EuCIA ROK Eco Impact Calculator

Background report

Version 1.0

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January 2023

Building a better working world

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1 Executive summary

EuCIA is the Brussels - based leading Association of the European Composites Industry, representing European National Composite Associations as well as industry specific sectors. Over 10.000 companies and an estimated 150.000 employees are actively involved in composite products manufacturing across Europe.

One of the focus areas of EuCIA is the notion that composites can contribute to a more sustainable society. The best methodology for quantifying environmental impacts of products is a Life Cycle Assessment (LCA).

However, development and use of LCAs in the composite industry is still low but growing in comparison to other material sectors. The official method for executing and reporting LCAs is time consuming, expensive and often data is not sufficiently available: it requires specialized software and expertise as well as independent verification of data and methodology. For small companies this is not affordable, especially as products are very diverse and production series often small. This is the main reason why EuCIA asked EY Climate Change and Sustainability Services (EY CCaSS) in 2014 to develop the EU Eco Impact Calculator tool for composite products.

KCarbon is the governmental industry promotion agency for C-materials and Carbon composites in the Republic of Korea. It was formerly known as KCTECH, which was a R&D Institute for Carbon composites. It focuses on the composites industry with special interest for lowering the CO2 footprint of carbon fiber and other carbon products like graphite, graphene and activated carbon in order to strengthen the competitiveness of its carbon industry.

In 2021, KCarbon expressed its interest to use EuCIA's Eco Impact Calculator for the South Korean composite industry. It was agreed that EuCIA would develop and license a South Korean (ROK) version of the Eco Impact Calculator for KCarbon.

The main objective of the tool is to provide the possibility of making a calculation of the impact of composite products without having specialized knowledge on environmental impact calculations: The tool is designed to enable non-specialists to make an environmental impact calculation of their composite products. The tool calculates the environmental impact of a composite product from cradle to gate, hence including the raw materials, transport, processing and waste generation up to the point-of sale.

To build the Eco Impact Calculator, data on materials and processes were gathered and/or developed. The main materials and processes used by the composites industry were identified, resulting in a list of 42 materials and 8 conversion processes.

The 42 selected materials were matched with available data or modelled using available proxies in LCA databases, such as the EcoInvent (EI 3.8) and ELCD database (ELCD 3); including those developed by Plastics Europe.

The conversion processes are the production processes of composite parts. The production processes are modelled on the basis of primary information of European composites manufacturers retrieved through questionnaires, unless industry was not able to deliver data for the development of the tool. In these cases, where the conversion processes were deemed essential for the development of the tool, these processes were modelled. The ultimate aim of EuCIA is to include at least 15 conversion processes which were identified as representative for the conversion processes used in the composites industry.

In the ROK Eco Impact Calculator tool, users are able to perform calculations by selecting one or more of the materials currently available in the tool, and consequently using these materials as input for the conversion processes. To facilitate the user the tool includes a number of subsequent screens with pull down menus.

The output of the tool is available in an Eco Report (PDF format) which contains the results of the environmental impact calculations in three indicators according to three impact assessment methods: Carbon footprint (kg CO2 eq.), Cumulative Energy Demand (MJ) and ILCD (16 impact categories). Additionally, the tool has the unique functionality of generating a SimaPro CSV file, which can be used by downstream stakeholders to import into their SimaPro LCA software to further facilitate environmental impacts assessments of assemblies containing composite products.

The calculations and modelling used in the tool are based upon LCA standards and guidelines. However, full compliance has been left out-of-scope for this version of the tool, because this is not a requirement for the sector yet. The output is very similar to the so called Environmental Product Declaration (EPD) or Type III Environmental declarations (a way to communicate LCA results in a transparent, dense format). The development of such a declaration is described in ISO 14025. The results of the tool can however not be used as an official EPD, since the approach, methodology and data used for the current version of the tool have not been independently verified.

The tool is made available online (https://k-ecocalculator.eucia.eu) and will be available free of charge until further notice.

2 Introduction

2.1 Background

The composites industry is characterized by a large number of small manufacturing companies that produce composite products in small series or as one-off products. The clients of the composite industry include large multinational companies in sectors such as the automotive sector and composite products are used in large building and infrastructural projects. The suppliers to the composite product manufacturing sector are also mostly large companies.

In all sectors, the pressure on sustainable performance is increasing. National, European (like the EU PEF Guide) and global initiatives promote the development of standards and product specific guidelines. More and more the suppliers of materials and components are asked to come up with detailed information on the Life Cycle performance of their products or components. Industries that produce end products frequently use Life Cycle Assessment (LCA) data to improve the environmental performance of their products. Increasingly information on environmental impacts is used in external communication as well as in supply chains, both up- and downstream. This means the provision of such information is becoming more and more important.

EuCIA is the Brussels - based leading Association of the European Composites Industry, representing European National Composite Associations as well as industry specific Sector Groups. One of the focus areas of EuCIA is the notion that composites can contribute to a more sustainable society. However, development and use of LCAs in the composite industry is still low, but growing in comparison to other material sectors. The official method for executing and reporting LCAs is time consuming, expensive and often data are not sufficiently available: it requires special software and specialized consultants. For a small composite manufacturing company, this is not affordable, especially as products are very diverse and production series often small. This is the main reason why EuCIA initiated the development of an EU Eco Impact Calculator tool for composite products and components in 2014.

At the request of KCarbon (the Korean Carbon Industry promotion agency), EuCIA developed a new version of the Eco Impact Calculator in 2022 for the composite market in South Korea. The main objective of this tool is to provide the possibility of making a calculation of the environmental impact of a composite product without the specialized knowledge on LCAs. The tool calculates the environmental impact of a composite product from cradle to gate. This report describes the methodology and datasets used in the ROK Eco Impact Calculator.

2.2 Initiator

EuCIA represents European National Composite Associations as well as industry specific Sector Groups. More than 10.000 companies and an estimated 150.000 employees are actively involved in composites production across Europe. Their main mission is representation of National Composite Associations, targeting end-segments sectors or potential product groups or processes at EU level. The mission of EuCIA is structured in 3 pillars:

- We Know: industrial education and sharing of best practices
- We Show: being active at EU level and influencing decision making
- We Grow: industrial growth and membership expansion across Europe

KCarbon is a newly launched governmental industry promotion agency for C-materials and Carbon composites in South Korea. It was formerly known as KCTECH, which was R&D Institute for Carbon composites. It focuses on the composites industry with special interest for lowering the CO2 footprint of carbon fiber and other carbon products like graphite, graphene and activated carbon in order to strengthen the competitiveness of its carbon industry.

In 2021, KCarbon expressed its interest to use EuCIA's Eco Impact Calculator for the South Korean composite industry. It was agreed that EuCIA develops and license the ROK version of the Eco Impact Calculator for KCarbon, with the support of EY Climate Change and Sustainability Services (EY), who developed the original Eco Impact Calculator for EuCIA.

2.3 Execution and responsibilities

2.3.1 Steering group

A steering group was set up to guide the development of the ROK Eco Impact Calculator, which consisted of the following persons:

- Roberto Frassine, President, EuCIA
- Raphaël Pleynet, Managing Director, EuCIA
- Jaap van der Woude, Chairman and overall project manager, EuCIA
- Hyeyun Kim, Senior Manager Korea, Eckert Schulen (representative for KCarbon)
- Michel van Wijk, Engagement partner, EY
- Alexander van der Flier, Project leader, EY
- Ramaka Grund, IT project leader, EY
- Matthias Maltha, Project content and management, EY

The steering group was responsible for making operational decisions and monthly meetings were organized to discuss the progress of the project. Based on the input from the steering group, the report was prepared by Alexander van der Flier, Matthias Maltha and Oliver Gibbs under the supervision of Michel van Wijk.

2.3.2 Project team EY

The execution of the project was supervised by the engagement partner Michel van Wijk. The full team of EY who worked on this project consisted of:

- Alexander van der Flier
- Ramaka Grund
- Aldo Quispel
- Matthias Maltha
- Oliver Gibbs
- Michael Fernandes
- Dion Engels

2.4 Project approach

Due to the lack of a (public) composites database in the Republic of Korea (ROK), the EU data in the Eco Impact Calculator was considered to be a good basis for the ROK Eco Impact Calculator. The project approach thus consisted of using input and output data from the European Eco Impact Calculator as used in the period 2015-2021, updating these datasets based on the most recent information in LCA databases, and updating the results based on the latest impact methods. In addition, the datasets were adjusted to align with the regional situation of the Republic of South Korea (ROK) and South East Asia instead of the European context. At this time, no specific input and output data from industry in the Republic of South Korea (ROK) or South East Asia has been gathered and included in the ROK Eco Impact Calculator, but this could be an option for the coming years.

3 Goal and scope

This chapter describes the goal and scope of the project. It also specifies the functional unit and the choices concerning allocation, system boundaries and assessment methods.

3.1 Goal

The goal of this project was the development of the ROK Eco Impact Calculator tool which includes tailor-made datasets for the composite industry in the Republic of South Korea and South East Asia and a report on the LCA methodology and developed datasets. The tool has to provide a reliable calculation of the environmental impact. This means that both the underlying data as well as the way that the data is processed is reliable. EY has selected the best available data and adjusted existing datasets where required. The calculation methods comply with international standards and guidelines. Primary users are the people working at the composite component manufacturers in production, product development and R&D. They have technical knowledge of composites, but limited knowledge on LCA or calculating environmental impacts.

This means that the variables that the users can choose from are all technical, not environmental. The interface is self-explanatory (no- or limited instruction needed) and easy and quick to use. The main objective of the tool is to make a reliable calculation of the environmental impact of a composite part.

The output of the tool will have the quality level that it can be used in downstream LCA assessments and is based on ISO 14040/44. The output is very similar to the so called Environmental Product Declaration (EPD) or Type III Environmental declarations (a way to communicate LCA results in a transparent, dense format). The development of such a declaration is described in ISO 14025. The results of the tool can however not be used as an official EPD, since the approach, methodology and data used for the current version of the tool have not been independently verified.

The target audience of this tool is first of all KCarbon and the parties of interest in the Republic of South Korea. In addition, all composite part practitioners, such as OEMs, academia as well as the public in general, are targeted. The results of this project can be used to supply the users of the tools mentioned above with the company specific data of the composite panel of this study.

3.2 Functional unit

The functional unit (or more precisely the declared unit) of the environmental profile that the ROK Eco Impact Calculator tool will provide is the production of a composite product, with or without core, shaped to its final dimensions and painted if applicable. The products for which the users of the ROK Eco Impact Calculator tool will make an environmental profile have a broad variety in compositions, sizes and shapes. The tool contains environmental data for the production of 1 kg product. By filling out the amounts used, the Eco Impact Calculator will calculate the environmental profile for a specific product.

3.3 System boundaries

The process flow diagram below shows the life cycle phases included in the study and the system boundaries of the life cycle as assessed. The system boundary determines the processes that are included in the life cycle of the product system in this study. The production of the used machines, moulds (also if they are only used once) and use of brushes etc. are not part of the calculation. The assessments are performed cradle to gate, excluding the Use-phase and End-of-Life phase as well as transport to the client. The system boundaries and the included materials and processes for the tool are shown in Figure 1.

