all those from different suppliers).

The waste produced by the companies was divided into "non-hazardous waste for disposal", "non-hazardous waste for recovery", "hazardous waste for disposal" and "hazardous waste for recovery". The textile scraps and packaging waste (paper and plastic) sent for recovery were accounted separately.

4.2 Raw materials production (upstream)

The upstream processes that were modelled are the following:

- Acrylic polymer production
- Reagents production
- Awning metal structure production

To model the production of the acrylic polymer, a dataset from GaBi Professional sp40 database was selected. This choice was made according to the fact that this production technology is a well-established one and that no significant changes are reported from the geographical and temporal point of view. The dataset selected is defined as "*Polyacrylonitrile Fibres (PAN)*" and its inventory was compiled by Thinkstep, including polymerization, dissolving, and spinning. The dataset is representative for the EU-28 situation, focusing on the main technologies. The general comment describing the dataset is the following: *"The dataset covers all relevant process steps/technologies over the supply chain of the represented cradle-to-gate inventory with good overall data quality. The inventory is mainly based on industry data and is completed, where necessary, by secondary data. The dataset is based on primary data from internationally prevalent production process, connected with regional precursor chains".*

To use as much primary data as possible, we used the distance between Parà S.p.A. and suppliers to model the transport of the acrylic to Ják Spinning.

Concerning the chemical reagents, as already mentioned, the section 3 of the safety data sheets (SDS) was the reference for the composition. As primary data were not available, GaBi Professional 2022.1 and ecoinvent 3.7 database were adopted as data sources for chemical reagents.

To model the metal structure manufacture, aluminium was chosen as material. The choice was made after web research for awning retailers, to see which material is preferred for this type of structure. Most of sold awning for outdoor have an aluminium structure. A second output of the research is the weight of the structure. To the final weight of the whole awning product (structure plus fabric), the weight of the fabric was subtracted to get the mass related to the aluminium structure only. As input values, a common weight for the whole packed product as ready for the shipping is 19 kg. By subtracting 2.17 kg related to the fabric (see section 3.2.1), a weight equal to 16.83 kg was calculated for the aluminium structure. The weight related to the packaging (cardboard, plastic, etc.) was not considered as no data were available.

To model the aluminium structure, a dataset from GaBi Professional sp.40 was selected, i.e. *EU-28: Aluminium ingot mix*. As no specific information were available, the worst-case scenario was adopted, and the aluminium is assumed to be primary material. The dataset represents an ingot manufactured as a mixture of imported and locally produced ingot. The import statistics and electricity mixes are based on the 2010 reference year.

Finally, for the awning assembly, the transport of the parts (i.e., the textile and the aluminium structure) to the factory was modelled following the indications in the PEF Guidance (Zampori & Pant, 2019) for the EU scenario:

- 130 km by truck (>32 t, EURO 4)
- 240 km by train (average freight train)
- 270 km by ship (barge).

4.3 Treatment of acrylic fabric pre-consumer waste

The first step in the acrylic pre-consumer waste recycling process, is a chemical treatment. This treatment is aimed at removing dangerous substances whose presence could compromise the quality of secondary raw material and prevent its recycling. A removal rate of 90-95% is considered as optimal.

This treatment is done in collaboration with Soft Chemicals by means of their products, and it is structured as follows:

1. First step
    a. 50-60 minutes at 95-98°C
    b. Water ratio: 1:5
    c. Recipe "B" is used:
        i. SOFTWET IP97 8 g/l
        ii. SEQUESTER EMG/SB 30 g/l
        iii. DETERGENT B10P 4 g/l
2. Second step:
    a. 50-60 minutes at 95-98°C
    b. Water ratio: 1:5
    c. Recipe "B" is used:
        i. SOFTWET IP97 8 g/l
        ii. SOFTCLEANER T NEW 30 g/l
        iii. NaOH 36 Bè 15 g/l

To model the solution heating to 98°C (considering an initial temperature of 20°C), an energy input of 0.328 MJ for 1 L was assumed[5]. The underpinning calculation is based on the following figures:

a) heat capacity (C) of water: 4182 J/kg ˚C
b) mass of water (m): 1 kg (i.e., 1L)
c) Difference in temperature (ΔT) = 100°C — 20°C = 78°C
d) Final formula: E (J) = m*C*ΔT = 1*4182*78 = 326196.0 J = 0.326 MJ

Additionally, the project investigated the best wastewater treatment suitable to eliminate up to 99% of the dangerous substances removed from textiles before discharging the wastewater (see P.I.ECO, 2022 for further information).

Based on the chemical components present in the products used for the treatment of waste, the parameters most influenced within wastewater characteristics are the following:

- pH
- Biological Oxygen Demand (BOD)
- Chemical Oxygen Demand (COD)
- Surfactants
- Solvents

Values related to the listed parameters are reported in Table 8 (source: P.I.ECO, 2022).

[5] https://www.bbc.co.uk/bitesize/guides/z2gjtv4/revision/5

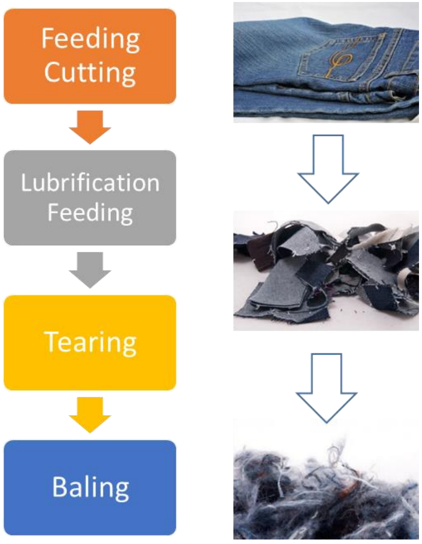
Table 8 Waste textile treatment: wastewater parameters

PARAMETER	VALUE	UNIT
pH	12.33	-
Colour	Only perceptible with a 1:40 dilution ratio	
Suspended solids	76	mg/L
BOD	7993	mg/L
COD	56360	mg/L
Zinc	0.7113	mg/L
Sulphate (as SO4)	251.6	mg/L
Ammonia nitrogen (as NH4)	106	mg/L
Nitrous nitrogen (as N)	1.7	mg/L
Chlorinated organic solvents	0.285	mg/L
Tetrachloroethylene	0.0951	mg/L
Surfactants (total)	3659.76	mg/L
Anionic	0.34	mg/L
Non-ionic	3659.42	mg/L

After testing the best option, the selected wastewater is the biological one. The biological treatment of wastewater consists in the biodegradation by microorganisms. The biodegradation process applies to all the organic substances in the water to be treated and return them as simpler and harmless substances, from an environmental point of view.

4.4 Recycled acrylic yarn manufacturing (CETI)

After the removal of finishing hazardous products and contaminants, the effective recycling of the fabric is reached through mechanical reduction from fabric to fibre through multiple steps: cut the fabric in small pieces thanks to a cutting machine in order to get pieces of about 10 cm²; load these pieces in the tearing machine constituted with four cylinders equipped with metallic teeth or metallic clothing (the population of teeth is higher and higher when the product goes ahead in the tearing machine to avoid rests of yarn in your fibres that will give problems at carding and spinning machines). This tearing process is done with addition of a sizing agent (mix of lubricant and water) that will lubricate the fibres and the metallic clothing of the drums of the tearing machine to reduce the coefficient of friction between fibres and metallic teeth and avoid the creation of static electricity on the fibres which makes them stick to metallic parts. This expedient will reduce fibre breakage, to obtain longer fibres at the output of the tearing machine to make more performing yarn and specifically a fine yarn. At the end of the tearing process, you make bales (about 100 kg) of regenerated fibres, that will be mixed with other bales during the spinning process.



Once textiles are reduced to fibres, they will be transformed into new yarn with ring spinning process and doubling, also mixing them with by-products not suitable for normal spinning process. Furthermore, the waste of the thread will be recycled mixing it with regenerated fibres from card, winding opened thread and recycled-fabric fibre, each up to 33% to reach a 100% recycled material. If needed, the mixing percentage could be changed, and virgin fibre might be added for better product performance. The fibres with different waste origin will be mixed and blended for carding process, ring spinning and doubling, with various tests and settings to do in order to find the best working condition and top technical and quality aspect. The whole process of mechanical recycling derives from other sector (e.g. cotton or polyester fabric) but is innovative for the application to outdoor acrylic fabrics and has to be studied, adjusted and implemented to obtain a high-quality recycled fibre.

The recycled material undergoes three processes: tearing, carding, spinning (open-end). The carding process is identified as the point of substitution, thus corresponding to the point in the value chain where secondary raw materials substitute primary materials.

4.5 Production of the chemical products (Soft chemicals)

Soft Chemicals supplies four types of chemical agents used for finishing the fabrics for awnings:

- Imbiber
- Catalyst
- Water repellent fluorine free
- Bio-polyurethane

Additionally, the partner supplies the chemicals used to treat the acrylic waste to remove the fabric finishing:

- Imbiber
- Chelating agent
- Emulsifying and dispersing agent
- Detergent

The company processes the chemical reagents to obtain the finished products, and this activity is quite similar for all the chemicals used within this study. Moreover, all the processes are conducted without additional heating, so this type of input is not included in the inventory.

Considering this aspect and the fact that the chemical agents needed for the awning's fabric constitute the 9% of the whole production of Soft Chemicals, data on water and energy consumption have been estimated as the 9% of the total consumption.

The total energy consumed comes from the photovoltaic panels located on the company buildings. To model it, the process "*IT: Electricity from photovoltaic*" from GaBi Professional sp.40 was used.

The water is used in two ways: to dilute the chemical products and to clean the cisterns and the tanks. For each chemical, the amount of water needed to cover both the aspects is calculated and added directly to the production process.

The packaging for all the chemicals was added to the inventory and to the model as well. Three products (i.e. the catalyst, the fluorocarbon resin, the melamine resin) are packed into intermediate bulk containers (IBC). The imbiber is packed into metal tanks. To model the IBC, the high-density polyethylene and the injection moulding process were selected. Whereas, for the metal tank material, the steel was used. Details about the datasets used are reported in Table 9. Plastic material scraps in IBC HDPE production were modelled as sent to incineration.

Table 9 Datasets used for modelling the packaging (Soft Chemicals).

