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Life cycle assessment of CFGF – Continuous Filament Glass Fibre Products

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Report prepared for

Glass Fibre *Europe*
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by

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Executive Summary

Glass Fibre Europe, the European Glass Fibre Producers Association commissioned PwC to prepare the following report that presents the cradle-to-gate life-cycle inventory and life-cycle impact assessment results of several continuous filament glass fibre products (direct and assembled rovings, wet and dry chopped strands, as well as chopped strand mats and continuous filament mats). Data were collected from 11 plants based in the European Union, the United-Kingdom and Norway. Companies who took part to the data collection include: 3B the fiberglass company, Saint Gobain-Vetrotex Deutschland, Johns Manville Slovakia, Lanxess nv, European Owens Corning Fiberglass SRL, Nippon Electric Glass.

Continuous filament glass fibre products are mainly used in the reinforcement of thermosetting and thermoplastic resins. These composite materials are used in a wide variety of applications in different sectors and industries such as : automotive and transport, electrical and electronics, as well as in construction. Other markets for composite materials include pipes and tanks, agricultural equipment, industrial machinery, wind-turbine blades and the sports, leisure and marine sectors. The second most important end-use is the manufacture of yarns, which are used in markets similar to those of composites, although clearly for different applications.

The present study is an update of two previous studies performed 10 and 5 years ago. It has been conducted according to the requirements of International Standards (ISO 14040 and ISO 14044). An external critical review was carried out by an independent LCA expert, Dipl.-Ing. (FH) Angela Schindler, who was already in charge of the critical review of the two first studies in 2011 and 2016.

Results show that most of the energy consumption, depletion of non-renewable resources, increase of greenhouse gas emissions, acidification, air emissions of heavy metals come from the glass melting stage. By contrast, downstream process stages, where Continuous Filament Glass Fibre (CFGF) products are adapted so as to correspond to the customer requirements (coating by chemicals, chopping, …) play a limited role on the LCA results. Consequently, the LCA results of the CFGF products studied are only 10-40% apart.

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General introduction

1. Context of the assessment

Glass Fibre Europe, the European Glass Fibre Producers Association, represents approximately 95% of the European production of CFGF – Continuous Filament Glass Fibre.

CFGF has been commercially manufactured and marketed for more than 70 years. During this time, it has become one of the world's most useful and beneficial man-made materials.

Continuous filament glass fibre is produced and supplied in a variety of forms: roving, chopped strand, yarn, mat, fabric, tissue, etc.

The main end-use of CFGF products is the **reinforcement of thermosetting and thermoplastic resins**. These composite materials are used in a wide variety of applications:

- the automotive and transport sectors,
- the electrical/electronics industry,
- the construction industry,
- Other markets for composite materials include pipes and tanks, agricultural equipment, industrial machinery, wind-turbine blades and the sports, leisure and marine sectors.

The second most important end-use is **the manufacture of yarns**, which are used in markets similar to those of composites, although clearly for different applications.

Over the past decade, the improvement of the environmental performance of products across their life cycle has been a growing concern. In the construction sector, the development of "green" buildings has led to an increase in demand for information on the environmental impacts of building products in different EU countries, such as the United Kingdom, France, Germany. Major companies are now heavily involved in product eco-design.

As a growing number of Life Cycle Assessments (LCA) are being carried out for applications of continuous filament glass fibre, Glass Fibre Europe launched a LCA study of the CFGF products, in particular the following five products: **direct roving, assembled roving, chopped strands (dry and wet) and mats (chopped strand mats and continuous filament mats).**

2. Goal of the study

The study aims at obtaining robust LCA results at the European level for several CFGF products, in order to inform manufacturers and users of the environmental impacts of their production. In addition, Glass Fibre Europe intends to publish the results on the European Commission's LCA database, ELCD.

The study is an update of a study published by Glass Fibre Europe in 2016 on the same products and perimeter, which was itself an update of study published in 2011 on direct and assembled roving and chopped strands.

3. Structure of this report

This report presents the methodology applied for the second phase of the project and is structured as follows:

- Sections I and II present the goal and scope of the study;
- Section III presents the assumptions considered and the data collected;
- Section IV presents the results.

Section I - Definition of the assessment scope

1. Methodology used

The present report was produced in accordance with the methodological guidelines developed in ISO standards 14 040 (Environmental Management – Life cycle assessment – Principles and Framework) and ISO 14 044 (Environmental Management – Life cycle assessment – Requirements and guidelines). The *General guide for Life Cycle Assessment* published by the European Commission's Joint Research Centre (JRC) has also been taken into account, in order to comply with requirements for integrating environmental data into the ELCD database.

2. Functional unit and products studied

2.1 Functional unit

The environmental impacts are calculated for a same given service: the functional unit. The functional unit defines « the quantified performance of a product system for use as a reference unit ».

In order to compare various production sites and take into account the manufacturing, the conditioning, and the distribution of the product, the chosen functional unit is: "**Producing 1 kg of CFGF product in Europe**"[1]. The product can be referred to as **dry chopped strands, wet chopped strands, direct rovings** (single end rovings), **assembled rovings** (multi end rovings), **mats** (chopped strand mats, continuous filament mats).

2.2 Presentation of the studied system

The studied system corresponds to the industrial process of CFGF production. This process includes the extraction of resources necessary to produce the components (raw material, energy), the manufacture of the raw materials and the glass fibre product, and the delivery to the glass fibre production site.

Therefore, the analysis is a **Cradle-to-gate** approach: it is an assessment of a product life cycle from the raw material extraction and manufacture ('cradle') to the factory exit gate (i.e. before it is transported to the customer), including the packaging. The use and disposal phases of the product are not covered.

The perimeter of the project includes eleven glass fibre production sites, each producing at least one of the five studied products. *Table 2* in subsection 4 provides more details on the breakdown of products per site.

2.3 Definition of the system boundaries

2.3.1 Cut-off rule

Cut-off rules have been applied to include (or exclude) into the system boundaries the production or the transformation of a raw material, a component, a waste or a by-product:

- **For a raw material or a component:** The inclusion criterion proposed in the ISO 14040 and 14044 standards is the weight. All raw materials and consumable inputs are included so that at least 97% of total inputs are covered. This means that the sum of excluded inputs account for less than 3% of the total mass of the system's inputs.
  ***Note**: glass itself is not considered hazardous and is not mentioned on the SVHC (Substance of Very High Concern) list under the REACH (Registration, Evaluation and Authorization of*

[1] Note: in the context of the Product Carbon Footprint Guideline for the Chemical Industry (version 1, September 2022, Together for Sustainability), the declared unit would be 1 kg of CFGF product, within the cradle to gate approach considered in the project.

Chemicals) regulation. Based on the information received, no CFGF product manufactured by Glass Fibre Europe members contains more than 0.1% (w/w) of products of substance included in the SVHC list as updated on 10 June 2022.

- **For the recycled glass used as a raw material:** in most cases glass is recycled on the CFGF manufacturing site where it was recovered with a view of recycling. In rare cases, plant A (within data collection of this LCA project) recycles its glass waste but provides it to plant B (also included in this project) so that only plant B uses the recycled glass within its processes. In all cases the recycling is considered to happen as a closed loop. The impact of the transformation is accounted for as an input under glass production. The energy consumption and air emissions of the recycling process are included within the study whereas waste glass transport is considered negligible.
- **For the life cycle of a waste or a by-product. The predominant treatment (landfilling) was taken into account**. Incineration was not included as it represents less than 1.8% of waste generated on site and because exact composition of waste to be incinerated was unknown.
- **For energy flows:** whole energy consumption has been included in the calculation, even if the quantities were low.

2.3.2 List of the life cycle steps excluded from the studied system

According to the ISO 14 040 and 14 044 standards, certain operation categories can be excluded from the systems provided, if explicitly stated.

The studied system excludes the construction of the buildings of industrial sites as well as the manufacturing of machines and tools. This general assumption is justified from previous projects where construction of building sites proved to be negligible compared to the environmental impacts directly related to the manufacturing of industrial goods (e.g., raw materials and energy consumption).

It is indeed considered that the environment of each system is stabilized, meaning that the impacts on the environment related to the construction and the demolition of the buildings and the equipment are amortized on the whole utilization period. For example, refractory bricks used for the furnace are amortized over the life span of the furnace, which can reach several decades. As a result, assumed primary energy consumption due to the production of refractory bricks has been evaluated as inferior to 0.1% of the overall impacts of the product life cycle. In addition, bushings have been excluded from the scope of the studied system, although their use may represent an increase of about 10% of primary energy consumed and greenhouse gases emitted.

Note: Environmental data from the Ecoinvent Database (cf. Appendix 2) have been used for most of the generic data sources. Ecoinvent data are representative of raw materials produced in Europe. This database includes the construction of buildings and installations in the calculation of environmental impacts.

2.3.3 Systems boundaries of the production step

This LCA study covers the following glass fibre products:

- Dry chopped strands
- Wet chopped strands (7 to 14 % of humidity)
- Direct rovings (dry products)
- Assembled rovings (dry products)
- Mats (chopped strand mats, continuous filament mats)

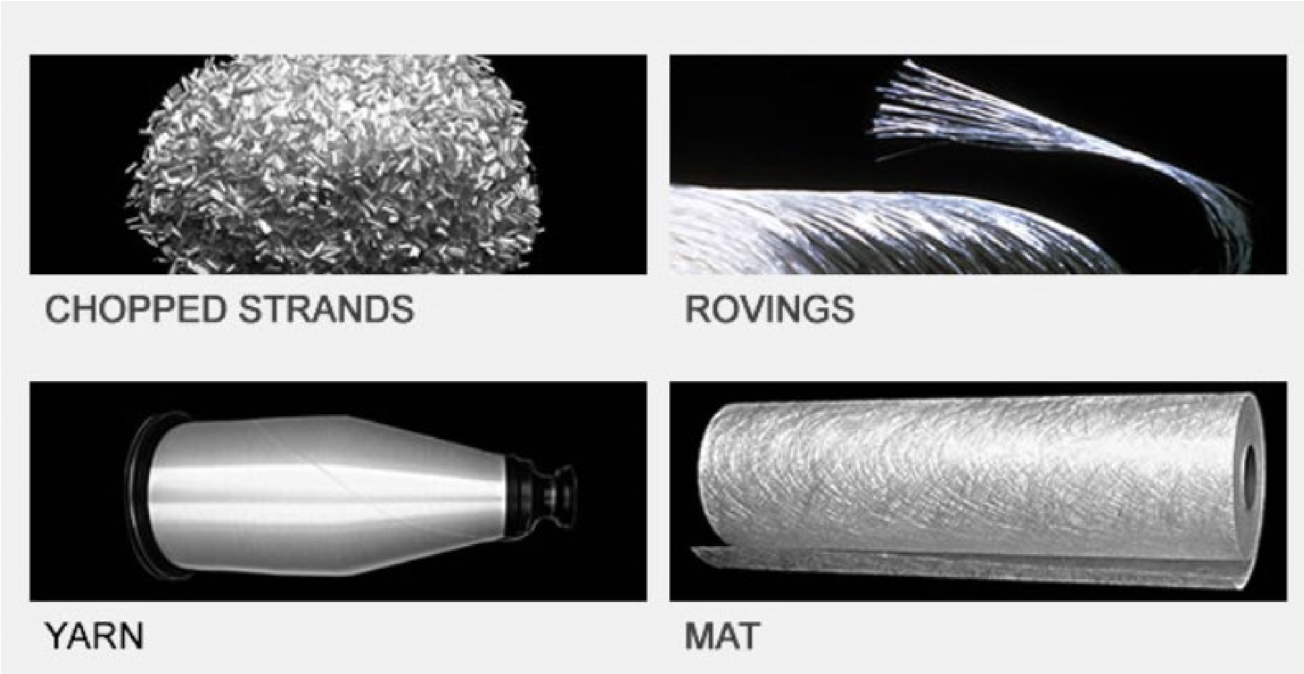


Figure 1 – Chopped strands, rovings and mats
Source: Glass Fibre Europe

It excludes other types of CFGF, e.g. yarns, technical fabrics, etc.

Production process
Continuous Filament Glass Fibres contain silica sand, limestone, kaolin, and dolomite and are produced using the same basic production process. Small amounts of specialty chemicals may also be added.

Raw materials are blended and then melted in a furnace at approximately 1500° C to form molten glass with a uniform controlled viscosity. The molten glass is then drawn through a multi-hole heat resistant precious tray called a **bushing**, which has up to a few thousands of precisely drilled openings through which the glass flows to form thin filaments. The filament's diameter ranges from 5 to 30 µm. They are treated by various chemical and physical processes called "**sizing**", which alter their properties and make them suitable for a wide range of specific reinforcement uses. This sizing, for example, helps to protect the filament during weaving or braiding. It also determines the adherence of the glass fibre to different resins and therefore the quality and properties of the end-use application (e.g. if the end-use application is thermoplastics, the sizing makes it have an affinity for polymers). The type of sizing depends on the further processing (pultrusion, winding, moulding, weaving, etc.).

Figure 2 sums up the main steps considered in the LCA study. This figure explicitly describes which production lines are considered in the scope of the study, as well as the ones excluded. The CFGF manufacturing process is globally divided into **upstream process** (mostly blending of the raw materials and melting in the furnace) and **downstream process** (incl. sizing, forming, chopping, drying, packaging).

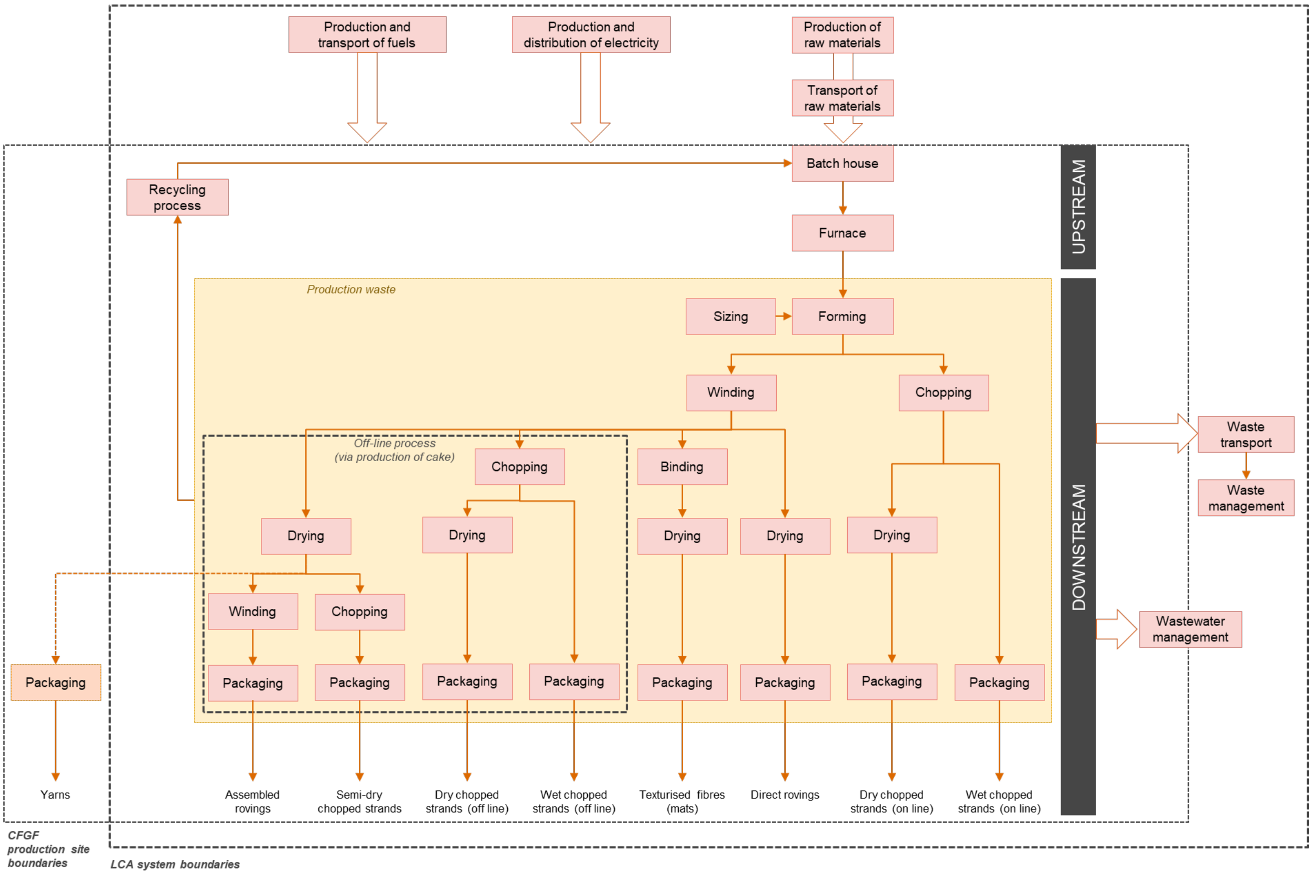


Figure 2 – System boundaries of the data collection in CFGF production sites and LCA system boundaries

Regarding sizing, many different chemical products can be consumed by production sites at this stage. A specific analysis was carried out during the first study (2011) to model this production from a LCA perspective. Seven product families were identified: silanes, film-formers, lubricants, defoamers, surfactants, pH modifiers and starches. For five of these families, a LCA model was developed (silanes, film-formers, lubricants, surfactants, pH modifiers, and starches - see Appendix 2). For defoamers, no model was developed, and the corresponding products are included in the list of products cut-offs from the system (see §2.3.1).

Notes:

- Depending on the sites, wastewater management can be performed fully on site, with possibly an additional treatment from municipal sewage treatment plants or is totally performed off site. In all cases, wastewater is treated before being released to the environment. Wastewater activities performed on site as well as off-site were included in the data collection.
- Transport of raw materials and transport of waste from the production site as well as type of waste treatment considered were also part of the data collection.

2.4 *Allocation methodology for the various products*

The industrial system studied often manufactures several products on a same site. However, only the consumption of resources and the emissions related to the functional unit have to be taken into account.