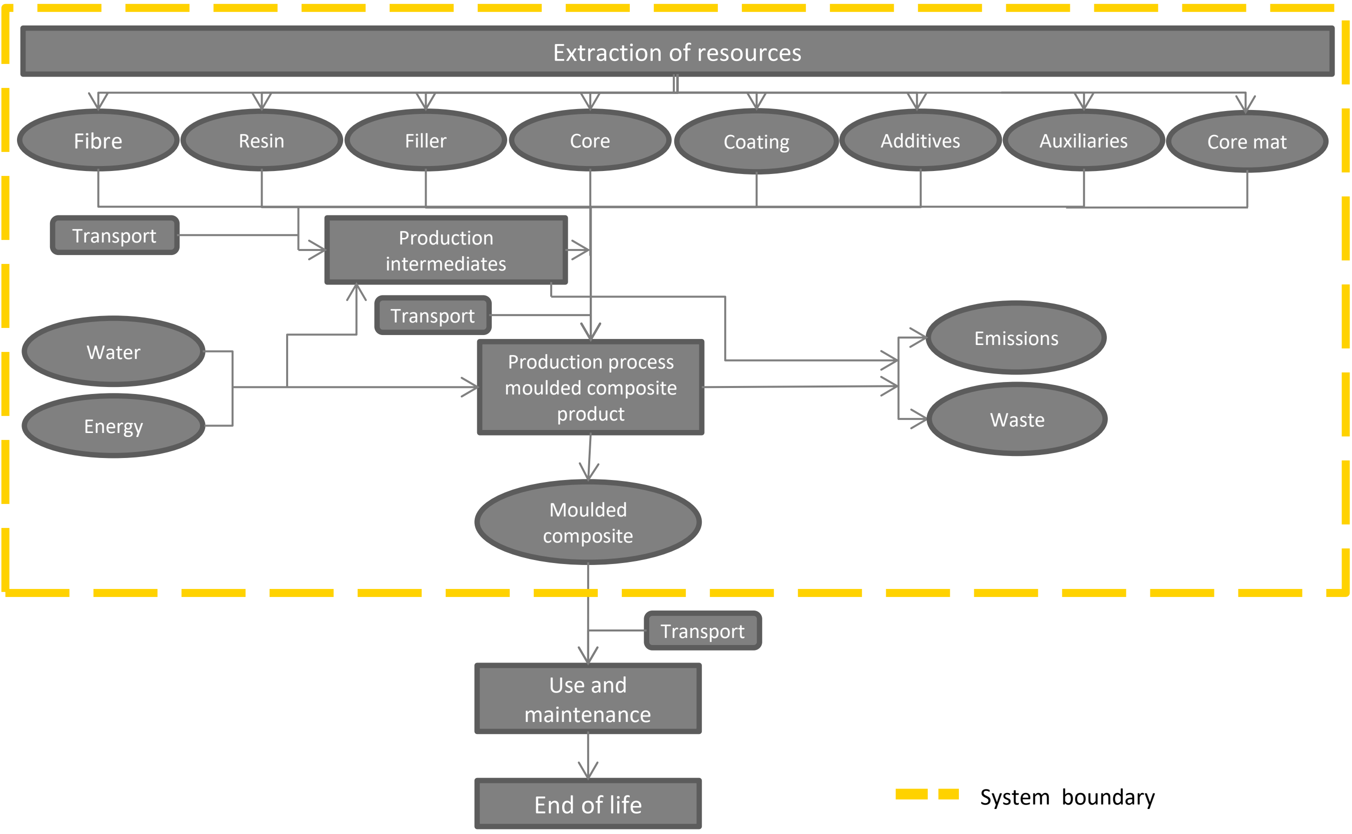

Figure 1: System boundaries for the materials and processes in the ROK Eco Impact Calculator

4 ROK Eco Impact Calculator

This chapter provides background information about the ROK Eco Impact Calculator tool and its calculation methods.

4.1 Structure

The tool is structured in such a way that non-experts can use the tool easily to make environmental impacts assessment of their composite products from cradle to grave. The high-level tool architecture is depicted in Figure 2.

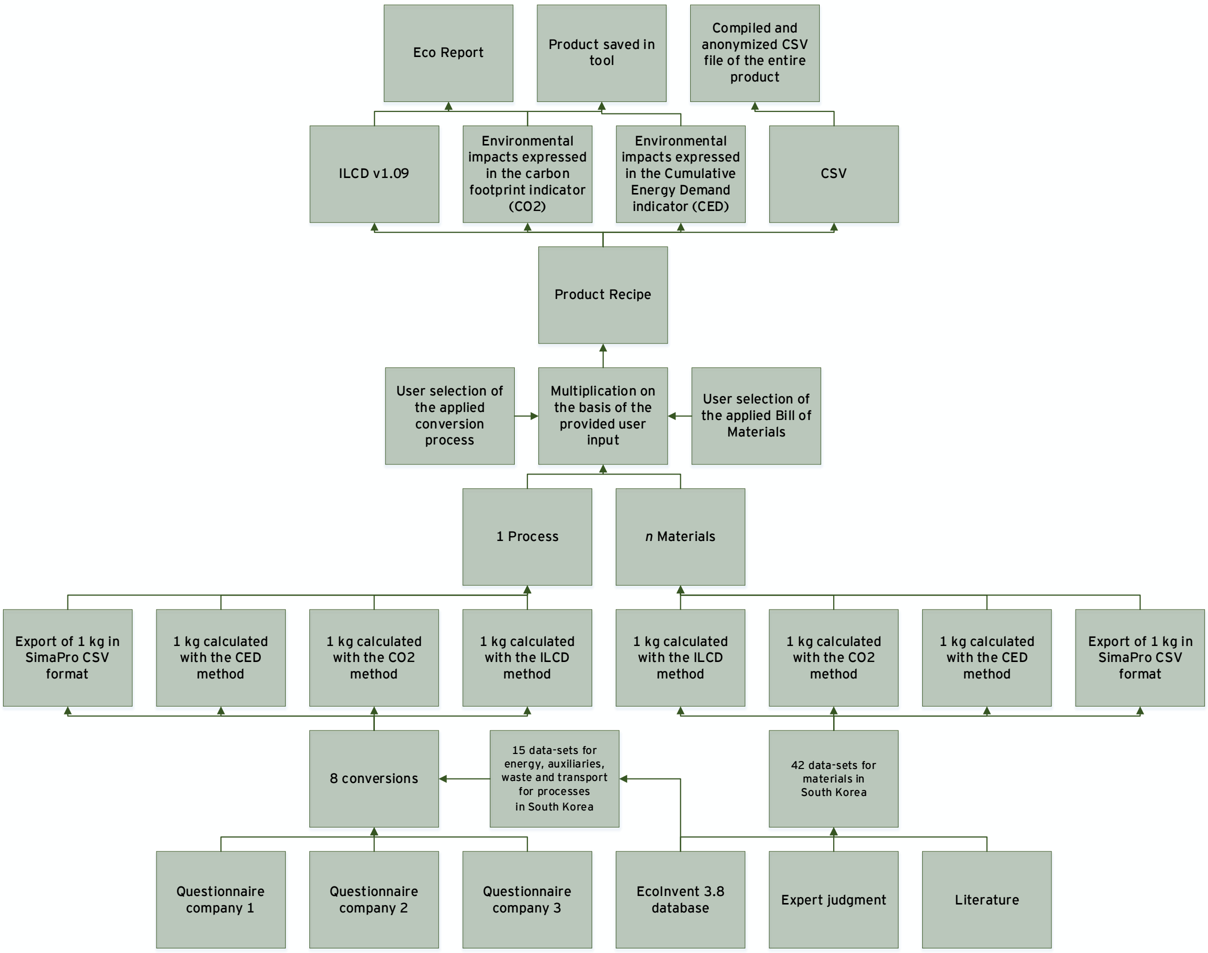

Figure 2: Tool architecture

4.1.1 Input

There are two different types of input for the tool. User input and input data. User input is described as the technical information of composite product manufacturing, and is provided by the users of the tool.

The input data for the tool is two-sided. On the one hand there is the data for the conversion processes themselves, and on the other there is the data on the materials. For the materials, 1 kg is modelled based on the available processes in the EcoInvent database enriched through expert judgement and literature. For some materials, proxy selection was required, of which the details can be found in the Materials Chapter 6. The materials were thereafter run through LCA software for three different assessment methods: The GHG protocol, Cumulative Energy Demand and International Reference Life Cycle Data System (ILCD). The results are transferred to the tool library (materials section). During the data collection process, several decisions are made concerning the materials in consultation with the Steering group. Chapter 6 shows a full list of the available materials in the tool in combination with the related database processes.

For the conversion processes, 17 processes have been identified that are able to cover most of the composite manufacturing. Due to the limitations relating to confidentiality and unexpected low data submission, for 5 processes enough questionnaires or industry data were received to be part of the first version of the tool. 3 processes have been modelled on basis of process analysis for energy and in comparison with existing EcoInvent process data the other impact categories. So in total 15 conversion processes are available in the tool.

The data delivered through the questionnaire is on conversion process factors, such as energy use, waste, emissions excluding the materials, since these are separately provided in the materials database. The units for the data (e.g. kWh electricity) are also pre-calculated through LCA software for three different assessment methods and aligned with the regional context of the Republic of South Korea (ROK) or South East Asia region. The results are transferred to the tool library (conversion processes section), and in the tool are multiplied by the average "score" for each unit to enable the user to calculate the environmental impacts of a specific process. The tool is structured this way in order to allow the user to input their own data as well for any conversion process they like.

4.1.2 Output

The output of the tool consists of an on-screen calculation of the environmental impacts of any product entered in the tool. Additionally users are able to download a PDF Eco Report, describing in detail the environmental impacts and how these are calculated. The products that are entered in the tool are automatically saved for further reference or recalculations.

Special attention is paid to the development of an export functionality. This export functionality is intended to facilitate easy communication of the detailed environmental data without compromising confidentiality, with clients of the composite industry. A SimaPro-CSV file can be generated for each calculated product, which can be imported directly by the client.

4.2 Life cycle inventory

EY has assessed which materials and processes are available in the databases EcoInvent and European reference Life Cycle Database (ELCD) including those developed by Plastics Europe. Besides EY has used the data that EY generated in previous LCA studies in the composite sector. The main objective was to obtain LCI data from EcoInvent where possible, to maximize consistency and comparability within the tool. For the materials for which data is not available, where possible, EY collected, estimated or used proxies

with the help of literature and expert opinions. For each production process EuCIA and EY collected data on the production of a composite product from manufacturers in Europe. The manufacturers have been requested, using a questionnaire, to provide data. At this time no specific input and output data from industry in the Republic of South Korea (ROK) or South East Asia have been gathered and included in the ROK Eco Impact Calculator, but this could be an option for the coming years.
Input and output data are collected on the following categories:

- Use of resources
- Emissions to air
- Discharges to water and soil

The non-elementary flows energy and waste are also included in the data inventory.

