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RECYCLING OF WASTE ACRYLIC TEXTILES

D6.1: Life Cycle Environmental Assessment Report for virgin acrylic textile

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Abstract	LCA analysis of an outdoor awning made by virgin acrylic, performed according to PEF method and CML method, and taking into account inputs and outputs of each process, such as energy, water and chemicals consumption, emissions and waste generation.
Keywords	

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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

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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 first 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 by virgin acrylic is considered as a starting point 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
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
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	**P**olycyclic 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 virgin acrylic textiles are documented, the whole life cycle of acrylic textile made of virgin fibre was evaluated “from cradle to grave”. The core production process was taken into consideration, together with the upstream processes performed to obtain the 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.

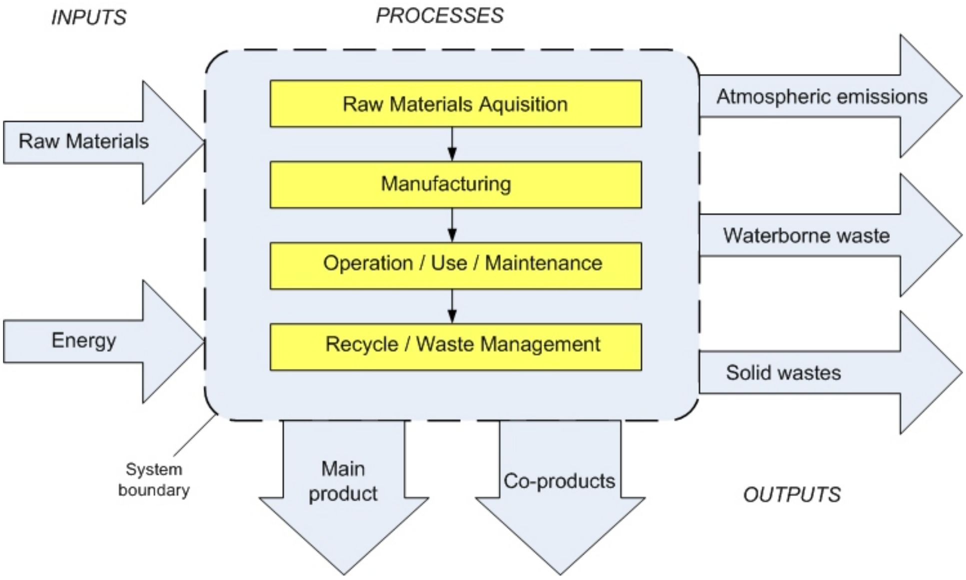

Figure 1 The main stages and typical inputs/outputs in an LCA.

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).

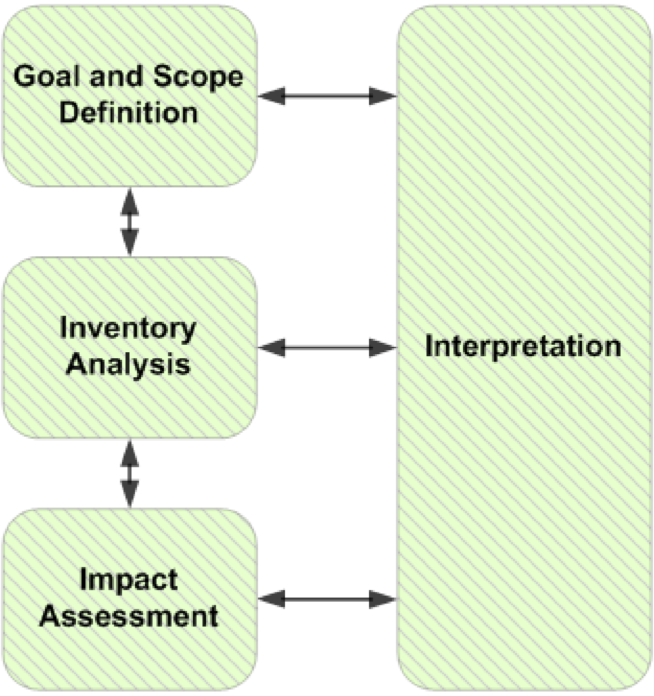

Figure 2 Stage of LCA (ISO 2006a).

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 chemical 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 aspect of the textile productive sector.

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,	Arm awning for outdoor. 100% virgin white acrylic fabric. Solution dyed acrylic. Coating with fluorocarbon (C6) and melamine resin.

Virgin acrylic	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 first part of the comparison of the environmental performance of an outdoor awning throughout its whole life cycle. The comparison will be 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 innovation case study it is recycled acrylic fabric.

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 why an important step is **to create a baseline situation**, which is the **goal of the present study**. This first evaluation allows to identify the main environmental pressures and, consequently, the impact hotspots. Additionally, it highlights what the improvements should focus on, taking into consideration all the aspects related to the product analysed, i.e. not only the fabric.

As a result, the baseline characterization, and its comparison with the innovation, 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 present study).
- Outdoor awning made in 100% recycled acrylic fabric.

3.2 Scope

According to the guidelines by the Joint Research Centre (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	100% virgin white acrylic fabric. Solution dyed acrylic. 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 4.11).

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
	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 polymer	PAN fibres Chemicals Energy Water	Acrylic yarn 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	PAN yarn Chemicals Energy Water	Acrylic fabric Air and water Emission Waste
Downstream	**Awning assembly**	Awning assembling.	Metal structure	Awning (ready for distribution)
	Awning distribution	Transport from factory to retailer/distribution center Transport from retailer/distribution center 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)
	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.
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 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 compartment (N)	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 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 4.10, 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 Ják Spinning. Therefore, the report created by the Association of Issuing Bodies was consulted (AIB, 2020). The data registered for Italy and Hungary in table 2 of the document have been integrated into the model and reported in Table 6 (reference year 2019).