2.4.1 International standard recommendations

ISO 14 040 and 14 044 standards recommend several solutions classified as follows:

1. Avoid allocations:
   - By collecting data at a more precise level so that it may be possible to follow the steps specifically related to the studied product;
   - By enlarging the system boundaries in order to include co-product production routes.

2. When 1) is not possible, dispatch the flow between the various products by using an allocation rule, which reflects the relations between the flow and the various products
3. When 2) is not possible, dispatch the flow between the various products by using an allocation rule based on economic or physical criteria (weight, energy, etc.)

2.4.2 Allocations performed in the framework of the study

Most sites produce several products for which some parameters cannot be differentiated or be specifically measured on an individual basis: energy consumption, water treatment, air emissions, waste etc.

Thus, when product-specific data were not available, the mass allocation was used for all sites. This consists in allocating a part of the impacts in proportion to the respective mass of the co-products.

Notes:

- in order to compare the results between the different products, all allocations have been calculated on a product weight basis.
- mass allocation was preferred to allocation based on price, in agreement with the ISO 14040 preference order (see §2.4.1). If an allocation based on price had been chosen instead, results would not have been drastically different, as prices of CFGF products are within a relatively narrow range.

In the following table, allocation methods are detailed at each stage of the process.

Table 1 – Allocation rules

Process stage	Type of allocation	Allocation rule (conversion factor)
Furnace and batch house	Mass allocation	weight of specific end-product/total weight of molten glass, i.e., mass-based allocation
Forming – fiberizing – chopping	Mass allocation	weight of specific end-product/total end-products weight
Utilities	Mass allocation	weight of specific end-product/total end-products weight
Sizing	Product-specific data collected or, in case of lack of data, mass allocation with consistency check with previous years' data	In case of mass allocation only: weight of specific end-product/total end-products weight
Drying	Mass allocation	weight of specific end-product/total end-products weight (excl. wet chopped strands)
Packaging	Product-specific data collected or, in case of lack of data, mass allocation with consistency check with previous years' data	In case of mass allocation only: weight of specific end-product/total end-products weight
Water treatment	Mass allocation	weight of specific end-product/total end-products weight
Waste	Mass allocation	weight of specific end-product/total end-products weight

3. Environmental impacts and flows studied

3.1 Environmental flows and energy recovery indicators

All environmental flows (i.e.: water use, emissions of pollutants into the air, water and soil) have been assessed as part of this project. The impact assessment results related to all environmental flows can be examined in the

LCA tables presented in Appendix 1. The flows which have been more precisely identified as significant are the following:

- Natural resources: consumption of oil, coal, natural gas, uranium, and water,
- Emissions into the air: CO_2, CH_4, N_2O, NO_x, SO_x, hydrocarbons and volatile organic compounds, metals, photo-oxidant formation,
- Emissions into water: phosphorus discharge, metals.
- Generation of non-hazardous industrial waste.

Water use refers to the withdrawal of water from water basins or drainage basins to be used in the process. This corresponds to the gross quantity of the total water volume– surface or underground – that is withdrawn from the natural environment for all purposes required in the studied system except water used for cooling in the specific case of electricity produced from thermal reactors. In this specific case, water pumped is brought back to the environment with no alteration in its properties apart from increased temperature.

The generation of non-hazardous waste may correspond to incineration or landfill waste treatment.

Indicators of potential impacts associated with these significant flows are analysed more precisely in section II-3.2 of this report.

In addition to these basic environmental flows, the consumption of total primary energy[2] is also calculated and presented and analysed in section IV-2.

[2] Total primary energy can be divided into non-renewable energy and renewable energy on the one hand, and combustible energy and material energy on the other. The following equation illustrates this definition:
Total primary energy = non-renewable energy + renewable energy = combustible energy + material energy

Combustible energy corresponds to the part of primary energy used by the production processes or transport. It is a quantity of energy that will not be possible to be recover later. Material energy corresponds to the part of primary energy contained in the material (when it can be used as fuel). It is a quantity of potentially reusable energy at the end-of-life period, if there are collection and recovery methods.

3.2 Selected environmental impact indicators

From the resource consumption and environmental flows, the following impact indicators are calculated and analysed:

Indicator	Environmental category	Calculation method
Greenhouse gas emissions of fossil origin (direct, 100 years) Impacts on climate change over a 100-year time frame is assessed using the amount of greenhouse gas emissions, expressed in carbon dioxide equivalent. It specifically takes into account the "fossil" emissions CO_2, N_2O (these emissions are derived, for example, from the combustion of fuel and from natural gas) and CH_4 emissions (for example from the fermentation of dumped waste) but does not take into account CO_2 "biomass" emissions, resulting for example from the combustion of waste in incinerators. The greenhouse effect is expressed in kg eq. CO_2.	AIR	IPCC[3], 2013
Emissions contributing to acidification The acidification impact category represents an increase of acid compounds such as nitrogen oxides and sulphur oxides in the atmosphere. The characterisation factor of a substance is calculated in moles of H+, which can be produced per kg, based on the production of H+ ions once solubilised in water.	AIR	EF 3.0[4]
Photochemical ozone formation (Tropospheric ozone formation) Under certain climatic conditions, the atmospheric emissions from industries and transport can react in a complex way under the influence of solar rays and lead to the formation of photochemical smog. A succession of reactions implicating volatile organic compounds and NO_x, lead to the formation of ozone, a super-oxidizing compound. The potential for the formation of photochemical oxidizers is expressed in kg eq. NMVOCs (non methane volatile organic carbon).	AIR	EF 3.0
Eutrophication, aquatic freshwater Eutrophication is defined as the enrichment of waters in nutritive elements, as a consequence of human intervention. Oxygen depletion is the possible consequence of such enrichment. The characterisation method used by PwC is based on the method selected by JRC for impacts on freshwater, focussing on phosphate rejects. It is based on the capacity of a substance to contribute to algae profusion. This contribution is translated into oxygen depletion taking into account the quantity of oxygen consumed when algae decompose. Characterisation factors are given in gram equivalent phosphorus.	WATER	EF 3.0
Depletion of abiotic resources (minerals and metals) This indicator quantifies the depletion of the environment in terms of its mineral resources. Living resources and their associated impacts such as the disappearance of species or the loss of biodiversity are excluded from this category. This indicator provides more information about the depletion of different subjects than on the impact caused by their extraction from the natural environment. The calculation is made in comparison with estimated remaining stocks and with the consumption rate of the current economy. This indicator is expressed in kg eq. antimony (antimony is a chemical element, atomic number 51). As an example, 1 kg platinum ore corresponds to 2.22 kg eq. antimony, and 1 kg of boron corresponds to 0.00043 kg eq.	RESOURCES	EF 3.0

[3] IPCC: International Panel on Climate Change.

[4] Third version of characterisation factors recommended for Environmental Footprints by the Joint Research Center (JRC), as discussed in "Supporting information to the characterisation factors of recommended EF Life Cycle Impact Assessment methods, Version 2 from ILCD to EF 3.0", Fazio et al., JRC, 2018.

antimony (source: CML).

Indicator	Environ-mental category	Calculation method
Human toxicity, cancer Toxicity is basically defined as the degree to which a substance can damage an organism. For these categories of environmental impacts, it is necessary to determine in detail the emissions then to analyse their impacts. Many of substances can have the potential to damage humans or ecosystems when released to the environment and should thus have characterization factors for the human and ecotoxicity categories of impact. The emission of some substances (such as heavy metals) can have specific impacts on human health. Assessments of effects related to the human toxicity impact category are focused on effects resulting from direct exposure to chemicals. Assessments of human toxicity are based on tolerable concentrations (or "safe doses") in air, water, and on air quality guidelines, tolerable daily intake and acceptable daily intake. The USEtox method is based on a comprehensive comparison of existing Life Cycle Impact Assessment (LCIA) toxicity characterisation models aiming to identify specific sources of differences and the indispensable model components. It was developed to provide Characterisation Factors (CFs) for **human toxicity** and **freshwater ecotoxicity** in Life Cycle Assessment and gives recommended LCIA CFs for more than 1,000 chemicals for these both toxicity impacts. CFs for human toxicity and ecotoxicity account for the environmental persistence (fate), the accumulation (exposure), and the toxicity (effect) of a chemical in the human body or in the ecosystem. Characterization factors are used to obtain the potential impact associated with each contaminant emission. The quantities of contaminants released into the environment during the life cycle are multiplied by these CFs to obtain an **impact score** for human toxicity or ecotoxicity (Jolliet, et al., 2005). The CF for human toxicity is defined as **human toxicity potential** (HTP) and is expressed in **comparative toxic units** (CTU_h in $cases/kg_{emitted}$) providing the estimated increase in morbidity in the total human population per unit mass of a chemical emitted.	HUMAN	EF 3.0 (USETOX 2.0)

Characterisation factors from EF 3.0 for acidification, tropospheric ozone formation, depletion of abiotic resources, eutrophication and human toxicity are those available on the European Platform on Life Cycle Assessment website in November 2019. Characterisation factors for global warming potential are those recommended by the IPCC. The list of characterisation factors used are presented in Appendix 3.

All these impact indicators were selected based on their relevance considering the raw materials and the manufacturing processes involved. The selection was carried out in the first version of the report in 2011, then it was updated in its 2nd version in 2016, and finally the indicators were questioned for the current version in 2022.

The following table summarizes the operational changes in the list of indicators used, as a result of the update of methods carried out between the 2016 and the 2022 LCA studies of CFGF products.

Selected environmental indicator	Change in the definition and coefficients between the 2016 and the 2022 studies
Greenhouse gas emissions	Same method used.
Emissions contributing to acidification	Replacement of CML by EF 3.0. The unit has changed from g eq. SO2 to mol eq. H+, therefore the present results cannot be compared with the previous version of this study. The new indicator is in line with the recommendations of The *General guide for Life Cycle Assessment* published by the European Commission's Joint Research Centre (JRC).
Tropospheric ozone formation	Replacement of CML by EF 3.0. The unit has changed from g eq. ethylene to kg eq. NMVOC (non-methane volatile organic compounds), therefore the present results cannot be compared with the previous version of this study.
Water eutrophication – aquatic freshwater	Replacement of CML by EF 3.0. The influence of nitrogen is now excluded from this impact method, only phosphorus is considered, therefore the present results cannot be compared with the previous version of this study. Marine and terrestrial eutrophication are not considered in this LCA.
Depletion of abiotic resources (elements)	Replacement of CML by EF 3.0. Some variation between the elements included in the impact method makes the comparison between the previous study hardly feasible.
Total primary energy indicator	No change
Human toxicity	The Usetox method has been updated to the version 2.0. Due to the improvements made between the versions 1.0 and 2.0, the present results cannot be compared with the previous version of this study.
Water use	No change.
Solid waste production	No change in definition. Now calculated from the ecoinvent datasets.

A comparison of LCA results between 2016 and 2022 using the same list of indicators used in 2016 is presented in Appendix 1.

3.3 List of excluded indicators

The following indicators have not been selected for the environmental performance assessment of the CFGF products.

3.3.1 Biodiversity

Currently, the consideration of biodiversity in LCA studies is not deemed robust enough. This indicator is usually not included in the existing studies in this field.

Therefore, this indicator has not been selected.

3.3.2 Other PEF indicators

The other indicators from the Product Environmental Footprint (PEF) program of the European Union were not considered relevant for this study. These indicators are:

- Abiotic depletion (fossil), that is close to the fossil component of the total primary energy considered.
- Marine and terrestrial eutrophication, whose sources of impact are similar to those of acidification, based on internal calculations.
- Water scarcity, because the impact on water is captured through the total consumption of water.
- Particulate matter, which is often correlated to global warming potential and acidification potential in terms of order of magnitude and sources of impact.
- Land use, ozone depletion, ionising radiation, human toxicity (non cancer) and ecotoxicity (freshwater), considered as less relevant for CFGF products.

However, those indicators can be calculated from the inventories prepared.

4. Data quality requirements

The purpose of the study is to perform the life cycle assessment of CFGF products. In accordance with the ISO 14 040 and 14 044 standards, the requirements related to data quality cover the following criteria:

- **temporal factor:** the data used need to reflect the **current** situation. Year 2021 has been selected for the project-specific data collection on the CFGF process.
  Note: background data (e.g., raw material and energy production, transport) come from bibliographic data and are usually 5-10 years old.
- **geography:** the data need to be representative of the "cradle-to-gate" process outlined in paragraph 2.2. The production sites we have selected appropriately reflect this process for European CFGF production. Glass Fibre Europe members that took part to the data collection represent 95%[5] of the CFGF production in Europe.
- **technology:** the data have to reflect the current **average technology**. Most of the CFGF production sites in Europe were included in the study.

These factors are observed in the following way:

- The data related to the production of the other raw materials are taken from publicly-available data frequently used in similar LCA projects; these datasets are representative of the European situation or, if this level is not available, of country- or site-specific levels.
- The electricity production has been computed by using country-specific electricity models, or by using models based on specific renewable energy sources when the supply of electricity was covered by a green contract (market based approach).

Table 2 - Coverage per product

	Dry chopped strands	Wet chopped strands	Direct rovings	Assembled rovings	Mats
Number of sites	8	8	7	3	2

For mats, for confidentiality reasons, results are presented as Min-Max intervals that contain the results of the two sites. The average provided correspond to the average of the Min-Max intervals.

[5] Source: Glass Fibre Europe, as a minimum estimation. Only one small producer in Europe, representing less than 5% of the production, did not participate in the study.

Section II - Data collection method and modelling

This section presents the sources of data specifically related to the studied CFGF products and the assumptions considered for calculations of life cycle inventories. References used in this report are listed in Appendix 2.

The TEAM™ software has been used to model systems and calculate life cycle inventories and environmental impacts. TEAM™ is PwC's life cycle assessment tool for products.

1. Data collection method

Two different types of data have been used to model the production of CFGF products.

1.1. Generic data used

Generic data have been used to model:

- the extraction and manufacturing of raw materials for glass production, chemicals for sizing, and water treatment and packaging materials;
- transportation of raw materials and waste (see paragraph 2);
- waste treatment (landfill).

Generic data are derived from the Ecoinvent 3 and ELCD databases (see appendix 2).

1.2. Specific data collection

Site-specific data have been collected by using individual questionnaires, in order to characterize the production processes and their related physical flows:

- raw materials consumption;
- energy consumption (electricity, natural gas, fuel, etc);
- water use;
- water pollutant emissions;
- air pollutant emissions;
- waste generation and their end-of-life;
- water discharged;
- annual molten glass production;
- annual CFGF production (total site and product-specific).

Concerning chemical products for sizing, a great variety of products can be consumed by sites. Considering the limited quantity of these chemicals used as compared to the quantity of glass produced (1.3% on average), they were classified into 6 categories (silanes, film-formers, lubricants, surfactants, pH modifiers, starches). Sites were requested to detail how much of each category was used per CFGF product studied. During the final LCA calculations, one LCI model was considered per product category for manufacturing (see appendix 2).

Data consistency checks were systematically implemented; sites were re-contacted whenever inconsistencies or outliers were detected. These checks included: data completeness, mass balance (consumption of raw materials vs glass production), consistency of values within the sites (breakdown per product and per processing step) and consistency of values between sites. Moreover, values collected for 2021 were compared to 2015 values. Finally, a general rule was applied for missing data: when site-specific data were not available from one or several sites, data from the sites where information was available were used to derive a weighted average. This average value was then applied to the sites where no data were available. This procedure was used for some discharges of water, transport distance and air emissions from sizing.

Eventually, no outlier remained in the datasets collected for the project.

1.3. Data consolidation

All data have been analysed separately, to allocate physical flows to the studied products at the site level. This calculation method can be described as a “vertical” averaging approach:

i. Results from each questionnaire were used to obtain product-specific datasets.
ii. Life cycle inventories (LCIs) have been calculated for each site and for each studied product, so that the calculations resulted in one inventory per product and per site.
iii. The European average has then been calculated from all LCIs referring to the same product, with a weighting for each contributing site corresponding to the annual production volume of the considered product.

2. Transportation of solid raw materials

2.1 Source of generic data used

The transport models by truck, barge and train are issued from the ecoinvent database. The datasets represent the service of 1 ton of product transported over 1 km. They are built on average European journeys, average load factors and average empty trips.

2.2 Transport steps taken into account

The two transport steps taken into account in the study are the raw material transport to the CFGF production site and the transport of waste from the site to the treatment plant.

When no transport data was provided in the questionnaire, an average of the other sites was used per input category as an estimate. One exception was made: the values of a neighbouring site were used because they were considered more relevant than an average of sites located in other countries.

3. Water treatment

In addition to wastewater treatment, some sites are equipped with industrial water treatment plants used to filter the water used for sizing, product cooling or other process stages. Not all sites have data available to track consistently the pollutants emitted into the water. Data quality on emissions to water is limited by the requirement of the sites to track all pollutants. Nonetheless, based on the exhaustive information collected by several sites, the impact of this life cycle stage is negligible, therefore no extrapolation has been performed for sites where detailed information was missing (two sites).

However, two types of water treatment configurations have been identified among the production sites. Some sites operate a treatment plant within their installations and discharge the water into the environment afterwards. These sites have water pollutant data available.
Most sites discharge their water into municipal treatment plants, possibly after on-site treatment. For these sites, water releases to the environment were often not available. In the case of lack of data, a typical abatement rate was applied based on the type of water treatment plant. When site-specific abatement rates were available, they were applied. When no information was provided concerning the water treatment plant, it was considered by default as a physico-chemical water treatment plant, which is a worst-case assumption.

Table 3 – Typical wastewater treatment abatement rates in municipal plants

Type of water treatment plant	Suspended matter	Biological chemical demand – 5 days (BOD_5)	Chemical oxygen demand (COD)	NTK (total org. nitrogen)	Phosphorous
Physico-chemical (default)	80%	40%	40%	10%	80%
Biological	90%	90%	80%	15%	0%

4. Waste management

4.1 Generic waste

In all cases, waste transport from the site to the end-of-life treatment plant has been included, considering the road transport from the site to the treatment or elimination plant.

Depending on the context, the waste produced by manufacturing sites is landfilled, incinerated or recycled.

Impacts of landfilling have been taken into account. When no on-site recycling of glass is implemented, most of the waste produced is landfilled.