TYPE OF PACKAGING	DATASET	SOURCE
Intermediate bulk containers (IBC)	Polyethylene (HDPE/PE-HP) blow moulding	GaBi Professional sp40
Metal tank	EU: Steel plate (blast furnace route)	Worldsteel (World Steel Association)

The company has provided test reports for water emissions. To include this aspect, the values provided referred to 2019 have been included in the model. The concentration values have been multiplied by the volume of water used declared by the company. With the aim of using the available primary data as much as possible, for emissions whose value is reported as a threshold (for example, COD <5 mg / L), the threshold figure was taken into consideration in the study as a concentration and included in the inventory. Of all the emission flows reported in the test reports provided by the company, a few were excluded due to unavailable match with existing flows in the database.

The flows excluded represents the 33% of total inputs/outputs for Soft Chemicals (leading to an overall coverage of 67%). However, their concentration was always reported as the minimum threshold and, in terms of mass released in the water compartment, the coverage remains quite high (i.e., 81%). Hence, these emissions were considered negligible in terms of both inventory and impacts.

4.5.1 Modelling of chemicals

This section describes the chemicals involved in the analyzed processes and the choices related to their modeling in the inventory.

For the determination of the production process of chemicals it was decided to take the composition from the Safety Data Sheet (SDS), as the only source of information available. Section 3 of the safety datasheets generally provides information on the composition of the chemical. The information usually reported includes the name and / or trade name and other identifying elements (such as CAS number, registration number, etc.) of substances, ingredients or impurities which:

- contribute to the overall hazard classification; or
- they are present in concentrations above certain risk levels; or
- are subject to occupational exposure limits.

In addition, for mixtures, the concentration or concentration range of the constituent is indicated. Chemical suppliers can choose whether to list the complete composition of the substance or mixture by reporting all constituents or components, even non-hazardous ones.

The choice of using the SDS is a first approximation. Other criteria chosen for the modeling of chemicals are:

- Where there are concentration ranges, it was decided to take the highest value, thus placing it in the most significant case.

- Where there was a percentage of water, it was added with the *EU-28: Process water* (source *Sphera*) to reach 100%.
- For the chemical compounds listed below, since there are no selected generic data, assumptions were made motivated by chemical analogy and synthetic methodologies.

An average vehicle was assumed for the transport of the listed products to Parà S.p.A. (*GLO: Truck, Euro 3, up to 7.5t, gross weight*, source Sphera). The distance was calculated taking into consideration the supplier's location. The transport was allocated to the quantity of chemicals transported, calculated based on the recipe provided by Soft Chemicals.

The products and their details are reported separately. In the modelling phase, the percentage compositions are taken from the Safety Data Sheet of the product.

4.6 Production of the awning fabric (Parà S.p.A.)

The company processes the yarn coming from CETI to obtain a final acrylic fabric destined to awning assembly. The waste fraction coming from the first production of fabric (considered in the present study) is near zero; however, an overall efficiency of the process is estimated around 85%, thus leading to 15% of final textile waste. These parameters come from the virgin acrylic fabric standard process and were deemed suitable to model a real production situation.

The manufacturing process in Parà is composed as follows:

1. Warping
2. Weaving
3. Washing with water
4. Finishing (foulard impregnation and rameuse)
5. Quality check with cutting and packaging

The company provided primary data about energy consumption. It presents an energy supply from multiple sources. A first source is the electricity grid, modelled as already indicated in the introduction to this section. A second source of energy are the photovoltaic panels, modelled as in Soft Chemicals, by means of the same dataset. A third energy source is the natural gas, used in a boiler and in a cogeneration plant (energy and heat). To avoid double counting in the model, the data has been broken down, distributing the input of natural gas between the boiler and the cogeneration plant. The original data in m^3 has been converted into MJ and the amount of heat and electricity generated by cogeneration has been subtracted.

Primary data on water consumption as occurring in the whole process was included. The water source for water are two internal wells and no treatment is applied. For these reasons, this input is modelled as a direct input from nature. Within the REACT Innovation scenario, the water used in the finishing process was assumed to be the same as in the baseline scenario. The reason lies in the fact that the finishing step was like a lab-scale test for the company; therefore, the water consumption is not efficient (i.e., the machinery has been fully emptied and recharged more times, which is not in the usual production process).

As chemical agents, no additional products are included in the process with regard to what is already mentioned in Soft Chemicals section (see par. 4.5).

Finally, concerning the packaging used to send the fabric to the awning assembly site, the material considered are listed in Table 10.

Table 10 Datasets used for modelling the packaging (Parà).

TYPE OF PACKAGING	DATASET	SOURCE
Plastic (assumed LDPE)	RER: Polyethylene film (PE-LD)	PlasticsEurope (Sphera)

Board box	RER: corrugated board box production + RER: Containerboard production, linerboard, kraftliner +RER: Containerboard production, linerboard, testliner	ecoinvent 3.8

Concerning the wastes, the value associated with "textile waste" was taken as processing waste on the total incoming fibre. For textile waste in general, incineration was chosen as end of life. The waste identified as mud (CER 070312) was excluded from the analysis as no proper dataset was available to model it.

Among packaging waste, paper and plastic streams were modelled as explained in the introduction of this section. Whereas the metal scraps were considered as incinerated. As a general choice, to keep the mass balance, the values linked to plastic and metal types of packaging were associated to the amount of packaging used by Soft Chemicals for its products. The end-of-life related to the packaging used by Parà was modelled separately.

The waste identified as mixed waste (CER 150106) was considered as Non-Hazardous Waste to Disposal and modelled as sent to landfill.

All the transport distances related to waste was included as primary data from Parà.

For reasons of mass balance, the volume of water sent to water treatment has been assumed equal to the volume of water entering the process.

The company has provided test reports from water and air emissions. The latter have been associated to the production of energy from the combustion of natural gas; in order not to double count them, the values relating to these emissions have been neglected because they are already included in the process used to model the energy input from natural gas.

To include water emissions, the values provided referred to 2019 have been included in the model. The concentration values have been multiplied by the volume of water used declared by the company. With the aim of using the available primary data as much as possible, for emissions whose value is reported as a threshold (for example, COD <5 mg / L), the threshold figure was taken into consideration in the study as a concentration and included in the inventory. Of all the emission flows reported in the test reports provided by the company, a few were excluded:

- Animal and vegetable oils/fats: no match with available flows in the database).
- Sedimentable solids (tot): no match with available flows in the database).
- Anionic/cationic surfactants: they are summed in total unspecific surfactants to match the flows in the database.

The flows excluded represents the 6% of total inputs/outputs for Parà (leading to an overall coverage of 94%).

4.7 Assembly

To properly model, the parts of the awning life cycle that are not under the direct responsibility of the companies, the guidelines of the Product Environmental Footprint (Zampori & Pant, 2019) tare taken as main reference.

The assembly phase takes into consideration the assembly step of the awning. Parà stated that, in the case of awnings market, the fabrics are sold to two main types of customers:

- Manufacturers who offer a cut-service of the fabric or directly the fabric made up to their customers who set up the structure offering to the market the complete sun protection device.
- Manufacturers who set up, assemble, and set the structure arriving directly to the end customer.

From the model point of view, this stage accounts only for the transportation of the two parts (the aluminium structure and the fabric) from the suppliers to the assembly factory. According to the guidelines from Zampori & Rana (2019), an EU scenario was built with the following features:

- 130 km by truck (>32 t, EURO 4).
- 240 km by train (average freight train).
- 270 km by ship (barge).

4.8 Distribution

To properly model, the parts of the awning life cycle that are not under the direct responsibility of the companies, the guidelines of the Product Environmental Footprint (Zampori & Pant, 2019) tare taken as main reference.

To apply the criteria, the following values were determined:

- Ratio between products sold through retail, distribution centre (DC) and directly to the final client:
    - 50% sold through retail.
    - 50% sold through distribution centre (DC).
    - 0% sold directly to the final client.
- For factory to retail: distribution between local, intracontinental, and international supply chains:
    - 100% local supply chain.

The choice of a local supply chain was based on the location of most of retailers listed on Parà website (i.e., Italy). This excluded an intracontinental or international supply-chain.

According to these parameters, the transports are modelled as follows:

1. 50% from factory to retail/DC:
    a. 100% local supply chain: 1,200 km by truck (>32 t, EURO 4).
2. 50% from DC to final client:
    a. 100% Local: 250 km round trip by van (lorry <7.5t, EURO 3, utilisation ratio of 20%).
3. 50% from retail to final client:
    a. 62%: 5 km, by passenger car (average)
    b. 5%: 5 km round trip, by van (lorry <7.5t, EURO 3 with utilisation ratio of 20%).
    c. 33%: no impact modelled.

In absence of a cargo process representing a passenger car, a light duty vehicle (<3.5 t, EURO 4) was used.

No material losses were considered during distribution.

4.9 Use

As reported in the PEF Guidance (Zampori & Pant, 2019), the use stage describes how the product is expected to be used by the end user (e.g., the consumer). The use stage starts when the end user uses the product till it leaves its place of use and enters the end of life (EoL) life cycle stage.

The use phase includes all the products needed to the proper use of the product, to ensure its function during the whole lifetime. For this reason, the manufacturer's (i.e., Parà) instructions directed towards the consumer in the use stage were considered as a basis for modelling this phase.

For the fabric maintenance, Parà recommends to handwash it with soap. Since we had no information about the amount of required soap, another data source was consulted. For the awning use phase, we assumed a washing/cleaning step once a year. Data were taken from Castellani et al. (2019), taking into consideration the use of the "all-purpose cleaner". Within the report by Castellani et al., 4.7 g of cleaner + 0.55 L of water are used to clean a surface equal to 0.24 m^2. By keeping the same proportions, in the case of the awning, the surface is about 7.48 m^2. This requires 146.5 g of detergent and 17.14 L of water. In the present study, the water is not warmed.

4.10 Recycling and End-of-Life

In the baseline model, the end-of-life scenario associated to the awning fabric is composed by incineration and landfill. On the other hand, the aluminium material of the awning structure is assumed to be partly recycled, partly incinerated, and partly landfilled.

According to Zampori and Pant (2019), two transport routes have been included:

- Consumer transport from home to sorting place: 1 km by light duty vehicle (<3.5 t, EURO 4), as proxy for passenger car.
- Transport from sorting place to incineration plant or recycle site: 100 km by truck (>32 t, EURO 4).

The end-of-life scenarios for both acrylic fabric and aluminium structure were modelled according to the Circular Footprint Formula (CFF), indicated in Zampori and Pant (2019). The CFF is composed as presented in Figure 5.