Table 6 Energy Residual Mix for Italy and Hungary.

ENERGY SOURCE	ITALY (%)	HUNGARY (%)
Renewables	9.50%	10.87%
Coal	17.75%	15.78%
Natural gas	55.88%	23.22%
Oil	1.70%	0.34%
Lignite	0.50%	0.39%
Nuclear	9.02%	47.93%
Fossil unspecified	5.65%	1.47%

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 (%)	HUNGARY (%)
RENEWABLES		
Hydro	2.05%	1.23%
Photovoltaics	4.36%	3.36%
Wind	1.10%	1.97%
Biomass	1.17%	4.28%
Geothermal	0.01%	0.02%
Other renewables (biogas)	0.80%	0.00%
FOSSILS UNSPECIFIED		
Coal gases	4.98%	0.44%

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.

For all the partners, we have chosen to model the recycling and energy recovery of two types of packaging (plastic and paper). Within the model, a process was created that divides the waste, respectively paper or plastic, according to its fate (disposal, energy recovery, recycling), in accordance with the values found in the reports of COMIECO (2019) and COREPLA (2019). For paper, 8% goes to energy recovery, 80% goes to recycling and 12% goes to disposal. For plastics, 43% goes to energy recovery, 44.5% goes to recycling and 12.5% goes to disposal.

The further step in the calculation is compliant with the indications in the GENERAL PROGRAM INSTRUCTIONS (GRI) FOR THE INTERNATIONAL EPD® SYSTEM (EPD International, 2019). When quantifying the impacts related to energy recovery, those deriving from the destruction of the waste must be attributed to the person who generates the waste while those deriving from the use of the thermal energy produced should be attributed to the subsequent product life cycle. In the present case, it is not possible to establish the yield of waste combustion, therefore, following what reported in the GRI, it has been assumed to divide the impacts with the following approach:

- 50% of the impacts derive from the treatment of the waste (attributed to the project partner companies).
- 50% of the impacts derive from energy recovery (not attributed to the project partner companies).

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 Ják Spinning 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 sp.40 and ecoinvent 3.6 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 a 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 Yarn manufacturing (Ják Spinning)

Ják Spinning supplies the yarn for the production of the fabric for awnings. Data from the company mostly concern the energy consumption, the lubricants used and the final packaging of the yarn. This data has been collected directly from the company and have been used to model the spinning step.

From primary source is another significant information: the process efficiency. Ják Spinning stated that the product's yield is 98-98.5%, on average. In the current analysis, 98% was considered. The waste yarn was considered as sent to incineration in a municipal plant.

4.4 Production of the chemical products (Soft chemicals)

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

- Imbiber
- Catalyst
- Fluorocarbon resin
- Melamine resin

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 8. Plastic material scraps in IBC HDPE production were modelled as sent to incineration.

Table 8 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 Production of the awning fabric (Parà)

The company processes the yarn coming from Ják Spinning to obtain a final acrylic fabric destined to awning assembly. The overall efficiency of the process is estimated around 85%, thus leading to 15% of final textile waste (now addressed to incineration).

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.

As chemical agents, a few additional products are included in the process. They are listed in Table 9, together with their modelling details.

Table 9 Datasets used for modelling the chemical agents (Parà).

CHEMICAL AGENT	DATASET	SOURCE
Acetic acid	DE: Acetic acid from methanol (low pressure carbonylation) (Monsanto process)	GaBi Professional sp.40
Perchloroethylene	RoW: Tetrachloroethylene production	Ecoinvent 3.6
Mineral oil for finishing	EU-28: Wax/Paraffins at refinery	GaBi Professional sp.40

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%).

4.6 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).

4.7 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.

4.8 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.

4.9 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 10, the parameters are introduced and explained. In Table 10 and Table 11, all the parameters adopted are reported, both as values and as datasets.

Table 10 Parameters of the Circular Footprint Formula

PARAMETER	EXPLANATION
A	Allocation factor of burdens and credits between supplier and user of recycled materials.

PARAMETER	EXPLANATION
B	Allocation factor of energy recovery processes. It applies both to burdens and to credits.
Q_{Sin}	Auality 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.
$E_{recycled}$ (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 11 CFF parameters as used in the current study.

PARAMETER	VALUE	DATASET	FURTHER DETAILS
ACRYLIC FABRIC (only incineration and disposal are considered)			
R_1	0	-	No recycled content in the product

PARAMETER	VALUE	DATASET	FURTHER DETAILS
R_2	0	-	No recycling process in the EoL
B	0	-	Default value in PEF studies (Zampori and Pant, 2019)
R_3	0.45	-	Default value for EU-28 (Annex C in Zampori and Pant, 2019)
E_{ER}		EU-28: Textiles in municipal waste incineration plant	Source: GaBi Professional sp40
LHV	21 MJ/kg		Source: GaBi Professional sp40
$X_{ER,heat}$ $X_{ER,elec}$	44%		Source: GaBi Professional sp40
$E_{SE,heat}$		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: Textiles on landfill	Source: GaBi Professional sp40. 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 transport by truck (EURO 4)	Source: European Aluminium
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

PARAMETER	VALUE	DATASET	FURTHER DETAILS
			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

4.10 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 timeframe.

Concerning the secondary data, they were taken from:

- the GaBi database (GaBi Professional, service pack 40; Sphera, 2020) and its Extension databases:
  - Ia: Intermediates organic.
  - Ib: Intermediates inorganic.
  - IXa: End of life.
  - XV: Textile finishing.
- the Ecoinvent v3.6 database (Ecoinvent, 2019).