Impacts of waste incineration have not been included in the analysis because the nature of the waste was not well defined. Moreover, only a small fraction of waste from the CFGF manufacturing process is incinerated.

Externally recycled waste has been modelled only through the transport of the waste to the recycling facility, while internally recycled waste has not been attributed any impact.

4.2 On-site recycled glass waste

In some cases, more frequently than in 2015, waste glass from the CFGF manufacturing is recycled internally and has been accounted as recovered matter. The corresponding quantity of recycled glass has been accounted as an input raw material to produce melted glass. The impacts of the recycling unit are in the glass production step. mpacts of this recycling step include the energy required to transform the waste into an input raw material and associated air emissions.

When on-site recycling of glass is implemented, recycled glass makes up between 20% and 90% of the total generated waste and represents less than 20% of the raw materials consumed.

5. Electricity production

As a general rule, the consumption of electricity has been modelled on a market-based approach.

When no green electricity supply was claimed by the site, the country-specific electricity mixes have been considered. The ecoinvent LCAs "market for electricity, medium voltage" have been used, which means that the electricity generation in the country, the imports of electricity, and the losses during transport (when relevant) are included in the model. The shares of electricity technologies are valid for the year 2018 and have been calculated based on statistics from 2018: IEA World Energy Statistics and Balances.

When a green electricity contract was in place at the plant, the impact of electricity production has been modelled based on the actual technology of the supplier. Two scenarios have been modelled using the country specific impacts for each technology in the corresponding country: production of hydropower, and production of offshore wind. Evidence of renewable electricity contracts (guarantees of origin) were reviewed and confirmed the whole coverage of the consumption and the source of renewable electricity.

Section III - Results

1. Reading guide

The following section provides the reader with a description of the production stages and specific information regarding the scope. Graphic results are presented for each indicator.

Five key steps are identified for a CFGF product over its “cradle to gate” life production cycle. For the sake of readability, charts and graphs use shortened labels to present the following steps:

- **Total**: complete cradle-to-gate impact
- **Glass production**: upstream production of molten glass (production and consumption of energy, water use, raw materials extraction, including the production and transport of raw material components for glass formulation) and other marginal energy consumptions not included in the next steps.
- **Sizing**: production and consumption of energy, production and transport of raw materials.
- **Downstream process (excluding sizing):** forming, chopping, drying, packaging and utilities: Production of CFGF end-product (production and consumption of used energies, water use, raw materials).
- **Waste and wastewater treatment plants**: Transport of solid waste to treatment plant and landfilling, production and consumption of energy used for water treatment (for both water usage and water release), water use, waste and wastewater generation, production and transport of processing chemicals used during the water treatment.

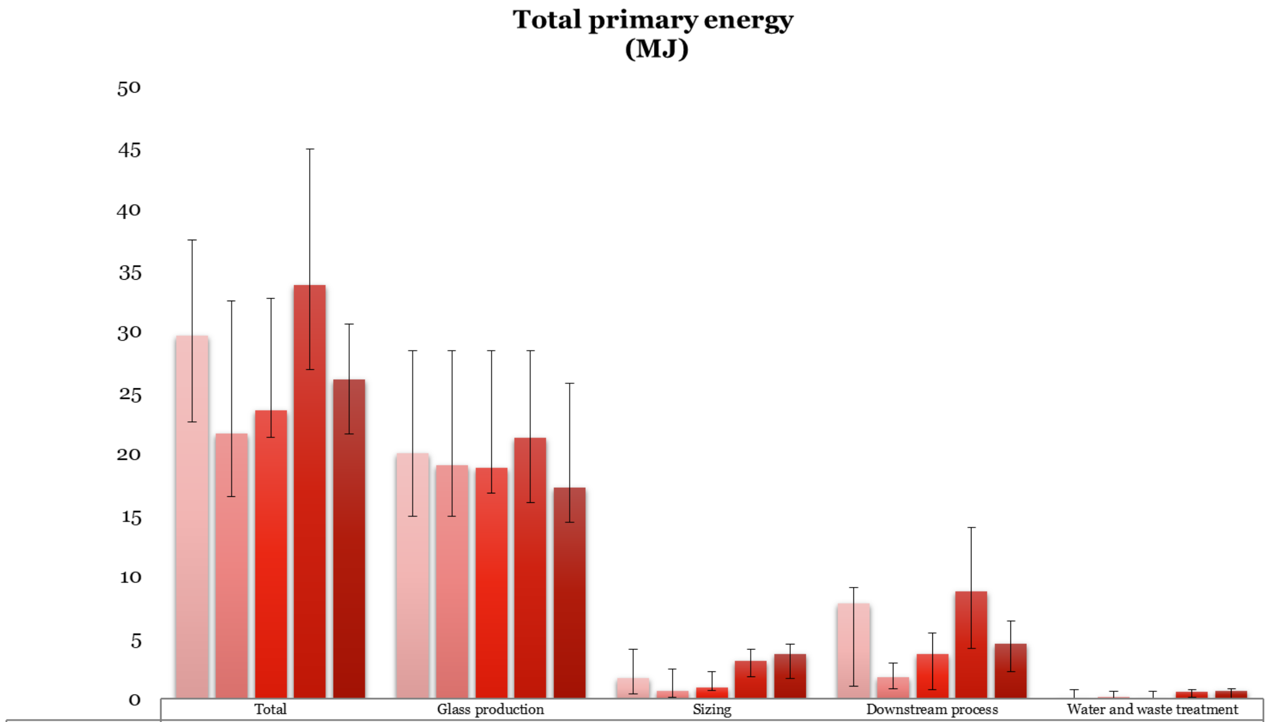
The following sections present the environmental impacts of producing 1 kilogram of CFGF product available at the factory gate.

The error bars on the graphs represent, for all products except mats, the minimum and maximum values observed on the products from all the different sites where data was collected. For mats, for confidentiality reasons, the minimum and maximum values were determined based on the two site values obtained and on the dispersion of values observed for the other CFGF products. The average values for mats represent the middle of the min and max values.

When averages on glass fibre products are provided, they consist in weighted averages that take into account the production tonnage of each product category.

2. Natural resources consumption

2.1 Total primary energy



	Total	Glass production	Sizing	Downstream process	Water and waste treatment
Dry chopped strands	29.6	20.1	1.7	7.8	0.1
Wet chopped strands	21.6	19.1	0.6	1.8	0.1
Direct rovings	23.5	18.9	0.9	3.7	0.1
Assembled rovings	33.8	21.3	3.1	8.8	0.6
Mats	26.0	17.3	3.7	4.5	0.6

Figure 3 – Total primary energy consumption (MJ)

On average, 26.6 MJ of primary energy are consumed to produce one kilogram of CFGF product, of which 72% is due to the glass melting process (extraction and transport of raw materials, furnace consumptions). Although primary energy is mostly consumed at the furnace stage, a significant part (22%) of energy is consumed during the downstream process, mainly for drying and by utilities.

When examining in detail the contributions within the molten glass production stage, the consumption of natural gas and oxygen in the furnace accounts for 60% in average of this energy consumption. This significant contribution of upstream energy to the energy demand of molten glass production is depicted in Figure 4. The second highest contributing stage is the raw material production stage, which accounts for 20%.

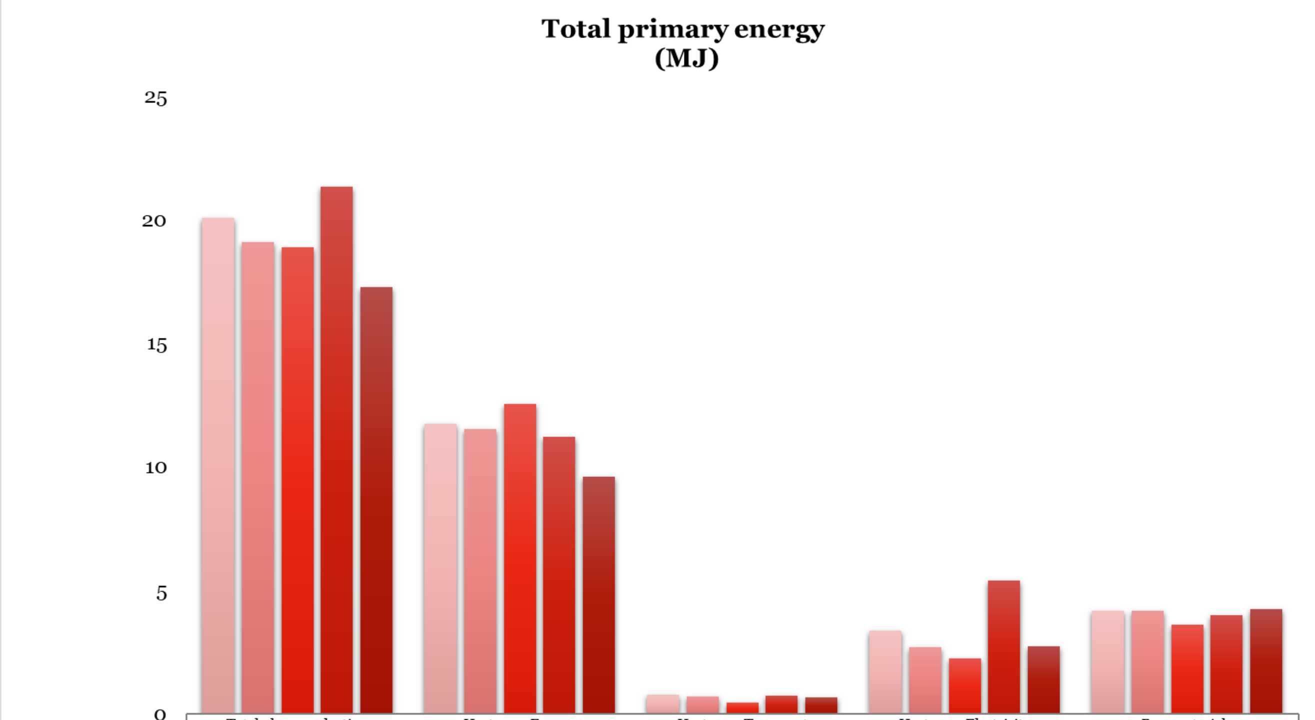
Note: When on-site energy consumption was not available according to the breakdown of the process stages (this happened for several sites), all energy consumption was allocated to the glass production. This explains why the minimum values for the sizing, downstream processes and waste and water treatment can be close to zero.

Figure 3 shows the difference between wet and dry chopped strands, primarily due to the higher amount of energy required for drying. Wet chopped strands have a total primary energy consumption 27% lower than dry chopped strands.

On average, 15.0 MJ of primary energy (including fossil fuel production and combustion as well as electricity consumption) is consumed in the furnace[6].

[6] Note: this mean value is in the mid-range given by the BREF on the glass manufacturing industry (2013) of 7 – 18 MJ. However, please note that the BREF value is not a primary energy value.

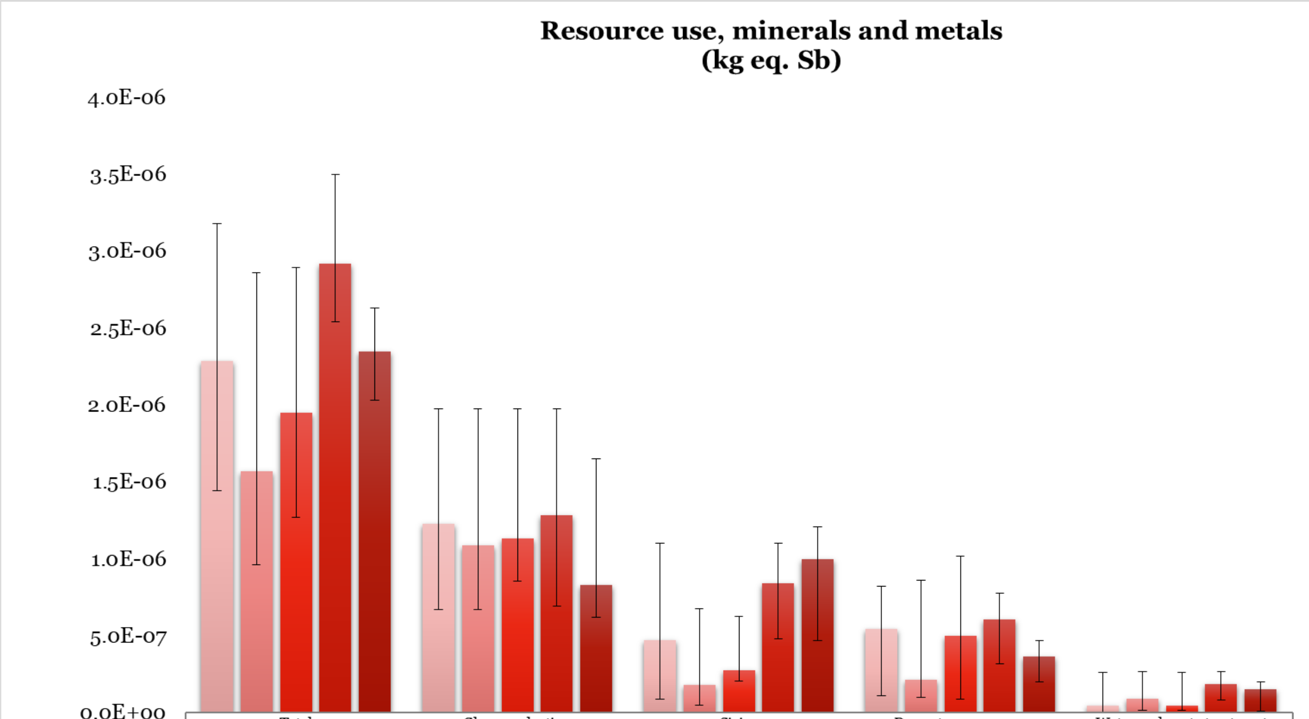
Note: as explained in §2.3 (section II), the calculations performed do not include production of the bushings, a capital equipment made of precious metals. Including this consumption would increase both energy consumption and greenhouse gas emissions by about 10%.



	Total glass production	Upstream Energy	Upstream Transport	Upstream Electricity	Raw materials
Dry chopped strands	20.1	11.7	0.8	3.4	4.2
Wet chopped strands	19.1	11.5	0.7	2.7	4.2
Direct rovings	18.9	12.5	0.5	2.3	3.6
Assembled rovings	21.3	11.2	0.7	5.4	4.0
Mats	17.3	9.6	0.7	2.7	4.2

Figure 4 – Total primary energy consumption breakdown for glass production

2.2 Natural resources depletion



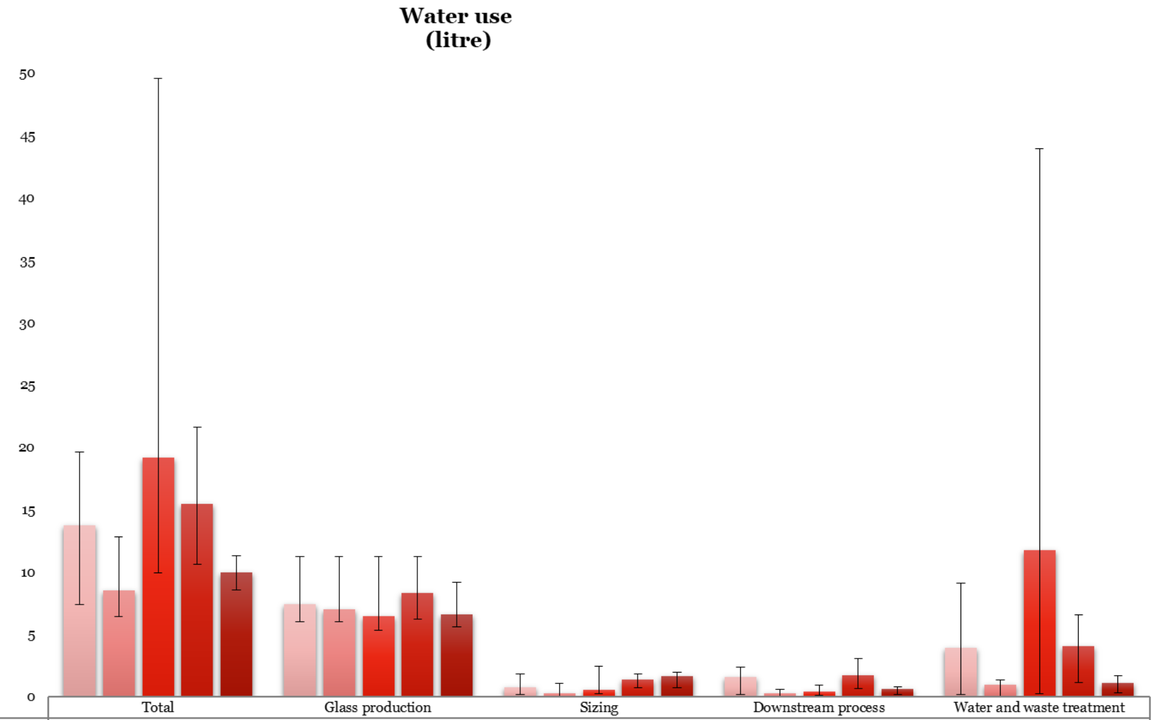
	Total	Glass production	Sizing	Downstream process	Water and waste treatment
Dry chopped strands	2.3E-06	1.2E-06	4.7E-07	5.4E-07	4.5E-08
Wet chopped strands	1.6E-06	1.1E-06	1.8E-07	2.2E-07	9.0E-08
Direct rovings	2.0E-06	1.1E-06	2.8E-07	5.0E-07	4.7E-08
Assembled rovings	2.9E-06	1.3E-06	8.4E-07	6.1E-07	1.9E-07
Mats	2.3E-06	8.3E-07	1.0E-06	3.7E-07	1.5E-07

Figure 5 – Abiotic depletion potential - elements (kg eq. Sb)

Abiotic resources depletion is mainly due to raw material consumption at the glass production stage which includes the upstream production of molten glass (i.e., production and consumption of energy, and raw materials extraction, including the production and transport of raw material components for glass formulation). The consumption of chemicals at the sizing phase also contributes to the impact on abiotic depletion, especially for assembled rovings and mats.