Material

$$(1-R_1)E_V + R_1 \times \left(AE_{recycled} + (1-A)E_V \times \frac{Q_{Sin}}{Q_p}\right) + (1-A)R_2 \times \left(E_{recyclingEoL} - E_V^* \times \frac{Q_{Sout}}{Q_P}\right)$$

Energy

$$(1-B)R_3 \times (E_{ER} - LHV \times X_{ER,heat} \times E_{SE,heat} - LHV \times X_{ER,elec} \times E_{SE,elec})$$

Disposal

$$(1-R_2-R_3) \times E_D$$

Figure 5 The Circular Footprint Formula

In Table 11, the parameters are introduced and explained. In Table 11 and Table 12, all the parameters adopted are reported, both as values and as datasets.

Table 11 Parameters of the Circular Footprint Formula

PARAMETER	EXPLANATION
A	Allocation factor of burdens and credits between supplier and user of recycled materials.
B	Allocation factor of energy recovery processes. It applies both to burdens and to credits.
Q_{Sin}	Quality of the ingoing secondary material, i.e. the quality of the recycled material at the point of substitution.
Q_{Sout}	Quality of the outgoing secondary material, i.e. the quality of the recyclable material at the point of substitution.
Q_P	Quality of the primary material, i.e. quality of the virgin material.
R_1	It is the proportion of material in the input to the production that has been recycled from a previous system.
R_2	It is the proportion of the material in the product that will be recycled (or reused) in a subsequent system. R2 shall therefore take into account the inefficiencies in the collection and recycling (or reuse) processes. R2 shall be measured at the output of the recycling plant.
R_3	It is the proportion of the material in the product that is used for energy recovery at EoL.

PARAMETER	EXPLANATION
$E_{recycled}$ (E_{rec})	Specific emissions and resources consumed (per functional unit) arising from the recycling process of the recycled (reused) material, including collection, sorting and transportation process.
$E_{recyclingEoL}$ (E_{recEoL})	Specific emissions and resources consumed (per functional unit) arising from the recycling process at EoL, including collection, sorting and transportation process.
E_v	Specific emissions and resources consumed (per functional unit) arising from the acquisition and pre-processing of virgin material.
E^*_v	Specific emissions and resources consumed (per functional unit) arising from the acquisition and pre-processing of virgin material assumed to be substituted by recyclable materials.
E_{ER}	Specific emissions and resources consumed (per functional unit) arising from the energy recovery process (e.g. incineration with energy recovery, landfill with energy recovery, etc.).
$E_{SE,heat}$ $E_{SE,elec}$	Specific emissions and resources consumed (per functional unit) that would have arisen from the specific substituted energy source, heat and electricity respectively.
E_D	Specific emissions and resources consumed (per functional unit) arising from disposal of waste material at the EoL of the analysed product, without energy recovery.
$X_{ER,heat}$ $X_{ER,elec}$	The efficiency of the energy recovery process for both heat and electricity.
LHV	Lower heating value of the material in the product that is used for energy recovery.

Table 12 CFF parameters as used in the current study.

PARAMETER	VALUE	DATASET	FURTHER DETAILS
RECYCLED/VIRGIN ACRYLIC FABRIC			
R_1	0.7	Recycling process as in the present project.	Recycling process described in par.4.3.
E_V	0.3	Polyacrylonitrile Fibres (PAN)	Secondary data for polymer production: Sphera.
A	0.8		Default value for textiles (Annex C in Zampori and Pant, 2019)
$E_{recycled}$		Material collection Material transport Chemical treatment Tearing	Source: primary data (par.4.3 and par.4.5).
Q_{Sin}/Q_P	0.9		Default value (Annex C in Zampori and Pant, 2019). Note: since there were no specific data available, the figure was taken even if referred to PET mechanical recycling.

PARAMETER	VALUE	DATASET	FURTHER DETAILS
R_2	0.11	-	Default value (Annex C in Zampori and Pant, 2019).
B	0	-	Default value in PEF studies (Zampori and Pant, 2019)
R_3	0.35	-	Default value for Italy (Annex C in Zampori and Pant, 2019)
E_{ER}		EU-28: Textiles in municipal waste incineration plant	Source: Sphera.
$E_{recyclingEoL}$ (E_{recEoL})		Polyethylene terephthalate (PET) granulate secondary; no metal fraction (Sphera)	Source: Sphera. "From post-consumer plastic waste, via grinding, metal separation, washing, pelletization"
Q_{Sout}/Q_P	0.9		Default value (Annex C in Zampori and Pant, 2019). Note: since there were no specific data available, the figure was taken even if referred to PET mechanical recycling.
E^*_v		Polyethylene terephthalate granulate (PET, amorph)	Source: Sphera.
LHV	21 MJ/kg		Source: Sphera
$X_{ER,heat}$ $X_{ER,elec}$	44%		Source: Sphera
$E_{SE,heat}$		EU-28: Process steam from natural gas 95%	Source: Sphera
$E_{SE,elec}$		EU-28: Electricity grid mix	Source: Sphera
E_D	$1-R_2-R_3$	EU-28: Textiles on landfill	Source: Sphera. Note: no energy recovery accounted.
		ALUMINIUM STRUCTURE	
R_1	0		No recycled content in the product
A	0.2		Default value for aluminium material (Annex C in Zampori and Pant, 2019)
E_v		EU-28: Aluminium ingot mix	The same dataset used to model the structure.
R_2	0.85		Default value for aluminium material (Annex C in Zampori and Pant, 2019)
$E_{recyclingEoL}$ (E_{recEoL})		EU28+EFTA+Turkey: Aluminium remelting: wrought alloys ingot from scrap (2015) + 100 km	Source: European Aluminium

Parameter	Value	Dataset	Further details
		transport by truck (EURO 4)	
Q_{Sout}/Q_P	1		Default value (Annex C in Zampori and Pant, 2019). Note: since there were no specific data available, the figure was taken even if referred to packaging aluminium
E^*_v		EU28+EFTA: Primary aluminium production ingot mix Europe (2015)	Source: European Aluminium
B	0		Default value in PEF studies (Zampori and Pant, 2019)
R_3	0.068		Calculated as indicated in Annex C (Zampori and Pant, 2019): Municipal waste treatment fraction (0.15) * EU-28 Incineration fraction (0.45)
E_{ER}		IT: Non-ferro metals, aluminium, less than 50µm in waste incineration plant	Source: GaBi Professional sp40. Note: Proxy. No energy recovery in the dataset related to more than 50µm aluminium. No European dataset available.
LHV	23 MJ/kg		Source: GaBi Professional sp40
$X_{ER,heat}$ $X_{ER,elec}$	NA		Note: included in the Er dataset but not retrievable in the dataset documentation. Despite this, the dataset was used because classified as "very good overall quality" in the PEF quality validation scheme
$E_{SE,heat}$		EU-28: Process steam from natural gas 95%	Source: GaBi Professional sp40
$E_{SE,elec}$		EU-28: Electricity grid mix	Source: GaBi Professional sp40
E_D		EU-28: Inert matter (aluminium) on landfill	Source: GaBi Professional sp40

4.11 Data quality

Within the current study, the data used were divided into primary data and secondary data.

All primary data were acquired directly through interviews and compilation of questionnaires on MS Excel® files by the management of the partner companies and were used for:

- Energy and water consumption related to core processes occurring in the plants considered in the analysis.
- Use of chemicals related to core processes occurring in the plants considered in the analysis.
- Type and characteristics of the packaging related to the output products.
- Suppliers (as companies or geographic sites) of packaging and chemicals.
- Waste from plants, both as type and as destination.

All specific data were collected with reference to the year 2019 and 2021 timeframe.

Concerning the secondary data, they were taken from:

- the GaBi database (GaBi Professional, Sphera, 2022) and its Extension databases:
  - Ia: Intermediates organic.
  - Ib: Intermediates inorganic.
  - IXa: End of life.
  - XV: Textile finishing.
- the Ecoinvent v.3.7.1 database (Ecoinvent, 2021).

With reference to these data from secondary sources:

1. **Geographical representativeness (GeR)**: where possible, data representative of the geographical area of reference (Europe) has been privileged, both from the technological point of view and from the energy mix.
   a. In case of specific European data failure, Country-specific data (i.e. Italy, given the two Italian partners) have been privileged and lastly those, which represent a global average.
2. **Technological representativeness (TeR)**: the technologies used in the datasets are equivalent to those used in the processes where the activity takes place; in particular, data sets with the following wording were privileged: *"The dataset covers all relevant process steps / technologies over the supply chain of the represented cradle-to-gate-inventory with good overall quality. The inventory is mainly based on industry data and is completed, where necessary, by secondary data. The dataset is based on primary data from internationally prevalent production process, connected with regional precursor chains ".*
3. **Time-related representativeness (TiR)**: the datasets used have a temporal validity as recent as possible so that they can represent the situation of the reference year (2019).
4. **Data quality**: all the datasets chosen within the model have a "good" overall quality as stated from the data providers. For specific datasets, scores are reported:
   a. Acrylic production:
      i. GaBi = 1.8 interpreted into "good overall quality" in the GaBi quality validation scheme.
      ii. ILCD = 2.3 interpreted into "basic overall quality in the ILCD quality validation scheme.
      iii. PEF = 1.8 interpreted into "very good overall quality" in the PEF quality validation scheme.
   b. Process water:
      i. GaBi = 1.7 interpreted into "good overall quality" in the GaBi quality validation scheme.
      ii. ILCD = 1.8 interpreted into "basic overall quality in the ILCD quality validation scheme.
      iii. PEF = 1.7 interpreted into "very good overall quality" in the PEF quality validation scheme.
   c. Aluminium ingot mix:
      i. GaBi = 1.8 interpreted into "good overall quality" in the GaBi quality validation scheme.
      ii. ILCD = 1.9 interpreted into "basic overall quality in the ILCD quality validation scheme.
      iii. PEF = 1.8 interpreted into "very good overall quality" in the PEF quality validation scheme.
   d. Transports means (trucks and light duty vehicle)
      i. GaBi = 1.5 interpreted into "good overall quality" in the GaBi quality validation scheme.
      ii. ILCD = 1.7 interpreted into "basic overall quality in the ILCD quality validation scheme.
      iii. PEF = 1.5 interpreted into "excellent overall quality" in the PEF quality validation scheme.