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.

4.10.1 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.

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.

4.11 System model

To build a model in GaBi v.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.

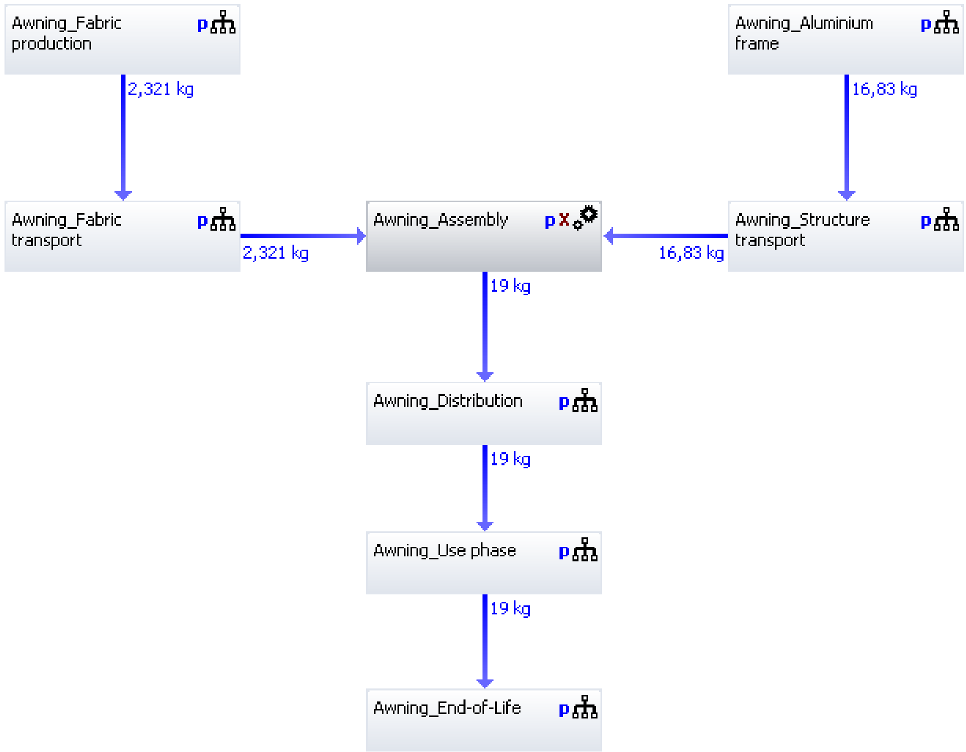

Figure 6 GaBi model of awning life cycle.

4.12 Allocation rules

The following allocation rules as reported in Table 12 were used.

Table 12 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 13: the set of indicators recommended by European Commission when conducting the Product Environmental Footprint studies in the most recent version (v.3).
    - Table 14: 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[5].

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

Table 13 LCIA results for EF v.3.

INDICATOR	UNIT	TOTAL	FABRIC PRODUCTION	ALUMINIUM STRUCTURE	ASSEMBLY	DISTRIBUTION	USE	EOL
Climate change	kg CO_2 eq.	2.40E+02	2.46E+01	1.52E+02	3.28E-01	5.06E+00	8.60E-01	5.74E+01
Ozone depletion	kg CFC-11 eq.	1.48E-05	1.48E-05	1.72E-10	1.18E-15	9.28E-16	2.14E-15	-5.16E-10
Human tox, non-cancer	CTUh	2.95E-06	2.03E-07	1.71E-06	3.77E-09	5.70E-08	7.79E-09	9.67E-07
Human tox, cancer	CTUh	1.39E-07	4.75E-09	8.13E-08	6.74E-11	1.05E-09	2.24E-10	5.13E-08
Particulate matter	Disease incidences	1.08E-05	3.49E-07	7.78E-06	3.73E-08	1.90E-07	2.93E-08	2.37E-06
Photoch. Ozone formation	kg NMVOC eq.	5.33E-01	5.51E-02	3.03E-01	2.61E-03	3.33E-02	2.33E-03	1.36E-01
Ionizing radiation	kBq U235 eq.	2.53E+01	2.99E+00	2.49E+01	2.34E-02	1.84E-02	5.55E-02	-2.73E+00
Acidification	mol H+ eq.	1.20E+00	5.40E-02	7.42E-01	2.19E-03	3.61E-02	3.95E-03	3.60E-01
Eutrophication freshwater	kg P eq.	6.35E-04	5.02E-04	8.37E-05	9.75E-07	1.54E-05	4.01E-06	2.90E-05
Eutrophication marine	kg N eq.	1.83E-01	2.11E-02	9.80E-02	1.05E-03	1.76E-02	6.60E-04	4.43E-02
Eutrophication terrestrial	mol N eq.	1.96E+00	2.02E-01	1.07E+00	1.16E-02	1.95E-01	7.16E-03	4.77E-01
Ecotox freshwater	CTUe	1.13E+03	1.79E+02	6.93E+02	3.13E+00	5.05E+01	1.66E+01	1.88E+02
Land use	Pt	3.92E+02	7.82E+01	2.67E+02	1.58E+00	2.37E+01	4.35E-01	2.06E+01
Water scarcity	m^3 world equiv.	4.78E+01	3.15E+00	2.27E+01	1.38E-02	4.93E-02	6.50E+00	1.54E+01
Resource use, energy carriers	MJ	3.14E+03	4.90E+02	1.97E+03	4.57E+00	6.74E+01	2.41E+01	5.82E+02
Resource use, mineral and metal	kg Sb eq.	3.85E-05	2.12E-05	1.90E-05	3.72E-08	4.11E-07	1.74E-06	-3.98E-06

Table 14 LCIA results for CML2001.