Note: due to a change in the underlying LCA model for raw materials and energy, and to an update of the impact characterization factors, the current results cannot be directly compared with those of the previous study. A comparison between 2016 and 2022 LCA studies is performed in appendix 1.

2.3 Water use



	Total	Glass production	Sizing	Downstream process	Water and waste treatment
Dry chopped strands	13.7	7.4	0.8	1.6	3.9
Wet chopped strands	8.5	7.0	0.3	0.3	1.0
Direct rovings	19.2	6.5	0.5	0.4	11.8
Assembled rovings	15.5	8.3	1.4	1.7	4.1
Mats	10.0	6.6	1.6	0.6	1.1

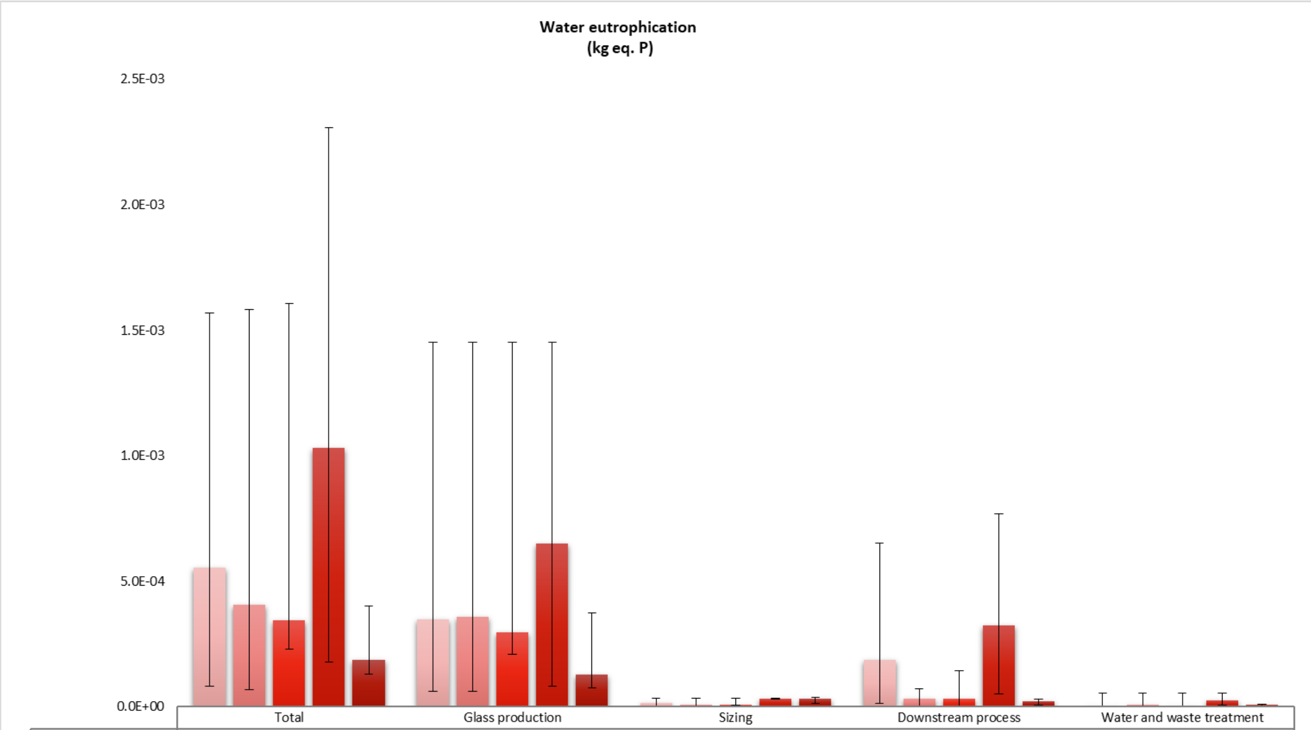
Figure 6 – Water use (litre)

On average, producing one kilogram of CFGF product consumes 15 liters of water. It is drawn mainly from rivers, wells and public water networks.

Among the water consumed at the glass production stage, more than two thirds is required for the production of raw materials.

As for the water consumed on-site, the ratio of water consumption ranges between 2 and 44 liters per kg of finished product, with an average at 8 liters per kg. Such high dispersion of water management practices among sites is mostly observed among direct roving producers, as observed in Figure 6 at the water and waste treatment stage.

3. Eutrophication, freshwater



	Total	Glass production	Sizing	Downstream process	Water and waste treatment
Dry chopped strands	5.55E-04	3.49E-04	1.48E-05	1.88E-04	3.27E-06
Wet chopped strands	4.07E-04	3.59E-04	7.14E-06	3.20E-05	9.16E-06
Direct rovings	3.44E-04	2.98E-04	8.76E-06	3.14E-05	4.93E-06
Assembled rovings	1.03E-03	6.51E-04	3.32E-05	3.24E-04	2.49E-05
Mats	1.88E-04	1.27E-04	3.07E-05	2.21E-05	7.52E-06

Figure 7 – Eutrophication, freshwater (kg eq. P)

The eutrophication of freshwaters happens when phosphorus is released into waters and soils, and in the case of CFGF, the main contributor concerns phosphate into waters.

The source of eutrophication lies mainly in the production of electricity, and to some extent in the production of oxygen and in the upstream extraction and processing of raw materials. That is why 70% of the impact comes from the glass production stage, and 26% comes from the downstream process where electricity is also consumed.

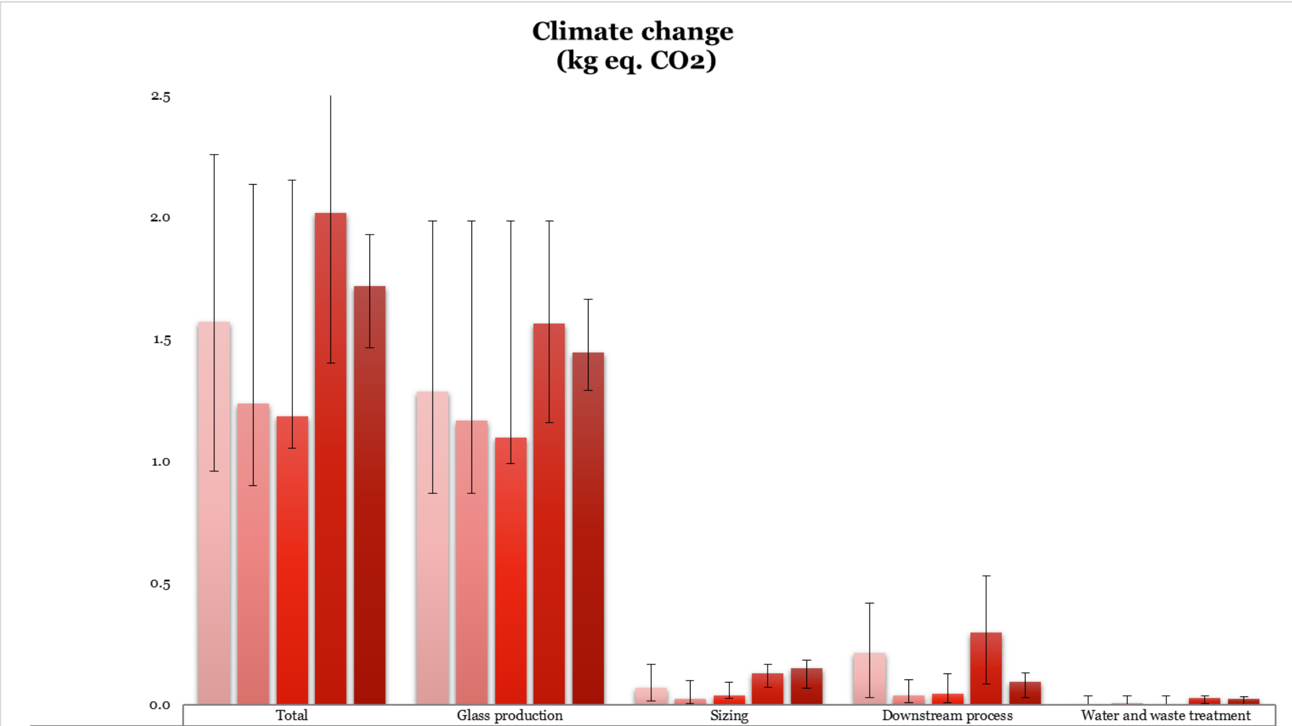
The high variability in the results comes from one site which pulls the average (2.31E-03 kg eq. P) and the maximum values upwards and presents a strong gap with the others. This is explained by the combination of high electricity consumption and a very impactful electricity mix.

The on-site water rejects, which are measured at the waste and water treatment stage, are masked by upstream impacts: they represent only 1.4% of the eutrophication impact.

Note: due to a change in the eutrophication methodology, the current results cannot be compared with those of the previous study. In particular, the unit is not the same.

4. Air emissions

4.1 Greenhouse gas emissions



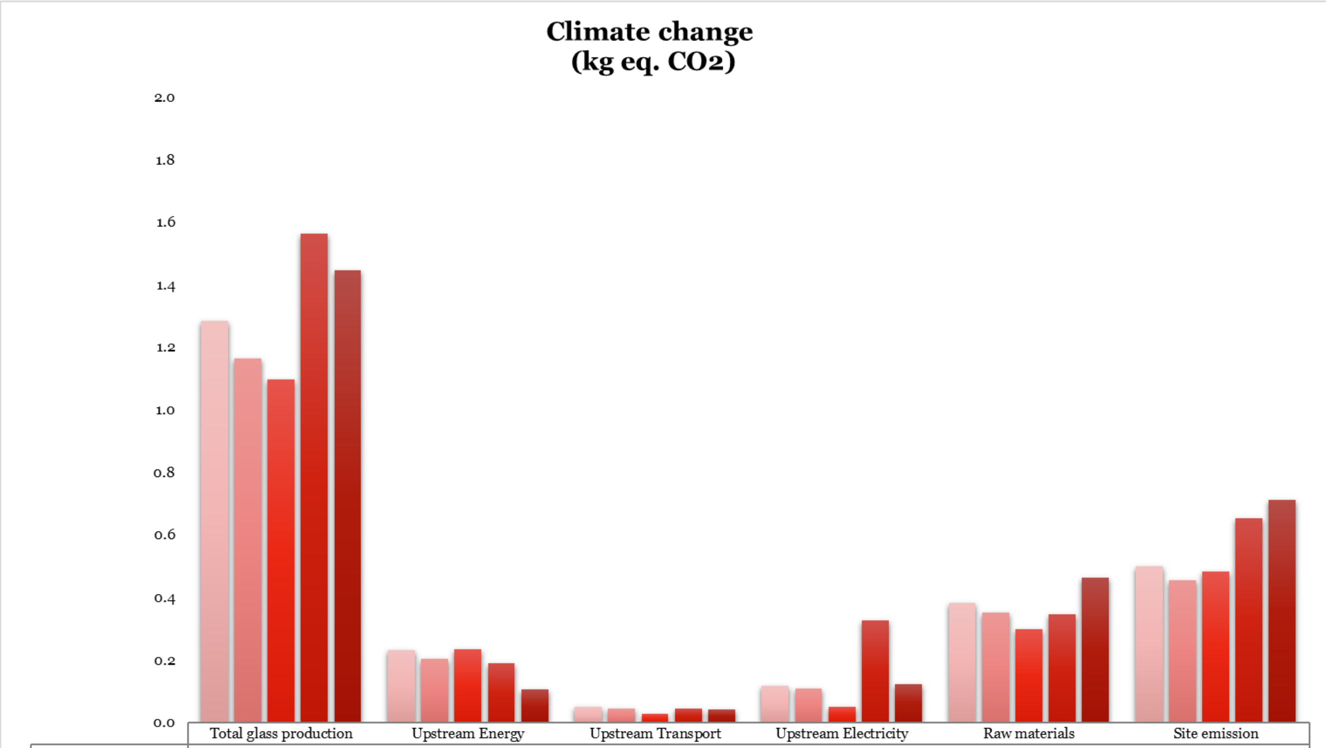
	Total	Glass production	Sizing	Downstream process	Water and waste treatment
Dry chopped strands	1.57	1.28	0.07	0.21	0.00
Wet chopped strands	1.24	1.17	0.02	0.04	0.01
Direct rovings	1.18	1.10	0.04	0.04	0.00
Assembled rovings	2.02	1.56	0.13	0.30	0.03
Mats	1.72	1.45	0.15	0.09	0.03

Figure 8 – Greenhouse gas emissions (kg eq. CO_2)

On average, the impact of CFGF production on climate change is 1.44 kg eq. CO_2. Direct emissions on site represent 0.53 kg eq. CO2 or 37% of total greenhouse gas emissions. These direct emissions are mainly due to the combustion of natural gas and other fossil fuels and process emissions.

Note: when on-site greenhouse gas emissions data were not available according to the process stages breakdown, all emissions were allocated to the glass production stage. This explains why the minimum values for sizing and downstream process may be close to zero.

In Figure 9, the breakdown of the contributors at glass production stage reflects the predominant contribution of process emissions to climate change (41%), primarily due to energy consumption from fossil fuels and, to a lesser extent, to decarbonation of raw materials. For the production of molten glass, 28 % of greenhouse gas emissions are due to the production of raw materials, 10% to upstream electricity production and 17% to fossil fuel and oxygen production (upstream energy).



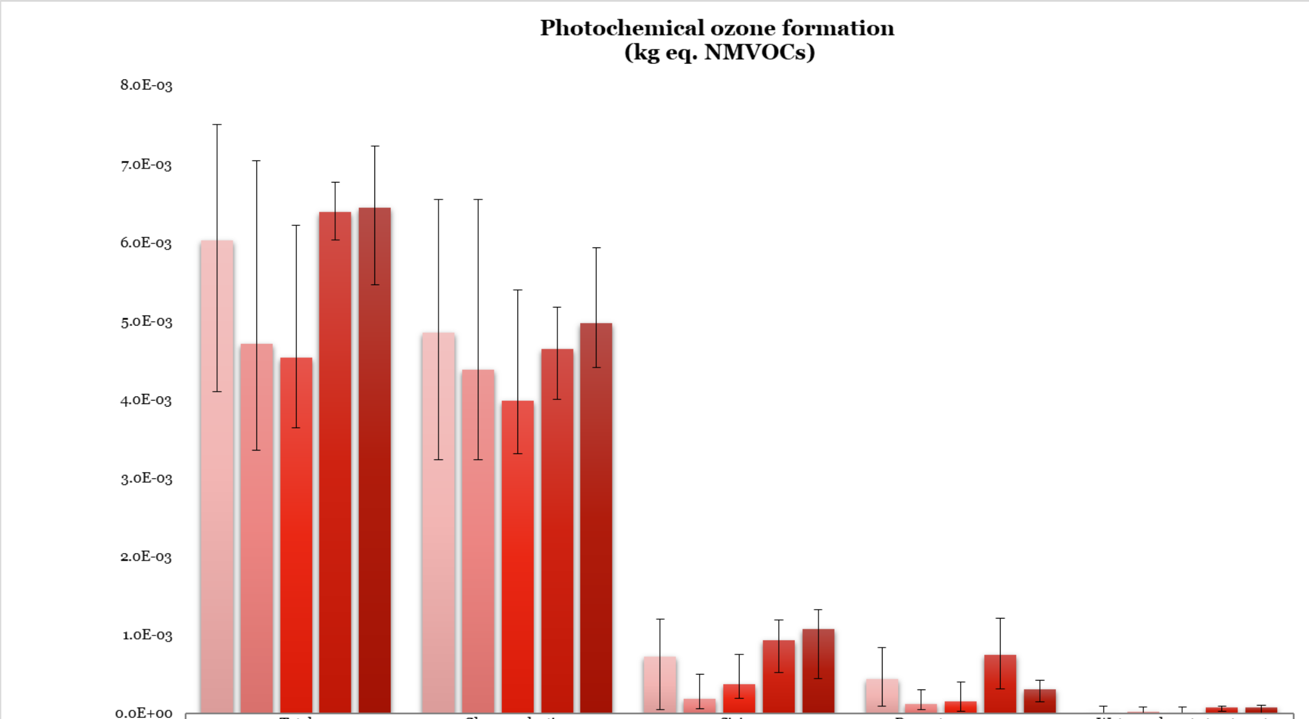
	Total glass production	Upstream Energy	Upstream Transport	Upstream Electricity	Raw materials	Site emission
Dry chopped strands	1.28	0.23	0.05	0.12	0.38	0.50
Wet chopped strands	1.17	0.21	0.04	0.11	0.35	0.45
Direct rovings	1.10	0.24	0.03	0.05	0.30	0.48
Assembled rovings	1.56	0.19	0.04	0.33	0.35	0.66
Mats	1.45	0.11	0.04	0.12	0.46	0.71

Figure 9 – Breakdown of the contributions to climate change at glass production

The average direct greenhouse gas emissions (469 kg eq CO_2/ton of molten glass) due to the molten glass production at the furnace stage can be compared to the average value of 540 kg eq CO_2/ton of molten glass (calculated in 2010 over 2008-2009), and the new benchmark value of 309 kg eq CO_2/ton of molten glass (phase IV of EU ETS, 2021-2025).

Carbon dioxide is the source of more than 93-95% of greenhouse gas emissions emitted during CFGF production. Methane is the second largest source. Both gases explain around 99% of greenhouse gas emissions within the studied system.