4.11.1 Data completeness

The specific (primary) data provided by the companies cover all the processes occurring in their facilities that contribute to the production of the fabric needed for the awning. The emissions coming from these processes were included in the analysis as well, directly retrieved from test reports, where applicable for the activity of the plant (i.e., for Soft Chemicals and Parà production plants).

Concerning the polyacrylonitrile fibres and the process water, the overall completeness of the dataset used is stated as follows: *"Coverage of at least 95% of mass and energy of the input and output flows, and 98% of their environmental relevance (according to expert judgement)".*

Since no primary data were available specifically for the awning arm manufacturing, modelling this stage through secondary data based on average products could affect the overall completeness of this step. However, the completeness of the dataset "Aluminium ingot mix" is stated as follows: *"1% cut-off criteria applied for non-hazardous inputs and outputs except alloying elements which are not considered. No cut-off criteria for hazardous products and emissions (ex. PAH, PFC, BaP, etc.) – Infrastructure not included. All ancillary processes (electricity, caustic soda, etc.) included. Cut-off rules for each unit process: coverage of at least 95% of mass and energy of the input and output flows, and 98% of their environmental relevance (according to expert judgement)".*

Awning distribution is based on established indications (i.e., Zampori and Pant, 2019), by means of default scenarios. Datasets used to model this phase are the ones indicated by the guidelines with the following coverage reported: *"Coverage of at least 95% of mass and energy of the input and output flows, and 98% of their environmental relevance (according to expert judgement)".*

Data collection for awning use started from the primary information by Parà about the maintenance of fabric. In fulfilling its function, this part of the awning was deemed the more significant for this phase, as it represents the actual sun protection. For this reason, the collected data covers the yearly fabric cleaning as assumed at the beginning of the study.

No primary data were available for the awning EoL, but the data coverage for this life cycle stage is based on established indications (i.e., Zampori and Pant, 2019), by means of default scenarios in order to cover most of possible fates.

4.12 System model

To build a model in GaBi v.10.6.2.9 representing the whole system (background + foreground) within the system boundaries, a few sub-models were created and then linked in a general scheme. The diagram illustrating the whole model is shown in Figure 6.

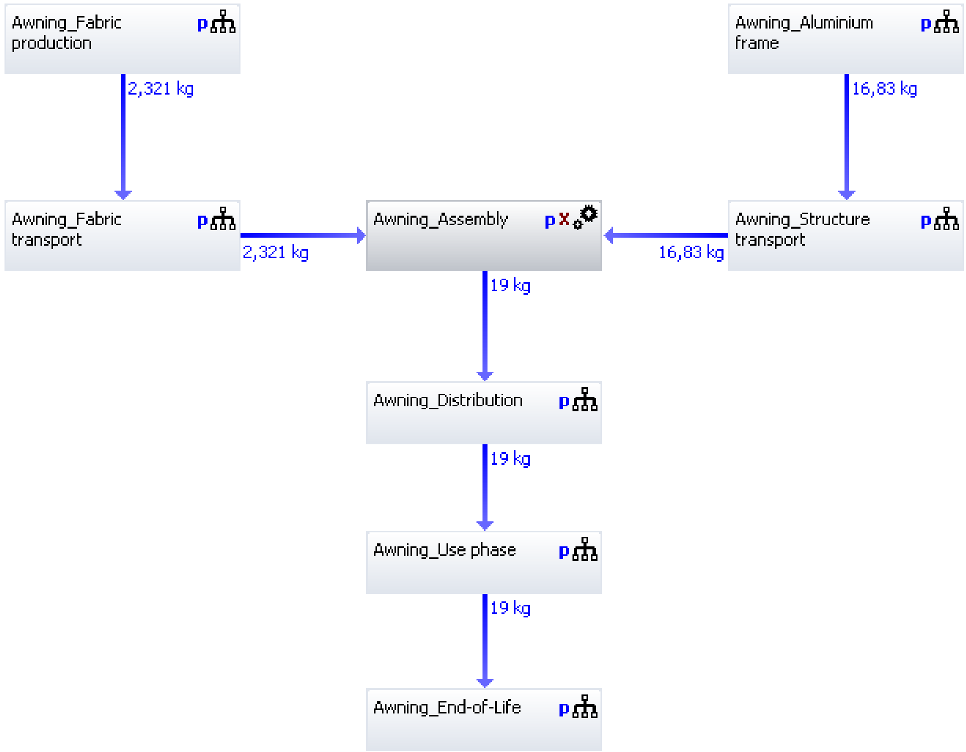


Figure 6 GaBi model of awning life cycle.

4.13 Allocation rules

The following allocation rules as reported in Table 13 were used.

Table 13 Allocation rules

PROCESS	ALLOCATION RULE	DETAILS
Transport	Mass	The allocation of impacts is based on the distance and the mass of the good being transported.
Manufacturing of chemical agents	Mass	When data from the industry (consumption of energy, water, etc...) were collected, an allocation based on physical relationship (mass) was done to obtain the consumption related to the acrylic fabric.
Fabric manufacturing	Mass	

5 LIFE CYCLE IMPACT ASSESSMENT

The goal of the Life Cycle Impact Assessment (LCIA) is to quantify the environmental impacts resulting from the environmental pressures arising from the system analysed, i.e., resulting from the emissions in water and air and the resources consumptions related to a specific productive activity.

In this step of the study, the data calculated in the inventory, are converted to "impact scores" according to different indicators. Each indicator has its own model underpinning the scoring, based on the environmental pressure that considers. The output of this calculation allows for an in-depth evaluation about the hotspot in the system, i.e., the main contributors to the impact, and it better shows where to intervene to enhance the environmental performance.

The objective therefore consists in attributing the energy/material consumption and emissions obtained in the inventory phase to specific impact categories through a classification process and then in characterizing their environmental impacts (see section 3.2.3). This step of the study may include an iterative process of reviewing the scope of the analysis initially defined, to determine when and how much the objectives of the study have been achieved, or to modify them, if the evaluation indicates that they cannot be achieved.

Focusing on the present analysis, the following results refer to the production of an outdoor awning:

- Impact categories:
    - Table 14: the set of indicators recommended by European Commission when conducting the Product Environmental Footprint studies in the most recent version (v.3).
    - Table 15: the set of indicators of CML2001 in its most updated version.

The values shown in the following tables are reported as the sum of the impact derived from the main activities (e.g., production of polyamide, regranulation process, spinning, texturing), and from the upstream and downstream activities (e.g., production of electricity, production of any lubricating oils).

Results are further analysed in section 6, to highlight the most contributing elements in the system.

Negative results for POCP in CML

This phenomenon only appears for the impact category groups CML 2001 - Nov. 2010 and newer versions of CML. The negative POCP in the trucks is caused by the division of the NOX emissions into the two single emissions NO2 and NO during the upgrade from GaBi 4 to GaBi 5/6. The NO has a negative effect on the POCP since it reduces the close ground ozone formation.

There is a discussion in the scientific LCA community about this taking place since the message "We drive a truck and clean the air'" is questionable[6].

[6] http://www.gabi-software.com/international/support/gabi-faq/

Table 14 LCIA results for EF v.3.

Indicator	Unit	Total	Fabric production	Aluminium structure	Assembly	Distribution	Use	EoL
Climate change	kg CO_2 eq.	4.13E+02	1.84E+02	6.65E+02	2.94E+00	4.74E+01	1.66E+01	-5.03E+02
Ozone depletion	kg CFC-11 eq.	5.60E-08	5.51E-08	1.79E-10	7.11E-13	5.00E-13	6.02E-14	6.94E-10
Human tox, non-cancer	CTUh	4.79E-07	1.44E-07	1.51E-06	2.65E-09	4.43E-08	4.51E-09	-1.22E-06
Human tox, cancer	CTUh	5.94E+01	1.65E+01	1.48E+02	3.24E-01	5.08E+00	8.59E-01	-1.11E+02
Particulate matter	Disease incidences	1.47E-05	8.56E-06	1.16E-05	4.07E-08	5.16E-07	1.74E-06	-7.78E-06
Photoch. Ozone formation	kg NMVOC eq.	1.86E-06	2.49E-07	7.32E-06	3.70E-08	1.91E-07	2.93E-08	-5.97E-06
Ionizing radiation	kBq U235 eq.	6.25E-07	2.09E-07	1.72E-06	3.76E-09	5.71E-08	7.79E-09	-1.38E-06
Acidification	mol H+ eq.	2.12E-01	3.45E-02	7.09E-01	2.16E-03	3.59E-02	3.95E-03	-5.73E-01
Eutrophication freshwater	kg P eq.	1.39E-17	2.66E-18	4.73E-17	3.96E-20	2.84E-20	5.92E-22	-3.61E-17
Eutrophication marine	kg N eq.	6.99E-09	2.46E-09	1.80E-08	5.42E-11	9.51E-10	1.94E-10	-1.46E-08
Eutrophication terrestrial	mol N eq.	1.44E-08	3.33E-09	6.37E-08	9.48E-12	2.99E-11	3.05E-11	-5.26E-08
Ecotox freshwater	CTUe	7.90E-04	7.16E-04	7.93E-05	1.12E-06	1.82E-05	4.01E-06	-2.86E-05
Land use	Pt	1.38E-07	6.18E-08	2.12E-07	1.09E-09	1.26E-08	3.24E-09	-1.52E-07
Water scarcity	m^3 world equiv.	1.38E+01	2.45E+00	2.25E+01	1.37E-02	5.70E-02	6.50E+00	-1.77E+01
Resource use, energy carriers	MJ	1.41E-01	3.56E-02	2.88E-01	2.59E-03	3.33E-02	2.33E-03	-2.21E-01
Resource use, mineral and metal	kg Sb eq.	1.01E+03	4.17E+02	1.91E+03	4.47E+00	6.69E+01	2.41E+01	-1.41E+03

Table 15 LCIA results for CML2001.

