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Life cycle assessment of CFGF – Continuous Filament Glass Fibre Products

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Report prepared for

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by

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Executive Summary

GlassFibreEurope, 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 fiber 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 and Norway. Companies who took part to the data collection include: 3B the fiberglass company, Saint Gobain-Vetrotex Deutschland, Johns Manville Europe, Lanxess Deutschland, European Owens Corning Fiberglass, PPG Industries Fiber Glas bv.

Continuous filament glass fiber products are mainly used in 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 and 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.

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

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 10-25% apart.

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Section I - General introduction

1. Context of the assessment

GlassFibre*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 60 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, GlassFibre*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, GlassFibre*Europe* intends to publish the results on the European Commission’s LCA database, ELCD.

The study is an update of a first study published by GlassFibre*Europe* five years ago on direct and assembled rovings 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 II - 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**". 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). 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 paragraph 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 Chemicals) regulation. Based on the information received, no CFGF product manufactured by GlassFibre*Europe* members contains more than 0.1% of products on the SVHC list
- **For the life cycle of a waste or a by-product. The predominant treatment (landfilling) was taken into account**. Incineration was not included, 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)

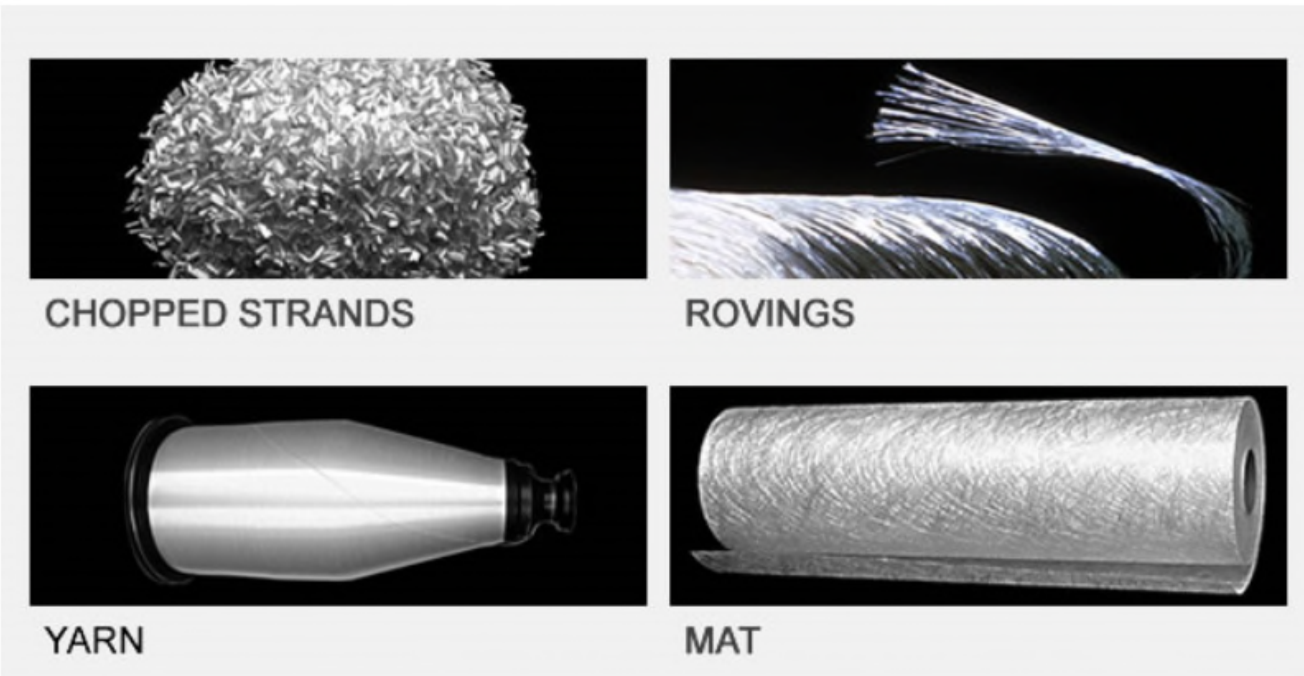


Figure 1 – Chopped strands, rovings and mats
Source: http://www.glassfibreeurope.eu/about-glassfibreeurope/products/

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 approx. 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 range 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 taken into account 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).

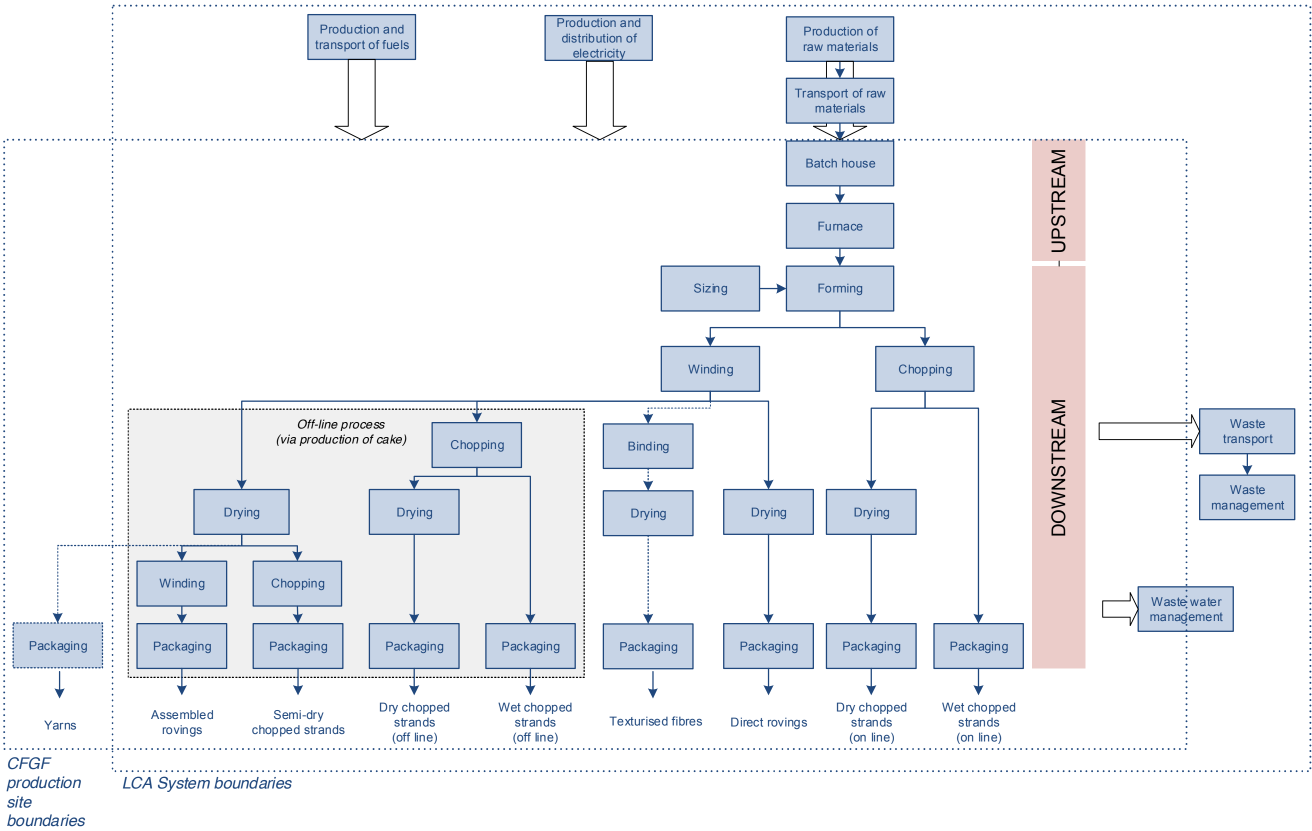


Figure 2 – System boundaries of the data collection in CFGF production sites and LCA system boundaries

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. Six product families were identified: silanes, filmformers, lubricants, defoamers, surfactants, pH modifiers. For five of these families, a LCA model was developed (silanes, filmformers, lubricants, surfactants, pH modifiers see Appendix 2). For defoamers, no model was developed and the corresponding products are included in the list of products cut-off 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 product studied;
   - 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 dry product 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 price range of 20% (typically[1] between 1 to 1.25 €/kg).

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

[1] Note: some mat products (continuous filament mats) can be 2.5 times more expensive than the rest of the continuous filament products. However, these products represent a small fraction of the CFGF products.

Process stage	Type of allocation	Allocation rule (conversion factor)
Sizing	Product-specific data collected	-
Drying	Mass allocation	weight of specific end-product/total end-products weight (excl. wet chopped strands)
Binder coating	Product-specific data collected	
Packaging	Product-specific data collected	-
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: nitrogen and phosphorus discharge, COD, BOD_5, metals. Note: BOD5 is part of COD. Only COD is taken into account to calculate Eutrophication (see Table 10),
- Generation of non hazardous industrial waste.

Water use refers to the withdrawal of water from water basins or drainage basins to 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 that specific case, water pumped is brought back to the environment with no alteration apart from heating.

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

Indicators of potential impacts associated with these significant flows are analyzed 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 procedures 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 analyzed:

Indicator	Environ-mental 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 gram equivalent SO_2, which can be produced per mole. CML[4] developed the characterisation method used by PwC.	AIR	CML-4.2
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 g eq. ethylene.	AIR	CML-4.2
Water eutrophication 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 developed by the Centre of Environmental Science (CML), Leiden University. 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 phosphate.	WATER	CML-4.2
Depletion of abiotic resources (elements) 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 antimony (source: CML).	RESOURCES	CML-4.2

[3] IPCC: International Panel on Climate Change.
[4] CML: University of Leiden (The Netherlands).