4.2 *Photochemical ozone formation*



	Total	Glass production	Sizing	Downstream process	Water and waste treatment
Dry chopped strands	6.03E-03	4.85E-03	7.22E-04	4.42E-04	1.52E-05
Wet chopped strands	4.71E-03	4.38E-03	1.83E-04	1.26E-04	2.15E-05
Direct rovings	4.53E-03	3.99E-03	3.74E-04	1.55E-04	1.39E-05
Assembled rovings	6.40E-03	4.64E-03	9.36E-04	7.42E-04	7.53E-05
Mats	6.45E-03	4.98E-03	1.08E-03	3.11E-04	8.00E-05

Figure 10 – Photochemical ozone formation (kg eq. NMVOCs)

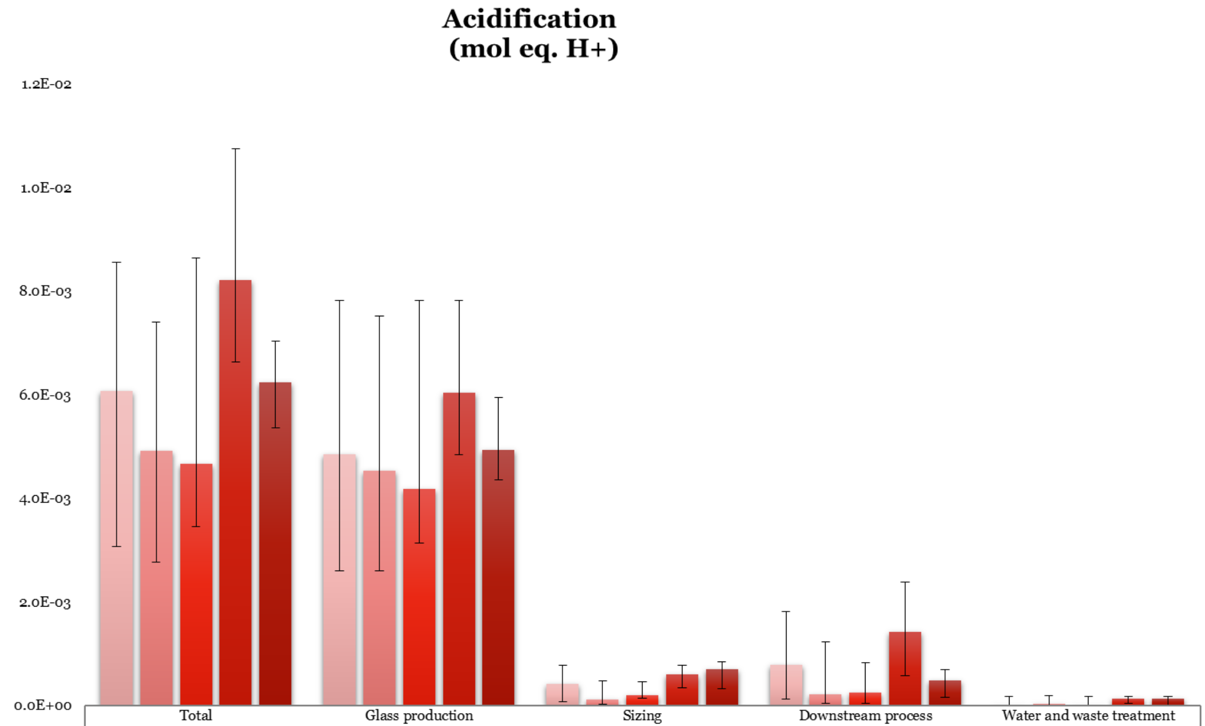
Contributions to tropospheric ozone formation are mainly due to emissions from glass production, accounting for around 80% of this impact category. The sizing, on the other hand ranges between 4-17% depending on the products.

The major contributors in decreasing order are the following:

- Nitrogen oxides (30-50%)
- Carbon monoxide (1-40%)
- Non-methane volatile organic compounds (NMVOC) (7-15%)
- Sulphur oxides (3-7%)
- Ethanol (0-13%)

Note: due to a change in the methodology, the current results cannot be compared with those of the previous study. In particular, the unit is not the same.

4.3 *Acidification*



	Total	Glass production	Sizing	Downstream process	Water and waste treatment
Dry chopped strands	6.07E-03	4.85E-03	4.13E-04	7.91E-04	2.06E-05
Wet chopped strands	4.91E-03	4.54E-03	1.20E-04	2.12E-04	4.00E-05
Direct rovings	4.66E-03	4.18E-03	2.02E-04	2.55E-04	2.35E-05
Assembled rovings	8.21E-03	6.05E-03	6.09E-04	1.42E-03	1.36E-04
Mats	6.25E-03	4.94E-03	7.00E-04	4.83E-04	1.29E-04

Figure 11 – Acidification (mol eq. H+)

When considering dry chopped strands as a representative example of the diversity of the situations, we notice that sulfur oxides represent 55-70% of total contributions to acidification and nitrogen oxides around 30-45%, when ammonia never overcomes 4% of the total acidification effect.

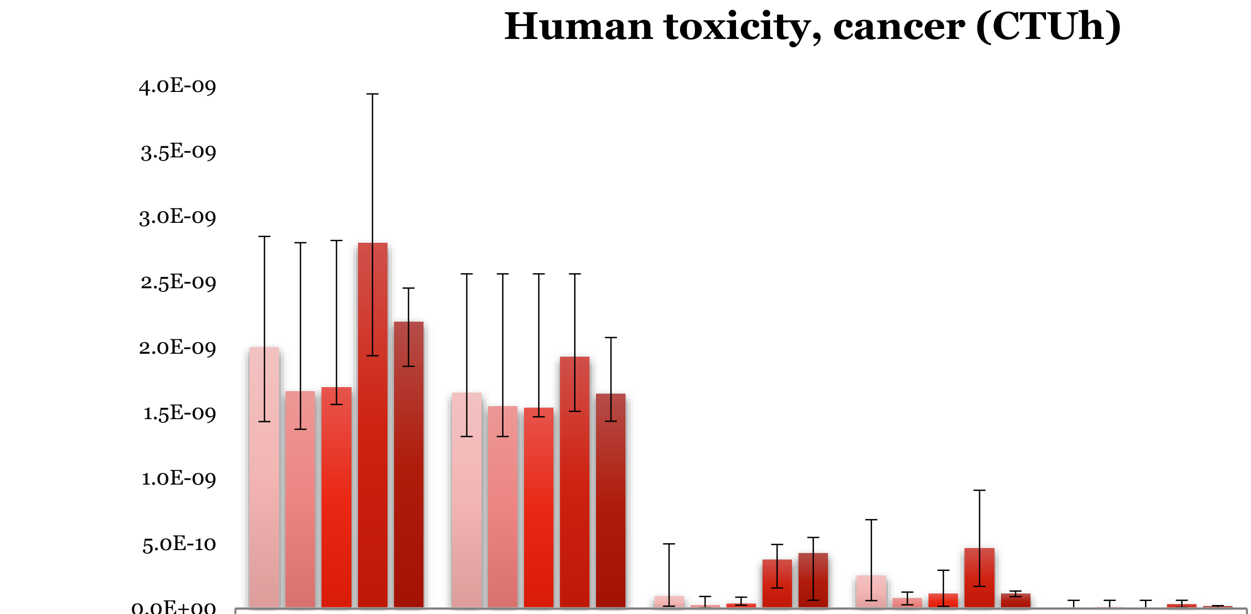
On overall, the glass production phase gathers 82% of the impact, followed by the downstream process with 11%.

Again, for DCS, within the glass production phase which represents 80% of the impact on average, the contribution to acidification is split between the following sub-stages, with a high variability between manufacturers depending on their production processes:

- Raw material production (10-50%)
- Furnace (15-40%)
- Oxygen production (when used) (15-25%)
- Electricity production (5-50%)
- Supply of thermal energy (5-15%)

Note: due to a change in the methodology, the current results cannot be compared with those of the previous study. In particular, the unit is not the same.

4.4 *Human toxicity, cancer*



	Total	Glass production	Sizing	Downstream process	Water and waste treatment
Dry chopped strands	2.0E-09	1.6E-09	9.4E-11	2.5E-10	4.1E-12
Wet chopped strands	1.7E-09	1.5E-09	2.4E-11	7.9E-11	1.1E-11
Direct rovings	1.7E-09	1.5E-09	3.8E-11	1.1E-10	5.7E-12
Assembled rovings	2.8E-09	1.9E-09	3.7E-10	4.6E-10	3.3E-11
Mats	2.2E-09	1.6E-09	4.2E-10	1.1E-10	1.7E-11

Figure 12 – Human toxicity, cancer (CTUh)

Human toxicity, as calculated in the USEtox approach, can be attributed to, by order of importance:

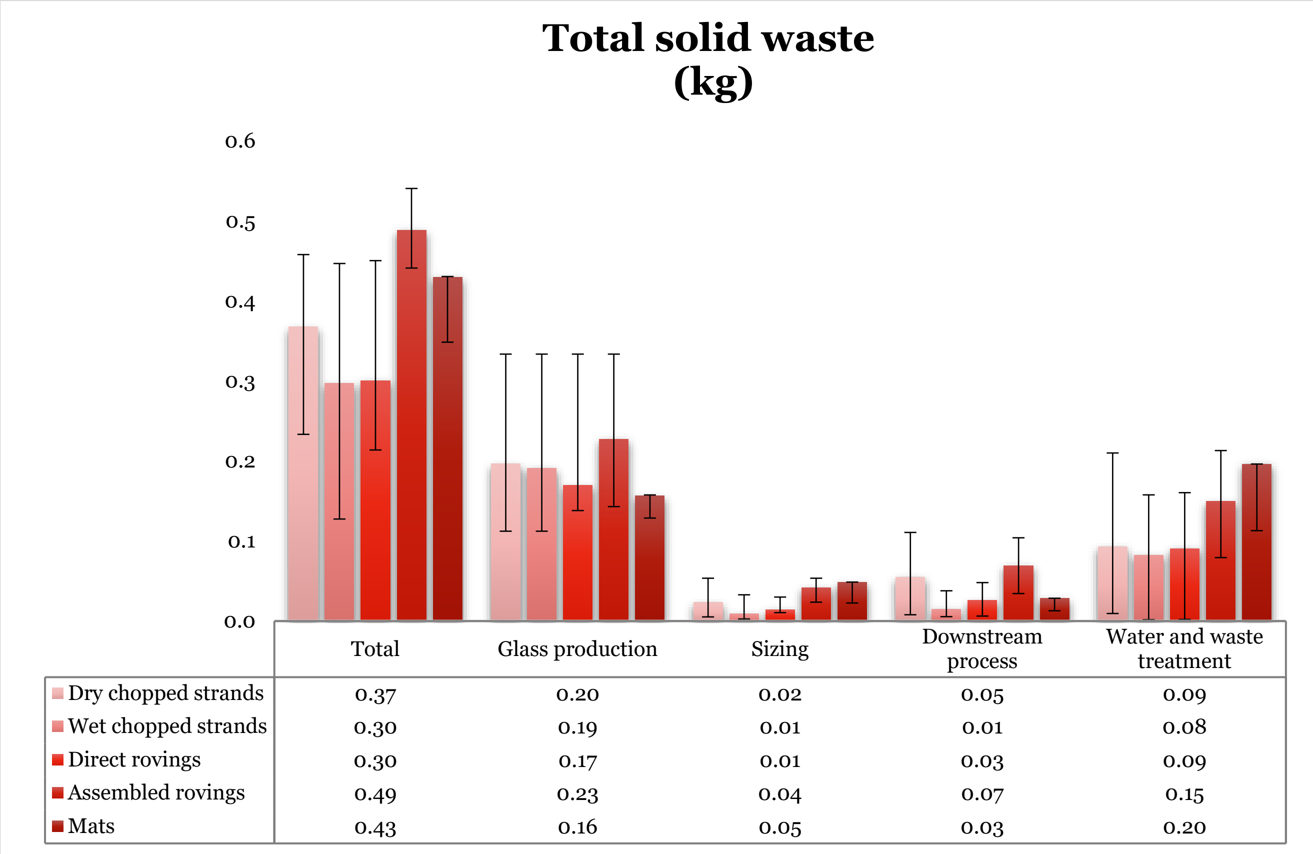
- Raw material production (between 35% and 85% of the impact for DCS);
- Oxygen production (10-15% when in use);
- Electricity production, depending on the country energy mix;
- Sizing, including the production of chemicals, electricity and emissions of VOCs;
- Air emissions from the site furnace.

Although they play a minor role in the total human toxicity impact (<5%), at furnace level, the main elements contributing to human toxicity are air emissions of mercury, chromium (VI), arsenic, nickel and lead.

Regarding the production of raw materials, the main contributors are the emissions of nickel into waters and soils, and the emissions of chromium VI into waters, which together represent 65-85% of the human toxicity impact in the case of DCS.

Note: due to a methodological update of the human toxicity impact, the current results cannot be compared with those of the previous study.

5. Total solid waste



	Total	Glass production	Sizing	Downstream process	Water and waste treatment
Dry chopped strands	0.37	0.20	0.02	0.05	0.09
Wet chopped strands	0.30	0.19	0.01	0.01	0.08
Direct rovings	0.30	0.17	0.01	0.03	0.09
Assembled rovings	0.49	0.23	0.04	0.07	0.15
Mats	0.43	0.16	0.05	0.03	0.20

Figure 13 – Total solid waste (kg)

Solid waste is mainly generated during the raw material production and the glass discarded at the forming stage. At site level, waste streams, which are related to glass production waste and other industrial waste, are mostly disposed in landfills.

However, a significant share of the waste is recycled (44%); the corresponding quantities were taken into account in the calculations to reduce the quantity of waste produced. Approximately 50% of this recycled waste consists in waste glass that is recycled on site or sent to another CFGF manufacturing site. When recycled glass is used as a furnace input, it represents between 4 and 16% of the raw materials weight.

As for incinerated waste, it is mainly composed of sludges from wastewater treatment and to lesser extent of other industrial wastes.

Table 4 –Management of waste produced on CFGF production site

Flow	**Waste fractions breakdown (as wt% to total waste produced)**
Non-hazardous waste to landfill	54 %
Waste sent to recycling[7]	44 %
Non-hazardous waste to incineration	1.7 %
Hazardous waste landfilled	0.4 %

[7] This category is not accounted for in the solid waste indicator. It is shown in this table to show the importance of recycling as opposed to other waste management options.

Appendices

1. Impact assessment results

E Total Primary Energy

	Wet chopped strands			Dry chopped strands			Assembled rovingss			Direct rovings			Mats		
Unit : MJ	Average	Min	Max	Average	Min	Max	Average	Min	Max	Average	Min	Max	Average	Min	Max
TOTAL	21.6	16.5	32.4	29.6	22.6	37.4	33.8	26.9	44.8	23.5	21.3	32.6	26.0	21.6	30.5
Glass Production	19.1	14.9	28.4	20.1	14.9	28.4	21.3	16.0	28.4	18.9	16.8	28.4	17.3	14.4	25.7
Sizing	0.6	0.1	2.4	1.7	0.4	4.1	3.1	1.8	4.1	0.9	0.7	2.2	3.7	1.7	4.5
Downstream	1.8	0.8	2.9	7.8	1.0	9.1	8.8	4.1	14.0	3.7	0.8	5.4	4.5	2.2	6.4
Water and Waste treatment	0.1	0.0	0.6	0.1	0.0	0.7	0.6	0.1	0.8	0.1	0.0	0.6	0.6	0.0	0.8

Total IPCC-Greenhouse effect 2013 (direct, 100 years)

	Wet chopped strands			Dry chopped strands			Assembled rovingss			Direct rovings			Mats		
Unit : kg eq. CO_2	Average	Min	Max	Average	Min	Max	Average	Min	Max	Average	Min	Max	Average	Min	Max
TOTAL	1.24	0.90	2.14	1.57	0.96	2.26	2.02	1.40	2.63	1.18	1.05	2.15	1.72	1.46	1.93
Glass Production	1.17	0.87	1.99	1.28	0.87	1.99	1.56	1.16	1.99	1.10	0.99	1.99	1.45	1.29	1.66
Sizing	0.02	0.01	0.10	0.07	0.02	0.17	0.13	0.07	0.17	0.04	0.03	0.09	0.15	0.07	0.18
Downstream	0.04	0.01	0.11	0.21	0.03	0.42	0.30	0.09	0.53	0.04	0.01	0.13	0.09	0.03	0.13
Water and Waste treatment	0.01	0.00	0.04	0.00	0.00	0.04	0.03	0.01	0.04	0.00	0.00	0.04	0.03	0.00	0.03

Water Used (total)

	Wet chopped strands			Dry chopped strands			Assembled rovingss			Direct rovings			Mats		
Unit : litre	Average	Min	Max	Average	Min	Max	Average	Min	Max	Average	Min	Max	Average	Min	Max
TOTAL	8.5	6.5	12.8	13.7	7.4	19.6	15.5	10.6	21.6	19.2	9.9	49.6	10.0	8.6	11.3
Glass Production	7.0	6.0	11.3	7.4	6.0	11.3	8.3	6.2	11.3	6.5	5.3	11.3	6.6	5.6	9.2
Sizing	0.3	0.0	1.1	0.8	0.2	1.8	1.4	0.7	1.8	0.5	0.3	2.4	1.6	0.8	2.0
Downstream	0.3	0.1	0.6	1.6	0.2	2.4	1.7	0.7	3.1	0.4	0.1	0.9	0.6	0.2	0.8
Water and Waste treatment	1.0	0.1	1.3	3.9	0.2	9.1	4.1	1.1	6.5	11.8	0.3	43.9	1.1	0.3	1.7

Total NF EN 15804 A2-Acidification

	Wet chopped strands			Dry chopped strands			Assembled rovingss			Direct rovings			Mats		
Unit : mol eq. H+	Average	Min	Max	Average	Min	Max	Average	Min	Max	Average	Min	Max	Average	Min	Max
TOTAL	4.91E-03	2.76E-03	8.55E-03	6.07E-03	3.08E-03	8.57E-03	8.21E-03	6.63E-03	1.08E-02	4.66E-03	3.45E-03	8.64E-03	6.25E-03	5.36E-03	7.04E-03
Glass Production	4.54E-03	2.60E-03	7.83E-03	4.85E-03	2.60E-03	7.83E-03	6.05E-03	4.84E-03	7.83E-03	4.18E-03	3.14E-03	7.83E-03	4.94E-03	4.36E-03	5.95E-03
Sizing	1.20E-04	3.27E-05	4.59E-04	4.13E-04	7.61E-05	7.73E-04	6.09E-04	3.50E-04	7.73E-04	2.02E-04	1.39E-04	4.66E-04	7.00E-04	3.22E-04	8.48E-04
Downstream	2.12E-04	4.95E-05	4.73E-04	7.91E-04	1.33E-04	1.81E-03	1.42E-03	5.72E-04	2.39E-03	2.55E-04	4.12E-05	8.35E-04	4.83E-04	1.54E-04	6.94E-04
Water and Waste treatment	4.00E-05	9.70E-06	1.80E-04	2.06E-05	5.95E-06	1.79E-04	1.36E-04	4.10E-05	1.81E-04	2.35E-05	8.74E-06	1.80E-04	1.29E-04	1.01E-05	1.70E-04