Indicator	Unit	Total	Fabric production	Aluminium structure	Assembly	Distribution	Use	EoL
GWP	kg CO_2 eq.	6.12E+01	1.85E+01	1.46E+02	3.13E-01	4.91E+00	8.38E-01	-1.09E+02
GWP excl. biogenic	kg CO_2 eq.	5.76E+01	1.60E+01	1.46E+02	3.17E-01	4.98E+00	8.34E-01	-1.10E+02
ODP	kg R11 eq.	6.27E-08	6.17E-08	2.10E-10	8.37E-13	5.89E-13	7.12E-14	8.70E-10

POCP	kg Ethene eq.	-4.17E-05	2.85E-03	3.41E-02	-1.40E-04	-1.04E-02	2.52E-04	-2.67E-02
Acidification	kg SO_2 eq.	1.75E-01	2.73E-02	6.25E-01	1.51E-03	2.44E-02	3.34E-03	-5.07E-01
Eutrophication	kg Phosphate eq.	2.67E-02	9.16E-03	3.61E-02	3.69E-04	6.24E-03	2.69E-04	-2.54E-02
Human tox	kg DCB eq.	4.15E+01	1.09E+00	2.63E+02	9.65E-03	1.32E-01	3.78E-02	-2.23E+02
Freshwater ecotox	kg DCB eq.	1.14E+00	9.58E-01	8.42E-01	1.55E-03	2.65E-02	7.09E-03	-6.92E-01
Marin ecotox	kg DCB eq.	5.25E+04	1.34E+03	3.32E+05	1.06E+01	8.86E+01	3.77E+01	-2.81E+05
Terrestrial ecotox	kg DCB eq.	1.15E-01	3.20E-02	3.69E-01	7.19E-04	1.22E-02	7.24E-04	-3.00E-01
ADP fossil	kg Sb eq.	7.84E+02	2.86E+02	1.60E+03	4.13E+00	6.68E+01	2.32E+01	-1.20E+03
ADP elements	kg Sb eq.	2.92E-05	1.13E-05	5.01E-05	4.60E-08	5.77E-07	3.35E-06	-3.61E-05

As it is possible to see, the impact scores highlight the significant contribution of the aluminium structure production. This result is influenced both from the inventory (i.e., the weight of the aluminium structure is higher than the fabric, thus leading to a higher material requirement) and from the environmental pressures coming from primary aluminium production. In fact, raw material extraction and manufacturing process steps require considerable amount of energy[7], thus leading to a remarkable resource consumption. Additionally, the primary aluminium production generates different types of air emissions (IPCC, 2006; European Aluminium, 2018):

- Carbon dioxide emissions from the consumption of carbon anodes in the reaction to convert aluminium oxide to aluminium metal.
- Perfluorocarbons (PFCs) emissions of tetrafluoromethane (CF_4) and hexafluoroethane (C_2F_6) during anode effects.
- Smaller amounts of process emissions, such as CO, SO_2, and NMVOC.

On the other hand, for the fabric production, the most significant contributions come from the PAN production, the energy consumption, and the finishing resins (fluorocarbon and melamine). The PAN production generates most of air emissions (e.g. heavy metals to air) and energy resource consumption, in terms of inventory amount. As a result, its impact score for most of indicators is important compared to the rest of fabric production activities. Concerning the resins, some air emissions (e.g. chloroethene, heavy metals) and water emissions (e.g. heavy metals) are leading their contribution to the fabric impact.

[7] Per ton of aluminium produced, electrical consumption has been reduced by 50 percent from the levels necessary 50 years ago. Electrical energy usage requirements have dropped approximately 10 percent in the past 20 years. Today, electric power represents about 20 to 40 percent of the cost of producing aluminium (source: https://www.aluminium.org/industries/production/primary-production)

5.1 Results for the EF v.3 subcategories

For the sake of completeness, the results obtained for all the subcategories of the EF method are reported in Table 16.

The indicators below differentiate the impact scores according to different aspects of the indicators:

- Climate change: the impacts due to biogenic carbon, fossil carbon and emissions from land use change (LUC) are indicated.
- Toxicity-related indicators: the impacts due to the emissions of inorganic, metal and organic compounds are indicated.

Table 16 LCIA results per the EF v.3 sub-categories.

INDICATOR	UNIT	TOTAL	FABRIC PRODUCTION	ALUMINIUM STRUCTURE	ASSEMBLY	DISTRIBUTION	USE	EOL
Climate change	kg CO_2 eq.	4.13E+02	1.84E+02	6.65E+02	2.94E+00	4.74E+01	1.66E+01	-5.03E+02
Climate change, biogenic	kg CO_2 eq.	2.58E+02	9.67E+01	4.52E+02	2.67E+00	4.58E+01	1.47E+01	-3.54E+02
Climate change, fossil	kg CO_2 eq.	1.34E+02	7.15E+01	1.88E+02	2.39E-01	9.90E-01	1.83E+00	-1.28E+02
Climate change, LUC	kg CO_2 eq.	2.07E+01	1.59E+01	2.47E+01	3.58E-02	6.26E-01	8.78E-02	-2.06E+01
HTox, non-cancer	CTUh	4.79E-07	1.44E-07	1.51E-06	2.65E-09	4.43E-08	4.51E-09	-1.22E-06
HTox, non-cancer, inorganic	CTUh	1.17E-08	5.65E-09	1.37E-08	3.53E-11	4.49E-10	1.63E-10	-8.28E-09
HTox, non-cancer, metal	CTUh	1.23E+01	5.52E+00	2.49E+01	2.40E-02	1.88E-02	5.55E-02	-1.81E+01
HTox, non-cancer, organic	CTUh	1.69E+02	3.93E+01	1.49E+02	1.84E+00	2.83E+01	4.46E-01	-4.99E+01
HTox, cancer	CTUh	5.94E+01	1.65E+01	1.48E+02	3.24E-01	5.08E+00	8.59E-01	-1.11E+02
HTox, cancer, inorganic	CTUh	1.67E+00	1.38E-01	2.27E-01	1.32E-03	1.66E-02	1.75E-03	1.28E+00
HTox, cancer, metal	CTUh	5.76E+01	1.63E+01	1.47E+02	3.21E-01	5.03E+00	8.57E-01	-1.12E+02
HTox, cancer, organic	CTUh	1.94E-01	1.46E-01	3.31E-02	1.87E-03	3.43E-02	5.28E-04	-2.20E-02
Ecotox freshwater	CTUe	7.90E-04	7.16E-04	7.93E-05	1.12E-06	1.82E-05	4.01E-06	-2.86E-05
Ecotox, inorganic	CTUe	5.61E-02	1.36E-02	9.36E-02	1.04E-03	1.77E-02	6.59E-04	-7.05E-02
Ecotox, metals	CTUe	5.88E-01	1.30E-01	1.02E+00	1.15E-02	1.96E-01	7.15E-03	-7.76E-01
Ecotox, organic	CTUe	2.14E-08	5.79E-09	8.17E-08	6.36E-11	9.81E-10	2.24E-10	-6.73E-08

5.2 Results for the CML GWP subcategories

For the sake of completeness, the results obtained for the subcategories related to the Global Warming Potential indicator of CML method are reported in Table 17. The indicators presented are all related to land use change.

Table 17 LCIA results per the CML GWP sub-categories related to land use change.

INDICATOR	UNIT	TOTAL	FABRIC PRODUCTION	ALUMINIUM STRUCTURE	ASSEMBLY	DISTRIBUTION	USE	EOL
GWP - incl. LUC excl. biogenic	kg CO_2 eq.	5.78E+01	1.61E+01	1.46E+02	3.19E-01	5.01E+00	8.34E-01	-1.10E+02
GWP - incl. LUC incl. biogenic	kg CO_2 eq.	6.13E+01	1.86E+01	1.46E+02	3.15E-01	4.94E+00	8.38E-01	-1.09E+02
GWP - LULUCF	kg CO_2 eq.	1.94E-01	1.46E-01	3.31E-02	1.87E-03	3.43E-02	5.28E-04	-2.20E-02

5.3 Normalization and weighting

The normalization and weighting factors as implemented in GaBi presented some issues:

- CML2001: normalization factors are included as available for the method. However, specific weighting factors were not included.
- EF v3: normalization and weighting factors were included for the method.

Normalization and weighting were carried out for EF v.3 only. The final single score and the relative contribution of both impact categories and life cycle stages is presented in Table 18. The most contributing indicators (i.e., covering at least 80% of the final single score) are: *Climate change (36.00%), Resource use, energy carriers (30.04%), Particulate matter (7.12%), Acidification (5.26), and Ecotoxicity, freshwater (4.68%).*

Table 18 Normalization and weighting results for EF v.3.

INDICATOR	TOTAL (%)	TOTAL (PT)	FABRIC PRODUCTION	ALUMINIUM STRUCTURE	ASSEMBLY	DISTRIBUTION	USE	EOL
Climate change	**36.14%**	0.155	4.30E-02	3.84E-01	8.43E-04	1.32E-02	2.24E-03	-2.89E-01
Ozone depletion	0.00%	0.000	6.49E-06	2.10E-08	8.36E-11	5.89E-11	7.08E-12	8.17E-08
HTox, non-cancer	1.17%	0.005	1.68E-03	1.38E-02	3.01E-05	4.57E-04	6.24E-05	-1.10E-02
HTox, cancer	0.63%	0.003	7.30E-04	1.03E-02	8.02E-06	1.24E-04	2.82E-05	-8.48E-03
Particulate matter	**6.51%**	0.028	3.74E-03	1.10E-01	5.57E-04	2.87E-03	4.41E-04	-8.98E-02

INDICATOR	TOTAL (%)	TOTAL (PT)	FABRIC PRODUCTION	ALUMINIUM STRUCTURE	ASSEMBLY	DISTRIBUTION	USE	EOL
Photoch. Ozone formation	3.87%	0.017	4.19E-03	3.39E-02	3.06E-04	3.93E-03	2.74E-04	-2.60E-02
Ionizing radiation	3.40%	0.015	6.55E-03	2.95E-02	2.84E-05	2.23E-05	6.59E-05	-2.15E-02
Acidification	**5.53%**	0.024	3.85E-03	7.91E-02	2.41E-04	4.01E-03	4.41E-04	-6.39E-02
Eutrophication freshwater	0.32%	0.001	1.25E-03	1.38E-04	1.96E-06	3.17E-05	6.99E-06	-4.99E-05
Eutrophication marine	1.98%	0.009	2.06E-03	1.42E-02	1.58E-04	2.68E-03	9.98E-05	-1.07E-02
Eutrophication terrestrial	2.87%	0.012	2.72E-03	2.14E-02	2.41E-04	4.11E-03	1.50E-04	-1.63E-02
Ecotox freshwater	**4.34%**	0.019	8.28E-03	2.99E-02	1.33E-04	2.13E-03	7.46E-04	-2.26E-02
Land use	0.38%	0.002	3.81E-04	1.44E-03	1.78E-05	2.74E-04	4.32E-06	-4.83E-04
Water scarcity	2.38%	0.010	1.82E-03	1.67E-02	1.02E-05	4.23E-05	4.83E-03	-1.32E-02
Resource use, energy carriers	**30.08%**	0.129	5.33E-02	2.44E-01	5.73E-04	8.56E-03	3.08E-03	-1.81E-01
Resource use, min&met	0.41%	0.002	1.02E-03	1.37E-03	4.83E-06	6.12E-05	2.07E-04	-9.23E-04
Total - SINGLE SCORE	**100%**	**0.429**						

6 RESULTS INTERPRETATION

6.1 Identification of hotspots

Starting from the results presented in section 5, some further analyses were conducted to highlight the hotspot of the system considered in the study. According to the indications given in Zampori & Pant (2019), three levels of hotspots are examined. Contributors covering at least 80% of the total impact were considered significant for this analysis.