4.3 Data quality

The material, waste and energy flows for production processes in Europe are based on foreground data of one year between 2015 and 2022. We used data from EcoInvent 3.8 databases as well as manufacturing data, material data and company specific data. For example, company specific data was used for core mat products and for carbon fibre, a mix of scientific research and manufacturing data was used. Moreover, the conversion process data is relevant for production in the Republic of South Korea with a low voltage energy mix but based on operational data from European manufacturers.

For some essential composite production processes, no industry data was provided to enable the calculation of impacts in the Eco Impact Calculator. This required calculation of several processes, the quality of which is elaborated upon in Section 7.3. For the materials, background data is used as input for the tool wherever possible.

4.4 Allocation

Allocation is the split of environmental flows between two or more products or processes. This occurs with multi-input, multi-output, reuse and recycling processes. However, multi-input and multi-output processes are not part of this study, hence no allocation is used. The end of life stage is not included in this LCA.

4.5 Impact assessment methods

Three environmental impact assessment methods have been selected for this project. Each data point used for calculation of the final product entered in the tool, is calculated according to the following environmental impact assessment methods:

- International Reference Life Cycle Data System (ILCD) ILCD 2011 Midpoint+ (v1.09) V1.09 / EC-JRC Global, equal weighting
- Greenhouse Gas Protocol (v1.02) V1.02 / C02 eq (kg)
- Cumulative Energy Demand V1.11 / Cumulative energy demand

These impacts assessment methods are continuously evolving. Therefore it is recommended to update the calculations upon releases of new impacts assessment methods (e.g. adapted characterisation factors).

4.5.1 International Reference Life Cycle Data System (ILCD)

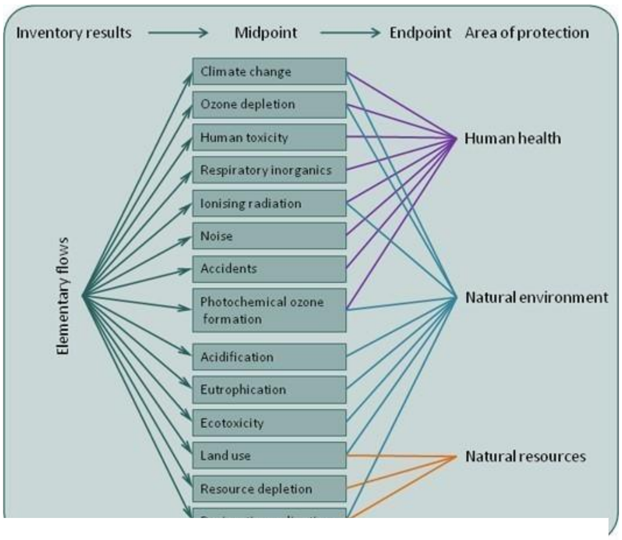

Figure 3

The ILCD provides a common basis for consistent, robust and quality-assured life cycle data, methods and assessments. This so-called Life Cycle Impact Assessment (LCIA) considers multiple impact categories that influence human health, natural environment and natural resources. The emissions and resources derived from a Life Cycle Inventory are assigned to each of these impact categories. They are then converted into indicators using factors calculated by impact assessment models. These factors reflect pressures per unit emission or resource consumed in the context of each impact category.

The development of the ILCD was coordinated by the European Commission and has been carried out in a broad international consultation process with experts, stakeholders, and the general public.

More information can be found on the website of the European Platform on Life Cycle Assessment.

The impact categories included in the Eco Impact Calculator follow the International Reference Life Cycle Data System (ILCD) ILCD 2011 Midpoint+ (v1.09) V1.09 / EC-JRC Global, equal weighting. They are listed below:

Impact category	Unit
Climate change	kg CO2 eq
Ozone depletion	kg CFC-11 eq
Human toxicity, non-cancer effects	CTUh
Human toxicity, cancer effects	CTUh
Particulate matter	kg PM2.5 eq
Ionizing radiation HH	kBq U235 eq
Ionizing radiation E (interim)	CTUe
Photochemical ozone formation	kg NMVOC eq
Acidification	molc H+ eq
Terrestrial eutrophication	molc N eq
Freshwater eutrophication	kg P eq
Marine eutrophication	kg N eq

Impact category	Unit
Freshwater ecotoxicity	CTUe
Land use	kg C deficit
Water resource depletion	m3 water eq
Mineral, fossil & ren resource depletion	kg Sb eq

4.5.2 Cumulative Energy Demand

Cumulative Energy Demand (CED) is the total measure of energy resources necessary for the supply of a product or a service. The CED specifies all non-renewable (i.e, fossil & nuclear energy) and renewable energy sources as primary energy values. Since the very first LCA studies, the cumulative energy demand CED (also called 'primary energy consumption') has been one of the key indicators being addressed. It includes the following impact categories:

Impact category	Unit
Non-renewable (fossil)	MJ
Non-renewable (nuclear)	MJ
Non-renewable (biomass)	MJ
Renewable (biomass)	MJ
Renewable (wind, solar, geothermal)	MJ
Renewable (water)	MJ

4.5.3 Greenhouse Gas Protocol

The Greenhouse Gas (GHG) Protocol is a multistakeholder partnership of businesses, non-governmental organizations (NGOs), governments, and others convened by the World Resources Institute (WRI) and the World Business Council for Sustainable Development (WBCSD). Launched in 1998, the mission of the GHG Protocol is to develop internationally accepted greenhouse gas (GHG) accounting and reporting standards and tools, and to promote their adoption in order to achieve a low emissions economy worldwide. In the Eco Impact Calculator, the following CO2 impact categories are included:

Impact category	Unit
Fossil CO2 equivalent	kg
Biogenic CO2 equivalent	kg
CO2 equivalent from land transformation	kg
CO2 uptake	kg

5 Conversion processes

The conversion processes are the production processes of composite parts. The production processes are modelled on the basis of primary information of European composites manufacturers retrieved through questionnaires, unless industry has not been able to deliver data for the development of the tool. In these cases, where the conversion processes are deemed essential for the development of the tool, these processes have been estimated - see section 5.1.

In 2014, the ultimate aim of EY and EuCIA was to include at least 17 moulding processes which were identified as representative for the conversion processes used in the composites industry. From the received questionnaires, 5 processes could be modelled, since the minimum of received datasets required for incorporation of processes in the tool was set to 3 in accordance with the EuCIA steering committee. The processes were averaged based on the minimum of 3 questionnaires of separate European composite manufacturers using the specific process, to ensure data quality as well as anonymity.

The following 8 processes are currently included in the tool:

- Pultrusion
- Resin infusion (RI)
- Resin transfer moulding (RTM)
- SMC compounding
- SMC compression moulding
- Thermoplastic compounding [1]
- Long Fibre Thermoplastics compounding [1]
- Thermoplastic injection moulding [1]

Painting and gel coating are included in the materials, since the material cannot be applied without these processes. Overhead is not included in the calculations of the tool, rather it is used to enable allocation of remaining inputs and outputs.

The conversion processes that EuCIA still wants to include in the Eco Impact Calculator are:

- Centrifugal casting
- Filament winding
- Spray-up
- Pre-forming
- Pre-preg autoclaving
- BMC compounding
- BMC injection moulding

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[1] Estimated processes based on calculations

5.1 Estimated conversion processes: TP compound, TP Injection moulding and Long Fibre Thermoplastics compounding

For most conversion processes the Eco Impact Calculator development team and partners were unable to obtain data from industry on the production process in- and outputs in the questionnaire developed for this purpose. Therefore, for key industry processes, such as injection moulding, EuCIA has decided to model these processes in the tool using publicly available data and existing datasets in EcoInvent. This section describes how calculations are combined with existing data and datasets to arrive at modelling on first principles basis of the most important conversion processes currently missing in the tool.
These processes are Thermoplastic compounding, thermoplastic injection moulding and LFT. The below paragraphs describe the calculation and modelling approaches for each of these conversion processes frequently used in the European composites industry.

5.1.1 Conversion of Glass Fiber and Thermoplastics into compounds and parts

Conversion of thermoplastic resins and reinforcement fibers and fillers either by extrusion or LFT processes into compounds and consequently by molding into parts are key technologies. Over 90% of the materials used is based on three base resins, polyamide, polypropylene and polyester reinforced with fiber glass, often in combination with small amounts of key additives. These resins as well as glass fiber form the center piece of this analysis.

The Eco Impact Calculator calculates Eco Factsheets for composites and compounds based on industry generated quality data as well as eco inventories in a transparent way following ISO 14040/044 standards. Regrettably in this case industry based data have not come available. This has prompted EuCIA to take a different approach: modelling of the compounding and molding processes on first principles following of course real industry practice. This has been done for energy as thermodynamic data are known for these materials. The result is referenced with data available from EcoInvent that match the processes for compounding and injection molding.

The model for compounding and LFT includes heating and melting of the resins as well as the heating for the glass fiber, followed by cooling of the strand and processing into granulate. For the molding process the energy to heat and inject and the cooling is obtained from literature data. Heat losses and the energy for auxiliary equipment were based on reasonable assumptions. These include higher losses at higher glass content, compensating for the lower throughput. The heat losses for LFT were assumed to be higher as the temperatures are higher and throughputs lower at a given glass content. In all cases the most conservative approach was taken: either the data as calculated i.e. compounding or as in the inventory i.e injection molding, whichever was the highest. The model data were then adjusted as such. This analysis has resulted in some interesting results.

Error! Reference source not found. below presents the total energy data calculated for polypropylene:

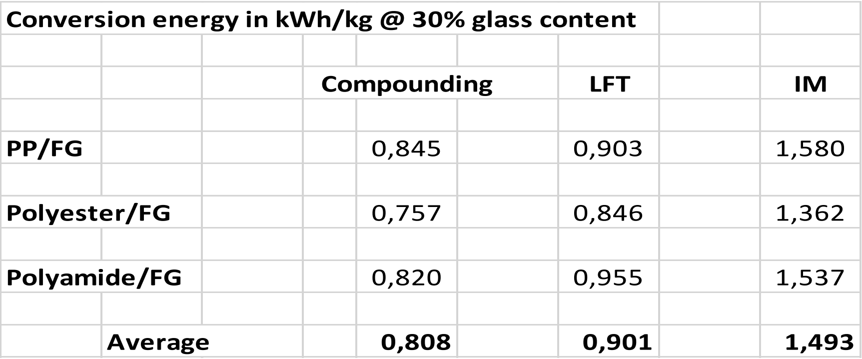
Table 1 Total energy data calculated for polypropylene for the different thermoplastic conversion processes. The amounts for 30% glass fiber content have been applied as energy values in the tool.

	Compounding	**LFT**	**Injection Moulding**		
Fiber content (%)	*Total all electric (kWh/kg)*	*Total all electric (kWh/kg)*	*Total all electric (kWh/kg) extrapolated*	*Total natural gas (m3/kg) extrapolated*	*Total LPG (l/kg) extrapolated*
20	0,864	na	1,4894	0,1339	9,484E-03
30	**0,845**	**0,903**	**1,4783**	**0,1329**	**9,413E-03**
40	0,824	0,887	1,4586	0,1311	9,288E-03
50	0,801	0,866	1,4302	0,1285	9,107E-03
60	0,775	0,841	1,3931	0,1252	8,870E-03
70	na	0,812	1,3472	0,1211	8,578E-03

It can be concluded that the variation in energy needed for each process is very small. For instance for compounding all data lie within +/- 10% of the 30% G/F value. Given this observation it is concluded that only one value for PP compounding suffices in the model given the assumptions in the model itself. Another observation is the small contribution of the conversion process compared to the CED of the resins. The CED for polypropylene, polyester and polyamide are 82, 76, and 132 MJ /kg respectively. The CED for glass fiber is 36 MJ/kg.