Total NF EN 15804 A2-Photochemical ozone formation

	Wet chopped strands			Dry chopped strands			Assembled rovingss			Direct rovings			Mats		
Unit : kg eq. NMVOCs	Average	Min	Max	Average	Min	Max	Average	Min	Max	Average	Min	Max	Average	Min	Max
TOTAL	4.71E-03	3.36E-03	7.04E-03	6.03E-03	4.11E-03	7.50E-03	6.40E-03	6.04E-03	6.77E-03	4.53E-03	3.64E-03	6.23E-03	6.45E-03	5.46E-03	7.23E-03
Glass Production	4.38E-03	3.23E-03	6.55E-03	4.85E-03	3.23E-03	6.55E-03	4.64E-03	4.01E-03	5.18E-03	3.99E-03	3.31E-03	5.40E-03	4.98E-03	4.40E-03	5.94E-03
Sizing	1.83E-04	5.58E-05	4.95E-04	7.22E-04	5.16E-05	1.20E-03	9.36E-04	5.23E-04	1.19E-03	3.74E-04	1.95E-04	7.58E-04	1.08E-03	4.50E-04	1.32E-03
Downstream	1.26E-04	4.71E-05	3.04E-04	4.42E-04	8.83E-05	8.46E-04	7.42E-04	3.12E-04	1.21E-03	1.55E-04	2.78E-05	3.96E-04	3.11E-04	1.47E-04	4.26E-04
Water and Waste treatment	2.15E-05	5.22E-06	8.67E-05	1.52E-05	5.78E-06	9.29E-05	7.53E-05	2.30E-05	9.86E-05	1.39E-05	6.13E-06	8.65E-05	8.00E-05	8.77E-06	1.04E-04

Total NF EN 15804 A2-Eutrophication, freshwater

	Wet chopped strands			Dry chopped strands			Assembled rovingss			Direct rovings			Mats		
Unit : kg eq. P	Average	Min	Max	Average	Min	Max	Average	Min	Max	Average	Min	Max	Average	Min	Max
TOTAL	4.07E-04	6.81E-05	1.58E-03	5.55E-04	8.05E-05	1.57E-03	1.03E-03	1.77E-04	2.31E-03	3.44E-04	2.30E-04	1.61E-03	1.88E-04	1.31E-04	4.00E-04
Glass Production	3.59E-04	5.99E-05	1.45E-03	3.49E-04	5.99E-05	1.45E-03	6.51E-04	8.33E-05	1.45E-03	2.98E-04	2.10E-04	1.45E-03	1.27E-04	7.49E-05	3.73E-04
Sizing	7.14E-06	3.42E-06	3.32E-05	1.48E-05	4.33E-06	3.40E-05	3.32E-05	3.21E-05	3.40E-05	8.76E-06	5.46E-06	3.32E-05	3.07E-05	1.39E-05	3.73E-05
Downstream	3.20E-05	2.44E-06	7.08E-05	1.88E-04	1.40E-05	6.51E-04	3.24E-04	5.07E-05	7.68E-04	3.14E-05	3.62E-06	1.44E-04	2.21E-05	7.07E-06	3.06E-05
Water and Waste treatment	9.16E-06	4.84E-07	5.54E-05	3.27E-06	1.17E-07	5.54E-05	2.49E-05	4.90E-06	5.54E-05	4.93E-06	1.96E-07	5.54E-05	7.52E-06	7.86E-07	9.79E-06

Total NF EN 15804 A2-Resource use, minerals and metals

	Wet chopped strands			Dry chopped strands			Assembled rovingss			Direct rovings			Mats		
Unit : kg eq. Sb	Average	Min	Max	Average	Min	Max	Average	Min	Max	Average	Min	Max	Average	Min	Max
TOTAL	1.57E-06	9.63E-07	2.86E-06	2.29E-06	1.44E-06	3.18E-06	2.92E-06	2.54E-06	3.50E-06	1.95E-06	1.27E-06	2.89E-06	2.35E-06	2.03E-06	2.63E-06
Glass Production	1.09E-06	6.68E-07	1.97E-06	1.23E-06	6.68E-07	1.97E-06	1.28E-06	6.91E-07	1.97E-06	1.13E-06	8.57E-07	1.97E-06	8.30E-07	6.22E-07	1.65E-06
Sizing	1.79E-07	4.95E-08	6.77E-07	4.73E-07	9.04E-08	1.10E-06	8.40E-07	4.81E-07	1.10E-06	2.76E-07	2.05E-07	6.25E-07	9.96E-07	4.71E-07	1.21E-06
Downstream	2.15E-07	9.72E-08	8.59E-07	5.45E-07	1.12E-07	8.19E-07	6.08E-07	3.17E-07	7.77E-07	4.99E-07	8.60E-08	1.02E-06	3.67E-07	1.98E-07	4.66E-07
Water and Waste treatment	9.04E-08	1.32E-08	2.64E-07	4.46E-08	3.11E-09	2.64E-07	1.88E-07	8.42E-08	2.65E-07	4.70E-08	1.33E-08	2.64E-07	1.52E-07	1.21E-08	2.00E-07

Waste (total)

	Wet chopped strands			Dry chopped strands			Assembled rovingss			Direct rovings			Mats		
Unit : kg	Average	Min	Max	Average	Min	Max	Average	Min	Max	Average	Min	Max	Average	Min	Max
TOTAL	0.30	0.13	0.45	0.37	0.23	0.46	0.49	0.44	0.54	0.30	0.21	0.45	0.43	0.35	0.49
Glass Production	0.19	0.11	0.33	0.20	0.11	0.33	0.23	0.14	0.33	0.17	0.14	0.33	0.16	0.13	0.24
Sizing	0.01	0.00	0.03	0.02	0.01	0.05	0.04	0.02	0.05	0.01	0.01	0.03	0.05	0.02	0.06
Downstream	0.01	0.01	0.04	0.05	0.01	0.11	0.07	0.03	0.10	0.03	0.01	0.05	0.03	0.01	0.04
Water and Waste treatment	0.08	0.00	0.16	0.09	0.01	0.21	0.15	0.08	0.21	0.09	0.00	0.16	0.20	0.11	0.23

Total NF EN 15804 A2-Human toxicity, cancer

	Wet chopped strands			Dry chopped strands			Assembled rovingss			Direct rovings			Mats		
Unit : CTUh	Average	Min	Max	Average	Min	Max	Average	Min	Max	Average	Min	Max	Average	Min	Max
TOTAL	1.66E-09	1.37E-09	2.80E-09	2.00E-09	1.43E-09	2.84E-09	2.79E-09	1.93E-09	3.93E-09	1.69E-09	1.56E-09	2.81E-09	2.19E-09	1.85E-09	2.45E-09
Glass Production	1.54E-09	1.31E-09	2.56E-09	1.65E-09	1.31E-09	2.56E-09	1.92E-09	1.51E-09	2.56E-09	1.54E-09	1.47E-09	2.56E-09	1.64E-09	1.43E-09	2.07E-09
Sizing	2.44E-11	6.15E-12	9.25E-11	9.39E-11	1.81E-11	4.94E-10	3.74E-10	1.57E-10	4.90E-10	3.78E-11	2.61E-11	8.71E-11	4.21E-10	6.40E-11	5.43E-10
Downstream	7.93E-11	2.86E-11	1.26E-10	2.52E-10	6.07E-11	6.79E-10	4.62E-10	1.69E-10	9.04E-10	1.13E-10	1.60E-11	2.93E-10	1.13E-10	9.11E-11	1.34E-10
Water and Waste treatment	1.05E-11	1.45E-12	6.29E-11	4.07E-12	8.25E-13	6.28E-11	3.29E-11	7.93E-12	6.31E-11	5.66E-12	8.83E-13	6.28E-11	1.68E-11	1.35E-12	2.21E-11

Figure 14 – Summary results

Comparison of 2016 and 2022 results using indicators used in 2016

The following table compares values between 2016 and 2022 results. To make results comparable, the 2016 results have been recalculated to use the 2022 oxygen production model and the electricity grids used in 2022.

Results per 1 kg of glass fibre product		Dry choppped strands			Wet chopped strands			Direct rovings			Assembled rovings			Mats		
		2022	2016	% (2022-2016)/2016	2022	2016	% (2022-2016)/2016	2022	2016	% (2022-2016)/2016	2022	2016	% (2022-2016)/2016	2022	2016	% (2022-2016)/2016
Total Primary Energy	MJ	29.6	29.2	2%	21.6	26.1	-17%	23.5	25.7	-8%	33.8	34.3	-1%	26.0	42.4	-39%
CML 4.2 - Abiotic Depletion Potential (elements)	kg eq. Sb	9.9E-07	6.9E-07	43%	6.9E-07	5.1E-07	35%	8.1E-07	6.0E-07	36%	1.4E-06	8.0E-07	76%	1.3E-06	9.3E-07	36%
Water use	litre	13.7	11.3	22%	8.5	11.2	-24%	19.2	8.2	135%	15.5	14.6	6%	10.0	7.5	33%
CML 4.2 - Eutrophication	g eq. PO4	2.2	1.7	29%	1.6	1.5	6%	1.4	1.9	-22%	3.8	3.7	3%	1.1	1.5	-28%
Total IPCC-Greenhouse effect 2013 (direct, 100 years)	kg eq CO2	1.57	1.49	5%	1.24	1.30	-5%	1.18	1.33	-11%	2.02	1.98	2%	1.72	1.92	-10%
CML 4.2 - Photochemical oxidation (high NOx)	g eq. ethylene	3.0	2.4	26%	2.1	2.0	4%	2.1	1.7	18%	3.3	2.5	33%	3.7	3.2	17%
CML 4.2 - Air Acidification	g eq. SO2	5.01	5.0	1%	4.09	4.63	-12%	3.84	4.86	-21%	6.89	7.07	-3%	5.22	5.87	-11%
USEtox - Human toxicity - 2010 (Fresh water)	unit	3.1E-07	2.1E-07	47%	2.1E-07	1.9E-07	11%	2.0E-07	2.1E-07	-6%	4.7E-07	3.8E-07	24%	2.6E-07	1.9E-07	33%
Solid waste	kg	0.37	0.21	78%	0.30	0.24	23%	0.30	0.27	12%	0.49	0.27	79%	0.43	0.34	25%

Figure 15 – Comparison of 2022 and 2016 results

Once this recalculation is performed, on average per 1 kg of CFGF product, between 2016 and 2022, total primary energy consumption is decreasing by 8.1%, greenhouse gas emissions by 3.2%, air acidification by 9.4%.

For abiotic depletion, eutrophication, photochemical oxidation and human toxicity, results are worse in the 2022 report, due to upstream LCA model change. Indeed, some model upgrades that were implemented in order to comply with the most recent LCA practices make the comparison uncertain.

Normalisation of results

Results obtained in 2022 can be compared to average environmental impacts currently generated per person in Europe, as calculated by the Joint Research Centre of the European Commission[8].
As presented in the table below, impact of CFGF production is representing less than 0.1% of environmental impacts occurring in EU27.

Indicator	Unit	Maximum per 1 kg CFGF product	Impact per 1 person.yr (source: JRC)	Robustness of estimation (source JRC)	Normalisation of results (total GFE, number of persons)	Normalisation (%)
Resource use, minerals and metals	kg eq Sb	2,92E-06	1,01E-01	medium	21 452	0,004%
Greenhouse gas emissions	kg CO2 eq	2,03	9,22E+03	very high	163 189	0,03%
Acidification	moles H+	8,21E-03	4,73E+01	high	128 791	0,03%
Photochemical ozone formation	kg eq NMVOC	6,45E-03	3,17E+01	medium	150 975	0,03%
Human toxicity - cancer	CTUh	2,79E-09	3,69E-05	low	56 102	0,01%
Eutrophication - freshwater	kg eq P	1,03E-03	1,48	medium to low	516 392	0,10%

8 "Normalisation method and data for Environmental Footprints", JRC Technical Reports, European Commission, Report EUR 26842 EN, 2014.

2. Data sources for modelling

Time period of ecoinvent data is made of an interval between the first year of data source used in the LCI and the last update (electricity mix and other underlying data).

	Data source	Year
Raw materials – glass production		
Kaolin	Ecoinvent v3.8 Kaolin production (Europe)	2007 - 2021
Sand	ELCD Very fine milled silica sand (Europe)	2011
Limestone	Ecoinvent v3.8 Limestone production, crushed, washed (Rest of the World)	2007 - 2021
Quick lime	Ecoinvent v3.8 Quicklime production, milled, loose (Canada-Quebec)	2007 - 2021
Colemanite	Ecoinvent v3.8 calcium borates production (Turkey)	2007 - 2021
Fluorspar	Ecoinvent v3.8 Fluorspar production, 97% purity (Global)	2007 - 2021
Penta borax	Ecoinvent v3.8 Borax, anhydrous, powder, at plant (Europe)	2007 - 2021
Sodium sulfate	Ecoinvent v3.8 Sodium sulfate production, from natural sources (Europe)	2007 - 2021
Sodium carbonate	Ecoinvent v3.8 Modified Solvay process, Hou's process (Global)	2007 - 2021
Hydrated lime	Ecoinvent v3.8 Lime production, hydrated, packed (Rest of the World)	2007 - 2021
Dolomite	Ecoinvent v3.8 Dolomite production (Europe)	2007 - 2021
Sodium nitrate	Ecoinvent v3.8 Sodium nitrate production (Europe)	2011 - 2021
Gypsum	Ecoinvent v3.8 Gypsum quarry operation (Rest of the World)	2007 - 2021
Feldspar	Ecoinvent v3.8 Feldspar production (Europe)	2007 - 2021
Magnesium oxide	Ecoinvent v3.8 Magnesium oxide production (Europe)	2007 - 2021
Burnt dolomite	Ecoinvent v3.8 with a modification by PwC Magnesium oxide production (Europe) – as a proxy, with a correction on the resource flow (dolomite instead of magnesium ore)	2007 - 2021
Power, Fuels and oxidizer		
Electricity	Ecoinvent v3.8 - Market for electricity, medium voltage (per country)	2018

	Data source	Year
	- Electricity production, wind, 1-3MW turbine, offshore - Electricity production, hydro, reservoir, alpine region - Electricity production, hydro, run-of-river - Electricity production, hydro, pumped storage Note: these modules for electricity generation are likely to evolve quicker than others over the years.	
Natural gas	Ecoinvent v3.8 Natural gas production, high pressure, (Rest of the World)	1991 - 2021
Propane	Ecoinvent v3.8 Natural gas production - propane, (Rest of the World)	1991 - 2021
Light fuel oil	Ecoinvent v3.8 light fuel oil production, petroleum refinery operation (Europe w/o CH)	2014 - 2021
Heavy fuel oil	Ecoinvent v3.8 Heavy fuel oil production, petroleum refinery operation (Europe w/o CH)	2014 - 2021
Oxygen	Ecoinvent v3.8 Oxygen production, air separation, cryogenic (Europe)	1997 - 2021
Raw materials – sizing		
Silane	Ecoinvent v3.8 Silicon tetrachloride production (Global)	2000 - 2021
Filmformer	PwC modelling from: - 33% polyurethane, flexible foam from Toluene diisocianate and long chain Polyether polyols (PlasticsEurope, 2015) - 33% maleic anhydride grafted PP : 10% maleic anhydride (maleic anhydride, at plant, Ecoinvent v3.8 (Europe, 2021) and 90% polypropylene, Ecoinvent v3.8 (Europe, 2021) - 33% bisphenol A epoxy resin: 10% bisphenol A production powder, Ecoinvent v3.8, (Europe, 2021) and 90% epoxy resin, liquid, Ecoinvent v3.8 (Europe, 2021)	2000 - 2021
Starch	Ecoinvent v3.8 and PwC modelling from: - maize starch production, Ecoinvent v3.8 (Germany, 2021) and Potato starch production, Ecoinvent v3.8 (Germany, 2021)	2002 - 2021
Lubricant	Ecoinvent v3.8 lubricating oil production (Europe)	2000 - 2021
Surfactant	Ecoinvent v3.8 alkylbenzene sulfonate, linear at plant (Europe)	1995 - 2021
PH-modifier	PwC modelling from acetic acid production, product in 98% solution state, Ecoinvent v3.8 (Europe) and dilution to 80% acetic acid in H2O	2007 - 2021
Raw materials – packaging		
Plastic (PET)	Ecoinvent v3.8 polyethylene terephthalate production, granulate, amorphous (Europe)	1999 - 2021
Big bags (PP)	Ecoinvent v3.8	2011 - 2021

	Data source	Year
	Polypropylene production, granulate (Europe)	
Wood	Ecoinvent v3.8 EUR-flat pallet production	2022 - 2021
Cardboard	Ecoinvent v3.8 corrugated board box production (Europe)	2009 - 2021
Raw materials – water treatment		
Flocculant	PwC modelling as a solution of 35 % of iron sulfate (Ecoinvent v3.8, Europe) in water	1993 - 2021
Sodium hydroxide	Ecoinvent v3.8 Sodium hydroxide to generic market for neutralising agent (Europe)	2000 - 2021
Sodium hypochlorite	Ecoinvent v3.8 Sodium hypochlorite production, product in 15% solution state (Europe)	1997 - 2021
Sodium bicarbonate	Ecoinvent v3.8 Soda production, solvay process	2007 - 2021
Bentonite	Ecoinvent v3.8 Activated bentonite production (Germany)	1997 - 2021
Iron chloride	Ecoinvent v3.8 Iron (III) chloride production, product in 40% solution state (Rest of the World)	1995 - 2021
Transport		
River transport	Ecoinvent v3.8 Transport, freight, inland waterways, barge (Europe)	1998 - 2021
Rail transport	Ecoinvent v3.8 Market group for transport, freight train (Europe)	2016 - 2021
Road transport	Ecoinvent v3.8 Transport, freight, lorry >32 metric ton, EURO6	2009 - 2021

3. Methods for calculating environmental impacts

3.1 Abiotic depletion potential (elements)

This indicator reflects the depletion of mineral resources in the environment. The living resources and their corresponding impacts such as the species extinction or the loss of biodiversity are excluded. This indicator provides more information on the depletion of different materials than on the impacts induced by their extraction from the natural environment. The computation is performed by comparing the remaining stock of resources and the consumption rate of the current economy. The unit used for this indicator is kg eq antimony (antimony is a chemical compound with the atomic number 51). For example, 1 kg of platinum ore corresponds to 2.22 kg eq antimony (source: EF v3.0). Note: those coefficients are different than those used in the 2016 study.