The normalization and weighting factors as implemented in GaBi presented some issues:

- CML2001: normalization factors are included as available for the method. However, specific weighting factors were not included.
- EF v.3: normalization and weighting factors were included for the method. However, the normalization references were not in their most updated version.

Normalization and weighting were carried out for EF v.3 only. However, the calculation is not used for the hotspots' identification.

6.1.1 Most relevant life cycle stages

The relative contribution of each life cycle stage is presented in Table 19 as percentage on the total impact. For clarity reasons, the negative contribution of EoL was converted to a positive number, and the total weighted score was recalculated. The percentage impact contribution for any life cycle step is assessed to this new total.

Table 19 Life cycle stages contribution to total impacts (EF v.3, calculated on the weighted results).

INDICATOR	FABRIC PRODUCTION	ALUMINIUM STRUCTURE	ASSEMBLY	DISTRIBUTION	USE	EOL
Climate change	**6%**	**52%**	**0%**	**2%**	**0%**	**39%**
Ozone depletion	101%	0%	0%	0%	0%	-1%
HTox, non-cancer	6%	51%	0%	2%	0%	41%
HTox, cancer	4%	52%	0%	1%	0%	43%
Particulate matter	**2%**	**53%**	**0%**	**1%**	**0%**	**43%**
Photoch. ozone formation	6%	49%	0%	6%	0%	38%

INDICATOR	FABRIC PRODUCTION	ALUMINIUM STRUCTURE	ASSEMBLY	DISTRIBUTION	USE	EOL
Ionising rad	11%	51%	0%	0%	0%	37%
Acidification	**3%**	**52%**	**0%**	**3%**	**0%**	**42%**
Eutroph freshwater	85%	9%	0%	2%	0%	3%
Eutroph marine	7%	47%	1%	9%	0%	36%
Eutroph terrestrial	6%	48%	1%	9%	0%	36%
Ecotox freshwater	**13%**	**47%**	**0%**	**3%**	**1%**	**35%**
Land use	15%	55%	1%	11%	0%	19%
Water scarcity	5%	46%	0%	0%	13%	36%
Resource use, energy carriers	**11%**	**50%**	**0%**	**2%**	**1%**	**37%**
Resource use, min&met	28%	38%	0%	2%	6%	26%

Table 20 Life cycle stages contribution to total impacts (CML2001, calculated on the LCIA results).

INDICATOR	FABRIC PRODUCTION	ALUMINIUM STRUCTURE	ASSEMBLY	DISTRIBUTION	USE	EOL
GWP	**7%**	**52%**	**0%**	**2%**	**0%**	**39%**
GWP excl. biogenic	6%	52%	0%	2%	0%	40%
ODP	101%	0%	0%	0%	0%	-1%
POCP	5%	64%	0%	-19%	0%	50%
Acidification	**2%**	**53%**	**0%**	**2%**	**0%**	**43%**
Eutrophication	12%	47%	0%	8%	0%	33%
Human Tox	0%	54%	0%	0%	0%	46%
Freshwater ecotox	**38%**	**33%**	**0%**	**1%**	**0%**	**27%**
Marine ecotox	0%	54%	0%	0%	0%	46%
Terrestrial ecotox	4%	52%	0%	2%	0%	42%
ADP fossil	**9%**	**50%**	**0%**	**2%**	**1%**	**38%**

Indicator	Fabric production	Aluminium structure	Assembly	Distribution	Use	EoL
ADP elements	11%	49%	0%	1%	3%	36%

Fabric production, aluminium structure manufacturing and end-of-life covers more than 80% of the total impact, for both the LCIA method used. This result was previously highlighted by the normalization and weighting results for EF v.3 (see section) 5.3.

As already evident in the results tables in section 5.15, the most impacting life cycle stage for most of categories (both as EF v.3 and CML) is the production of the aluminium structure. This contribution is quite high due to the use of primary aluminium: this material extraction and its treatments carries remarkable burdens, leading to high impact score especially for heavy metals and particles emissions to air, and resource (metal and mineral) depletion.

Especially for the EF v.3, the EoL stage for some impact categories shows a negative contribution, thus leading to a benefit to the overall impacts. This credit is coming from the energy recovery from incineration activities, and from the material recycling of the aluminium.

6.1.2 Most relevant processes

To highlight the top contributing processes, a few impact categories selected, with the aim of giving an overview of the most impacting substances.

Based on the results, the selected categories are the following:

- Climate change / GWP
- Acidification
- Resource use, fossil / ADP fossils
- Ecotoxicity, freshwater / Freshwater Aquatic Ecotoxicity Pot.
- Particulate matter (EF only)

This analysis was conducted based on the most contributing life cycle stages. Therefore, aluminium structure manufacture, fabric production and awning EoL are taken into consideration.

In Table 21 , Table 22 and Table 23 the most contributing processes are reported (i.e. covering at least the 80% of the total impact for each life cycle stage). For the EoL stage, some processes have a negative impact, thus leading to a benefit. To deal with negative numbers, the procedure indicated in Zampori & Pant (2019) was followed:

- Consider the absolute values (i.e., impacts of processes or flows to have a plus sign, namely a positive score),
- The total impact score needs to be recalculated including the converted negative scores.
- The total impact score is set to 100%.

- The percentage impact contribution for any process or elementary flow is assessed to this new total.

Table 21 Process contribution related to the production of the aluminium structure.

LCIA Method	Indicator	Aluminium extrusion	Aluminium ingot mix
EF v.3	Climate Change - total	7.16%	92.97%
	Ecotoxicity, freshwater - total	8.39%	91.64%
	Acidification	2.76%	97.22%
	Resource use, fossils	9.43%	90.57%
	Particulate matter	2.73%	97.27%
CML2001	Global Warming Potential (GWP 100 years)	6.85%	93.15%
	Freshwater Aquatic Ecotoxicity Pot.	2.08%	97.86%
	Acidification Potential	2.75%	97.28%
	Abiotic Depletion (ADP fossil)	8.50%	91.88%

Table 22 Process contribution related to the production of the awning fabric.

LCIA Method	Indicator	Waste acrylic recycling	Carding	Open-end spinning	Fabric weaving & finishing	Polyacrylonitrile fibres	Other
EF v.3	Climate Change - total	17.95%	29.14%	3.27%	36.45%	13.20%	0.02%
	Ecotoxicity, freshwater - total	22.83%	30.23%	16.64%	19.95%	10.34%	0.02%
	Acidification	20.91%	35.22%	3.23%	24.46%	16.18%	0.05%
	Resource use, fossils	19.70%	32.02%	14.85%	21.99%	11.58%	0.02%
	Particulate matter	39.84%	23.65%	4.46%	21.28%	10.75%	0.13%
CML2001	Global Warming Potential (GWP 100 years)	16.49%	27.43%	3.46%	40.98%	11.52%	0.01%
	Freshwater Aquatic Ecotoxicity Pot.	24.01%	2.59%	9.91%	62.36%	1.07%	0.10%
	Acidification Potential	21.43%	33.93%	3.37%	25.50%	15.56%	0.06%
	Abiotic Depletion (ADP fossil)	16.82%	33.83%	2.34%	30.94%	16.04%	0.03%

Table 23 Process contribution related to the awning end-of-life.

LCIA METHOD	INDICATOR	FABRIC EOL	ALUMINIUN INGOT MIX (E_V) (WITHIN METAL EOL)	ALUMINIUM REMELTING ($EREC_{EoL}$) (WITHIN METAL EOL)	OTHER
EF v.3	Climate Change - total	2.22%	93.28%	3.82%	0.69%
	Ecotoxicity, freshwater - total	1.45%	94.58%	2.04%	1.93%
	Acidification	0.44%	97.40%	1.95%	0.21%
	Resource use, fossils	2.03%	90.04%	6.01%	1.92%
	Particulate matter	0.27%	98.35%	1.13%	0.26%
CML2001	Global Warming Potential (GWP 100 years)	1.65%	93.89%	3.78%	0.68%
	Freshwater Aquatic Ecotoxicity Pot.	0.49%	98.72%	0.62%	0.17%
	Acidification Potential	0.04%	97.92%	1.80%	0.24%
	Abiotic Depletion (ADP fossil)	0.74%	93.33%	5.11%	0.82%

6.1.3 Most relevant inventory flows

To highlight the flows contributors for the processes illustrated above, the same impact categories were selected, with the aim of giving an overview of the most impacting substances. As defined in Zampori & Pant (2019), the most relevant elementary flows are those contributing cumulatively at least with 80% to the total impact for each most relevant process.

Table 24, Table 25 and **Errore. L'origine riferimento non è stata trovata.** illustrate the most contributing flow for the processes mentioned in section 6.1.2. Concerning the EoL stage, one of the most contributing processes is already analysed for the manufacturing of the aluminium structure stage.

Table 24 Flow contribution for the "Aluminium ingot mix" process (this is valid also for the most contributing process in the EoL stage, E^*_v).

		ALUMINIUM INGOT MIX	
LCIA method	**Indicator**	**Flow**	**%**
EF v.3	Climate Change - total	CO_2 to air	89.1%
		Other	10.9%
	Acidification	SO_2 to air	75.60%
		NO_x to air	23.90%
		Other	0.5%
	Ecotox freshwater	Chloride to fresh water	66.30%
		Aluminium to fresh water	23.20%
		Other	10.5%
	Resource use, fossils	Natural gas	33%
		Crude oil	25.4%
		Hard coal	24.4%
		Other	17.2%
	Particulate matter	$PM_{2.5}$ to air	49.9%
		SO_2 to air	44.7%
		Other	5.4%
CML2001	Global Warming Potential (GWP 100 years)	CO_2 to air	89.8%
		Other	10.2%

		ALUMINIUM INGOT MIX	
LCIA method	**Indicator**	**Flow**	**%**
	Freshwater Aquatic Ecotoxicity Pot.	PAHs to fresh water	45.4%
		Vanadium to air	11.2%
		PAHs to air	8.7%
		Ni to fresh water	7.4%
		Ba to fresh water	5.9%
		Hydrogen fluoride to air	4.6%
		Other	16.8%
	Acidification Potential	SO_2 to air	78.6%
		NO_x to air	18.3%
		Other	3.1%
	Abiotic Depletion (ADP fossil)	Natural gas	38.9%
		Crude oil	29.90%
		Hard coal	28.80%
		Other	2.4%

Table 25 Flow contribution for the acrylic recycling (mechanical and chemical treatment), yarn carding (mixing recycled and virgin fibre) and fabric manufacturing.