INDICATOR	UNIT	TOTAL	FABRIC PRODUCTION	ALUMINIUM STRUCTURE	ASSEMBLY	DISTRIBUTION	USE	EOL
GWP	kg CO_2 eq.	2.38E+02	2.44E+01	1.49E+02	3.20E-01	4.93E+00	8.38E-01	5.79E+01
GWP excl. biogenic	kg CO_2 eq.	2.36E+02	2.38E+01	1.50E+02	3.21E-01	4.95E+00	8.34E-01	5.65E+01
ODP	kg R11 eq.	1.83E-05	1.83E-05	3.14E-10	1.57E-15	1.24E-15	2.85E-15	-9.28E-10

POCP	kg Ethene eq.	4.67E-02	4.52E-03	3.61E-02	-1.39E-04	-1.04E-02	2.52E-04	1.63E-02
Acidification	kg SO_2 eq.	1.04E+00	4.18E-02	6.53E-01	1.53E-03	2.46E-02	3.34E-03	3.19E-01
Eutrophication	kg Phosphate eq.	7.35E-02	1.13E-02	3.75E-02	3.69E-04	6.19E-03	2.69E-04	1.79E-02
Human tox	kg DCB eq.	3.24E+02	1.46E+00	2.63E+02	1.02E-02	1.39E-01	3.79E-02	5.98E+01
Freshwater ecotox	kg DCB eq.	1.74E+00	5.01E-01	8.51E-01	1.61E-03	2.75E-02	7.09E-03	3.54E-01
Marin ecotox	kg DCB eq.	4.94E+05	2.07E+03	3.33E+05	1.10E+01	9.30E+01	3.78E+01	1.59E+05
Terrestrial ecotox	kg DCB eq.	6.43E-01	3.79E-02	3.64E-01	6.73E-04	1.13E-02	7.25E-04	2.29E-01
ADP elements	kg Sb eq.	9.42E-05	2.32E-05	5.91E-05	4.21E-08	4.64E-07	3.35E-06	8.02E-06
ADP fossil	kg Sb eq.	2.80E+03	4.25E+02	1.65E+03	4.23E+00	6.74E+01	2.33E+01	6.24E+02

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[6], 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.

[6] 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 15.

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 15 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.	2.40E+02	2.46E+01	1.52E+02	3.28E-01	5.06E+00	8.60E-01	5.74E+01
Climate change, biogenic	kg CO_2 eq.	2.10E+00	4.09E-01	1.97E-01	1.24E-03	1.50E-02	1.75E-03	1.47E+00
Climate change, fossil	kg CO_2 eq.	2.38E+02	2.42E+01	1.52E+02	3.25E-01	5.01E+00	8.58E-01	5.59E+01
Climate change, LUC	kg CO_2 eq.	1.45E-01	9.42E-03	6.07E-02	2.30E-03	4.09E-02	5.37E-04	3.11E-02
HTox, non-cancer	CTUh	2.95E-06	2.03E-07	1.71E-06	3.77E-09	5.70E-08	7.79E-09	9.67E-07
HTox, non-cancer, inorganic	CTUh	3.51E-07	4.95E-08	2.22E-07	1.13E-09	1.31E-08	3.24E-09	6.20E-08
HTox, non-cancer, metal	CTUh	2.59E-06	1.51E-07	1.48E-06	2.63E-09	4.37E-08	4.51E-09	9.03E-07
HTox, non-cancer, organic	CTUh	2.89E-08	4.97E-09	1.62E-08	3.50E-11	4.21E-10	1.63E-10	7.09E-09
HTox, cancer	CTUh	1.39E-07	4.75E-09	8.13E-08	6.74E-11	1.05E-09	2.24E-10	5.13E-08
HTox, cancer, inorganic	CTUh	7.97E-17	2.22E-18	4.22E-17	3.76E-20	2.43E-20	5.25E-22	3.52E-17
HTox, cancer, metal	CTUh	3.26E-08	2.81E-09	1.81E-08	5.66E-11	9.92E-10	1.94E-10	1.05E-08
HTox, cancer, organic	CTUh	1.06E-07	1.94E-09	6.33E-08	1.08E-11	5.39E-11	3.06E-11	4.08E-08
Ecotox freshwater	CTUe	1.13E+03	1.79E+02	6.93E+02	3.13E+00	5.05E+01	1.66E+01	1.88E+02
Ecotox, inorganic	CTUe	8.59E+02	1.25E+02	4.79E+02	2.85E+00	4.88E+01	1.47E+01	1.88E+02
Ecotox, metals	CTUe	2.40E+02	5.08E+01	1.91E+02	2.44E-01	1.01E+00	1.83E+00	-5.25E+00
Ecotox, organic	CTUe	3.13E+01	3.03E+00	2.27E+01	3.62E-02	6.30E-01	8.78E-02	4.83E+00

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 16. The indicators presented are all related to land use change.

Table 16 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.	2.37E+02	2.38E+01	1.50E+02	3.23E-01	5.00E+00	8.35E-01	5.65E+01
GWP - incl. LUC incl. biogenic	kg CO_2 eq.	2.38E+02	2.44E+01	1.49E+02	3.22E-01	4.97E+00	8.39E-01	5.80E+01
GWP - LULUCF	kg CO_2 eq.	1.45E-01	9.40E-03	6.07E-02	2.30E-03	4.09E-02	5.37E-04	3.11E-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. However, the normalization references were not in their most updated version and the results could be biased. For this reason, the calculation is not used for the hotspots' identification.