Indicator	Environ-mental category	Calculation method
Human toxicity 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 analyze 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	USETOX 1.0

Characterisation factors from CML for acidification, tropospheric ozone creation, depletion of abiotic resources and eutrophication are those available from the CML website in March 2013. Characterisation factors for human toxicity are those available from the USEtox website in February 2010 (USEtox 1.0). The list of characterisation factors used are presented in Appendix 3.

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 2011 and the 2016 LCA studies of CFGF products.

Selected environmental indicator	Change in the definition and coefficients between the 2011 and the 2016 studies
Greenhouse gas emissions	Conversion coefficients of the gases were updated (most relevant change regarding the current report is for methane, coefficient update from 25 to 28) Note: No major change is induced on the CFGF LCA impact assessment results, as CO2 is the key contributor to this indicator.
Emissions contributing to acidification	Same method used
Tropospheric ozone formation	The influence of SO_x, NO_2 and NO air emissions is now integrated.
Water eutrophication	The influence of air emissions of nitrogen and soil emissions of nitrogen and phosphate is now integrated
Depletion of abiotic resources (elements)	The previous version integrated the contribution of fossil fuels, which are now excluded from this indicator. Contribution of fossil fuels is studied via the total primary energy indicator.
Total primary energy indicator	No change
Human toxicity	New indicator that was not included in the previous report.
Water use	No change (this indicator was previously called “water consumption”, but was renamed “water used” in compliance with ISO 14046:2014).

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.

4. Data quality requirements

The purpose of the study is to analyze the life cycle 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 2015 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. GlassFibre*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.

Table 2 - Coverage per product

	Dry chopped strands	Wet chopped strands	Direct rovings	Assembled rovings	Mats
Number of sites	8	6	7	5	2

For each product, except mats, data were collected from at least five independent companies.

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: GlassFibreEurope, as a minimum estimation.

Section III - 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 mainly derived from the Ecoinvent 3 and TEAM™ databases (DEAM).

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) were classified into 5 categories (silanes, film-formers, lubricants, surfactants, pH modifiers). 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 between sites and with bibliographical reference values. Moreover, values collected for 2015 were compared to 2010 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 water rejects and air emissions from sizing.

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

1.3. Data consolidation

All data have been analyzed separately, in order 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 Transport model

The model used to calculate the fuel consumption for each transport step considers that the load transported by trucks affects the fuel consumption of those trucks. We consider that a part of the real consumption is constant and that the other part depends on the transported load. The model used to estimate the fuel consumption of a truck depending on its load, while taking into account an "empty return" factor is the following:

$$Cc * km * (1/3*Cr/Cu + 2/3*(1+R)) * Q/Cr$$

With:

– Cc = Truck fuel consumption in litre per km
– km = transport distance of the load in km
– Cr = real load in the truck, including the packaging weight
– Cu = the maximum load of the truck (for instance 24 t)
– R = empty return ratio
– Q = quantity of transported material

When information about the empty return ratio was missing, a default value of 30% has been chosen, as a conservative default value. Note: given the very small contribution of transport to total results, this assumption has a very limited impact on the results.

Furthermore, when the transport distance was not provided in the questionnaires, an estimation has been performed.

2.2 Source of generic data used

The data used for the modelling of the fuel combustion in a truck engine come from data used in EMEP/EEA emission inventory guidebook 2009 (updated 2012) for heavy duty vehicles).

The data used for the modelling of the fuel combustion in a ship engine come from the EcoTransIT tool (Ecological Transport Information Tool for Worldwide Transports, commissioned by DB Schenker Germany and UIC (International Union of Railways) in 2011.

Although these background data sources could be discussed, they can be accepted considering that raw materials transport is only contributing for 2% of total primary energy consumed.

2.3 Transport steps taken into account in the study

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.

3. Water treatment

In addition to waste water 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 the pollutants emitted into the water. When data were unavailable, the general rule explained in paragraph 1.2 was used.

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 waste water 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

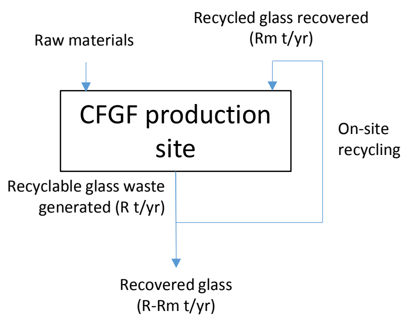
In all cases, waste transport from the site to the end-of-life treatment plant has been included, taking into account the road transport from the site to the treatment or elimination plant.

Most of the waste produced by manufacturing sites is landfilled, the rest is incinerated or recycled.

Impacts of landfilling have been taken into account.

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 (see §5).

Waste glass from the CFGF manufacturing process is recycled in very few cases. In that case, glass is recycled on site and the net production of glass waste to be recycled has been accounted as recovered matter. This net quantity of recovered matter is calculated as the difference between the generation of recyclable glass waste and the quantity of recycled glass actually recycled in the furnace during the same year (see diagram on the right). This approach is known as a "stock method". No other source of glass recycling exists in the studied system.



When on-site recycling of glass is implemented, the quantity of glass recovered on site currently represents less than 10% of the raw materials consumed.

5. Electricity production

Country-specific electricity mixes have been considered for the electricity consumed on site. A European average model has been used when associated with generic data.

Data used for the electricity mixes and the loss due to transportation come from 2013 representative statistics established by the International Energy Agency (IEA) : "Electricity Information 2015". Data used for the modelling of each power sector, except nuclear power sector, comes from a publication by the European Environment Agency (EEA), the "EMEP/EEA air pollutant emission inventory guidebook 2009, updated June 2010", section on Energy Industries. Data about the nuclear power sector has been modelled after a study initially carried out by PwC-Ecobilan for EDF and AREVA in 1998 and has been updated regarding energy efficiency of nuclear power plants. Energy efficiencies for power plants (fossil and nuclear) come from country-level information published in Energy Efficiency Indicators for Public Electricity Production from Fossil Fuels, IEA 2008.

Table 4 – Country specific electricity mixes and distribution losses (2013)

Electricity mix 2013	Coal and peat	Oil	Gas	Nuclear	Hydro	Wind	Other sources (burden free)[6]	Distribution losses
Belgium	6.18%	0.19%	25.06%	51.10%	2.07%	4.36%	11.05%	4.80%
France	4.33%	0.43%	3.00%	74.00%	13.21%	2.80%	2.22%	6.56%
Germany	46.35%	1.14%	10.86%	15.37%	4.55%	8.17%	13.58%	3.87%
Norway	0.10%	0.02%	1.83%	0.00%	96.11%	1.41%	0.52%	7.99%
Czech Republic	50.85%	0.05%	1.98%	35.31%	4.18%	0.55%	7.07%	4.71%
Italy	16.73%	5.34%	37.57%	0.00%	18.86%	5.14%	16.35%	7.31%
Netherlands	27.30%	1.24%	54.69%	2.87%	0.11%	5.58%	8.22%	4.45%
Slovakia	12.23%	1.49%	8.30%	54.52%	17.92%	0.02%	5.52%	2.64%
United Kingdom	36.73%	0.60%	26.62%	19.66%	2.11%	7.92%	6.36%	7.47%
European average	27.74%	1.88%	15.56%	26.88%	12.33%	7.21%	8.40%	6.39%

[6] Other sources: geothermal, solar, biomass and animal products, industrial waste, municipal waste, non-specified assumed being free of environmental impacts

Section IV - 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).
- **Sizing**: production and consumption of energy, production and transport of raw materials.
- **Downstream process (excl. 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 were collected. For mats, for confidentiality reasons, the minimum and maximum values were fixed 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.