Error! Reference source not found. below, shows that the variation between the resins lies close around t he same value. Although different peak temperatures were set (see below) the thermodynamic data seems to compensate for it as well as the use of auxiliary equipment.

Table 2: Total energy per conversion process calculated for three different resin and glass fiber combination.



Conversion energy in kWh/kg @ 30% glass content			
	Compounding	**LFT**	**IM**
PP/FG	0,845	0,903	1,580
Polyester/FG	0,757	0,846	1,362
Polyamide/FG	0,820	0,955	1,537
Average	**0,808**	**0,901**	**1,493**

Our conclusion is therefore that one energy value per conversion process is adequate independent of glass content or resin. As mentioned above these data match the data in EcoInvent for comparable processes very well for energy. It is therefore a reasonable assumption to use the other process data to construct all data for these processes. The appendix explains in detail the above mentioned observations for thermoplastic compounding.

5.1.2 Thermoplastic compounding

In conclusion: Due to the lack of industry data EuCIA has created energy consumption data for key conversion processes through modelling based on first principles and reasonable process assumptions. It has also been concluded that per process one data set suffices irrespective of resin and glass fiber content as can be concluded from the data as modelled. With the above assumptions we use the energy values for thermoplastic compounding at 30% m/m glass content.

For thermoplastic composite compounding [Extrusion, plastic pipes {RER}| production | Alloc Rec] was used as a proxy to obtain the additional process parameters, such as ancillary materials, water use, waste etc. Though EuCIA feels that this approach is adequately supporting the needs for a trustworthy Eco Impact Calculator Tool, we welcome any comment from industry to either confirm or to improve on the proposed data set for thermoplastic processing. The dataset described above is not directly used in modelling, but the input data is used to estimate input parameters for thermoplastic compounding. Since the input data is not expected to have changed significantly, these input values have not been updated using the latest EcoInvent datasets.

5.1.2.1 In more detail: Thermoplastic Compounding

The short fiber thermoplastic compounding process is pictured below.

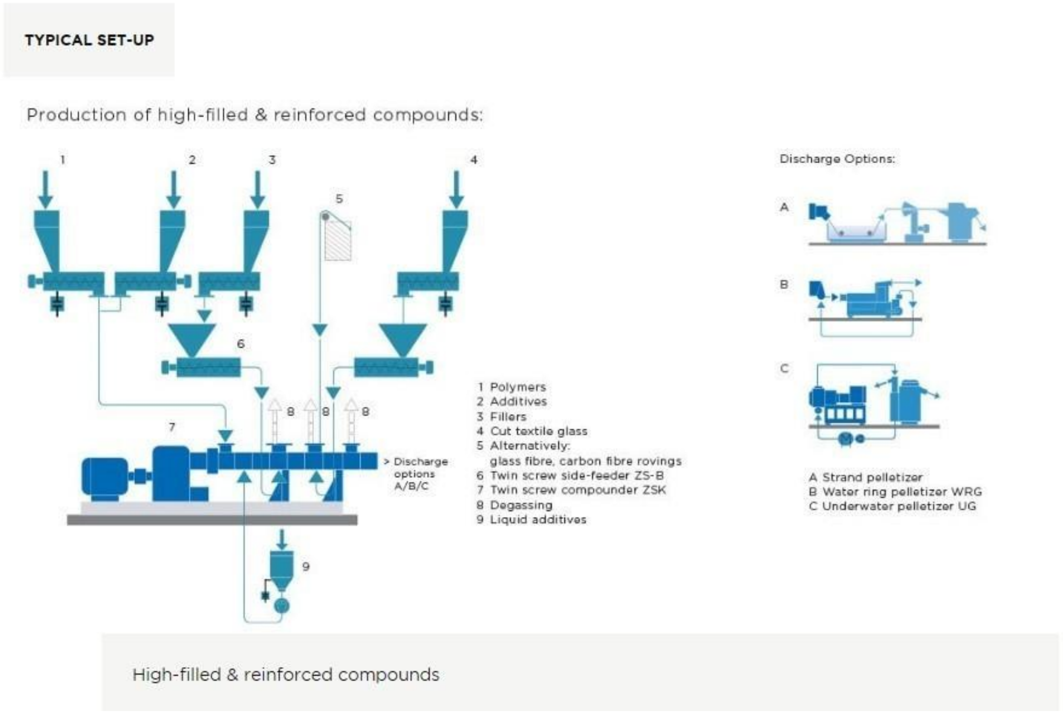


Figure 4 https://www.coperion.com/en/industries/plastics/compounding/

Intertwining screws of proprietary design are driven by a high powered electromotor receiving at various openings the resin, additives and eventually when all is properly molten the fiber glass reinforcements. The latter are added generally as chopped strands and will be reduced to lengths varying from around 200 to 500 microns, depending on conditions, and fully dispersed. The mixture will exit the extruder as strands, immediately water cooled and at a residual temperature of 60 to 90 ºC chopped into granulate. This is the product that is bagged to be shipped to parts producers. Openings in the extruder allow for degassing i.e. water vapor and some volatiles that form during the heating process. Virtually all energy that is used in this process is electrical. The high powered electromotor increases the friction in the resin mixture, increasing the temperature significantly by itself, while the screw housing is heated in various zones to allow the right properties for the granulate. Extruder throughputs can be several or more metric tons per hour to maximize the use of capital invested specifically for the larger volume applications

To allow an estimate for the energy needed for the conversion processes a calculation based on available data from the open literature is performed. This can be seen as a first principles approach, which will form the basis for further estimates for the total energy needed for thermoplastic compounding. In **Error! Reference source not found.** the calculation is shown for heating the resins to their typical extrusion temperatures. From this calculation it becomes clear that the use of a single average coefficient of thermal expansion C_p or two, one for the solid phase and one for the liquid is not resulting in a large difference, reason why the two phase approach is used for further calculations. The total energy of melting is surprisingly identical for these resins and quite higher than the energy needed to heat glass fiber to comparable temperatures. Later we will see that increased content of glass fibers, although affecting extruder throughput will lead to a small reduction in energy needed for higher glass contents by this approach.

NB Although the polyester melting energy is clearly lower, inclusion of the auxilary equipment will make the difference relatively small, justifying the conclusion for one data set for all resins.

Table 3 Detailed overview of the calculation for heating different types of resins to their typical extrusion temperatures. This table does not include energy data related to auxiliary equipment.

Minimum energy need calculation based on thermodynamic data									
	One-step**	**Two-step*****					**Results**		**Cp + melt energy**
	Cp j/K/kg	**Cp solid**	**Cp liq**	**Tm**	**melt energy***	**max extruder T**	**Cp 1-step**	**Cp 2-step**	**total**
		J/K/Kg		C	MJ/Kg		MJ/Kg		MJ/Kg
PP	1800	1640	2139	160	0,207	260	0,432	0,443	0,650
PET	1300	1140	1587	250	0,14	280	0,338	0,310	0,450
PBT		1217	1607	223	0,145	280		0,339	0,484
PA6	1700	1467	2280	220	0,23	280	0,442	0,430	0,660
PA66	1670	1449	2165	264	0,257	300	0,468	0,432	0,689
Fiber glass	840					300	0,235		
	*	http://www.tainstruments.com/pdf/literature/TN048.pdf							
	**	https://www.professionalplastics.com/professionalplastics/ThermalPropertiesofPlasticMaterials.pdf							
	***	http://polymerdatabase.com/polymer%20physics/Cp%20Table.html							

Conversion process energy calculation

A full calculation has to allow for the variability of the glass content, the heat loss during the compounding itself, the cooling of the water used for reducing the strand temperature of the strand, the granulating process as wel as the energy used by the hoppers and the feeding system. As mentioned already estimates have to be made as no industrial data were available. In order not to understate the impact of the conversion process on the eventual composite parts a conservative approach has been followed. In the first place it is recognized that extruder throughput reduces as glass content is increased. In **Error! Reference source not found.** below our assumptions are presented.

Table 4 Assumption of heat loss percentages during thermoplastic compounding for different glass fiber contents.

Assumptions heat loss	
glass %	Loss %
20	40
30	50
40	60
50	70
60	80

As we hope to receive data from industrial parties, we may be able to be potentially more accurate. This holds also true for our estimate for the energy needed to re-use the cooling water. In addition it is estimated that 5% m/m water has to be evaporated, either through pre-drying of the granulate or evaporation. In calculations for injection molding it is assumed that the granulate input then is bone dry. Finally all auxiliary equipment has to be powered, including choppers, pumps, hoppers, etc. For that a fixed amount per kg is included. The calculations for typical 30% m/m glass fiber compounds are presented in **Error! Reference source not found.**.

Table 5 Energy calculations per kg of end product for a typical 30% m/m glass fiber compound. The amount of 0,845 kWh/kg has been used to model thermoplastic compounding.

	One-step***		Two-step**											Cp + melt energy		Glass	loss heating		total before and after 5% water drying@ 80C	Other equipment		Total	
	Cp j/K/kg		Mw	Cp solid		Tm	Cp liq			melt energy	max extruder T	Cp 1-step	Cp 2-step	totaal		30%	50%	60 C	efficiency 80%	Conservative estimate		All electric	
				J/K/mol	J/K/Kg	C	J/K/mol	J/K/Kg		MJ/Kg		MJ/Kg	MJ/Kg	MJ/Kg		MJ/Kg	MJ/Kg	2/3rd by water, 50% efficiency	MJ/Kg	MJ/Kg		MJ/Kg	kWh/Kg
PP	1640		42,1	69	1640	160	90	2139		0,207	260	0,3936	0,44344	0,65044		0,5158	0,2579	**0,6131**	**0,1568**	**1,5**		3,04	**0,845**
Fiber glass	840										260	0,2016											
PET	1300		192,2	219	1140	250	305	1587		0,14	300	0,364	0,34147	0,48147									
PBT			220,2	268	1217	223	354	1607		0,145	300	0	0,37081	0,51581									
average														0,49864		**0,4196**	**0,2098**	**0,5166**	**0,1568**	**1,5**		2,80	0,779
Fiber glass	840										300	0,2352											
PA6	1700		113,2	166	1467	220	258	2280		0,23	300	0,476	0,47579	0,70579									
PA66	1670		226,3	328	1449	264	490	2165		0,257	300	0,4676	0,43157	0,68857									
														0,69718		**0,5586**	**0,2793**	**0,5886**	**0,1568**	**1,5**		3,08	0,856
Fiber glass	840										300	0,2352											

The total amount of energy needed is for all resins about equal and compares well with data available in literature (EcoInvent). With the above assumptions we may assume then that acceptable values for energy use for thermoplastic compounding at 30% m/m glass content have been determined.