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 17. The most contributing indicators to the final single scores are Ionizing radiation (36.6%), Climate change (25.1%) and Resource use, energy carriers (16%).

In particular, the significant importance of Ionizing radiation could be the result of the elevated fraction of nuclear power in the Hungary energy mix (used for Ják Spinning). However, this outcome could be due as well to the extremely low normalization factor in the version implemented in GaBi (i.e., it is 30 times lower, compared to the most updated one). This increases the normalized results and finally its relative importance in the single score.

Table 17 Normalization and weighting results for EF v.3.

INDICATOR	TOTAL (%)	TOTAL (PT)	FABRIC PRODUCTION	ALUMINIUM STRUCTURE	ASSEMBLY	DISTRIBUTION	USE	EOL
Climate change	**25.1%**	0.630	6.45E-02	3.98E-01	8.60E-04	1.33E-02	2.25E-03	1.50E-01
Ozone depletion	0.1%	0.002	1.93E-03	2.25E-08	1.53E-13	1.21E-13	2.79E-13	-6.72E-08
HTox, non-cancer	0.9%	0.024	1.62E-03	1.37E-02	3.01E-05	4.56E-04	6.23E-05	7.74E-03
HTox, cancer	0.6%	0.016	5.44E-04	9.31E-03	7.72E-06	1.20E-04	2.57E-05	5.87E-03
Particulate matter	6.4%	0.162	5.26E-03	1.17E-01	5.62E-04	2.86E-03	4.41E-04	3.57E-02
Photoch. Ozone formation	2.5%	0.063	6.47E-03	3.56E-02	3.06E-04	3.91E-03	2.74E-04	1.60E-02
Ionizing radiation	**36.6%**	0.919	1.09E-01	9.06E-01	8.50E-04	6.68E-04	2.02E-03	-9.89E-02
Acidification	5.3%	0.134	6.02E-03	8.27E-02	2.45E-04	4.02E-03	4.41E-04	4.01E-02
Eutrophication freshwater	0.0%	0.001	8.73E-04	1.46E-04	1.70E-06	2.68E-05	6.98E-06	5.04E-05
Eutrophication marine	1.1%	0.028	3.20E-03	1.49E-02	1.59E-04	2.68E-03	1.00E-04	6.72E-03
Eutrophication terrestrial	1.6%	0.041	4.23E-03	2.24E-02	2.42E-04	4.09E-03	1.50E-04	9.99E-03
Ecotox freshwater	2.0%	0.051	8.05E-03	3.12E-02	1.41E-04	2.27E-03	7.46E-04	8.45E-03
Land use	0.1%	0.001	2.78E-04	9.52E-04	5.61E-06	8.43E-05	1.55E-06	7.33E-05
Water scarcity	1.4%	0.035	2.33E-03	1.68E-02	1.02E-05	3.65E-05	4.81E-03	1.14E-02
Resource use, energy carriers	**16.0%**	0.401	6.27E-02	2.52E-01	5.85E-04	8.63E-03	3.09E-03	7.45E-02
Resource use, min&met	0.2%	0.005	2.52E-03	2.26E-03	4.42E-06	4.88E-05	2.07E-04	-4.73E-04
Total - SINGLE SCORE	**100%**	**2.51**						

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 18 as percentage on the total impact.

Table 18 Life cycle stages contribution to total impacts (EF v.3).

INDICATOR	FABRIC PRODUCTION	ALUMINIUM STRUCTURE	ASSEMBLY	DISTRIBUTION	USE	EOL
Climate change	**10%**	**63%**	0%	2%	0%	**24%**
Ozone depletion	**100%**	**0%**	0%	0%	0%	**0%**
HTox, non-cancer	**7%**	**58%**	0%	2%	0%	**33%**
HTox, cancer	**3%**	**59%**	0%	1%	0%	**37%**
Particulate matter	**3%**	**72%**	0%	2%	0%	**22%**
Photoch. ozone formation	**10%**	**57%**	0%	6%	0%	**26%**
Ionising rad	**12%**	**99%**	0%	0%	0%	**-11%**
Acidification	**5%**	**62%**	0%	3%	0%	**30%**
Eutroph freshwater	**79%**	**13%**	0%	2%	1%	**5%**
Eutroph marine	**12%**	**54%**	1%	10%	0%	**24%**
Eutroph terrestrial	**10%**	**54%**	1%	10%	0%	**24%**
Ecotox freshwater	**16%**	**61%**	0%	4%	1%	**17%**
Land use	**20%**	**68%**	0%	6%	0%	**5%**
Water scarcity	**7%**	**48%**	0%	0%	14%	**32%**
Resource use, energy carriers	**16%**	**63%**	0%	2%	1%	**19%**
Resource use, min&met	**55%**	**49%**	0%	1%	5%	**-10%**

Table 19 Life cycle stages contribution to total impacts (CML2001).