2. Natural resources consumption

2.1 Total primary energy

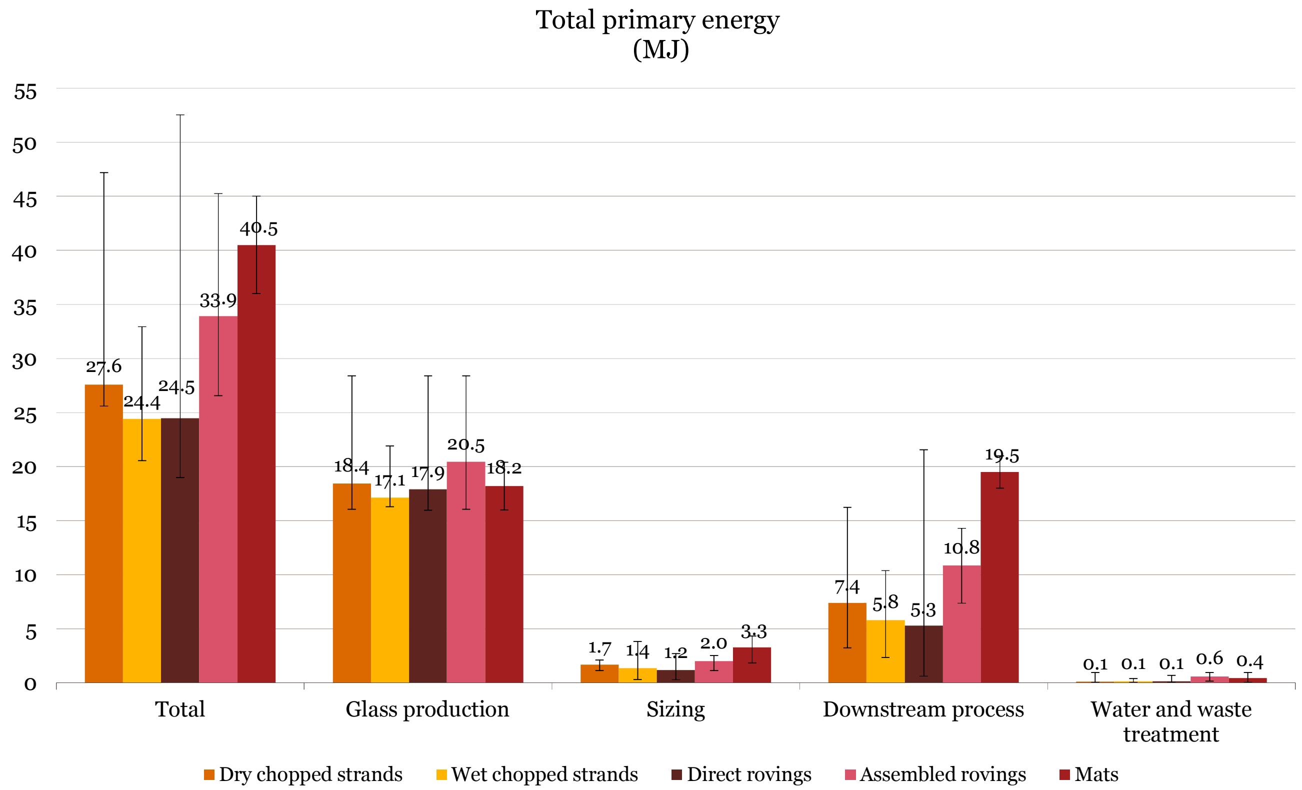


Figure 3 – Total primary energy consumption (MJ)

On average, 27.7 MJ of primary energy are consumed to produce one kilogram of CFGF product, of which 67% is due to the glass melting process (extraction and transport of raw materials, furnace). Natural gas represents 55% of this energy consumption. Although primary energy is mostly consumed at the furnace stage, a significant part (27%) of energy is consumed during the downstream process, mainly for drying and by utilities like recycling lines.

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 and downstream processes can be close to zero.

Figure 3 shows the difference between wet and dry chopped strands, partly due to the higher amount of energy required for drying. Wet chopped strands have a total primary energy consumption 12% lower than dry chopped strands.

When looking further at the contributors within the molten glass production stage, process energy consumption represents 56% of primary energy consumed at the glass production stage, and 37% of total primary energy demand (see Figure 4).

On average, 15 MJ of primary energy (including fossil fuel production and combustion as well as electricity consumption) is consumed in the furnace. This mean value is in the mid-range given by the BREF on the glass manufacturing industry (2013) of 7 – 18 MJ.

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 the energy consumption and greenhouse gas emissions by about 10%.

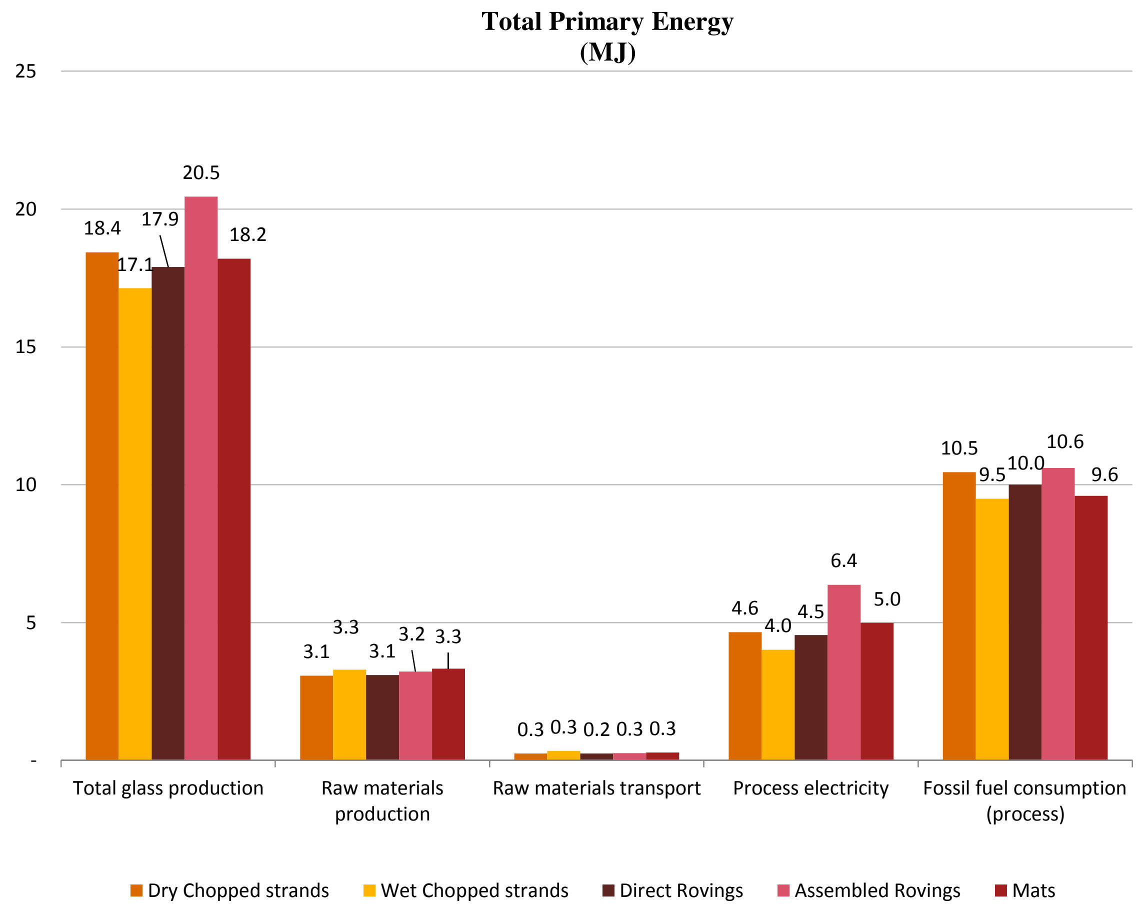


Figure 4 – Total primary energy consumption breakdown for glass production

2.2 Natural resources depletion

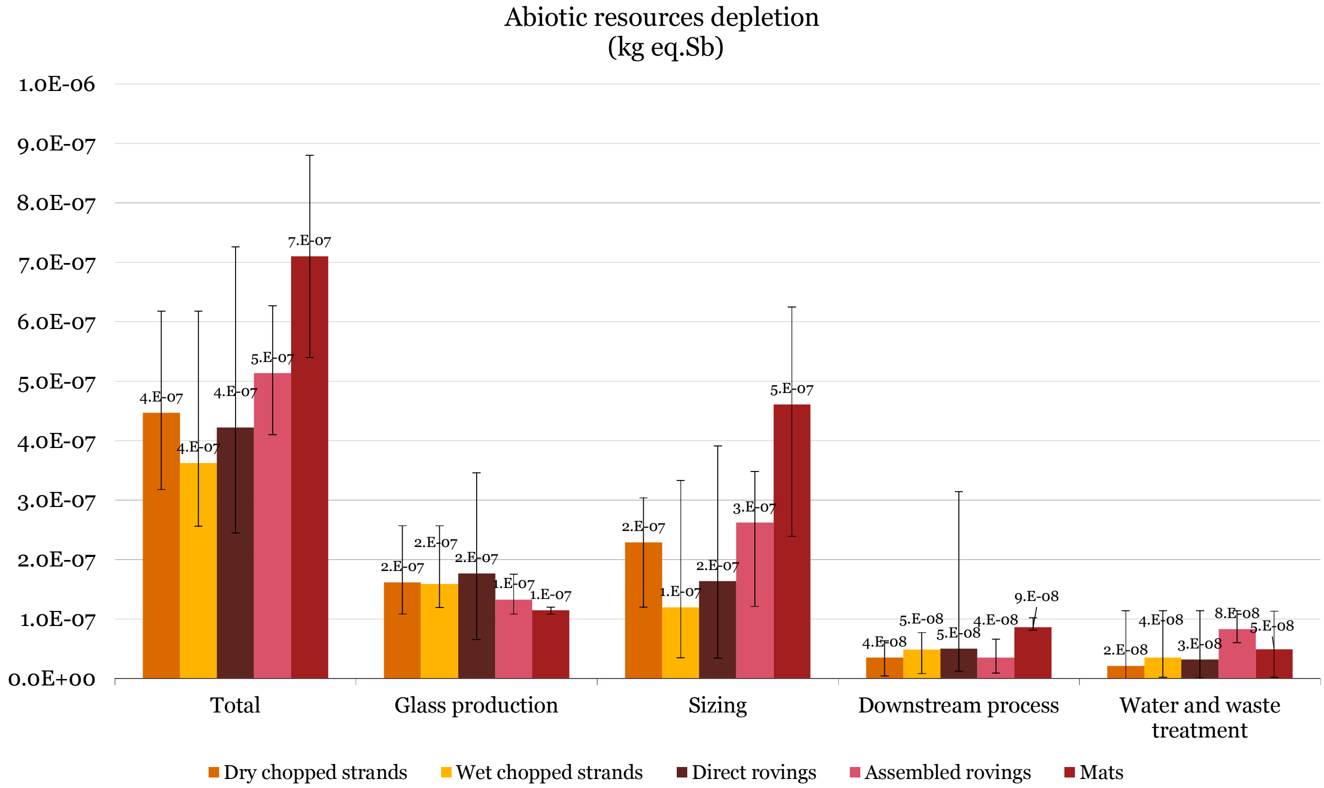


Figure 5 – Abiotic depletion potential - elements (kg eq. Sb)

Abiotic resources depletion is mainly due to raw material consumption at the sizing stage. Production of mineral resources also play a role. In particular, borax is contributing for less than 0.5 % of abiotic resources depletion.