For thermoplastic composite compounding [Extrusion, plastic pipes {RER}| production | Alloc Rec.] was used as a proxy to obtain the additional process parameters, such as ancillary materials, water use, waste etc. The dataset described above is not directly used in modelling, but the input data is used to estimate input parameters for thermoplastic compounding. Since the input data is not expected to have changed significantly, these input values have not been updated using the latest EcoInvent datasets.

Dependency on glass content

With a model that seems to provide reasonable results comparable with literature sources, it can be investigated what the effect is of the glass content on the total energy needed. Here a key assumption is provided in **Error! Reference source not found.**. With increased glass content throughputs will be lower t o allow in the first place for less friction and thus fiber degradation, so total energy use will be up. The longer dwell time, be it short, will result in more heat losses. Additional heating around the extruder itself has to be provided. The data in table 2 are estimates as mentioned before, but clearly show our idea of the dependency of energy needed at higher glass content. The other dependencies i.e. cooling,

Table 6 Overview conversion energy for different glass fiber percentages

Conversion energy in kWh/kg										
		glass %		**20**	**30**	**40**	**50**	**60**		**average**
PP/FG				0,864	0,845	0,824	0,801	0,775		0,822
Polyester/FG				0,765	0,757	0,748	0,737	0,725		0,746
Polyamide/FG				0,864	0,820	0,786	0,742	0,693		0,781
										0,783

Hoppers and choppers are assumed identical per kg produced. **Error! Reference source not found.** shows the results. These show that the use of energy decreases slightly with increased glass content, which follows from the original thermodynamic data. We are very well aware that some variation in the use of energy specifically with choppers and other auxiliary equipment may change, but it is a fair assumption that with all the unknowns variations are minor for the conversion of fiber glass reinforced compounds. We assume that the effect will not be largely different either with other fillers like mica, talcum or clay for comparable reasons. Special compounds, especially at the high end for automotive like high temperature resistant applications may require more energy, but the above calculations can give already an indication of the magnitude of that effect.

In summary, the abovementioned analysis supports the conclusion that within the accuracy of all assumptions it is allowed to present one number for the energy of conversion of glass fiber and thermoplastics into compound for three quite different resins and over a broad range of glass contents. This is based on a proper analysis of the underlying thermodynamics for heating and cooling of the materials.

5.1.3 Long Fibre Thermoplastic Compounding

In conclusion: Due to the lack of industry data EuCIA has created energy consumption data for key conversion processes through modelling based on first principles and reasonable process assumptions. It has also been concluded that per process one data set suffices irrespective of resin and glass fiber content as can be concluded from the data as modelled. With the above assumptions we use the energy values for LFT compounding at 30% m/m glass content.

For LFT compounding [Extrusion, plastic pipes {RER}| production | Alloc Rec.] was used as a proxy to obtain the additional process parameters, such as ancillary materials, water use, waste etc. The dataset described above is not directly used in modelling, but the input data is used to estimate input parameters for thermoplastic compounding. Since the input data is not expected to have changed significantly, these input values have not been updated using the latest EcoInvent datasets.

Though EuCIA feels that this approach is adequately supporting the needs for a trustworthy Eco Impact Calculator Tool, we welcome any comment from industry to either confirm or to improve on the proposed data set for thermoplastic processing.

5.1.3.1 In more detail: Long Fibre Thermoplastic Compounding

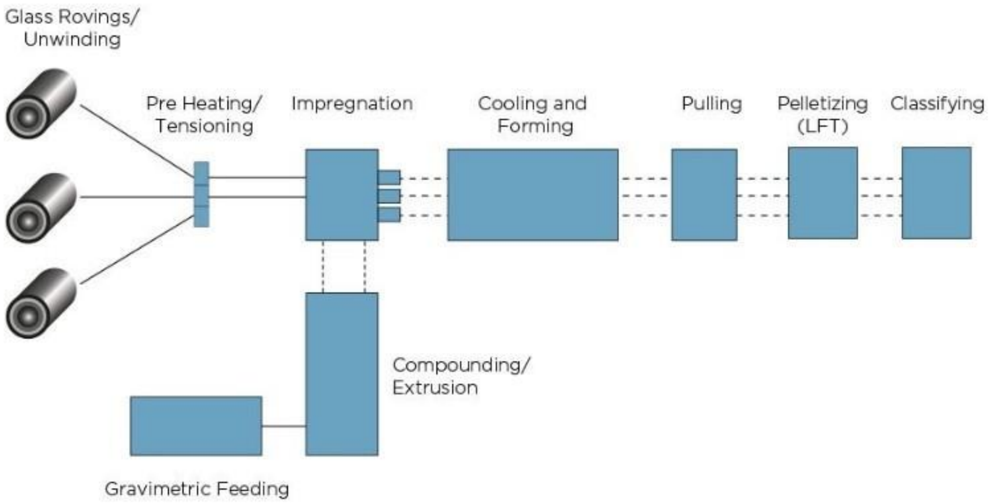


Figure 5 A typical process scheme for LFT processing is shown https://www.coperion.com/en/industries/plastics/lft-long-fiber-reinforced-thermoplastics/

For LFT the same assumptions have been used as for short fiber thermoplastic compounding with two differences. In the first place peak temperatures have been set higher i.e. 300, 360 and 400 ºC for polypropylene, polyester and polyamide respectively. In addition, as mentioned before the heat losses have been assumed higher for the slower process rates. Table 7 shows the assumptions used.

Table 7 Assumption of heat loss percentages during LFT compounding for different glass fiber contents.

Glass % m/m	Heat loss %
30	60
40	75
50	90
60	105
70	120

Auxilary equipment energy is assumed the same as for SF-TP compounding.

5.1.4 Thermoplastic Injection Moulding

In conclusion: Due to the lack of industry data EuCIA has created energy consumption data for key conversion processes through modelling based on first principles and reasonable process assumptions. It has also been concluded that per process one data set suffices irrespective of resin and glass fiber content

as can be concluded from the data as modelled. With the above assumptions we use the energy values for Thermoplastic Injection Moulding 30% m/m glass content. Additional input and output parameters such as water use, ancillary materials and waste are modelled based on the available proxy processes in the EcoInvent database. For thermoplastic composite injection moulding, these additional parameters are based on [Injection moulding {RER}| processing | Alloc Rec], which was used as a proxy. The dataset described above is not directly used in modelling, but the input data is used to estimate input parameters for thermoplastic injection moulding. Since the input data is not expected to have changed significantly, these input values have not been updated using the latest EcoInvent datasets.
Though EuCIA feels that this approach is adequately supporting the needs for a trustworthy Eco Impact Calculator Tool, we welcome any comment from industry to either confirm or to improve on the proposed data set for thermoplastic processing.

5.1.4.1 In more detail: Thermoplastic Injection Moulding

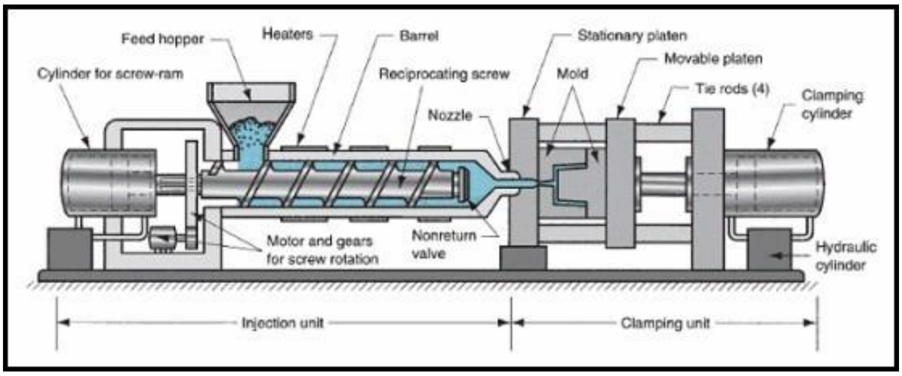


Figure 6 A typical scheme for injection moulding of thermoplastic parts is shown http://www.mechscience.com/injection-moldinginjection-molding-machineinjection-molding-processinjection-molding-on-plastics

Granules are plastisized in a single screw set up driven by an electromotor and heated to the desired temperature. Intermittently the mould, kept at a temperature significantly below the melting temperature of the resin, is being filled. This requires adequate cooling. The screw will contain several shots. For our calculations the same peak temperature is used as for compounding. To estimate the relative energy use for heating, injection and cooling a ratio for energy use of 50, 35 and 15 has been used, based on literature input (http://www.pitfallsinmolding.com/energyeffic1.html). The heating energy calculation is based on the same principles as in Table 8 assuming barrel heat losses as in Table 8. Energy for auxiliary equipment on the same basis as for the above processes has been included, lacking adequate data, while assuming that drying was not needed as it is included in the compounding process.

Table 8 Assumption of heat loss percentages during thermoplastic injection moulding for different glass fiber contents.

glass %	Loss %
20	40
30	50
40	60
50	70
60	80

6 Materials

This section describes the materials that are available in the tool upon release. The amount with which the process impacts need to be multiplied is determined by the amount of material indicated by the users for specific composite parts. All materials have been modelled and calculated for **1 kg.**, unless otherwise indicated. The materials in the tool are modelled using LCA databases, such as the EcoInvent (EI 3.8) and ELCD database (ELCD 3), and is in some cases refined. For some materials, a proxy dataset is used to approach the materials used in the composites industry. The database processes used to model the materials have specific naming, which is provided between brackets: [...]. As a standard Ecoinvent is used as the LCA database unless otherwise described.

The materials that can be selected as input for the calculation of the environmental impacts of the users' products are listed below per material input category.

6.1 Transport

Transport is added to all the materials modelled. It represents the transport of the product from its (raw material) supplier to the next phase in the product life cycle. In this case this is the location where the processing of the material into an end product or intermediate product takes place. For the Republic of Korea the following assumptions for the standard transport scenario are:

- 75% of the composite (raw) materials for the Republic of Korea is produced within the Republic of Korea
  - Transport within Republic of Korea assumes on average of 200 km by truck. The following split is assumed between EURO5 and EURO6 type trucks.
    - 75% of the trucks are EURO6
      - Dataset: [Transport, freight, lorry 16-32 metric ton, EURO6 {RoW}| transport, freight, lorry 16-32 metric ton, EURO6 | Cut-off, S]

    - 25% of the trucks are EURO5
      - Dataset: [Transport, freight, lorry 16-32 metric ton, EURO5 {RoW}| transport, freight, lorry 16-32 metric ton, EURO5 | Cut-off, S]

- 25% of the composite (raw) materials for the Republic of Korea is produced within South-East Asia. For these materials the following transport assumptions are included:
    - Transport from company to train station in South-East of Asia is assumed to be on average 100 km by truck.
        - Dataset: [Transport, freight, lorry 16-32 metric ton, EURO5 {RoW}| transport, freight, lorry 16-32 metric ton, EURO5 | Cut-off, S]

    - Transport from train station to harbour in South-East Asia is assumed to be on average 200 km by freight train.
        - Dataset: [Transport, freight train {CN}| market for | Cut-off, S]

    - Transport from harbour in South-East of Asia to harbour Republic of Korea assumed on average 4.700 km by ship. This distance is estimated based on the assumption that most of the materials are sourced from Malaysia, Singapore and Japan using a sea route calculator going from the port of Singapore to the port of Gunsan. As there are different types of materials in the Eco Impact Calculator a distinction is made between shipping transport for solid materials and for liquid materials.
        - For solid materials: Container ship
            - Dataset: [Transport, freight, sea, container ship {GLO}| market for transport, freight, sea, container ship | Cut-off, S]

        - For liquid materials: Tanker
            - Dataset: [Transport, freight, sea, tanker for liquid goods other than petroleum and liquefied natural gas {GLO}| market for transport, freight, sea, tanker for liquid goods other than petroleum and liquefied natural gas | Cut-off, S]

    - Transport from the harbour within the Republic of Korea to the processing site within Republic of Korea is assumed to be on average 200 km by truck. The following split is assumed between EURO5 and EURO6 type trucks.
        - 75% of the trucks are EURO6
            - Dataset: [Transport, freight, lorry 16-32 metric ton, EURO6 {RoW}| transport, freight, lorry 16-32 metric ton, EURO6 | Cut-off, S]

        - 25% of the trucks are EURO5
            - Dataset: [Transport, freight, lorry 16-32 metric ton, EURO5 {RoW}| transport, freight, lorry 16-32 metric ton, EURO5 | Cut-off, S]

6.2 Fibres

6.2.1 Glass Fibre

This material is modelled using the process [Glass fibre {RoW}| production | Cut-off, S].
The standard transport scenario for solid materials has been added to this dataset. More information on the transport scenario can be found in chapter 6.1.