Table 5 – Abiotic depletion potential coefficients (source: EF v3.0)

Flow	Unit	Value(*)
(r) Antimony (Sb, ore)	kg	1
(r) Arsenic (As, ore)	kg	0.00297
(r) Barium Sulphate (BaSO4, in ground)	kg	6.04E-006
(r) Bauxite (Al2O3, ore)	kg	5.77E-010
(r) Beryllium (Be, ore)	kg	1.26E-005
(r) Bismuth (Bi, ore)	kg	4.11E-005
(r) Boron (B, ore)	kg	4.27E-006
(r) Bromine (Br, ore)	kg	0.00439
(r) Cadmium (Cd, ore)	kg	0.157
(r) Chromium (Cr, ore)	kg	0.000443
(r) Cobalt (Co, ore)	kg	1.57E-005
(r) Copper (Cu, ore)	kg	0.00137
(r) Gallium (Ga, in ground)	kg	1.46E-007
(r) Gallium (Ga, ore)	kg	1.46E-007
(r) Germanium (Ge, ore)	kg	6.52E-010
(r) Gold (Au, ore)	kg	52
(r) Indium (In, in ground)	kg	0.00689
(r) Iodine (I, in water)	kg	0.025
(r) Iron (Fe, ore)	kg	5.24E-008
(r) Lead (Pb, ore)	kg	0.00634
(r) Lithium (Li, ore)	kg	1.15E-005
(r) Magnesium (Mg, ore)	kg	2.02E-009
(r) Manganese (Mn, ore)	kg	2.54E-006
(r) Mercury (Hg, ore)	kg	0.0922
(r) Molybdenum (Mo, ore)	kg	0.0178
(r) Nickel (Ni, ore)	kg	6.53E-005
(r) Niobium (Nb, ore)	kg	1.93E-008
(r) Palladium (Pd, ore)	kg	0.571
(r) Phosphate Rock (in ground)	kg	5.52E-006
(r) Platinium (Pt, ore)	kg	2.22
(r) Potassium (K, as K2O, in ground)	kg	1.6E-008
(r) Rhenium (Re, ore)	kg	0.603
(r) Selenium (Se, ore)	kg	0.194
(r) Silicon (Si)	kg	1.4E-011
(r) Silver (Ag, ore)	kg	1.18
(r) Sodium Carbonate (Na2CO3, in ground)	kg	5.5E-008

(r) Strontium (Sr, ore)	kg	7.07E-007
(r) Sulphur (S, in ground)	kg	0.000193
(r) Tantalum (Ta, in ground)	kg	4.06E-005
(r) Tellurium (Te, in ground)	kg	40.7
(r) Thallium (Tl, ore)	kg	2.43E-008
(r) Tin (Sn, ore)	kg	0.0162
(r) Titanium (Ti, ore)	kg	2.79E-008
(r) Tungsten (W, ore)	kg	0.00452
(r) Ulexite (NaCaB5O9.8H2O, ore)	kg	0.00427
(r) Vanadium (V, ore)	kg	7.7E-007
(r) Yttrium (Y, ore)	kg	5.69E-007
(r) Zinc (Zn, ore)	kg	0.000538
(r) Zirconium (Zr, ore)	kg	5.44E-006

3.2 Greenhouse effect

The "greenhouse effect" is the increase in the average temperature of the atmosphere caused by the increase in the average atmospheric concentration of various substances of anthropic[9] origin (CO2, methane, CFC,...). The unit used to evaluate the potential impact on the greenhouse effect of a substance is the GWP (Global Warming Potential), expressed in mass units of CO_2 equivalent. The GWP of a substance is the potential greenhouse effect of the instantaneous emission of one gram or one kilogram of the substance in relation to CO_2 (source IPCC, 1995). Carbon dioxide emissions of biological origin ("biomass CO2") are not counted as greenhouse effect gases of anthropic origin, in conformance with international agreements fixed by the inter-governmental panel on climate change (IPCC). The coefficients used to calculate this potential impact on the environment are shown below.

Table 6 : Greenhouse effect equivalence coefficients (source: IPCC 2013)

Elementary flow		Conversion factor
(a) Carbon Dioxide (CO2, fossil)	g	1
(a) Methane (CH4)	g	28
(a) Nitrous Oxide (N2O)	g	265
(a) Sulphur Hexafluoride (SF6)	g	23500

Other gases with direct contribution to global warming (CFCs, HFCs) are also included in the calculation but their total contribution was less than 0.1%.

[9] Anthropic: characterizes phenomena caused or maintained by man, either intentionally or not.

3.3 Acidification

This relates to the increase in the quantity of acidic substances in the low atmosphere, which is a cause of “acid rain” and the decline of certain forests. The unit used to evaluate the contribution of a substance to acidification is the mol H+ equivalent (source EF V3.0). Since the impacts of acidification are measured on a regional level, a product’s global acidification impact should be calculated by considering the spatial distribution of gas emissions contributing to this effect.

Table 7 : Acidification equivalence coefficients (source: EF v3.0)

Elementary flow		Conversion factor
(a) Ammonia (NH3)	g	3.02E-3
(a) Nitrogen Oxides (NOx as NO2)	g	7.40E-4
(a) Sulphur Oxides (SOx as SO2)	g	1.31E-3

The two main types of compounds involved in acidification are Sulphur and Nitrogen. The Acidification Potential of the compound is based on the number of H+ ions that may potentially be released.

Note*: More H^+ is released from SO_2 for the same quantity of pollutant. Therefore, the coefficient for SO_2 is larger than the coefficient for NO_2.*

3.4 Formation of photochemical ozone in the troposphere

Under certain climatic conditions, the atmospheric emissions of industry and transport can react with the solar photons and produce photochemical smog. A succession of reactions involving volatile organic compounds and NO_x leads to the formation of ozone, a super oxidizing compound.

Table 8 : Formation of photochemical ozone equivalence coefficients (source: EF v3.0), for the main compounds (above 0,001 kg NMVOC/g)

Elementary flow		Conversion factor
(a) Trimethyl Benzene (1,2,4-C6H3(CH3)3)	g	0.00233
(a) Trimethyl Benzene (1,3,5-C6H3(CH3)3)	g	0.00233
(a) Dimethyl Ethyl Benzene (3,5-(CH3)2CH2CH3C6H5)	g	0.00223
(a) Diethyl Toluene (3,5-(CH3CH2)2C6H5CH3)	g	0.00219
(a) Trimethyl Benzene (1,2,3-C6H3(CH3)3)	g	0.00214
(a) Butene (cis 2-CH3CHCHCH3)	g	0.00194
(a) Butene (trans 2-CH3CHCHCH3)	g	0.00191
(a) Propylene (CH2CHCH3)	g	0.0019
(a) Pentene (cis 2-C5H10)	g	0.00189
(a) Pentene (trans 2-C5H10)	g	0.00189
(a) Xylene (m-C6H4(CH3)2)	g	0.00187
(a) Isoprene (C5H8)	g	0.00184
(a) Butene (1-CH3CH2CHCH2)	g	0.00182
(a) Hexene (cis 2-C6H12)	g	0.00181
(a) Hexene (trans 2-C6H12)	g	0.00181
(a) Xylene (o-C6H4(CH3)2)	g	0.00178
(a) Ethyl Toluene (m-C6H4CH3C2H5)	g	0.00172

(a) Xylene (p-C6H4(CH3)2)	g	0.00171
(a) Ethylene (C2H4)	g	0.00169
(a) Pentene (1-CH3(CH2)2CHCH3)	g	0.00165
(a) Ethyl Toluene (p-C6H4CH3C2H5)	g	0.00153
(a) Ethyl Toluene (o-C6H4CH3C2H5)	g	0.00152
(a) Hexene (1-C6H12)	g	0.00148
(a) Butadiene (1,3-CH2CHCHCH2)	g	0.00144
(a) Methyl 2-Butene (2-C5H10)	g	0.00142
(a) Propionaldehyde (CH3CH2CHO)	g	0.00135
(a) Butyraldehyde (CH3CH2CH2CHO)	g	0.00134
(a) Methyl 1-Butene (2-C5H10)	g	0.0013
(a) Valeraldehyde (CH3(CH2)3CHO)	g	0.00129
(a) Ethyl Benzene (C6H5C2H5)	g	0.00123
(a) Methyl 1-Butene (3-C5H10)	g	0.00113
(a) Acetaldehyde (CH3CHO)	g	0.00108
(a) Toluene (C6H5CH3)	g	0.00108
(a) Propylbenzene (n-C6H5C3H7)	g	0.00107
(a) Isobutene (CH2C(CH3)2)	g	0.00106
(a) 1-Butanol (C4H10O)	g	0.00105
(a) Butanol (n-C4H9OH)	g	0.00105
(a) Hexanone (3-C6H12O)	g	0.00101
(a) Pentanol (3-C5H12O)	g	0.00101
(a) Pentanol (C5H120)	g	0.00101
(a) Nitrogen Monoxide (NO)	g	0.001
(a) Nitrogen Oxides (NOx as NO2)	g	0.001
(a) NMVOC (Non Methanic Volatile Organic Compounds)	g	0.001

3.5 Eutrophication, freshwater

Eutrophication of an aqueous environment (freshwater) is characterized by the introduction in waters and soils, for example, of nutrients in the form of phosphatized compounds, which leads to the proliferation of algae. In the first instance, this leads to a high consumption of dissolved CO_2 in the presence of light (by photosynthesis) and therefore to alkalizing of the water; and, in the second, the consequence is bacterial decomposition, which leads to a reduction in the content of dissolved oxygen in the water. This phenomenon can lead to the death of flora and fauna in the aquatic environment.

Other types of eutrophication (marine or terrestrial) consider the release of nitrogen in waters, soils and air, which are not taken into account here.

The coefficients used to calculate this potential impact on the environment are shown below.

Table 9 : Eutrophication equivalence coefficients (source: EF v3.0)

Elementary flow		Conversion factor
(w) Phosphates (PO4 3-, HPO4--, H2PO4-, H3PO4, as P)	g	0.001
(s) Phosphorus (P)	g	5,00E-05
(w) Phosphoric Acid (H3PO4)	g	0.00032
(s) Phosphates (PO4 3-)	g	1.6E-005
(w) Phosphorus (P)	g	0.001
(w) Phosphorous Matter (unspecified, as P)	g	0.001
(s) Phosphoric Acid (H3PO4)	g	1.6E-005

Note*: the previous report did consider the influence of air, water and soil emissions of nitrogen.*

3.6 Human toxicity, cancer effect

Toxicity is basically defined as the degree to which a substance can damage an organism. The emission of some substances (such as heavy metals) can have specific impacts on human health. Assessments of effects related to the human toxicity impact category are focused on effects resulting from direct exposure to chemicals.

Assessments of human toxicity are based on tolerable concentrations (or "safe doses") in air, water, and on air quality guidelines, tolerable daily intake and acceptable daily intake.

The USEtox method, recommended by EF v3.0, is based on a comprehensive comparison of existing Life Cycle Impact Assessment (LCIA) toxicity characterisation models aiming to identify specific sources of differences and the indispensable model components. It was developed to provide Characterisation Factors (CFs) for human toxicity and freshwater ecotoxicity in Life Cycle Assessment and gives recommended LCIA CFs for more than 1,000 chemicals for these both toxicity impacts[10].

CFs for human toxicity and ecotoxicity account for the environmental persistence (fate), the accumulation (exposure), and the toxicity (effect) of a chemical in the human body or in the ecosystem.

Characterization factors (CFs) are used to obtain the potential impact associated with each pollutant emission. The quantities of pollutants released into the environment during the life cycle are multiplied by these CFs to obtain an impact score for human toxicity or ecotoxicity (Jolliet, et al., 2005).

The CF for human toxicity is defined as human toxicity potential (HTP) and is expressed in comparative toxic units (CTUh in cases/kg emitted) providing the estimated increase in morbidity in the total human population per unit mass of a chemical emitted.

Table 10 – Human toxicity coefficients (source: EV 3.0, based on USEtox 2.0)

Elementary flow	Unit	Characterization factor
(a) Arsenic (As)	g	4,3981E-08
(a) Benzene (C6H6)	g	2,605E-10
(a) Benzo(a)pyrene (C20H12)	g	4,0765E-06
(a) Cadmium (Cd)	g	3,1768E-08
(a) Chromium (Cr VI)	g	7,8078E-08
(a) Formaldehyde (CH2O)	g	1,3216E-08
(a) Furan (C4H4O)	g	3,2039E-08
(a) Lead (Pb)	g	4,9718E-09
(a) Mercury (Hg)	g	1,0781E-06
(a) Nickel (Ni)	g	1,9757E-08
(a) Tetrachlorodibenzo p-Dioxin (TCDD, 2,3,7,8-	g	0,035175
(s) Chromium (Cr VI)	g	5,0324E-08
(s) Nickel (Ni)	g	1,7366E-08
(w) Arsenic (As3+, As5+)	g	1,8565E-08
(w) Benzene (C6H6)	g	1,0308E-10
(w) Cadmium (Cd++)	g	9,276E-10
(w) Chromium (Cr VI)	g	5,2671E-08
(w) Mercury (Hg+, Hg++)	g	1,2395E-08
(w) Nickel (Ni++, Ni3+)	g	6,2525E-09

Note: the elements listed in the above table are those contributing for more than 90% to the human toxicity indicator.

[10] Sources: Rosenbaum, R.K., Bachmann, T.M., Gold, L.S., Huijbregts, M.A.J., Jolliet, O., Juraske, R., Koehler, A., Larsen, H.F., MacLeod, M., Margni, M.D., McKone, T.E., Payet, J., Schuhmacher, M., van de Meent, D., Hauschild, M.Z., 2008. USEtox - The UNEP-SETAC toxicity model: Recommended characterisation factors for human toxicity and freshwater ecotoxicity in life cycle impact assessment. The International Journal of Life Cycle Assessment 13, 532-546. Hauschild, M.Z., Huijbregts, M.A.J., Jolliet, O., Macleod, M., Margni, M.D., van de Meent, D., Rosenbaum, R.K., McKone, T.E., 2008. Building a Model Based on Scientific Consensus for Life Cycle Impact Assessment of Chemicals: The Search for Harmony and Parsimony. Environmental Science and Technology 42, 7032-7037. Rosenbaum, R.K., Huijbregts, M.A.J., Henderson, A.D., Margni, M., McKone, T.E., van de Meent, D., Hauschild, M.Z., Shaked, S., Li, D.S., Gold, L.S., Jolliet, O., 2011. USEtox human exposure and toxicity factors for comparative assessment of toxic emissions in life cycle analysis: sensitivity to key chemical properties. The International Journal of Life Cycle Assessment 16, 710-727.