2.3 Water use

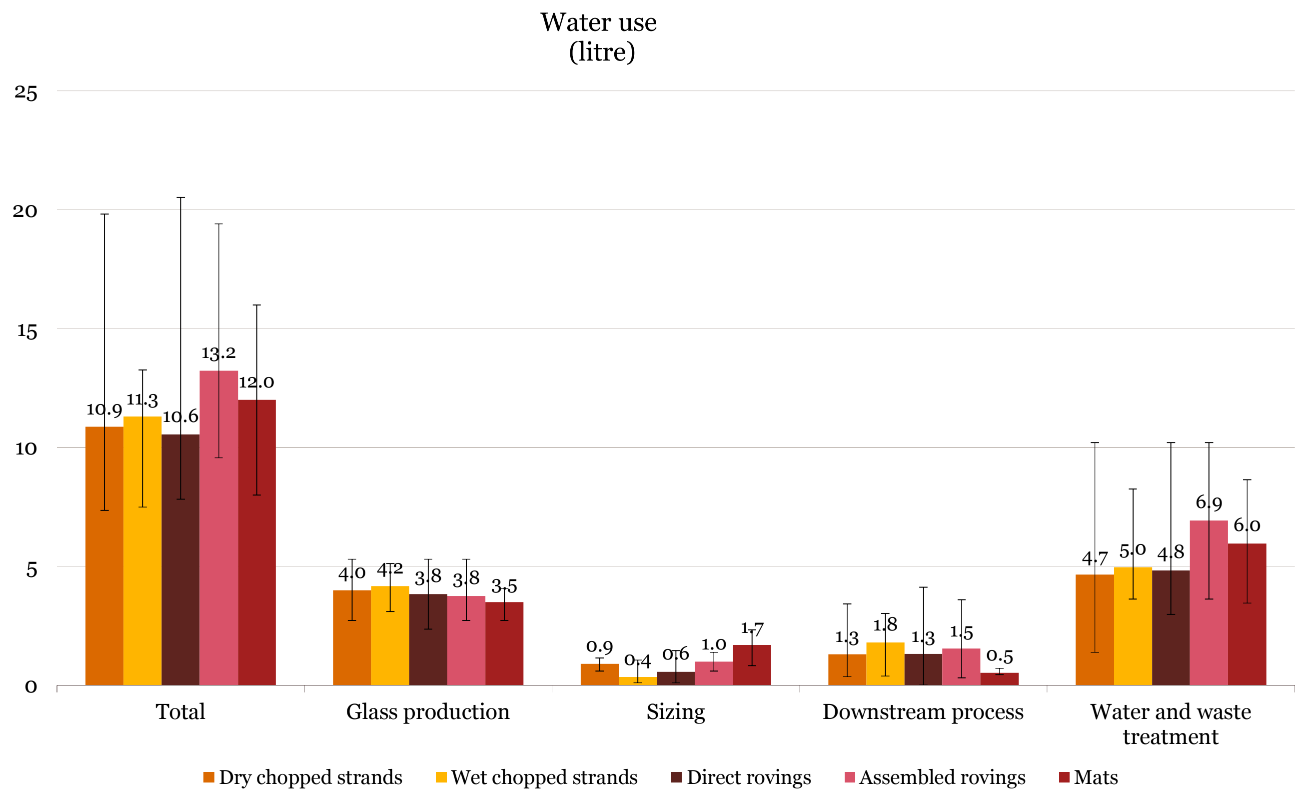


Figure 6 – Water use (litre)

On average, producing one kilogram of CFGF product consumes 12 litres of water. On-site water use has been allocated to the industrial water treatment plant. It is mainly sourced from river and well. Some sites can consume five times more water than others per kg of glass fiber produced, which reflects a high dispersion of the water management practices among the sites.

Note: as compared to the previous report, water use from raw materials is reduced due to LCA production model update (in particular kaolin, sand, limestone).

3. Water eutrophication

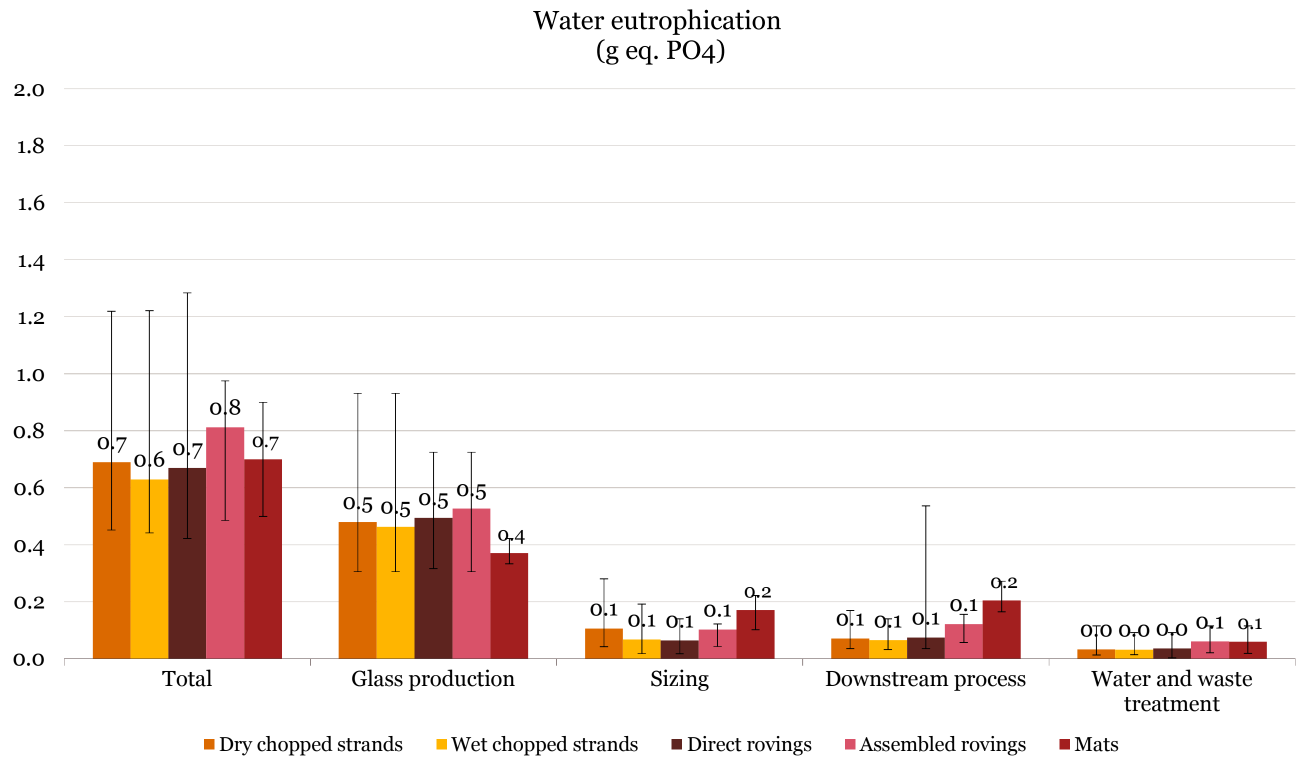


Figure 7 – Water eutrophication (g eq. PO_4)

The contribution to water eutrophication is split between:

- air emissions of NOx from raw material production (30%)
- air emissions of NH3 and NOx from sizing (25%).
- air emissions of NOx from the furnace (25%)
- water rejects of phosphate from the raw material production (20%).

Other water rejects represent less than 5% of the eutrophication impact sources. Impacts of water rejects from the site are measured at the waste-water treatment stage; however, they are actually mainly due to chemicals originating from the sizing process.