INDICATOR	FABRIC PRODUCTION	ALUMINIUM STRUCTURE	ASSEMBLY	DISTRIBUTION	USE	EOL
GWP	**10%**	**63%**	0%	2%	0%	**24%**

INDICATOR	FABRIC PRODUCTION	ALUMINIUM STRUCTURE	ASSEMBLY	DISTRIBUTION	USE	EOL
GWP excl. biogenic	**10%**	**63%**	0%	2%	0%	**24%**
ODP	**100%**	**0%**	0%	0%	0%	**0%**
POCP	**10%**	**77%**	0%	-22%	1%	**35%**
Acidification	**4%**	**63%**	0%	2%	0%	**31%**
Eutrophication	**15%**	**51%**	1%	8%	0%	**24%**
Human Tox	**0%**	**81%**	0%	0%	0%	**18%**
Freshwater ecotox	**29%**	**49%**	0%	2%	0%	**20%**
Marine ecotox	**0%**	**67%**	0%	0%	0%	**32%**
Terrestrial ecotox	**6%**	**57%**	0%	2%	0%	**36%**
ADP elements	**25%**	**63%**	0%	0%	4%	**9%**
ADP fossil	**15%**	**59%**	0%	2%	1%	**22%**

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
- Human toxicity, non-cancer / Human toxicity
- Acidification
- Resource use, mineral and metals / ADP elements
- Resource use, fossil / ADP fossils
- 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 20 , Table 21 and Table 22 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 20 Process contribution related to the production of the aluminium structure.

LCIA Method	Indicator	Aluminium ingot mix	Aluminium extrusion
EF v.3	Climate change	92%	8%
	HTox, non-cancer	97%	3%
	Acidification	96%	4%
	Resource use, energy carriers	90%	10%
	Resource use, min&met	85%	15%
	Particulate matter	95%	5%
CML2001	GWP	93%	7%
	Human Tox	100%	0%
	Acidification	96%	4%
	ADP fossil	91%	9%
	ADP elements	87%	13%

Table 21 Process contribution related to the production of the awning fabric.

LCIA Method	Indicator	Electricity (fabric manufact.)	Fluorocarbon C6	Acrylic production and spinning	Resin (melamine)	Other
EF v.3	Climate change	16%	1%	68%	1%	13%
	HTox, non-cancer	7%	2%	76%	2%	13%
	Acidification	0%	0%	75%	5%	20%
	Resource use, energy carriers	12%	0%	78%	1%	9%
	Resource use, min&met	4%	56%	8%	30%	1%
	Particulate matter	8%	3%	64%	7%	17%
CML2001	GWP	16%	1%	67%	1%	15%
	Human Tox	9%	10%	38%	30%	12%
	Acidification	10%	2%	75%	4%	9%
	ADP fossil	13%	0%	75%	1%	10%
	ADP elements	4%	54%	12%	28%	2%

Table 22 Process contribution related to the awning end-of-life.

LCIA Method	Indicator	Aluminium ingot mix (E_V)	Primary aluminium production ingot mix (E^*_V)	Aluminium re-melting (E_{recEoL})	Other
EF v.3	Climate change	62%	34%	2%	2%
	HTox, non-cancer	74%	24%	0%	2%
	Acidification	69%	29%	1%	1%
	Resource use, energy carriers	59%	37%	2%	1%
	Resource use, min&met	43%	55%	1%	1%

LCIA Method	Indicator	Aluminium ingot mix (E_V)	Primary aluminium production ingot mix (E^*_V)	Aluminium re-melting (E_{recEoL})	Other
	Particulate matter	61%	38%	0%	0%
CML2001	GWP	62%	34%	2%	3%
	Human Tox	58%	42%	0%	0%
	Acidification	70%	29%	1%	1%
	ADP fossil	63%	34%	2%	1%
	ADP elements	53%	45%	1%	1%

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 23, Table 24 and Table 25 illustrate the most contributing flow for the processes mentioned in section 6.1.2. Concerning the EoL stage, one of the most contributing process is already analysed for the manufacturing of the aluminium structure stage. Therefore, the flow contribution is reported for the Primary aluminium production ingot mix (E_r).

Table 23 Flow contribution for the "Aluminium ingot mix" process.

		Aluminium ingot mix	
LCIA method	**Indicator**	**Flow**	**%**
EF v.3	Climate change	CO_2 to air	88.1%
		Other	11.9%
	Human toxicity, non-cancer	Hg to air	79.9%
		CO to air	3.2%
		Other	16.9%
	Acidification	SO_2 to air	75.60%
		NO_x to air	23.90%
		Other	0.5%
	Resource use, energy carriers	Natural gas	34%
		Crude oil	25.2%
		Hard coal	24.6%
		Other	16.2%
	Resource use, mineral and metals	Lead	38.9%
		Molybdenum	29.6%
		Chromium	10.5%
		Silver	8.0%
		Other	13.0%
	Particulate matter	$PM_{2.5}$ to air	50.4%
		SO_2 to air	44.3%
		Other	5.3%
CML2001	GWP	CO_2 to air	89.2%

		Aluminium ingot mix	
LCIA method	**Indicator**	**Flow**	**%**
		Other	10.8%
	Human Tox	PAHs to air	87.4%
		Other	12.6%
	Acidification	SO_2 to air	78.6%
		NO_x to air	18.3%
		Other	3.1%
	ADP fossil	Natural gas	40%
		Crude oil	29.70%
		Hard coal	28.90%
		Other	1.4%
	ADP elements	Sodium chloride (rock salt)	66.30%
		Lead	12.20%
		Molybdenum	9.27%
		Other	12.2%

Table 24 Flow contribution for the acrylic production (PAN production and spinning) and electricity supply (fabric manufacturing).