6.2.2 Carbon Fibre

Overall, at the industry/commercial level and academic level, modelling the production of carbon fibre proves to be a challenge in terms of data availability. At the industrial level, this is due to the fact that such data often remains proprietary. At the academic level, there are only a few key studies with information publically available. For this specific modelling, the data was obtained from several different sources. These included set of researchers from universities such as KU Leuven, Nottingham University, data from the EU level via the European Life Cycle Database (ELCD), and via research conducted from the Institut für Textiltechnik (ITA) of the RWTH Aachen University led by Tim Roeding. The data was consolidated across various sources and when appropriate, averaged if there were multiple options for the relevant input or output. Specifically, this material is modelled using two processes: AN to PAN, and PAN to CF, which are described below in the supplementary information. These processes are representative for carbon fibre production in Europe and used as a proxy also for production in South-East Asia.

When modelling CF production in SimaPro, two general processes are modeled: first PAN production and then the conversion from PAN to CF. Data for raw materials was obtained from the studies of KU Leven, Nottingham University, and a presentation developed by the ITA from Aachen University titled "Carbon Fibre Production: Primary Energy Consumption". Following the research of ITA, a PAN to carbon fibre conversion factor (yield) of 42% was used.

Energy input values for electricity mix of Republic of Korea was created using 1 kwh [Electricity, low voltage {KR}| market for | Cut-off, S]. To model the energy input values of 1 MJ heat in South Korea: [Heat, district or industrial, natural gas {RoW}| heat production, natural gas, at industrial furnace >100kW | Cut-off, S].

Material inputs, which are discussed in the paper from Nottingham University (Meng et al., 2017) include: 2,38 kg [Polyacrylonitrile fibres (PAN), from acrylonitrile and methacrylate, prod. mix, PAN w/o additives EU-27 S] (ELCD LCA database), 2,77 kg [Water, decarbonised {RoW}| water production, decarbonised | Cut-off, S], 0,01 kg [Epoxy resin, liquid {RoW}| market for epoxy resin, liquid | Cut-off, S], and 0,02 kg [Sulfuric acid {RoW}| market for sulfuric acid | Cut-off, S]. Furthermore, from the ITA research, three material inputs were used: 0,1 kg [[Potassium permanganate {GLO}| market for | Cut-off, S], 0,02 kg [Ammonium bicarbonate {RoW}| market for ammonium bicarbonate | Cut-off, S], and 0,01 kg [Polydimethylsiloxane {GLO}| market for polydimethylsiloxane | Cut-off, S]. The last input mentioned is used as a proxy for the raw material silicone oil agent mentioned in ITA's research.

For transport in ROK, the standard transport scenario for solid materials was used. More information on the transport scenario can be found in chapter 6.1.

The primary emissions reported include CO_2 and NO_x gases (Meng et al., 2017). Regarding outputs, 0,63 kg CO_2 and 1,0 kg NO_x of emissions are modelled per 1kg of Carbon Fibre. Nitrogen oxide (NO_x) is modelled as the aggregation of 0,33 kg of Nitrogen monoxide (NO) and 0,67 kg Nitrogen dioxide (NO_2). The pollution abatement systems onsite at plants are not modelled.

6.2.2.1 In more detail: Carbon Fibre

The first process is the production of AN (acrylonitrile) to PAN (polyacrylonitrile) where a polyacrylonitrile precursor is formed via a solvent-based polymerization process (Das, 2011). Specifically, the fibres are obtained by the polymerisation of AN using dimethylformamide (DMF) as a solvent (Duflou et al., 2009). The specific process used to model this is [Polyacrylonitrile fibres (PAN), from acrylonitrile and methacrylate, prod. mix, PAN w/o additives EU-27 S], sourced from RWTH Aachen University led by Tim Roeding.

The two flowcharts show an overview of the inputs/outputs used during the PAN production process. Important for this process is the strength of precursor used. The necessity for using a higher precursor strength will be influenced by what grade of CF is being produced and for what purpose, e.g. automotive, aerospace, advanced aerospace/ satellite. Lower industrial grades used for automotive purposes can tolerate relatively higher impurity for precursor content (Das, 2011).

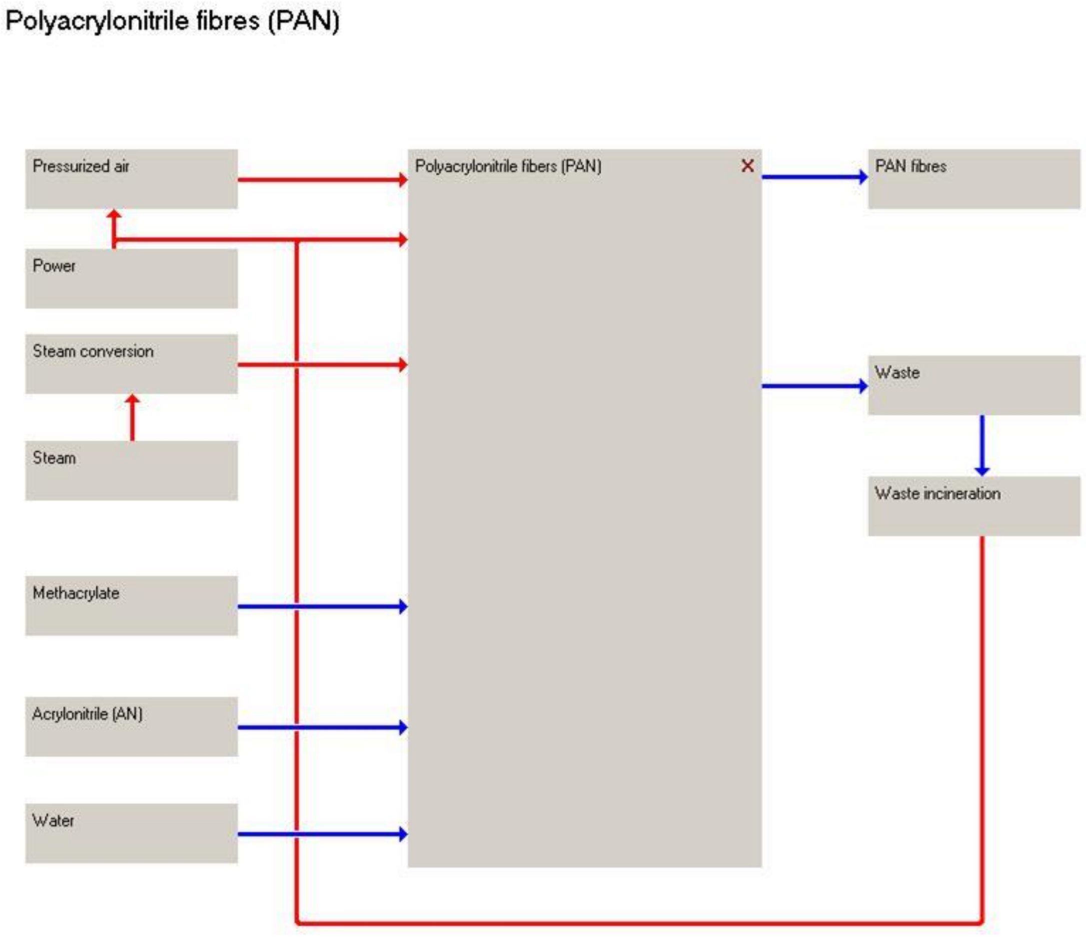


Figure 7: Overview PAN Production (Thinkstep, 2018) (Website: http://gabi-documentation-2018.gabi-software.com/xml-data/processes/db00901a-338f-11dd-bd11-0800200c9a66.xml.)

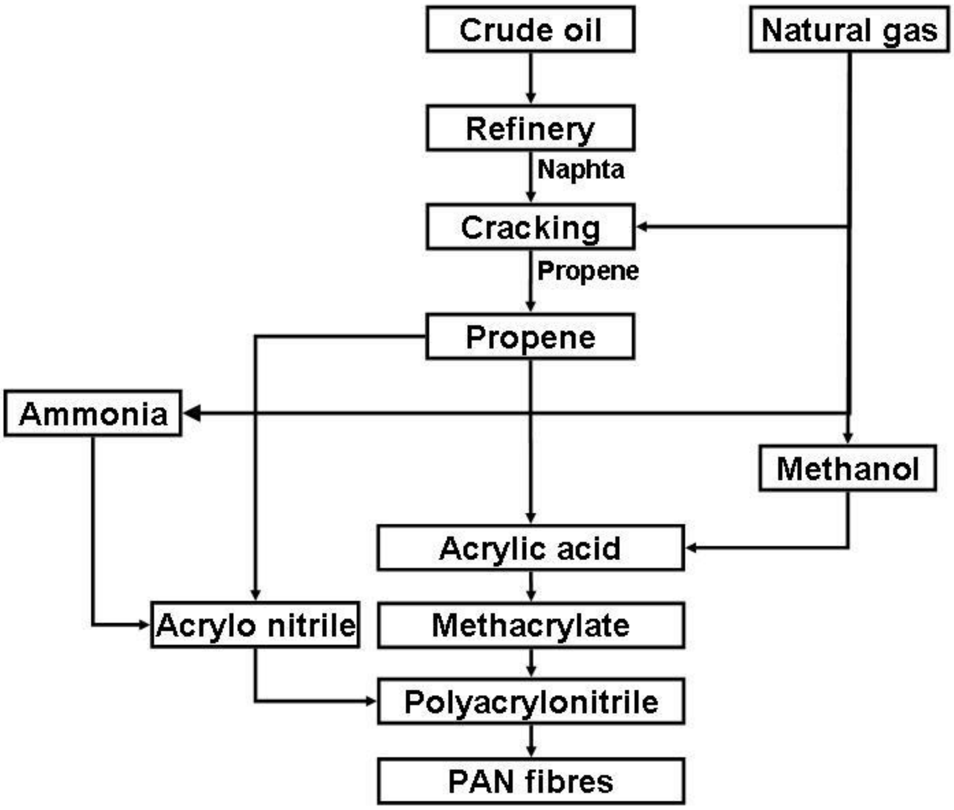


Figure 8: Overview CF Production (Thinkstep, 2018) (Website: http://gabi-documentation-2018.gabi-software.com/xml-data/processes/db00901a-338f-11dd-bd11-0800200c9a66.xml.)