4. Air emissions

4.1 Greenhouse gas emissions

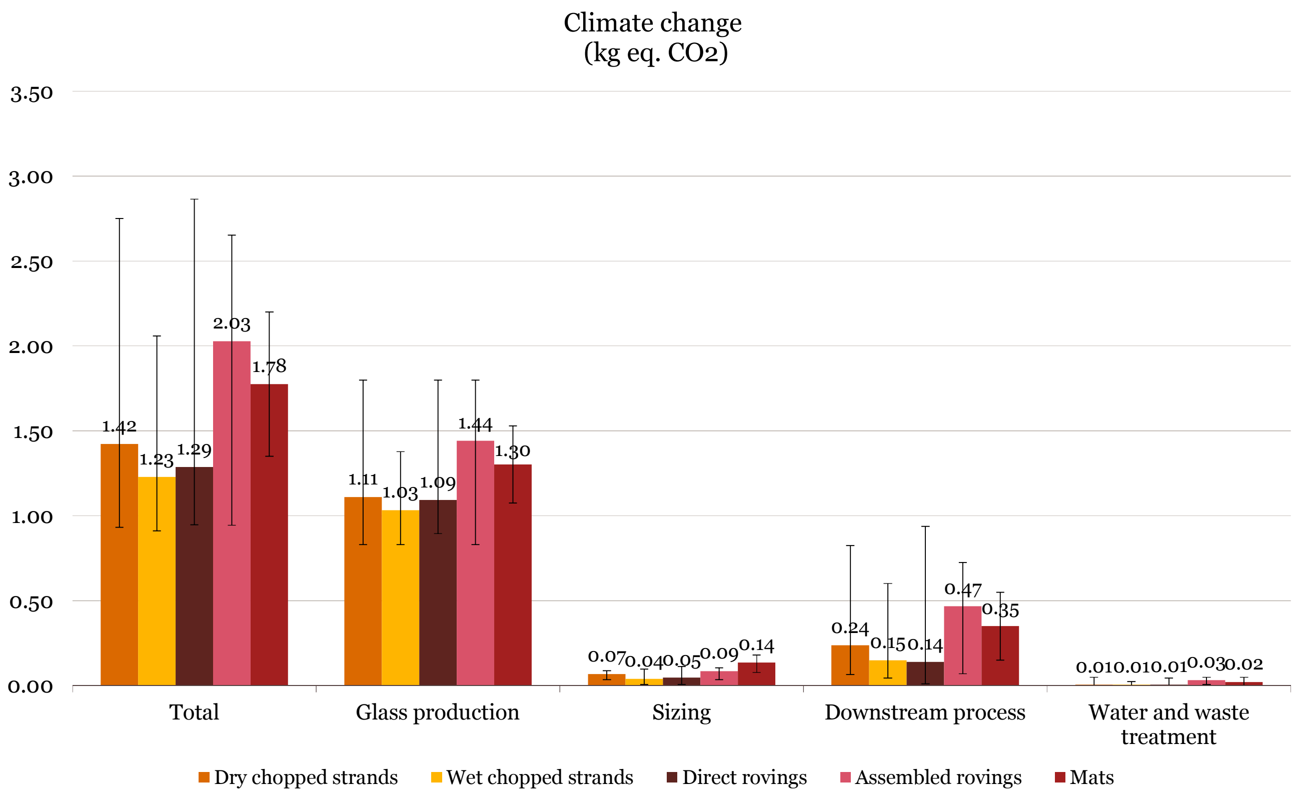


Figure 8 – Greenhouse gas emissions (kg eq. CO_2)

On average, the impact of CFGF production on climate change is 1.5 kg eq. CO_2. Direct emissions on site represent 0.57 kg eq. CO2 or 40% 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.

The breakdown of the contributors at glass production stage reflects (Figure 9) the predominant contribution of process emissions (energy consumption from fossil fuels and decarbonation of raw materials) to climate change (50 %) within this stage and 40 % of total greenhouse gas emissions. Over the glass production stage, 22 % of greenhouse gas emissions are due to the production of raw materials, 17% to electricity production and 11% to fossil fuel production.

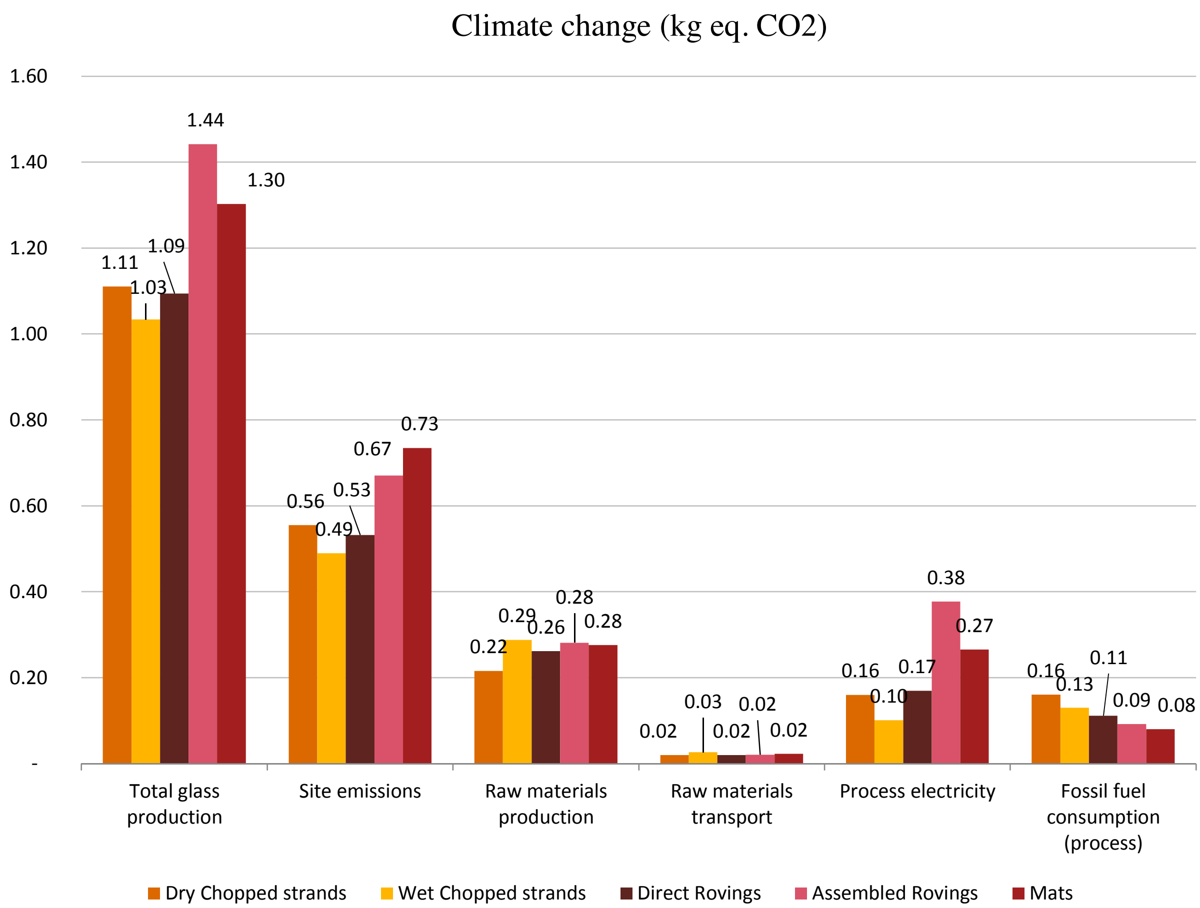


Figure 9 – Breakdown of the contributions to climate change at glass production

The average direct greenhouse gas emissions (504 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 calculated for the EU-ETS benchmark of 540 kg eq CO_2/ton of molten glass, and the benchmark value of 406 kg eq CO_2/ton of molten glass.

Carbon dioxide is the source of more than 90% 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 Tropospheric ozone formation

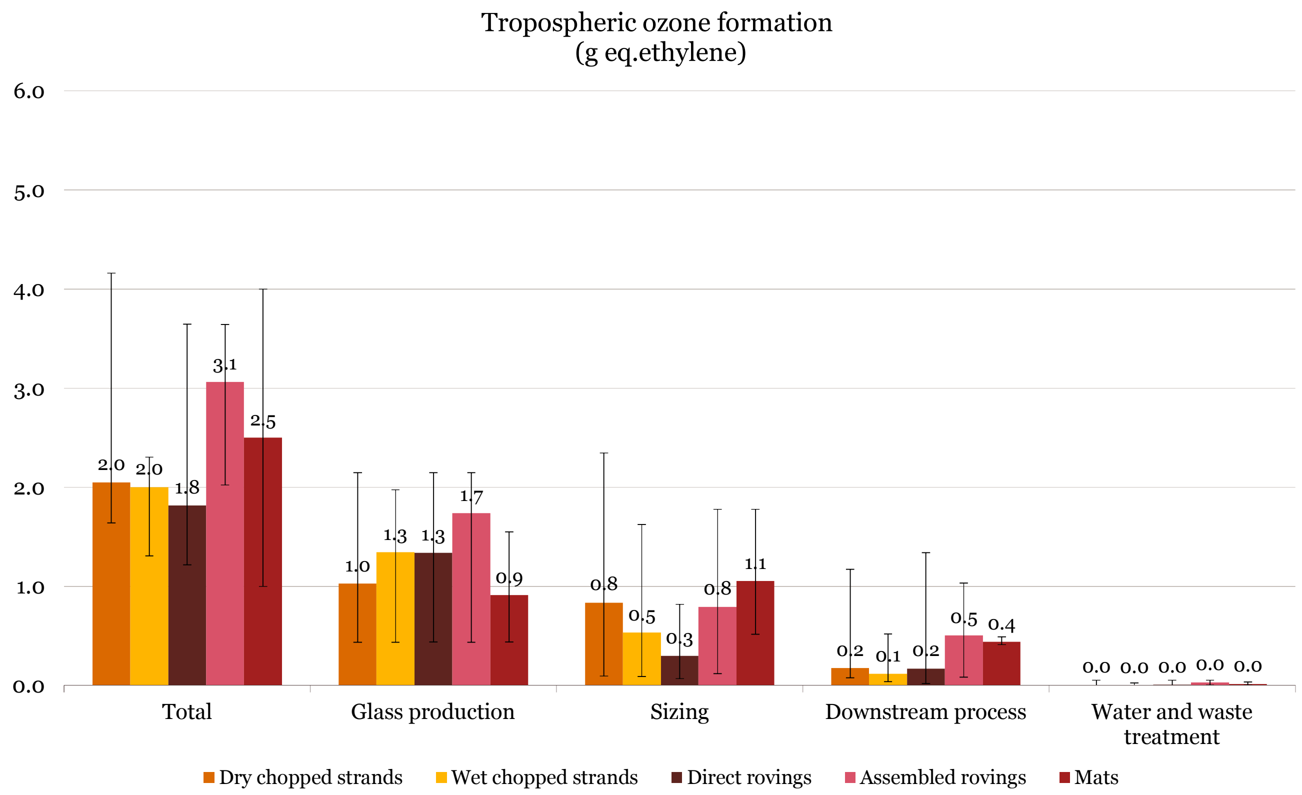


Figure 10 – Tropospheric ozone formation (g eq. ethylene)

Contributions to tropospheric ozone formation are mainly due to emissions from sizing (around 70%, unspecified volatile organic carbon, ethanol) and from the furnace (around 24%, non methanic volatile emissions, SO_2, NO_x, CO). Larger variations among sites can be observed compared to other indicators.