		FABRIC PRODUCTION		YARN CARDING		FABRIC WEAVING AND FINISHING	
LCIA method	**Indicator**	**Flow**	**%**	**Flow**	**%**	**Flow**	**%**
EF v.3	Climate change	CO_2 to air	51.6%	CO_2 to air	88.2%	CO_2 to air	86.8%
		Methane (biotic) to air	37.9%				
		Other	10.5%	Other	18.3%	Other	13.2%
	Acidification	SO_2 to air	52.20%	NO_x to air	68.30%	NO_x to air	49.3%
		NO_x to air	31.80%	SO_2 to air	28.70%	SO_2 to air	31.2%

		FABRIC PRODUCTION		YARN CARDING		FABRIC WEAVING AND FINISHING	
LCIA method	**Indicator**	**Flow**	**%**	**Flow**	**%**	**Flow**	**%**
		Other	16.0%	Other	3.0%	Other	19.5%
	Ecotox freshwater	Chloride to fresh water	65.60%	Chloride to fresh water	56.90%	Chloride to fresh water	47.70%
		Aluminium to fresh water	13.40%	Aluminium to fresh water	32.60%	Hydrogen sulphide to air	14.60%
		Ammonia to fresh water	7.19%			Aluminium to fresh water	5.29%
						Mevinphos to fresh water	7.38%
						Naled to fresh water	2.87%
						Parathion ethyl to fresh water	1.93%
						Endrin to fresh water	1.74%
		Other	13.8%	Other	10.5%	Other	18.5%
	Resource use, energy carriers	Crude oil	58.0%	Natural gas	37.5%	Natural gas	72.8%
		Natural gas	18.7%	Crude oil	31.0%	Crude oil	13.9%
		Uranium natural	18.5%	Uranium natural	27.5%		
		Other	4.8%	Other	4.0%	Other	13.3%
	Particulate matter	$PM_{2.5}$ to air	61.0%	$PM_{2.5}$ to air	29.1%	$PM_{2.5}$ to air	84.6%
		SO_2 to air	18.9%	SO2 to air	36.3%		
				Nox to air	30.5%		
		Other	20.1%	Other	4.1%	Other	15.4%
CML2001	GWP	CO_2 to air	68.5%	CO_2 to air	83.7%	CO_2 to air	73.9%
		CO_2 (biotic) to air	20.7%				
		Other	10.8%	Other	16.3%	Other	26.1%
	Acidification	SO_2 to air	59.5%	Nox to air	60.5%	NO_x to air	38.0%

		Fabric production		Yarn carding		Fabric weaving and finishing	
LCIA method	**Indicator**	**Flow**	**%**	**Flow**	**%**	**Flow**	**%**
		NO_x to air	26.7%	SO_2 to air	34.5%	SO_2 to air	32.6%
						Hydrogen sulphide to air	7.2%
						Hydrogen chloride	6.8%
		Other	13.8%	Other	5.0%	Other	22.2%
	Freshwater Aquatic Ecotoxicity Pot.	Coumaphos to fresh water	51.2%	Ni to fresh water	33.0%	Coumaphos to fresh water	63.8%
		Parathion ethyl to fresh water	3.0%	Ba to fresh water	18.6%	Cu (long-term) to fresh water	8.5%
		Cu (long-term) to fresh water	8.2%	V to fresh water	11.3%	Parathion ethyl to fresh water	3.8%
		Ni to fresh water	5.5%	Cd to fresh water	6.2%	Fenthion to fresh water	2.9%
		Ba to fresh water	4.3%	Phenol (hydroxy benzene) to fresh water	8.3%	Endrin to fresh water	2.2%
		Ni, ion (long-term) to fresh water	2.9%	Cu to fresh water	5.5%		
		Fenthion to fresh water	2.3%				
		Be (long-term) to fresh water	2.4%				
		Other	20.2%	Other	17.2%	Other	18.8%
	ADP fossil	Crude oil	71.10%	Natural gas	51.7%	Natural gas	60.2%
		Natural gas	22.9%	Crude oil	42.80%	Hard coal	13.30%
						Crude oil	11.30%
		Other	6.0%	Other	5.5%	Other	15.2%

6.2 Sensitivity

6.2.1 Comparison of different fossil energy sources

With respect to the energy mix used, an additional analysis was carried out to determine the fossil source to be included under the heading "other fossil sources", not better specified in the European Residual Mixes report (see section 4.1). Due to the lack of information related to LCA GWP results in the 2020 report from AIB, the sensitivity was conducted on year 2018 report (AIB, 2018).

In order to identify a suitable fossil source, a sensitivity analysis was carried out on the impacts (in CO_2 eq) to identify the most conservative option in order to be as consistent as possible in the impacts of the energy mix with those reported in the document prepared by the Association of Issuing Bodies related to 2018 residual mixes. The results are shown in Table 26. Following the results obtained, the "coal gases" source was chosen.

As a further check, a comparison was then made relating to the impacts of the energy mix adopted for this study and those attributed to the LCA of the residual mix as in the AIB report. The results are shown in Table 27.

Since the difference between the results was less than 5% for Italy, it was considered acceptable to use the energy mix as built with the "coal gases" source. Concerning Hungary, the choice of adopting "coal gases" as energy source, created a more significant difference (i.e. 17%). However, no other fossil sources were present in the database; therefore, "coal gases" was assumed, as the most impacting option between the ones available.

Table 26 GWP results for different fossil energy sources.

INDICATOR	UNIT	ELECTRICITY FROM COAL GASES	ELECTRICITY FROM PEAT	THERMAL ENERGY FROM NATURAL GAS
Global Warming Potential (GWP 100), excl bio. C, incl LUC, no norm/weight	kg CO_2 eq	1.143636557	0.0122861	0.073316497

Table 27 Comparison for GWP indicator between the present study and the European Residual Mixes report.

INDICATOR	RESULT	UNIT
ITALY		
GWP (F.U. = 1 MJ)	0.16	kg CO_2 eq
GWP (F.U. = 1 MJ)	160.57	g CO_2 eq
GWP (F.U. = 1 kWh)	577.59	g CO_2 eq
LCA GWP (F.U. = 1 kWh)Errore. Il segnalibro non è definito.	596	g CO_2 eq
Difference between the present study and AIB result	3%	

7 COMPARISON WITH BASELINE RESULTS

The LCIA outcome for the partially recycled awning as reported in par. 5 were compared to the baseline scenario calculated in the previous deliverable 6.1. For this analysis, the baseline scenario was updated at two levels

- Modelling: some updates were introduced to the model, in particular for the Circular Footprint Formula.
- Secondary data: the database (both Sphera and Ecoinvent) used to calculate the baseline was updated to a most recent version.

Both the updated were deemed appropriate to ensure a more robust general outcome for the project and a full comparability between the two scenarios.

The detailed LCIA outcome for the baseline is reported in par. 10. In the following the table, the comparison with the REACT Innovation is shown. For each indicator, the percentage difference between the impact scores is calculated.

Table 28 LCIA percentage comparison between Baseline and Innovation scenario. EF method.

INDICATOR	UNIT	BASELINE (PREV. DELIVERABLE)	REACT INNOVATION (THIS STUDY)	DIFFERENCE (%)
Climate change	kg CO_2 eq.	6.57E+01	5.94E+01	-10%
Ozone depletion	kg CFC-11 eq.	1.49E-05	5.60E-08	-99.6%
Human tox, non-cancer	CTUh	6.23E-07	6.25E-07	0.3%
Human tox, cancer	CTUh	2.04E-08	2.14E-08	5%
Particulate matter	Disease incidences	1.89E-06	1.86E-06	-2%
Photoch. Ozone formation	kg NMVOC eq.	1.54E-01	1.41E-01	-9%
Ionizing radiation	kBq U235 eq.	9.81E+00	1.23E+01	26%
Acidification	mol H+ eq.	2.24E-01	2.12E-01	-5%
Eutrophication freshwater	kg P eq.	5.35E-04	7.90E-04	47%
Eutrophication marine	kg N eq.	6.07E-02	5.61E-02	-8%
Eutrophication terrestrial	mol N eq.	6.41E-01	5.88E-01	-8%
Ecotox freshwater	CTUe	3.98E+02	4.13E+02	4%
Land use	Pt	1.80E+02	1.69E+02	-6%
Water scarcity	m^3 world equiv.	1.44E+01	1.38E+01	-4%
Resource use, energy carriers	MJ	1.06E+03	1.01E+03	-5%
Resource use, mineral and metal	kg Sb eq.	1.86E-05	1.47E-05	-21%

Table 29 LCIA percentage comparison between Baseline and REACT Innovation scenario. CML method.

INDICATOR	UNIT	BASELINE (PREV. DELIVERABLE)	REACT INNOVATION (THIS STUDY)	DIFFERENCE (%)
GWP	kg CO_2 eq.	6.54E+01	6.12E+01	-7%
GWP excl. biogenic	kg CO_2 eq.	6.41E+01	5.76E+01	-10%
ODP	kg R11 eq.	1.85E-05	6.27E-08	-99.7%
POCP	kg Ethene eq.	8.58E-04	-4.17E-05	-105%
Acidification	kg SO_2 eq.	1.83E-01	1.75E-01	-5%
Eutrophication	kg Phosphate eq.	2.76E-02	2.67E-02	-3%

Indicator	Unit	Baseline (prev. Deliverable)	REACT Innovation (this study)	Difference (%)
Human Tox	kg DCB eq.	4.17E+01	4.15E+01	-0.3%
Freshwater Ecotox	kg DCB eq.	6.27E-01	1.14E+00	82%
Marine Ecotox	kg DCB eq.	5.30E+04	5.25E+04	-1%
Terrestrial Ecotox	kg DCB eq.	1.21E-01	1.15E-01	-5%
ADP fossil	kg Sb eq.	3.24E-05	2.92E-05	-10%
ADP elements	kg Sb eq.	9.07E+02	7.84E+02	-14%

8 CONCLUSIONS AND RECOMMENDATIONS

The present study was conducted with the aim of quantifying the environmental performance of an outdoor awning made by 70% recycled acrylic (and 30% virgin acrylic), treated with bio-based finishing chemicals. The study includes a comparison with the baseline awning made by 100% virgin acrylic fabric.