Second is the production from PAN into CF which includes various sub processes. Such sub processes involve the following and are described by Das (2011): oxidation, pre-carbonization, surface treatment, washing, drying, sizing, an additional drying stage, and finally winding. Graphitization is an additional process, but will not be included in this modelling of production of CF as this is less common and is primarily used in university studies. The oxidation stage lasts for a duration of 30 minutes to an hour at a temperature of 300 °C. This sub process consumes the most energy and is exo-thermic, thereby posing risks for combustion onsite at a plant. Next, pre-carbonization occurs for only a few minutes at a high temperature of 1.100 °C, and potential emissions include cyanide and tarry gases. Following is carbonization, operating at two temperature stages: low and high ranging from 300-1.800 °C. The duration of this stage is a few minutes where PAN fibre is pyrolyzed to CF. During this stage, 50-60% of the original PAN weight is lost. In the next stage, surface treatment, this involves an anodic surface treatment bath where carboxyl groups are formed. Thereby improving the cohesion between fiber and resin used in the final composite. Subsequently is the washing stage, where electrolytes are removed via a warm water wash and carbon fibres pass through dip baths with a counter current water flow. Next is drying, where carbon fibre strands are pre-dried before sizing via contact with air and a roller dryer. The material is then sized via a sizing bath including the dispersion of water and expoxy particles. An additional drying stage is followed by the sizing, and finally the last stage is winding, whereby winders produce CF spools up to 12 kg in weight.

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6.2.3 Fabrics

Fabrics made out of the incumbent fibres are not yet included due to lack of data. We would welcome reliable and high-quality data for these materials to be able to integrate these also in the tool, such as:

- Glass Fibre Pre-form
- Glass Fibre Woven Roving
- Glass Fibre Non Crimp Fabric
- Carbon Fibre Fabrics
- Carbon Fibre Non Crimp Fabric

6.3 Resins

6.3.1 PolyAmide Resin (PA)

This material is modelled using 0,5 kg. of the Process [Nylon 6-6 {RoW}| market for nylon 6-6 | Cut-off, S] and 0,5 kg. of the process [Nylon 6 {RoW}| market for nylon 6 | Cut-off, S]. For transport in ROK, the standard transport scenario for solid materials was used. More information on the transport scenario can be found in chapter 6.1.

6.3.2 Polypropylene Resin (PP)

This material is modelled using the [Polypropylene, granulate {RoW}| production | Cut-off, S]. For transport in ROK, the standard transport scenario for solid materials was used. More information on the transport scenario can be found in chapter 6.1.

6.3.3 Polyethylene terephthalate Resin (PET)

This material is modelled using the [Polyethylene terephthalate, granulate, bottle grade {RoW}| production | Cut-off, S]. For transport in ROK, the standard transport scenario for solid materials was used. More information on the transport scenario can be found in chapter 6.1.

6.3.4 Other Thermoplastics Resins

Polybutylene Terephthalate Resin (PBT) was not included in this version of the tool, since no data was available for this material.

6.3.5 Polyurethane Resin (PU)

This material is modelled using 0,55 kg of the [Process [Methylene diphenyl diisocyanate {RoW}| production | Cut-off, S] and 0,45 kg of [Diethylene glycol {RoW}| ethylene glycol production | Cut-off, S]. For transport in ROK, the standard transport scenario for liquid materials was used. More information on the transport scenario can be found in chapter 6.1.

6.3.6 Epoxy Curing Agents

Two types of Epoxy Curing Agents have been included in the tool: Phthalic Anhydride and Ethylene diamine (EDA).

6.3.6.1 Phthalic anhydride

Phthalic anhydride is modelled using the Process [Phthalic anhydride {RoW}| production | Cut-off, S]. For transport in ROK, the standard transport scenario for liquid materials was used. More information on the transport scenario can be found in chapter 6.1.

6.3.6.2 Ethylene diamine

Ethylene diamine is modelled using the Process [Ethylenediamine {RoW}| production | Cut-off, S]. For transport in ROK, the standard transport scenario for liquid materials was used. More information on the transport scenario can be found in chapter 6.1.

6.3.7 Epoxy Resin

This material is modelled using the Process [Epoxy resin, liquid {RoW}| production | Cut-off, S]. For transport in ROK, the standard transport scenario for liquid materials was used. More information on the transport scenario can be found in chapter 6.1.

6.3.8 Isocyanate Resin

This material is modelled using the [Methylene diphenyl diisocyanate {RoW}| production | Cut-off, S]. For transport in ROK, the standard transport scenario for liquid materials was used. More information on the transport scenario can be found in chapter 6.1.

6.3.9 Phenolic Resin

This material is modelled using the Process [Phenolic resin {RoW}| production | Cut-off, S]. For transport in ROK, the standard transport scenario for liquid materials was used. More information on the transport scenario can be found in chapter 6.1.

6.3.10 DCPD-based Unsaturated Polyester Resin (UP)

This material is modelled using the process [Dicyclopentadiene based unsaturated polyester resin {RoW}| production | Cut-off, S]. For transport in ROK, the standard transport scenario for liquid materials was used. More information on the transport scenario can be found in chapter 6.1.

6.3.11 Isophthalic acid-based Unsaturated Polyester Resin (UP)

This material is modelled using the process [Isophthalic acid based unsaturated polyester resin {RoW}| production | Cut-off, S]. For transport in ROK, the standard transport scenario for liquid materials was used. More information on the transport scenario can be found in chapter 6.1.

6.3.12 Orthophthalic acid-based Unsaturated Polyester Resin (UP)

This material is modelled using the process [Orthophthalic acid based unsaturated polyester resin {RoW}| production | Cut-off, S]. For transport in ROK, the standard transport scenario for liquid materials was used. More information on the transport scenario can be found in chapter 6.1.

6.3.13 Pure Maleic Unsaturated Polyester Resin (UP)

This material is modelled using the [Maleic unsaturated polyester resin {RoW}| production | Cut-off, S]. For transport in ROK, the standard transport scenario for liquid materials was used. More information on the transport scenario can be found in chapter 6.1.

6.3.14 Unsaturated Polyester Resin (unspecified) (UP)

This material is modelled using 0,25 kg equal split of four materials: [Dicyclopentadiene based unsaturated polyester resin {RoW}| production | Cut-off, S], [Isophthalic acid based unsaturated polyester resin {RoW}| production | Cut-off, S], [Orthophthalic acid based unsaturated polyester resin {RoW}| production | Cut-off, S], and [Maleic unsaturated polyester resin {RoW}| production | Cut-off, S]. For transport in ROK, the standard transport scenario for liquid materials was used. More information on the transport scenario can be found in chapter 6.1.

6.3.15 Bisphenol A-based Vinyl Ester Resin (VE)

This material is modelled using the process [Bisphenol A epoxy based vinyl ester resin {RoW}| production | Cut-off, S]. For transport in ROK, the standard transport scenario for liquid materials was used. More information on the transport scenario can be found in chapter 6.1.

6.4 Fillers

6.4.1 Aluminium TriHydrate (ATH)

This material is modelled using the Process [Aluminium hydroxide {IAI Area, Asia, without China and GCC}| aluminium hydroxide production | Cut-off, S]. For transport in ROK, the standard transport scenario for solid materials was used. More information on the transport scenario can be found in chapter 6.1.

6.4.2 Calcium Carbonate

This material is modelled using the process Calcium carbonate, precipitated {RoW}| calcium carbonate production, precipitated | Cut-off, S]. For transport in ROK, the standard transport scenario for solid materials was used. More information on the transport scenario can be found in chapter 6.1.

6.4.3 Sand

This material is modelled using the process [Silica sand {RoW}| production | Cut-off, S]. For transport in ROK, the standard transport scenario for solid materials was used. More information on the transport scenario can be found in chapter 6.1.

6.4.4 Talc

For Talc, no exact LCA process could be identified in the LCA databases. Therefore as a proxy, this material is modelled using the process [Feldspar {RoW}| production | Cut-off, S]. For transport in ROK, the standard transport scenario for solid materials was used. More information on the transport scenario can be found in chapter 6.1.

6.5 Cores

6.5.1 Balsa

For Balsa, no process could be identified. Therefore as a proxy, this material is modelled using the process [Glued laminated timber, average glue mix {RoW}| glued laminated timber production, average glue mix | Cut-off, S]. This dataset was in m3. The density of balsa ranges from roughly 60 to 380 kg/m3 as the findings from Borrega et al., (2015) demonstrated. We have used 370 kg/m3 as the conservative figure. To get to 1kg of Balsa we modelled 1/380m3 = 0,00263 m3 of the dataset.
Source: Borrega et al., (2015), Mechanics of balsa (Ochroma pyramidale) wood; doi:10.1007/s00226-015-0700-5.

For transport in ROK, the standard transport scenario for solid materials was used. More information on the transport scenario can be found in chapter 6.1.

6.5.2 Polyethylene terephthalate (PET)

This material is modelled using the process [Polyethylene terephthalate, granulate, bottle grade {RoW}| production | Cut-off, S]. This dataset is used as there is no specific PET core dataset so this is the same as the dataset used for the PET resin. For transport in ROK, the standard transport scenario for solid materials was used. More information on the transport scenario can be found in chapter 6.1.

6.5.3 Polyisocyanurate (PIR)

This material is modelled using the Process [Polyurethane, rigid foam {RoW}| production | Cut-off, S]. For transport in ROK, the standard transport scenario for solid materials was used. More information on the transport scenario can be found in chapter 6.1.

6.5.4 Polyvinylchloride (PVC)

The new dataset has been modelled as 1,004 kg of the process [Polyvinylchloride, suspension polymerised {RoW}| polyvinylchloride production, suspension polymerisation | Cut-off, S] and 1 kg of the process for [Polymer foaming {RoW}| processing | Cut-off, S].

We included 1 kg of foaming, because in the service of foaming, 1 kg of input corresponds to 1 kg of expanded plastics. The converted amount of plastics is not included into this dataset. Thus, it should be used along 1 kg of plastic that can be foamed. In this instance it is included in the PVC material. For transport in ROK, the standard transport scenario for solid materials was used. More information on the transport scenario can be found in chapter 6.1.