4.3 Acidification

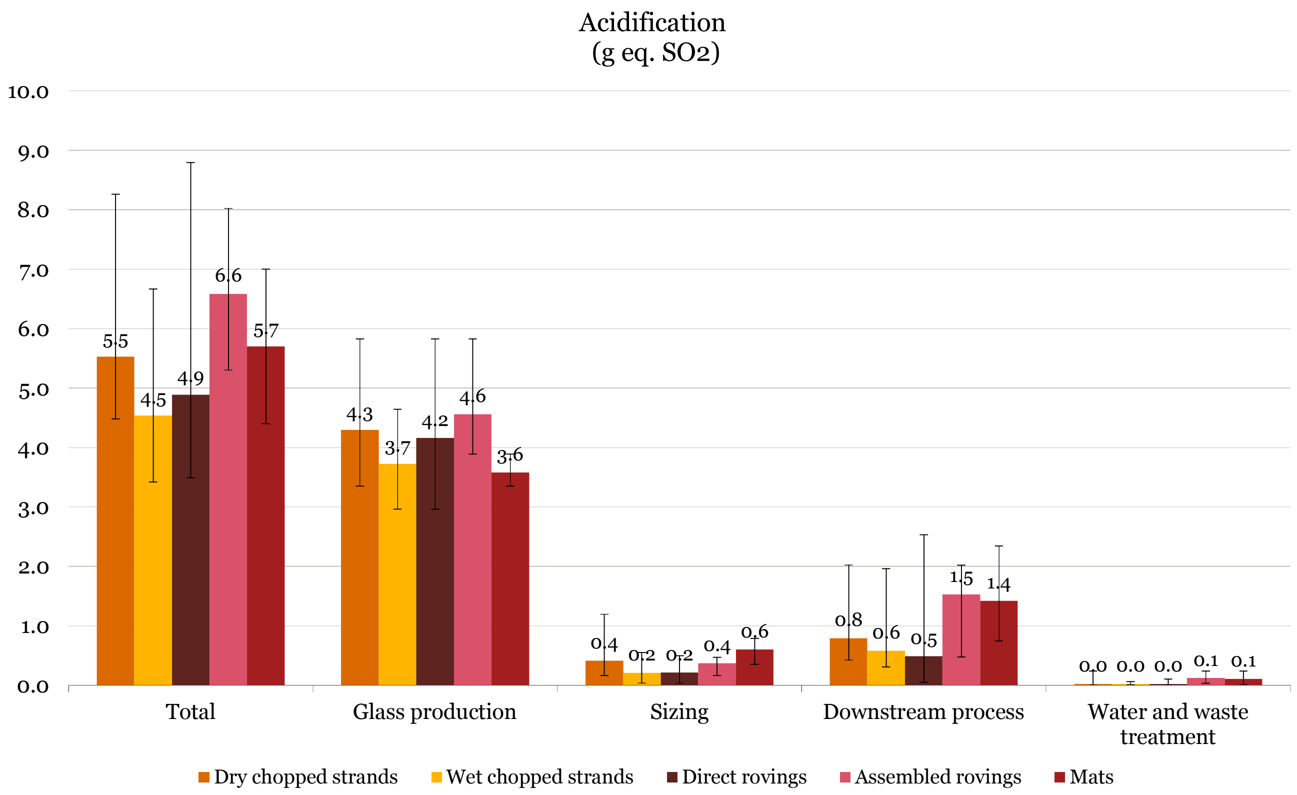


Figure 11 – Acidification (g eq. SO2)

Contribution to acidification is split between:

- SOx and NOx emissions released during raw material production (20-35%)
- SO_x and NOx emissions released at the furnace (15-30%)
- SOx and NOx emissions released during oxygen production (15-25%)
- NH3, SO2 and NOx emissions released at the sizing stage (5-16%)
- SOx and NOx emissions released during electricity production (5-15%)

Sulfur oxides represent 60-70% of total contributions to acidification and nitrogen oxides around 20-30%.

Direct emissions occurring at the furnace represent around one fourth of total acidifying emissions.

4.4 Human toxicity

Figure 12 – Human toxicity (unit)

Human toxicity, as calculated in the USEtox approach, is mainly due to:

- air emissions from the site furnace (lead, arsenic, cadmium and mercury).
- sizing
- natural gas production
- raw material production.

Relative contributions of these sources vary depending on the product and site considered, but each of these contributions is on average around 20%.

5. Total solid waste

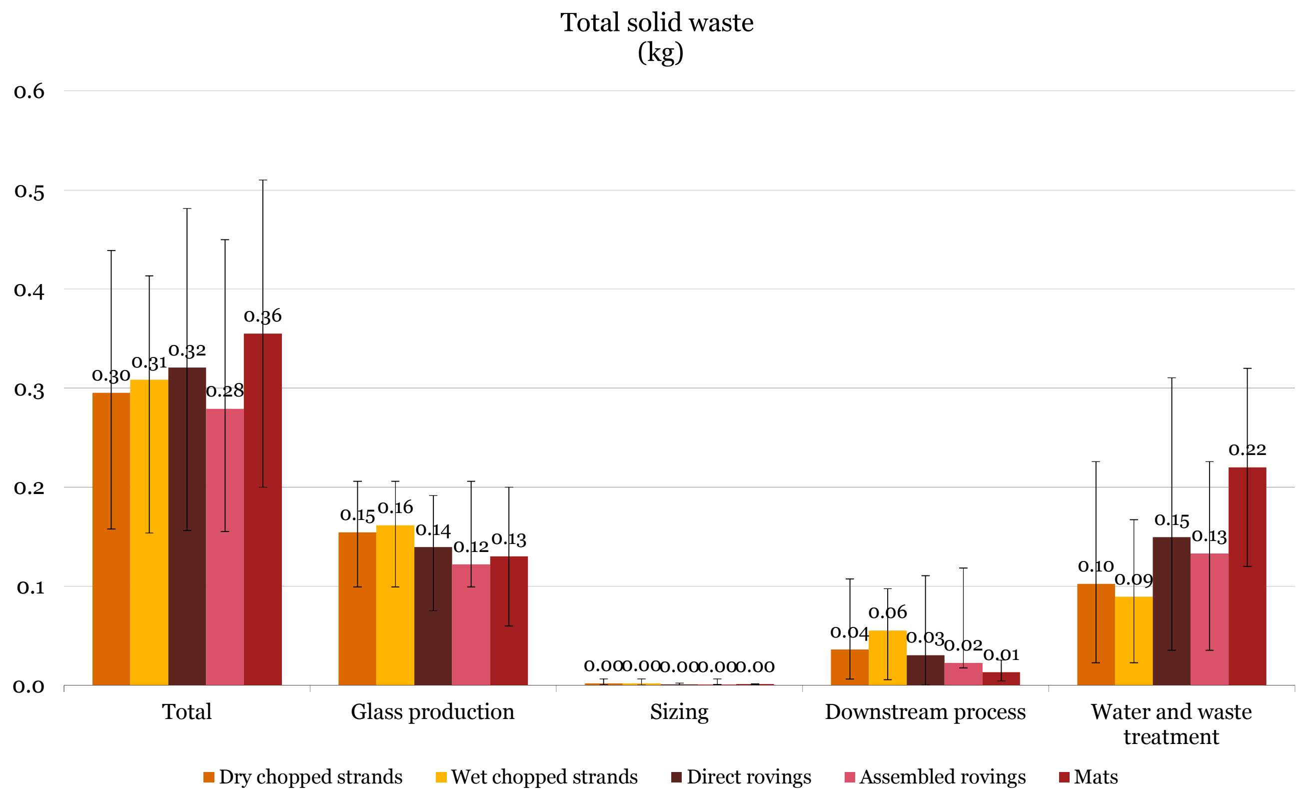


Figure 13 – Total solid waste (kg)

Solid waste is mainly generated from:

- the raw material production and
- the glass discarded at the forming stage,

and is mostly disposed of in landfills. Some of the waste glass is also marginally recycled on site; the corresponding quantities were taken into account in the calculations to reduce the quantity of waste produced.

Inert waste is related to upstream raw materials production and incinerated waste is mainly glass and sludge from water treatment plants.