The assessment was carried out with two different impact methods (i.e., Environmental Footprint v.3 and CML 2001, Jan. 2016 version), and both the methods are aligned in the results. Indeed, the most significant impact derives from the aluminium structure production, from the fabric manufacturing and the end-of-life on the whole awning.

The hotspots in the results interpretation phase bring some important considerations.

The greatest impact derives from the production of the aluminium structure: this outcome is confirmed in both scenarios (baseline and REACT Innovation). The raw materials extraction and processing generate significant emissions (e.g., heavy metals) and affect the resource depletion, thus leading to a remarkable impact for most of the environmental indicators. It is good to remind that on the aluminium structure manufacturing and on the PAN fibres production, no primary data were available. However, both the technologies are deemed well established, therefore the secondary data used should be representative.

Coming to the fabric production, the baseline highlighted that copper and lead extraction as well as the consumption of fossil energy sources (i.e., crude oil and natural gas) in the production of PAN fibre affect the resource indicator. On the other hand, emissions of phosphorus and phosphates into water highly contribute to eutrophication indicators, and CO_2 emissions (probably due to the fossil energy consumption) leads the climate change indicator. When the REACT recycling process is applied and a significant fraction (i.e., 70%) of recycled acrylic fibre is used in the awning fabric, the consequences are the following:

- Most of environmental indicators show a decrease in the impact: for EF indicators, benefits range from -2% (*Particulate matter*) to -99.6% (*Ozone depletion*); for CML indicators, benefits range from -0.3% (*Human toxicity*) to -99.7% (*Ozone depletion potential*). The POCP indicator show a -105% decrease: this result is due to the negative absolute value the REACT Innovation scored in the characterization phase (see par. 5 for further information on negative results in POCP).
- Some of indicators register an impact increase. EF *Human toxicity*, *Ecotoxicity*, *Eutrophication freshwater and Ionizing radiation* scores are higher for the REACT Innovation (from +0.3% to +47%) with regard to the baseline.

The higher impact observed for the *Ionizing radiation* indicator, is mainly due to a higher score in the recycled fabric manufacturing. The underpinning energy mix used in the mechanical recycling process, i.e., French energy mix (as this takes place within CETI, France) is characterized by a high fraction (i.e., 82.7%) of nuclear energy, which leads the score for this environmental indicator.

The *Eutrophication freshwater* indicator, as well as the *Human toxicity* and *Ecotoxicity* indicators, are influenced by the production of chemicals used both in the textile recycling (chemical treatment of pre-consumer waste) and in the fabric finishing step. For chemicals production, based on Soft Chemicals primary data, an average inventory profile for energy consumption and air/water emissions, was built and applied to all the products modelled within the study. The main differences in the chemicals' inventories are represented by the compounds included in each product (i.e., according to section 3 of the Safety Datasheets). This generates pretty similar results for the impact categories led by emissions into air and water, and by energy consumption (for instance, toxicity and eutrophication). Furthermore, compared to the baseline, the amount of chemicals used in the REACT Innovation scenario is higher. Indeed, 0.11 kg of chemicals for 1 kg of fabric are used in the baseline scenario (i.e., in the finishing step only). Whereas, in the REACT Innovation scenario, 1.22 kg of chemicals are used in the finishing step and 0.475 kg of chemicals are used in the chemical treatment of textile waste. It is good to stress the fact that the finishing step was like a lab-scale test for Parà; therefore, the chemical inputs as well as well the water needed, were measured specifically for the amount of REACT Innovation textile processed. From the efficiency point of view, the yield, including the amount of chemicals and water, could be improved once the finishing process is scaled-up to the usual production level of Parà.

The results obtained with the CML method, are aligned with the ones obtained with the EF v.3 method. The CML outcome highlighted as well an impact increase for the Freshwater ecotoxicity potential indicator; the reason for this increase lies in the same considerations made before.

As for the baseline, the energy consumption remains another contributing aspect in the fabric production. Energy efficiency solutions or certified renewable sources could improve performance also from an environmental point of view.

Finally, the recommendations for a whole greater robustness of the study could be as follows:

- Obtaining primary data for the manufacturing of acrylic fibres.
- Obtaining primary data for the manufacturing of the aluminium structure. The aim is to get a reliable information about the recycled content of aluminium, to also introduce this improvement in the system.
- Introducing a higher fraction of renewable energy, better if sourcing from certified origin.

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10 ANNEX 1 UPDATED RESULTS FOR BASELINE

In the following tables, the updated version of the LCIA results for the Baseline scenario are reported.

Table 30 LCIA results for the Baseline scenario in the updated version.

Indicator	Unit	Total	Fabric production	Aluminium structure	Assembly	Distribution	Use	EoL
Climate change	kg CO_2 eq.	4.29E+01	2.28E+01	1.48E+02	5.08E+00	3.24E-01	8.59E-01	-1.11E+02
Ozone depletion	kg CFC-11 eq.	8.74E-10	1.49E-05	1.79E-10	5.00E-13	7.10E-13	6.02E-14	6.94E-10
Human tox, non-cancer	CTUh	4.15E-07	2.07E-07	1.72E-06	5.71E-08	3.76E-09	7.79E-09	-1.38E-06
Human tox, cancer	CTUh	1.56E-08	4.81E-09	8.17E-08	9.81E-10	6.36E-11	2.24E-10	-6.73E-08
Particulate matter	Disease incidences	1.61E-06	2.81E-07	7.32E-06	1.91E-07	3.70E-08	2.93E-08	-5.97E-06
Photoch. Ozone formation	kg NMVOC eq.	1.05E-01	4.92E-02	2.88E-01	3.33E-02	2.59E-03	2.33E-03	-2.21E-01
Ionizing radiation	kBq U^{235} eq.	6.81E+00	2.99E+00	2.49E+01	1.88E-02	2.40E-02	5.55E-02	-1.81E+01
Acidification	mol H+ eq.	1.78E-01	4.64E-02	7.09E-01	3.59E-02	2.16E-03	3.95E-03	-5.73E-01
Eutrophication freshwater	kg P eq.	7.40E-05	4.61E-04	7.93E-05	1.82E-05	1.12E-06	4.01E-06	-2.86E-05
Eutrophication marine	kg N eq.	4.25E-02	1.82E-02	9.36E-02	1.77E-02	1.04E-03	6.59E-04	-7.05E-02
Eutrophication terrestrial	mol N eq.	4.58E-01	1.83E-01	1.02E+00	1.96E-01	1.15E-02	7.15E-03	-7.76E-01
Ecotox freshwater	CTUe	2.29E+02	1.69E+02	6.65E+02	4.74E+01	2.94E+00	1.66E+01	-5.03E+02
Land use	Pt	1.30E+02	5.04E+01	1.49E+02	2.83E+01	1.84E+00	4.46E-01	-4.99E+01
Water scarcity	m^3 world equiv.	1.14E+01	3.07E+00	2.25E+01	5.70E-02	1.37E-02	6.50E+00	-1.77E+01
Resource use, energy carriers	MJ	5.94E+02	4.71E+02	1.91E+03	6.69E+01	4.47E+00	2.41E+01	-1.41E+03
Resource use, mineral and metal	kg Sb eq.	6.09E-06	1.25E-05	1.16E-05	5.16E-07	4.07E-08	1.74E-06	-7.78E-06

Table 31 Normalization and weighting results for the Baseline scenario in the updated version.

INDICATOR	TOTAL (%)	TOTAL (PT)	FABRIC PRODUCTION	ALUMINIUM STRUCTURE	ASSEMBLY	DISTRIBUTION	USE	EOL
Climate change	38%	0.171	5.93E-02	3.84E-01	8.42E-04	1.32E-02	2.24E-03	-2.89E-01
Ozone depletion	0%	0.002	1.76E-03	2.10E-08	8.35E-11	5.89E-11	7.08E-12	8.17E-08
HTox, non-cancer	1%	0.005	1.66E-03	1.38E-02	3.01E-05	4.57E-04	6.24E-05	-1.10E-02
HTox, cancer	1%	0.003	6.06E-04	1.03E-02	8.02E-06	1.24E-04	2.82E-05	-8.48E-03
Particulate matter	6%	0.028	4.22E-03	1.10E-01	5.57E-04	2.87E-03	4.41E-04	-8.98E-02
Photoch. Ozone formation	4%	0.018	5.79E-03	3.39E-02	3.06E-04	3.93E-03	2.74E-04	-2.60E-02
Ionizing radiation	3%	0.012	3.55E-03	2.95E-02	2.84E-05	2.23E-05	6.59E-05	-2.15E-02
Acidification	6%	0.025	5.18E-03	7.91E-02	2.41E-04	4.01E-03	4.41E-04	-6.39E-02
Eutrophication freshwater	0%	0.001	8.04E-04	1.38E-04	1.96E-06	3.17E-05	6.99E-06	-4.99E-05
Eutrophication marine	2%	0.009	2.75E-03	1.42E-02	1.57E-04	2.68E-03	9.98E-05	-1.07E-02
Eutrophication terrestrial	3%	0.013	3.83E-03	2.14E-02	2.41E-04	4.11E-03	1.50E-04	-1.63E-02
Ecotox freshwater	4%	0.018	7.61E-03	2.99E-02	1.32E-04	2.13E-03	7.46E-04	-2.26E-02
Land use	0%	0.002	4.88E-04	1.44E-03	1.78E-05	2.74E-04	4.32E-06	-4.83E-04
Water scarcity	2%	0.011	2.28E-03	1.67E-02	1.02E-05	4.23E-05	4.83E-03	-1.32E-02
Resource use, energy carriers	30%	0.136	6.03E-02	2.44E-01	5.73E-04	8.56E-03	3.08E-03	-1.81E-01
Resource use, min&met	0%	0.002	1.49E-03	1.37E-03	4.82E-06	6.12E-05	2.07E-04	-9.23E-04
Total - SINGLE SCORE	**100%**	0.455						