4. Questionnaire for data collection

pwc

Project: LCA of glass fibre products

Questionnaire relative to the the studied product production process

3. Raw materials consumption

General data

Company	-
Name and location of the plant	
Year of data collection	2021

Person in charge of the data collection

Name	
Position	
Phone	
Email	

Comments on raw materials consumption

Annual production

		TOTAL site	Wet chopped strands (on + off line)	Dry chopped strands (on + off line)	Semi-dry chopped strands	Direct rovings	Assembled rovings	Chopped strand mats	Continuous filament mats	Other products
Annual production of melted glass	t									
Annual production of finished products	t									
% humidity	% (0-100)									

Please provide dry weight for other products

Please update values according to your case

RAW MATERIALS CONSUMPTION

RAW MATERIALS TRANSPORT

Road					Rail	Sea / River
Distance	Actual load	Empty return percentage rate	Fuel consumption	Maximum load	Distance	Distance
km	t	%	l/km	t	km	km
	Maximum load	30%	0,38	24		

Default values

UPSTREAM (Batch house + Furnace)

Please cover at least 98% of chemical products used in mass

		TOTAL site	Raw materials transport
Silicious sand (SiO_2)	t		
Kaoline	t		
Borax	t		
Colemanite	t		
Boric acid	t		
Limestone ($CaCO_3$)	t		
Quick lime (CaO)	t		
Fluorspar	t		
Dolomite	t		
Recycled glass (internally)	t		
Recycled glass (externally)	t		
<please specify>	t		
	t		

SIZING / COATING (chemical names)

Please cover at least 80% of chemical products

Detailed per studied products

		TOTAL site	Wet chopped strands	Dry chopped strands	Semi-dry chopped strands	Direct rovings	Assembled rovings	Chopped strand mats	Continuous filament mats	Raw materials transport
Silanes	t									
Filmformers	t									
Lubricants	t									
Defoamers	t									
Surfactants	t									
PH-modifiers	t									
<please specify>	t									
	t									
	t									
	t									

PACKAGING

		TOTAL site	Wet chopped strands	Dry chopped strands	Semi-dry chopped strands	Direct rovings	Assembled rovings	Chopped strand mats	Continuous filament mats	Raw materials transport
Plastic (wraping foil, PET)	t									
Cardboard	t									
Big bags (PP)	t									
Wood	t									
<please specify>	t									
	t									

INDUSTRIAL WATER TREATMENT

		TOTAL site
<please specify>	t	
	t	
	t	
	t	
	t	

WASTE WATER TREATMENT

		TOTAL site
<please specify>	t	
	t	
	t	
	t	
	t	

pwc

Project: LCA of glass fibre products

Questionnaire relative to the the studied product production process

4. Energy consumption

General data

Company	-
Name and location of the plant	
Year of data collection	2021

Person in charge of the data collection

Name	
Position	
Phone	
Email	

Comments on energy consumption

CONSUMPTION

TRANSPORT

Road					Rail	Sea
Distance	Actual load	Empty return percentage rate	Fuel consumption	Maximum load	Distance	Distance
km	t	%	l/km	t	km	km
Default values	Maximum load	30%	0,38	24		

General annual energy consumption

		TOTAL site	
Electricity (from the grid)	MWh		*Select Origin*
of which electricity from Energy Attribute Certificate (EAC) or Purchase Power Agreement (PPA))	MWh		
Natural Gas	MWh (LCV)		*Select Origin*
Biogas	MWh (LCV)		
Light fuel	MWh (LCV)		
Heavy fuel oil	MWh (LCV)		
Propane	MWh (LCV)		
Oxygen	m3		*Select Origin*
Hot water (purchased)	MWh		
Steam (purchased)	MWh		
<please specify>	MWh		

Conversion factor	LCV/HCV	LCV/HCV
Natural gas	1,110	0,901
Diesel / Light fuel oil	1,070	0,935
Heavy fuel oil	1,055	0,948
Propane	1,090	0,917

Energy transport

Detailed energy consumption

UPSTREAM (Batch house)

		TOTAL site
Electricity	MWh	

UPSTREAM (Furnace + Forehearth)

		TOTAL site
Electricity	MWh	
Natural gas	MWh (LCV)	
Light fuel	MWh (LCV)	
Heavy fuel oil	MWh (LCV)	
Propane	MWh (LCV)	
Oxygen	m3	
<please specify>	MWh	
	MWh	

SIZING / COATING

		TOTAL site
Electricity	MWh	
<please specify>	MWh	

Detailed per studied products

FIBERIZING (bushing)

		TOTAL site	Wet chopped strands	Dry chopped strands	Semi-dry chopped strands	Direct rovings	Assembled rovings	Chopped strand mats	Continuous filament mats
Electricity	MWh								
<please specify>	MWh								

FORMING / CHOPPING

		TOTAL site	Wet chopped strands	Dry chopped strands	Semi-dry chopped strands	Direct rovings	Assembled rovings	Chopped strand mats	Continuous filament mats
Electricity	MWh								
<please specify>	MWh								

BINDER COATING

		TOTAL site	Chopped strand mats	Continuous filament mats
Electricity	MWh			
Natural Gas	MWh (LCV)			
<please specify>	MWh			

DRYING

		TOTAL site	Dry chopped strands	Semi-dry chopped strands	Direct rovings	Assembled rovings	Chopped strand mats	Continuous filament mats
Electricity	MWh							
Natural Gas	MWh (LCV)							
<please specify>	MWh							

PACKAGING

		TOTAL site	Wet chopped strands	Dry chopped strands	Dry chopped strands	Direct rovings	Assembled rovings	Chopped strand mats	Continuous filament mats
Electricity	MWh								
<please specify>	MWh								

INDUSTRIAL WATER TREATMENT

		TOTAL site
Electricity	MWh	
<please specify>	MWh	

WASTE WATER TREATMENT

		TOTAL site
Electricity	MWh	
<please specify>	MWh	

GLASS FIBRE RECYCLING

		TOTAL site
Electricity	MWh	
Natural Gas	MWh (LCV)	
<please specify>	MWh	

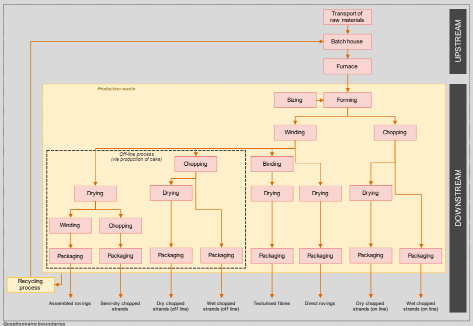
UTILITIES (e.g. boilers)

		TOTAL site	Wet chopped strands	Dry chopped strands	Dry chopped strands	Direct rovings	Assembled rovings	Chopped strand mats	Continuous filament mats
Electricity (from the grid)	MWh								
Natural Gas	MWh (LCV)								
<please specify>	MWh								

OTHER - please specify:

		TOTAL site	Wet chopped strands	Dry chopped strands	Dry chopped strands	Direct rovings	Assembled rovings	Chopped strand mats	Continuous filament mats
Electricity (from the grid)	MWh								
Natural gas	MWh (LCV)								
Light fuel	MWh (LCV)								
Heavy fuel oil	MWh (LCV)								
Propane	MWh (LCV)								
Oxygen	m^3								
<please specify>	MWh								
	MWh								

Process diagram



Project: LCA of glass fibre products
Questionnaire relative to the the studied product production process

5. Air emissions

General data

Company	-
Name and location of the plant	
Year of data collection	2021

Person in charge of the data collection

Name	-
Position	-
Phone	-
Email	-

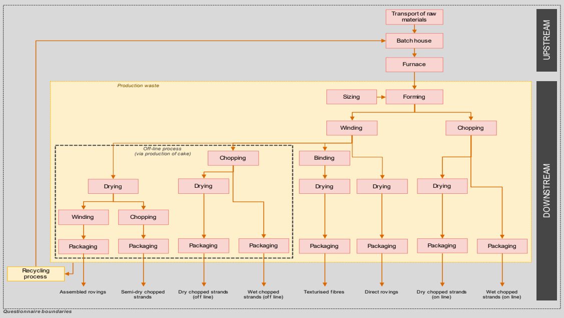
Comments on air emissions

General annual emissions

		TOTAL site
CO_2 (EU ETS value if applicable)	kg	

Note: please insert "NA" if the emission is not expected to be present

Process diagram



FURNACE (after filtre)

		TOTAL site
NOx (as NO_2)	kg	
SOx (as SO_2)	kg	
Dust / particulates (PM 10)	kg	
Dust / particulates (PM 2.5)	kg	
Dust / particulates (unspecified)	kg	
CO	kg	
CO_2 (from fuel combustion and process emissions)	kg	
VOCs	kg	
HCl	kg	
HF	kg	
NH_3	kg	
As	kg	
Se	kg	
Cr	kg	
Cr VI	kg	
Ni	kg	
Co	kg	
Pb	kg	
Sb	kg	
Cu	kg	
Sn	kg	
Mn	kg	
V	kg	
Cd	kg	
Hg	kg	
Tl	kg	
<please specify>	kg	
	kg	

SIZING / COATING: VOCs emissions

		TOTAL site	*Detailed per studied products* Wet chopped strands	Dry chopped strands	Semi-dry chopped	Direct rovings	Assembled rovings	Chopped strand mats	Continuous filament
VOCs total	kg								
Ethanol	kg								
Methanol	kg								
Formaldehyde	kg								
Ammonia	kg								
<please specify other main emissions>	kg								
	kg								
	kg								
	kg								
	kg								
	kg								

DRYING (e.g. fuel combustion, if available)

		TOTAL site
NOx (as NO_2)	kg	
SOx (as SO_2)	kg	
CO	kg	
CO_2	kg	
VOCs	kg	
Dust / particulates (PM 10)	kg	
Dust / particulates (PM 2.5)	kg	
Dust / particulates (unspecified)	kg	
<please specify>	kg	
	kg	
	kg	

INDUSTRIAL WATER TREATMENT

		TOTAL site
<please specify>	kg	
	kg	

WASTE WATER TREATMENT

		TOTAL site
<please specify>	kg	
	kg	
	kg	

GLASS FIBRE RECYCLING

		TOTAL site
NOx (as NO_2)	kg	
SOx (as SO_2)	kg	
CO	kg	
CO_2	kg	
VOCs	kg	
Dust / particulates (PM 10)	kg	
Dust / particulates (PM 2.5)	kg	
Dust / particulates (unspecified)	kg	
<please specify>	kg	

UTILITIES (e.g. combustion of boilers)

		TOTAL site
NOx (as NO_2)	kg	
SOx (as SO_2)	kg	
CO	kg	
CO_2	kg	
VOCs	kg	
Dust / particulates (PM 10)	kg	
Dust / particulates (PM 2.5)	kg	
Dust / particulates (unspecified)	kg	
<please specify>	kg	

pwc

Project: LCA of glass fibre products

Questionnaire relative to the the studied product production process

6. Water consumption and discharge into water

General data

Company	-
Name and location of the plant	
Year of data collection	2021

Person in charge of the data collection

Name	-
Position	-
Phone	-
Email	-

Comments on water consumption & discharge

General annual water consumption

		TOTAL site	Wet chopped strands	Dry chopped strands	Semi-dry chopped strands	Direct rovings	Assembled rovings	Chopped strand mats	Continuous filament mats
Water consumption from public network (potable water	m3								
Water consumption from industrial network	m3								
Water consumption from underground (well)	m3								
Water consumption from river	m3								

Discharge into water

Please insert below the amounts of pollutants after water treatment when available; else insert measures before water treatment in the municpal water treatment plant.

In case of discharge into municipal sewage network, please provide here all available information on pollution abatement at the municipal sewage treatment plant:		*(type of plant, pollution abatement rate...)*

		Discharge into natural environment	Discharge into municipal plant
Discharged water	m3		
BOD5 (5 Day biological Oxygen Demand)	kg		
Total nitrogen	kg		
Nk	kg		
COD (Chemical Oxygen Demand)	kg		
Suspended Matter	kg		
Total phosphorus	kg		
Cr VI	kg		
Pb	kg		
Cd	kg		
Cu	kg		
Cr	kg		
Hg	kg		
Ni	kg		
Zn	kg		
Sn	kg		
Fe	kg		
Al	kg		
F	kg		
Sb	kg		
Ba	kg		
AOX	kg		
HC total	kg		
B	kg		
<please specify>	kg		
	kg		
	kg		

pwc

Project: LCA of glass fibre products

Questionnaire relative to the the studied product production process

7. Waste management

General data

Company	-
Name and location of the plant	
Year of data collection	2021

Person in charge of the data collection

Name	-
Position	-
Phone	-
Email	-

Comments on waste

Note: please insert all weights for wet waste

		TOTAL site	Type of waste *select*	End of life *select*	Wet chopped strands (on + off line)	Dry chopped strands (on + off line)	Semi-dry chopped strands	Direct rovings	Assembled rovings	Chopped strand mats	Continuous filament mats	Waste transport: TRANSPORT – Road – Distance	Road – Actual load	Road – Empty return percentage rate	Road – Fuel consumption	Road – Maximum load	Rail – Distance	Sea – Distance
												km	t	%	l/km	t	km	km
											Default values		Maximum load	30%	0,38	24		
Glass waste (from forming)	t																	
Drain glass (cullet)	t																	
Finished product waste	t																	
Chemicals	t																	
Sludge (from waste water treatment)	t																	
Sludge (from industrial water treatment)	t																	
Dust from air pollution control system	t																	
Plastic	t																	
Paper and cardboard	t																	
Big bags	t																	
Metals	t																	
<please specify>	t																	
	t																	
	t																	
	t																	
	t																	

Detailed per studied products

5. Bibliography

Glass Fibre Europe website, www.Glass Fibre Europe.eu, for a description of the manufacturing process.

ISO 14040:2006 « Environmental management — Life cycle assessment — Principles and framework »

ISO 14044:2006 « Environmental management — Life cycle assessment — Requirements and guidelines »

ISO 14046:2014 « Environmental management — Water footprint — Principles, requirements and guidelines »

EcoInvent. Created in 1997, the ecoinvent Centre (originally called the Swiss Centre for Life Cycle Inventories) is a Competence Centre of the Swiss Federal Institute of Technology Zürich (ETH Zurich) and Lausanne (EPF Lausanne), the Paul Scherrer Institute (PSI), the Swiss Federal Laboratories for Materials Testing and Research (Empa), and the Swiss Federal Research Station Agroscope Reckenholz-Tänikon (ART). The present study uses the latest version of the EcoInvent database available, Ecoinvent version 3.8. Life cycle inventory data are proposed in this database under four allocation rules principles. The modules used were generated under the following principle of Ecoinvent 3.8: "Allocation, cut-off by classification". This system model subdivides multi-product activities by allocation, based on physical, economic, mass or other properties. By-products of waste treatment processes are cut-off, as are all by-products classified as recyclable. Markets in this model include all activities in proportion to their current production volume. www.ecoinvent.org

IPCC 2013. Fifth assessment report from the Intergovernmental Panel of Climate Change (IPCC) is available from http://www.ipcc.ch/report/ar5/wg1/

BREF 2013. Best Available Techniques (BAT) Reference Document for the Manufacture of Glass, Industrial Emissions Directive 2010/75/EU (Integrated Pollution Prevention and Control), JRC REFERENCE REPORT, European Commission, 2013. https://op.europa.eu/en/publication-detail/-/publication/ff8a3955-d0d0-46f5-8a15-4b638896cb56

Status of glass under REACH (Registration, Evaluation and Authorization of Chemicals) in reference to the Classification of certain borates and boron oxide (diboron trioxide) as SVHC (Substances of Very High Concern), Glass Fibre Europe

Previous LCA reports. Life cycle assessment of CFGF – Continuous Filament Glass Fibre Products, February 2012, Report prepared by PwC for Glass Fibre Europe and based on 2010 CFGF industry data, and the update of this report published in October 2016 based on 2015 CFGF industry data.

6. Peer review report

Angela Schindler
Umweltberatung

Critical Review Statement

Life Cycle Assessment of CFGF – Continuous Filament Glass Fibre Products

Commissioned by:	Glass Fibre Europe
Version:	02. November 2022 + update 31. January 2023
Prepared by:	PwC – Neuilly-sur-Seine cedex, Olivier Muller, Julien Mercier, Carlos Eduardo Ruiz Flores
Reviewed by:	Angela Schindler – Umweltberatung, Salem
References:	ISO 14040:2006: Environmental Management – Life Cycle Assessment – Principles and Framework ISO 14044:2006: Environmental Management – Life Cycle Assessment – Requirements and Guidelines ISO/TS 14071:2016: Environmental management - Life cycle assessment - Critical review processes and reviewer competencies: Additional requirements and guidelines to ISO 14044:2006

Scope of the Critical Review

The reviewer was tasked with assessing whether:

- the methods used to carry out the Life Cycle Assessment (LCA) are consistent with the relevant International Standards (ISO 14040, ISO 14044),
- the methods and inventory modelling used to carry out the LCA are scientifically and technically valid,
- the data and model results used are appropriate and reasonable in relation to the goal of the study,
- the interpretations reflect the limitations identified and the goal of the study, and
- the study report is transparent and consistent.

The critical review was performed after the LCA study was completed according to paragraph 6.2 of ISO 14044. This review statement is only valid for the specific report in its final version dated 02.11.2022 and updated 31.01.2023.

The verification of the LCI model and individual background datasets is outside the scope of this review.

Subject of this critical review is the LCA study (cradle-to-gate) covering the products being produced by members of Glass Fibre Europe.

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Review process

The first draft of the study report was submitted on 29.09.2022. The reviewer thoroughly checked this first version and provided back detailed comments of general, technical and editorial nature to PwC on 18.10.2022. These comments were discussed in a review meeting on 27.10.2022 to avoid any misunderstandings on the consultants' or the reviewer's side.

PwC revised the report and provided an updated version as well as answers to all review comments on 03.11.2022. The reviewer checked the implementation of the comments and agreed to conclude the critical review process. The final review statement for the report version 02.11.2022 was submitted on 07.11.2022.

In January 2023 PwC received further up-to-date data from single study members and integrated them in to the overall data collection. This new version, dated 31.01.2023 has been reviewed and accepted by the reviewer on 06.02.2023.

General evaluation

The study displays an update of LCA studies on the same products and equivalent geographical region as of 2012 and 2016. The study was performed in a professional manner, the report is well-structured and in conformity with ISO 14040 and ISO 14044.

The goal of the study is to obtain robust LCA results at European level for four main glass fibre products by assessing the environmental performance according to ISO 14040/44 and impact categories of the EF 3.0 methodology. The results are intended to be published and to be integrated in the European Commission's LCA database.

The scope comprises the cradle-to-gate assessment including the supply chain, the manufacturing and sizing and the packaging.

The methodological aspects of goal, intended application and audience of the LCA study are clearly described. All relevant methodological aspects, i.e. declared unit, system boundaries, cut-off criteria, data mapping and data quality, impact categories, applied software and databases are documented.

During the review process various aspects were listed in a comments table and discussed with the LCA practitioners of the study. Subsequently, they were appropriately addressed and integrated into the final report by the LCA practitioners:

- Clarification and clear documentation of methodological approach for looping of recycled glass material.
- The discussion on the result indicators covers
  - the justification of the selected indicators,
  - the emphasis on the difference of the impact categories of the previous and current environmental model (CML/EF 3.0)
  - the supplement of the assessment according to CML for proper understanding of the process developments in foreground as well as background data.
- Applying green electricity is a reasonable step towards sustainable development. For a resilient study, the evidence on official certificates was supplemented.

The interpretation provides a clear overview on the results and their limitations.

The results of this update show on the one hand side the stability of the selected approach and on the other hand the bandwidth of LCA data, caused by primary input information of the manufacturers as well as of developments in the background data.

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The study may be used as basis for further calculations and assessments along the downstream process chain of industry applying the considered products.

Despite all necessary due diligence performed during the critical review process by the reviewer, the commissioner of the LCA studies remains liable for the underlying information and data.

Conclusion

Overall, the LCA study can be considered very detailed and meeting the goal and scope.

The study has been documented precisely, diligently and in a clearly legible manner.

Underlying data, the life cycle model, assumptions and calculations are appropriate and lead to the requested results. The interpretation reflects the results in a suitable manner and relevant conclusions and recommendations are drawn.

This review statement only applies to the report and version(s) named in the title, but not to any other report versions, derivative reports, excerpts, press release, and similar documents.

Revision January 2023

With this study version, the primary data are further specified, resulting in minor changes of the impact assessment.
The revision of the comparison now focus on the changes in the activity data (primary data of the study's members) and suppresses the indirect effects of developments of electricity generation.

Salem, 07.11.2022 + 06.02.2023

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