Table 5 –Management of waste produced on CFGF production site

Flow	Waste fraction (as % weight to total waste produced)
Non-hazardous waste to landfill	73 %
Waste sent to recycling[7]	26 %
Non-hazardous waste to incineration	0.5 %
Hazardous waste landfilled	0.1 %

[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		
	Average	Min	Max	Average	Min	Max	Average	Min	Max	Average	Min	Max	Average	Min	Max
TOTAL	24.4	20.6	32.9	27.6	25.6	47.2	33.9	26.5	45.2	24.5	19.0	52.5	40.5	36.0	45.0
Glass Production	17.1	16.3	21.9	18.4	16.1	28.4	20.5	16.1	28.4	17.9	16.0	28.4	18.2	16.0	20.4
Sizing	1.4	0.3	3.8	1.7	1.1	2.1	2.0	1.1	2.5	1.2	0.3	2.7	3.3	1.8	4.3
Downstream	5.8	2.3	10.4	7.4	3.2	16.2	10.8	7.4	14.3	5.3	0.6	21.6	19.5	18.0	21.0
Water and waste treatment	0.1	0.0	0.4	0.1	0.0	1.0	0.6	0.2	1.0	0.1	0.0	0.7	0.4	0.0	1.0

Total IPCC-Greenhouse effect 2013 (direct, 100 years)	Wet chopped strands			Dry chopped strands			Assembled rovingss			Direct rovings			Mats		
	Average	Min	Max	Average	Min	Max	Average	Min	Max	Average	Min	Max	Average	Min	Max
TOTAL	1.2	0.9	2.1	1.4	0.9	2.8	2.0	0.9	2.7	1.3	0.9	2.9	1.8	1.4	2.2
Glass Production	1.03	0.8	1.4	1.11	0.8	1.8	1.44	0.8	1.8	1.09	0.9	1.8	1.3	1.1	1.5
Sizing	0.04	0.0	0.1	0.1	0.0	0.1	0.1	0.0	0.1	0.0	0.0	0.1	0.1	0.1	0.2
Downstream	0.15	0.0	0.6	0.2	0.1	0.8	0.5	0.1	0.7	0.1	0.0	0.9	0.4	0.2	0.6
Water and waste treatment	0.01	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Water Used (total)	Wet chopped strands			Dry chopped strands			Assembled rovingss			Direct rovings			Mats		
	Average	Min	Max	Average	Min	Max	Average	Min	Max	Average	Min	Max	Average	Min	Max
TOTAL	11.3	7.5	13.3	10.9	7.4	19.8	13.2	9.6	19.4	10.6	7.8	20.5	12.0	8.0	16.0
Glass Production	4.2	3.1	5.1	4.0	2.7	5.3	3.8	2.7	5.3	3.8	2.4	5.3	3.5	2.7	4.1
Sizing	0.4	0.1	1.1	0.9	0.6	1.1	1.0	0.6	1.4	0.6	0.1	1.5	1.7	0.8	2.3
Downstream	1.8	0.4	3.0	1.3	0.4	3.4	1.5	0.3	3.6	1.3	0.0	4.1	0.5	0.5	0.7
Water and waste treatment	5.0	3.6	8.3	4.7	1.4	10.2	6.9	3.6	10.2	4.8	3.0	10.2	6.0	3.5	8.6

Total CML 4.2 - Air Acidification	Wet chopped strands			Dry chopped strands			Assembled rovingss			Direct rovings			Mats		
	Average	Min	Max	Average	Min	Max	Average	Min	Max	Average	Min	Max	Average	Min	Max
TOTAL	4.5	3.4	6.7	5.5	4.5	8.3	6.6	5.3	8.0	4.9	3.5	8.8	5.7	4.4	7.0
Glass Production	3.7	3.0	4.6	4.3	3.3	5.8	4.6	3.9	5.8	4.2	3.0	5.8	3.6	3.3	3.9
Sizing	0.2	0.0	0.5	0.4	0.2	1.2	0.4	0.2	0.5	0.2	0.0	0.5	0.6	0.3	0.8
Downstream	0.6	0.3	2.0	0.8	0.4	2.0	1.5	0.5	2.0	0.5	0.1	2.5	1.4	0.7	2.3
Water and waste treatment	0.0	0.0	0.1	0.0	0.0	0.2	0.1	0.0	0.2	0.0	0.0	0.1	0.1	0.0	0.2

Total CML 4.2 - Photochemical oxidation (high NOx)	Wet chopped strands			Dry chopped strands			Assembled rovingss			Direct rovings			Mats		
	Average	Min	Max	Average	Min	Max	Average	Min	Max	Average	Min	Max	Average	Min	Max
TOTAL	2.0	1.3	2.3	2.0	1.6	4.2	3.1	2.0	3.6	1.8	1.2	3.6	2.5	1.0	4.0
Glass Production	1.3	0.4	2.0	1.0	0.4	2.1	1.7	0.4	2.1	1.3	0.4	2.1	0.9	0.4	1.6
Sizing	0.5	0.1	1.6	0.8	0.1	2.3	0.8	0.1	1.8	0.3	0.1	0.8	1.1	0.5	1.8
Downstream	0.1	0.0	0.5	0.2	0.1	1.2	0.5	0.1	1.0	0.2	0.0	1.3	0.4	0.4	0.5
Water and waste treatment	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.1	0.0	0.0	0.1	0.0	0.0	0.0

Total CML 4.2 - Eutrophication	Wet chopped strands			Dry chopped strands			Assembled rovingss			Direct rovings			Mats		
	Average	Min	Max	Average	Min	Max	Average	Min	Max	Average	Min	Max	Average	Min	Max
TOTAL	0.6	0.4	1.2	0.7	0.5	1.2	0.8	0.5	1.0	0.7	0.4	1.3	0.7	0.5	0.9
Glass Production	0.5	0.3	0.9	0.5	0.3	0.9	0.5	0.3	0.7	0.5	0.3	0.7	0.4	0.3	0.4
Sizing	0.1	0.0	0.2	0.1	0.0	0.3	0.1	0.0	0.1	0.1	0.0	0.1	0.2	0.1	0.2
Downstream	0.1	0.0	0.1	0.1	0.0	0.2	0.1	0.1	0.2	0.1	0.0	0.5	0.2	0.2	0.3
Water and waste treatment	0.0	0.0	0.1	0.0	0.0	0.1	0.1	0.0	0.1	0.0	0.0	0.1	0.1	0.0	0.1

Total CML 4.2 - Abiotic Depletion Potential (elements)	Wet chopped strands			Dry chopped strands			Assembled rovingss			Direct rovings			Mats		
	Average	Min	Max	Average	Min	Max	Average	Min	Max	Average	Min	Max	Average	Min	Max
TOTAL	3.6E-07	2.6E-07	6.2E-07	4.5E-07	3.2E-07	6.2E-07	5.1E-07	4.1E-07	6.3E-07	4.2E-07	2.4E-07	7.3E-07	7.1E-07	5.4E-07	8.8E-07
Glass Production	1.6E-07	1.2E-07	2.6E-07	1.6E-07	1.1E-07	2.6E-07	1.3E-07	1.1E-07	1.8E-07	1.8E-07	6.6E-08	3.5E-07	1.2E-07	1.1E-07	1.2E-07
Sizing	1.2E-07	3.5E-08	3.3E-07	2.3E-07	1.2E-07	3.0E-07	2.6E-07	1.2E-07	3.5E-07	1.6E-07	3.4E-08	3.9E-07	4.6E-07	2.4E-07	6.2E-07
Downstream	4.9E-08	8.5E-09	7.7E-08	3.5E-08	4.1E-09	6.3E-08	3.5E-08	9.2E-09	6.6E-08	5.0E-08	1.2E-08	3.1E-07	8.6E-08	8.1E-08	1.0E-07
Water and waste treatment	3.5E-08	1.9E-09	1.1E-07	2.1E-08	3.2E-10	1.1E-07	8.3E-08	6.0E-08	1.1E-07	3.2E-08	1.1E-09	1.1E-07	4.9E-08	2.1E-09	1.1E-07

Waste (total)	Wet chopped strands			Dry chopped strands			Assembled rovingss			Direct rovings			Mats		
	Average	Min	Max	Average	Min	Max	Average	Min	Max	Average	Min	Max	Average	Min	Max
TOTAL	0.31	0.15	0.41	0.30	0.16	0.44	0.28	0.16	0.45	0.32	0.16	0.48	0.36	0.20	0.51
Glass Production	0.16	0.10	0.21	0.15	0.10	0.21	0.12	0.10	0.21	0.14	0.08	0.19	0.13	0.06	0.20
Sizing	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00
Downstream	0.06	0.01	0.10	0.04	0.01	0.11	0.02	0.02	0.12	0.03	0.00	0.11	0.01	0.00	0.03
Water and waste treatment	0.09	0.02	0.17	0.10	0.02	0.23	0.13	0.04	0.23	0.15	0.04	0.31	0.22	0.12	0.32

Total USEtox - Human toxicity - 2010 (Fresh water)	Wet chopped strands			Dry chopped strands			Assembled rovingss			Direct rovings			Mats		
	Average	Min	Max	Average	Min	Max	Average	Min	Max	Average	Min	Max	Average	Min	Max
TOTAL	7.9E-08	3.7E-08	1.0E-07	6.9E-08	3.9E-08	1.5E-07	1.0E-07	4.4E-08	1.4E-07	8.1E-08	5.4E-08	1.8E-07	1.1E-07	7.0E-08	1.4E-07
Glass Production	6.3E-08	2.7E-08	8.9E-08	4.7E-08	2.7E-08	8.8E-08	5.9E-08	2.7E-08	8.8E-08	6.1E-08	4.2E-08	8.9E-08	5.3E-08	2.4E-08	8.2E-08
Sizing	6.6E-09	1.7E-09	2.0E-08	1.0E-08	5.2E-09	1.3E-08	1.2E-08	5.3E-09	1.5E-08	7.5E-09	1.6E-09	1.7E-08	2.1E-08	1.1E-08	2.8E-08
Downstream	7.8E-09	4.0E-09	2.0E-08	1.1E-08	7.0E-09	4.7E-08	2.4E-08	7.4E-09	4.1E-08	1.0E-08	3.1E-09	7.5E-08	3.4E-08	3.0E-08	3.9E-08
Water and waste treatment	1.7E-09	3.3E-10	5.5E-09	1.1E-09	1.0E-10	7.8E-09	4.9E-09	2.5E-09	7.8E-09	1.6E-09	1.2E-10	5.5E-09	3.5E-09	3.7E-10	7.8E-09