		Acrylic		Electricity	
LCIA method	**Indicator**	**Flow**	**%**	**Flow**	**%**
EF v.3	Climate change	CO_2 to air	87.3%	CO_2 to air	81.7%
		Other	12.7%	Other	18.3%
	Human toxicity, non-cancer	Hg to air	54.5%	Hg to air	69.7%
		As (V) to water	12%	CO to air	10.9%
		CO to air	6.4%		
		Chloride to water	9.9%		
		Other	17.2%	Other	19.4%
	Acidification	NO_x to air	62.80%	NO_x to air	72.20%
		SO_2 to air	33.00%	SO_2 to air	19.50%
		Other	4.2%	Other	8.3%
	Resource use, energy carriers	Natural gas	43.1%	Natural gas	98.3%
		Crude oil	32.6%		
		Uranium	16.0%		
		Other	8.3%	Other	1.7%
	Resource use, mineral and metals	Lead	39.2%	Gold	81.0%
		Copper	18.9%		
		Gold	13.7%		
		Silver	10.8%		
		Other	17.4%	Other	19.0%
	Particulate matter	SO2 to air	36.6%	$PM_{2.5}$ to air	59.0%
		$PM_{2.5}$ to air	34.7%	SO_2 to air	26.5%

		Acrylic		Electricity	
LCIA method	**Indicator**	**Flow**	**%**	**Flow**	**%**
		NO_x to air	24.7%		
		Other	4.0%	Other	14.5%
CML2001	GWP	CO_2 to air	89.7%	CO_2 to air	85.4%
		Other	10.3%	Other	14.6%
	Human Tox	PAHs to air	19.3%	PAHs to air	29.1%
		Hydrogen fluoride to air	11.3%	As(V) to air	14.5%
		Benzene to water	7.6%	Hydrogen fluoride to air	13.7%
		NO_x to air	7.4%	Benzene to air	10.6%
		As(V) to air	7.3%	Se to air	12.7%
		Ba to water	7.0%	NO_x to air	4.1%
		Benzene to air	6.7%		
		Se to air	4.9%		
		Se to water	4.1%		
		Acrylonitrile to air	3.8%		
		Ni to air	3.1%		
		Other	17.4%	Other	15.3%
	Acidification	NO_x to air	54.7%	SO_2 to air	47.2%
		SO_2 to air	38.9%	NO_x to air	44.8%
		Other	6.4%	Other	8.0%
	ADP fossil	Natural gas	51%	Natural gas	98.5%
		Crude oil	38.90%		
		Other	9.8%	Other	1.5%
	ADP elements	Sodium chloride (rock salt)	31.3%	Gold	80.6%
		Lead	23.8%		
		Copper	11.5%		
		Gold	8.3%		
		Silver	6.6%		
		Other	18.5%	Other	19.4%

Table 25 Flow contribution for the "Primary aluminium production ingot mix" (E^*_V) process

		Primary aluminium production ingot mix (E^*_V)	
LCIA method	**Indicator**	**Flow**	**%**
EF v.3	Climate change	CO_2 to air	88.7%
		Other	11.3%
	Human toxicity, non-cancer	Hg to air	63.9%
		Chlorine to water	10.30%
		Chloride to water	6.0%

		PRIMARY ALUMINIUM PRODUCTION INGOT MIX (E*$_V$)	
LCIA method	**Indicator**	**Flow**	**%**
		CO to air	5.5%
		Other	14.3%
	Acidification	SO_2 to air	72.10%
		NO_x to air	27.40%
		Other	0.5%
	Resource use, energy carriers	Natural gas	30%
		Uranium	27.9%
		Hard coal	24.8%
		Other	17.5%
	Resource use, mineral and metals	Copper	48.7%
		Molybdenum	19.3%
		Lead	17.8%
		Other	14.2%
	Particulate matter	$PM_{2.5}$ to air	68.0%
		SO_2 to air	28.0%
		Other	4.0%
CML2001	GWP	CO_2 to air	90.0%
		Other	10.0%
	Human Tox	PAHs to air	92.9%
		Other	7.1%
	Acidification	SO_2 to air	75.8%
		NO_x to air	21.2%
		Other	3.0%
	ADP fossil	Natural gas	41.4%
		Hard coal	34.5%
		Crude oil	22.0%
		Other	2.1%
	ADP elements	Sodium chloride (rock salt)	49.1%
		Copper	23.5%
		Molybdenum	9.3%
		Other	18.1%

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)[7]	596	g CO_2 eq
Difference between the present study and AIB result	3%	
HUNGARY		
GWP (per 1 MJ)	0.1025	kg CO_2 eq
GWP (per 1 MJ)	102.5	g CO_2 eq
GWP (per 1 kWh)	379.62	g CO_2 eq
LCA GWP (per 1 kWh)[7]	460	g CO_2 eq
Difference between the present study and AIB result	17%	

[7] Figure 4 within the European Residual Mixes report, available at: https://www.aib-net.org/facts/european-residual-mix

6.2.2 Awning service life

The considerations about the lifetime of an outdoor awning start from the textiles. Parà warranty is valid for 8 years from the purchase date and covers abnormal and excessive colour degradation due to normal sun, salt, and weather exposure.

A research conducted on the web, revealed that the lifespan of an outdoor awning could be from 5 to 15 years, depending on many factors. Since we had no control about the aluminium structure quality, we took into consideration the textile quality and the abovementioned warranty, assuming an 8 years lifetime for the baseline situation.

A sensitivity was conducted when considering the two extremes, i.e. 5 years and 15 years. The results are presented in Table 28 and Table 29, together with the increase/decrease of the total impact (as %) due to the change in the use-phase.

Table 28 EF v3 sensitivity results: awning service life.