6.6 Coatings

6.6.1 Gelcoat

1,02 kg of this material is modelled using 0,75 kg of the process [Isophthalic acid based unsaturated polyester resin {RoW}| production | Cut-off, S], 0,05 kg of [Aluminium hydroxide {RoW}| aluminium hydroxide production | Cut-off, S], 0,05 kg of [Feldspar {RoW}| production | Cut-off, S], 0,05 kg of [Calcium carbonate, precipitated {RoW}| calcium carbonate production, precipitated | Cut-off, S], 0,02 kg of [Chemical, organic {GLO}| production | Cut-off, S], 0.1 kg of Titanium dioxide {RoW}| production was modelled composing of rounded 0,63 kg of [Titanium dioxide {RoW}| production, chloride process | Cut-off, S] and rounded 0,37 kg of [Titanium dioxide {RoW}| production, sulfate process | Cut-off, S].

For transport in ROK, the standard transport scenario for solid materials was used. More information on the transport scenario can be found in chapter 6.1.

6.6.2 Protective Acrylic Urethane

This material is based on data provided by a leading European PAU manufacturer. The exact numbers are confidential, and therefore cannot be disclosed in this report. The modelled protective acrylic urethane consists of the following materials:

- [Xylene {RoW}| production | Cut-off, S],
- [Isopropyl acetate {RoW}| production | Cut-off, S],
- [Polymethyl methacrylate, beads {RoW}| production | Cut-off, S],
- [Butyl acetate {RoW}| production | Cut-off, S],
- [Aluminium sulfate, powder {RoW}| production | Cut-off, S]
- [Methylene diphenyl diisocyanate {RoW}| production | Cut-off, S],
- [Butyl acetate {RoW}| production | Cut-off, S],
- [Naphtha {RoW}| naphtha production, petroleum refinery operation | Cut-off, S],
- [Silica fume, densified {GLO}| silica fume, densified, Recycled Content cut-off | Cut-off, S]
- [Clay {RoW}| clay pit operation | Cut-off, S]
- [Titanium dioxide {RoW}| production
  - composed of 0,63 kg of [Titanium dioxide {RoW}| production, chloride process | Cut-off, S] and 0,37 kg of [Titanium dioxide {RoW}| production, sulfate process | Cut-off, S]

For transport in ROK, the standard transport scenario for solid materials was used. More information on the transport scenario can be found in chapter 6.1.

6.7 Additives

6.7.1 Accelerators

This material is modelled using the processes 1 kg [Chemical, organic {GLO}| production | Cut-off, S]. For transport in ROK, the standard transport scenario for solid materials was used. More information on the transport scenario can be found in chapter 6.1.

6.7.2 Flame Retardants

Two out of four selected flame retardants are represented in the tool. No data was available for brominated polystyrene and antimony oxide.

6.7.2.1 Aluminium TriHydrate (ATH)

ATH is modelled using the process [Aluminium hydroxide {IAI Area, Asia, without China and GCC}| aluminium hydroxide production | Cut-off, S]. For transport in ROK, the standard transport scenario for solid materials was used. More information on the transport scenario can be found in chapter 6.1.

6.7.2.2 Diammonium Phosphate

Diammonium Phosphate is modelled as [Diammonium phosphate {RoW}| diammonium phosphate production | Cut-off, S]. For transport in ROK, the standard transport scenario for solid materials was used. More information on the transport scenario can be found in chapter 6.1.

6.7.2 Peroxide

Peroxide is modelled using the process [Hydrogen peroxide, without water, in 50% solution state {RoW}| hydrogen peroxide production, product in 50% solution state | Cut-off, S]. For transport in ROK, the standard transport scenario for solid materials was used. More information on the transport scenario can be found in chapter 6.1.

6.8 Auxiliaries

6.8.1 Plastic Film

This material is modelled using 1.02 kg [Extrusion, plastic film {RoW}| extrusion, plastic film | Cut-off, S], and a 50/50 split of 1.02 kg [Nylon 6 {RoW}| market for nylon 6 | Cut-off, S and Nylon 6-6 {RoW}| market for nylon 6-6 | Cut-off, S]. For transport in ROK, the standard transport scenario for solid materials was used. More information on the transport scenario can be found in chapter 6.1.

6.8.2 Release Agent

This material is modelled using the process [Chemical, organic {GLO}| production | Cut-off, S]. For transport in ROK, the standard transport scenario for liquid materials was used. More information on the transport scenario can be found in chapter 6.1.

6.8.3 Methyl Ethyl Ketone

This material is modelled using the process [Methyl ethyl ketone {RoW}| production | Cut-off, S]. For transport in ROK, the standard transport scenario for liquid materials was used. More information on the transport scenario can be found in chapter 6.1.

6.8.4 Acetone

This material is modelled using the process [Acetone, liquid {RoW}| production | Cut-off, S]. For transport in ROK, the standard transport scenario for liquid materials was used. More information on the transport scenario can be found in chapter 6.1.

6.9 Core Mats

Core Mats represent non-woven mats volumized with microspheres. The environmental impacts per variant described below are calculated using as a basis a LCA study performed in 2013 by Lantor in cooperation with the University of Utrecht. This data has been updated and adjusted to take into account primary data for 2016 production for the different core mats. The scope of this LCA is from Cradle-to-Gate at Lantor in The Netherlands. The contents of this report are confidential, and therefore cannot be disclosed in this report.

For eight types of core mats the environmental impacts are modelled in the tool. They can be distinguished by thickness and weight per square meter:

Product	Name in Eco Impact Calculator
Soric TF 1.5	Core mat - surface enhancer (t=1,5 mm; 90g=1m2)
Soric TF 2	Core mat - surface enhancer (t=2 mm; 120g=1m2)
Soric TF 3	Core mat - surface enhancer (t=3 mm; 160g=1m2)
Soric XF 2	Core mat - flow medium (t=2 mm; 135g=1m2)
Soric XF 3	Core mat - flow medium (t=3 mm; 180g=1m2)
Soric XF 4	Core mat - flow medium (t=4 mm; 250g=1m2)
Soric XF 5	Core mat - flow medium (t=5 mm; 320g=1m2)
Soric XF 6	Core mat - flow medium (t=6 mm; 345g=1m2)

The modelling choices of the major constituents of Core Mats are PET staple fibres, Microspheres, and Binder, which are described in the following sections below.

For these products, a transport scenario was created for South Korea, taking into account the state of the product. More information on the transport scenario can be found in chapter 6.1.

6.9.1 PET staple fibres

This material is modelled using the process [Polyethylene terephthalate, granulate, amorphous {RoW}| production | Cut-off, S]. Since half of the PET staple fibres are recycled content, the process [Mixed plastics (waste treatment) {GLO}| recycling of mixed plastics | Cut-off, U] was used. This dataset was adjusted to select only PET granulate as the output to technospere ([Polyethylene terephthalate, granulate, bottle grade {RoW}| production | Cut-off, S]) and not all the other plastic materials included in the dataset. For electricity the dataset [Electricity, high voltage {KR}| production mix | Cut-off, S] was used.

6.9.2 Microspheres

This material is modelled using the processes:

- [Methyl methacrylate {RoW}| production | Cut-off, S]
- [Acrylonitrile {RoW}| Sohio process | Cut-off, S]
- [Isobutane {GLO}| market for isobutane | Cut-off, S], but adjusted to remove transport as a specific transport scenario from the supplier has been modelled.
- [Tap water {RoW}| tap water production, conventional treatment | Cut-off, S]
- [Magnesium oxide {RoW}| production | Cut-off, S]
- [2,3-dimethylbutan {RoW}| molecular sieve separation of naphtha | Cut-off, S]
- Fraction 8 from naphtha separation {RoW}| molecular sieve separation of naphtha | Cut-off, S]

6.9.3 Binder

This material is modelled using the processes:

- [Acrylic binder, without water, in 34% solution state {RoW}| acrylic binder production, product in 34% solution state | Cut-off, S]
- [Ammonia, anhydrous, liquid {CN}| ammonia production, steam reforming, liquid | Cut-off, S]
- [Tap water {RoW}| market for | Cut-off, S]

7 Looking ahead

7.1 Methodology

Life cycle assessments are continuing to grow in importance and neccessity as governments continue to create legislation that ensures that non-financial information is reported transparently and accurately, e.g. the EU Taxonomy and the Corporate Sustainabiltiy Reporting Directive (CSRD) on the European level, but also through global voluntuary initiatives such as Science Based Targets initiative. As mentioned in Section 2.1, there are exciting developments on the European level for unified LCA approaches for selected product categories, in particular the Product Environmental Footprint (PEF) project and its pilots which serves as the EU's flagship in this regard.

The importance of data availability for LCAs has long been recognized by the Republic of Korea, as the Korean Ministry of Environment already started developing an open access national LCI database by the mid 1990s[2]. Moreover, the governments of Japan and the Republic of Korea have been closely involved in a United Nations working group where they submitted a proposal to start developing an internationally unified LCA method[3]. During the development of this tool, no PEF Category Rules (PEFCR) or other data quality and methodology requirements were available to the project team for incorporation or consideration in the tool development.

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[2] Source: https://www.mdpi.com/2071-1050/13/11/6234

[3] Source: https://unece.org/sites/default/files/2021-11/GRPE-84-05r1e.pdf

7.2 Data acquisition

The main barrier for full development of the tool is data acquisition from the composite product manufacturers. Even though there have been numerous attempts to retrieve more data, response was lower than expected. In order to address the lack of data, EY has updated the questionnaire. The new questionnaire format can be found here:

Questionnaire-EuCIA.xlsx

The main aim of redesigning the questionnaire is to make it clearer for the companies how and what to fill in.

8 Limitations

An important limitation is the industry data used for the production processes. The production processes are modelled on the basis of primary information of European composites manufacturers retrieved through questionnaires, unless industry has not been able to deliver data for the development of the tool. This industry production data is used as the inputs and outputs in the conversion processes available in the tool. The production in- and output data is delivered by the composite product manufacturers themselves and is not audited at this time. Therefore there is an uncertainty with these data points.

The industry production data used to model the conversion processes is for 1 year of production (of at least 3 companies). It is likely that the environmental impacts of the conversion processes will change over time. If these changes, reflecting innovations implemented by composite product manufacturers, either by own initiative or enforced through increasingly stringent regulation, are not taken into account in the tool, this might jeopardize the reliability of the tool in the future. For now the focus has been on increasing the number of conversion processes and not updating the industry data of currently included conversion processes, but this is important for the future.

Packaging inputs are now included in the hazardous and non-hazardous waste datasets. For some processes the amount of waste is 20% which currently means you also have 20% packaging material. This could be improved.

The transport scenario chosen is too conservative for bulk materials like sand, talc, calcium carbonate. Here the impact of the transport causes a much higher environmental impact per kg of product compared to the old datasets used. Furthermore the tool could benefit strongly from inclusion of the ability to include transport distances of each material supplier that a user has in his company. This would further enhance the completeness and reliability of the tool, although transport is considered quite a minor contribution at this time to the environmental footprint of composite manufacturing.

Data quality is influenced by (amongst other factors) time-representativeness. Both for the process data as well as the materials, the tool should be able to be updated regularly according to new data, progressive insights in existing data as well as assessment methods. As the tool grows, this will increasingly require significant efforts to keep the tool up-to-date and of high quality.

A possible solution for this risk could be the development of an interactive dashboard, where companies can provide the required data as well as its underlying evidence directly in the tool. Using a company dashboard will have the added benefit of easier keeping the tool up to date in the long run and, when the evidence is also audited, increases the confidence in the provided data.