INDICATOR	UNIT	BASELINE (8 YEARS)	MIN (5 YEARS)	VARIATION (%)	MAX (15 YEARS)	VARIATION (%)
Climate change	kg CO_2 eq.	2.40E+02	2.40E+02	-0.1%	2.41E+02	0.3%
Ozone depletion	kg CFC-11 eq.	1.48E-05	1.48E-05	0.0%	1.48E-05	0.0%
HTox-Non-cancer	CTUh	2.95E-06	2.95E-06	-0.1%	2.96E-06	0.2%
HTox-Cancer	CTUh	1.39E-07	1.39E-07	-0.1%	1.39E-07	0.1%
Particulate matter	Disease incidences	1.08E-05	1.07E-05	-0.1%	1.08E-05	0.2%
Photoch. Ozone formation	kg NMVOC eq.	5.33E-01	5.32E-01	-0.2%	5.35E-01	0.4%
Ionising rad	kBq U235 eq.	2.53E+01	2.53E+01	-0.1%	2.54E+01	0.2%
Acidification	mol H^+ eq.	1.20E+00	1.20E+00	-0.2%	1.20E+00	0.3%
Eutroph freshwater	kg P eq.	6.35E-04	6.34E-04	-0.2%	6.39E-04	0.5%
Eutroph marine	kg N eq.	1.83E-01	1.82E-01	-0.1%	1.83E-01	0.3%
Eutroph terrestrial	mol N eq.	1.96E+00	1.96E+00	-0.1%	1.97E+00	0.3%
Ecotox freshwater	CTUe	1.13E+03	1.12E+03	-0.5%	1.14E+03	1.2%
Land use	Pt	3.92E+02	3.92E+02	0.0%	3.92E+02	0.1%
Water scarcity	m^3 world equiv.	4.78E+01	4.00E+01	-16.3%	6.00E+01	25.6%
Resource use, energy carriers	MJ	3.14E+03	3.13E+03	-0.3%	3.16E+03	0.7%
Resource use, min&met	kg Sb eq.	3.85E-05	3.78E-05	-1.7%	4.00E-05	4.0%

Table 29 CML2001 sensitivity results: awning service life.

INDICATOR	UNIT	BASELINE (8 YEARS)	MIN (5 YEARS)	VARIATION (%)	MAX (15 YEARS)	VARIATION (%)
GWP	kg CO_2 eq.	2.38E+02	2.37E+02	-0.1%	2.46E+02	3.4%
GWP excl. biogenic	kg CO_2 eq.	2.37E+02	2.36E+02	-0.1%	2.37E+02	0.3%
ODP	kg R11 eq.	1.83E-05	1.83E-05	0.0%	1.83E-05	0.0%
POCP	kg Ethene eq.	4.67E-02	4.66E-02	-0.2%	4.69E-02	0.5%
Acidification	kg SO_2 eq.	1.04E+00	1.04E+00	-0.2%	1.05E+00	0.3%
Eutrophication	kg Phosphate eq.	7.35E-02	7.34E-02	-0.1%	7.37E-02	0.3%
Human Tox	kg DCB eq.	3.25E+02	3.25E+02	0.0%	3.25E+02	0.0%

Freshwater ecotox	kg DCB eq.	1.74E+00	1.74E+00	-0.1%	1.75E+00	0.4%
Marine ecotox	kg DCB eq.	4.94E+05	4.94E+05	0.0%	4.94E+05	0.0%
Terrestrial ecotox	kg DCB eq.	6.43E-01	6.43E-01	0.0%	6.44E-01	0.1%
ADP elements	kg Sb eq.	9.42E-05	9.29E-05	-1.3%	9.71E-05	3.1%
ADP fossil	MJ	2.80E+03	2.79E+03	-0.3%	2.82E+03	0.7%

As the use phase has on average a not significant contribution, the results' variation according to different use scenarios are not remarkable.

There are only two indicators showing an evident difference:

- EF-Water scarcity: this indicator evaluates the water consumption, thus resulting in a higher score when the service life is longer. This outcome is due to the increase in the overall water use for the awning cleaning (once a year for 15 years vs once a year for 8 years).
- CML-GWP: this indicator evaluates the release of GHGs in the atmosphere. By increasing the awning service life, the use of detergent for cleaning the fabric increase as well. The detergent production is the most significant contributor to the higher score for this indicator in the 15-years scenario.

7 CONCLUSIONS AND RECOMMENDATIONS

The present study was conducted with the aim of quantifying the environmental performance of an outdoor awning made by 100% virgin acrylic. The study is meant to be the baseline for a future comparison with an awning made by recycled acrylic fabric.

The assessment was carried out for 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 highlighted by the analysis are as follows.

The greatest impact derives from the production of the aluminium structure, due to the raw materials extraction and processing: these activities generate significant emissions (e.g. heavy metals) and affect the resource depletion, thus leading to a remarkable impact for most of the environmental indicators. Another key contributor is the acrylic fabric. In particular, the manufacturing of the polyacrylonitrile fibre and of a few chemical agents used in the finishing (i.e. the resins) contribute more than the other parts considered in this step.

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 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.

However, it is good to keep in mind 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 quite representative. As the production processes for both materials is affecting the resource indicator, the environmental performance related to these activities could be favoured by using of recycled material. Starting from resource saving, introducing such an innovation may result in a positive improvement for other impact indicators when some activities are no more taking place due to the recycled material. In fact, some emissions coming from such activities and affecting other environmental indicators could be avoided.

Additionally, the EoL stage could take advantage as well from the recycling of materials and register higher benefits when recycling processes are introduced.

The energy consumption is the other most 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 greater robustness of the study are as follows:

- Introducing a recycling process and a recycle content for the acrylic fabric.
- Obtaining primary data for fabrication of the aluminium structure, or, at least, for the composition. The aim is to get a reliable information about the recycled content of aluminium, to also introduce this improvement in the system.
- Reducing or replace some of the finishing chemicals (e.g. resins)
- Introducing a higher fraction of renewable energy, better if sourcing from certified origin.

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