2. Data sources for modelling

	Data source	Year
Raw materials – glass production		
Kaolin	ELCD Kaolin Coarse filler - d50 3um: Production at plant (Europe)	2011
Sand	ELCD Very fine milled silica sand (Europe)	2011
Limestone	ELCD CaCO3 (> 63 um): Production (Europe)	2011
Quick lime	Ecoinvent 3. Quicklime production, milled, loose	2012
Colemanite	Ecoinvent 3 calcium borates production(Turkey)	2012
Fluorspar	Ecoinvent 3 Fluorspar production, 97% purity Ecoinvent 3	2012
Penta borax	Ecoinvent 3 Borax, anhydrous, powder, at plant (Europe)	2012
Sodium sulphate	Ecoinvent 3 Sodium sulfate production, from natural sources (Europe)	2012
Sodium carbonate	Sodium carbonate TEAM modelling of Solvay Process, raw materials from ELCD limestone (2011) and Ecoinvent 3 sodium chloride ammonium chloride production, at plant (2011)	
Hydrated lime	Ecoinvent 3 Lime production, hydrated, packed	2012
Dolomite	Ecoinvent 3 Dolomite production (Europe)	2012
Sodium nitrate	Ecoinvent 3 Sodium nitrate production (Europe)	2012
Gypsum	Ecoinvent 3 Gypsum quarry operation (Switzerland)	2012
Power, Fuels and oxidizer		
Electricity	TEAM modelling at the country level based on EMEP EAA, IEA bibliographical information and previous project of PwC Ecobilan with EDF, AREVA on the nuclear fuel cycle	2013
Natural gas	Ecoinvent 3 Natural gas production	2012
Propane	Ecoinvent 3 Natural gas production	2012
Light fuel oil Heavy fuel oil	Ecoinvent 3 Petroleum refinery operation	2012
Oxygen	DEAM database	2013

	Data source	Year
	Oxygen production (Europe)	
Raw materials – sizing		
Silane	Ecoinvent 2.0 tetrachlorosilane, at plant (GLO)	2007
Filmformer	TEAM modelling from: - 33% polyurethane, flexible foam from Toluene diisocianate and Long chain Polyether polyols (PlasticsEurope, 2012) - 33% maleic anhydride grafted PP : 10% maleic anhydride (maleic anhydride, at plant, Ecoinvent (Eruope, 2010)) and 90% polypropylene (PlasticsEurope, 2012) - 33% bisphenol A epoxyresin: 10% bisphenol A powder, at plant (Ecoinvent 3 Europe, 2010) and 90% epoxy resin, liquid (Ecoinvent 3, Europe 2010)	
Lubricant	Ecoinvent 3 lubricating oil, at plant (Europe)	2012
Surfactant	Ecoinvent 3 alkylbenzene sulfonate, linearat plant (Europe5)	2012
PH-modifier	TEAM modelling from acetic acid production, product in 98% solution state (Ecoinvent 3 Europe) and dilution to 80% acetic acid in H2O	2012
Raw materials – packaging		
Plastic (PE)	PlasticsEurope,	2005
Big bags (PP)	PlasticsEurope, Polypropylene, PP, granulate, at plant (Europe)	2012
Wood	Ecoinvent 3 EUR-flat pallet production	2010
Cardboard	Corrugated Cardboard, FEFCO (Europe)	2012
Raw materials – water treatment		
Flocculant	Modelled as a solution of 35 % of iron sulphate(Ecoinvent 3, Europe) in water	2012
Sodium hydroxide	PlasticsEurope Sodium hydroxide, chlor-alkali production mix, at plant	2011
Sodium hypochlorite	PlasticsEurope Sodium hypochlorite (NaOCl, 175 g Cl2/l)	2011
Bentonite	Ecoinvent 3 Activated bentonite production (Germany)	2012
Iron chloride	Ecoinvent 3 Iron (III) chloride production, product in 40% solution state	2012
Transport		
Sea and river transport	DEAM River transport (bulk, kg.km, 2012)	2012
Road transport	DEAM Road transport (HDV, litre, 2012)	2012

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: CML, version 4.2).

Table 6 – Abiotic depletion potential coefficients (source: CML, University of Leiden)

Flow	Unit	Value(*)
(r) Antimony (Sb, ore)	kg	1.00
(r) Arsenic (As, ore)	kg	0.00297
(r) Barium Sulphate ($BaSO_4$, in ground)	kg	6.04E-06
(r) Bauxite (Al_2O_3, ore)	kg	1.09E-09
(r) Beryllium (Be, ore)	kg	1.26E-05
(r) Bismuth (Bi, ore)	kg	0.0411
(r) Boron (B, ore)	kg	4.27E-03
(r) Cadmium (Cd, ore)	kg	0.156577
(r) Chromium (Cr, ore)	kg	4.43E-04
(r) Cobalt (Co, ore)	kg	1.57E-05
(r) Copper (Cu, ore)	kg	0.00137
(r) Gallium (Ga, ore)	kg	1.46E-07
(r) Germanium (Ge, ore)	kg	6.52E-07
(r) Gold (Au, ore)	kg	5.20E+01
(r) Indium (In, ore)	kg	0.00689
(r) Iodine (I, ore)	kg	2.50E-02
(r) Iron (Fe, ore)	kg	5.24E-08
(r) Lead (Pb, ore)	kg	0.00634
(r) Lithium (Li, ore)	kg	1.15E-05
(r) Magnesium (Mg, ore)	kg	2.02E-09
(r) Manganese (Mn, ore)	kg	2.54E-06
(r) Mercury (Hg, ore)	kg	0.0922
(r) Molybdenum (Mo, ore)	kg	1.78E-02
(r) Nickel (Ni, ore)	kg	6.53E-05
(r) Niobium (Nb, ore)	kg	1.93E-05
(r) Palladium (Pd, ore)	kg	0.570602
(r) Phosphate Rock (in ground)	kg	5.52E-06
(r) Platinium (Pt, ore)	kg	2.22E+00
(r) Potassium (K, as K_2O, in ground)	kg	1.60E-08
(r) Rhenium (Re, ore)	kg	0.603395
(r) Selenium (Se, ore)	kg	1.94E-01
(r) Silicon (Si)	kg	1.40E-11
(r) Silver (Ag, ore)	kg	1.18398
(r) Sodium (Na)	kg	5.50E-08
(r) Sodium Chloride (NaCl, in ground or in sea)	kg	1.64E-05
(r) Strontium (Sr, ore)	kg	7.07E-07
(r) Sulphur (S, in ground)	kg	0.000193

(r) Tantalum (Ta, ore)	kg	4.06E-05
(r) Thallium (Tl, ore)	kg	2.43E-05
(r) Tin (Sn, ore)	kg	0.0162
(r) Titanium (Ti, ore)	kg	2.79E-08
(r) Tungsten (W, ore)	kg	0.00452
(r) Uranium (U, ore)	kg	1.40E-03
(r) Vanadium (V, ore)	kg	7.70E-07
(r) Yttrium (Y, ore)	kg	5.69E-07
(r) Zinc (Zn, ore)	kg	0.000538
(r) Zirconium (Zr, ore)	kg	5.44E-06

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[8] 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 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). CO_2 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 7 : 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%.

[8] 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 SO_2 equivalent (source CML-4.2). 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 8 : Acidification equivalence coefficients (source: CML, University of Leiden, The Netherlands)

Elementary flow		Conversion factor
(a) Ammonia (NH3)	g	1.6
(a) Nitrogen Oxides (NOx as NO2)	g	0.5
(a) Sulphur Oxides (SOx as SO2)	g	1.2

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 SO2 for the same quantity of pollutant. As a consequence, the coefficient for SO2 is larger than the coefficient for NO2.

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 9 : Formation of photochemical ozone equivalence coefficients (source: CML, University of Leiden, The Netherlands)

Elementary flow		Conversion factor
(a) Acetaldehyde (CH3CHO)	g	0.641
(a) Acetic Acid (CH3COOH)	g	0.097
(a) Acetone (CH3COCH3)	g	0.094
(a) Acetylene (C2H2)	g	0.085
(a) Benzaldehyde (C6H5CHO)	g	-0.092
(a) Benzene (C6H6)	g	0.22
(a) Butadiene (1,3-CH2CHCHCH2)	g	0.85
(a) Butane (C4H10)	g	0.352
(a) Butene (1-CH3CH2CHCH2)	g	1.08
(a) Carbon Monoxide (CO)	g	0.027
(a) Chloroform (CHCl3, HC-20)	g	0.023
(a) Cumene (C9H12)	g	0.5
(a) Ethane (C2H6)	g	0.123
(a) Ethanol (C2H5OH)	g	0.399
(a) Ethyl Acetate (CH3COOC2H5)	g	0.209
(a) Ethyl Benzene (C6H5C2H5)	g	0.73
(a) Ethylene (C2H4)	g	1

(a) Formaldehyde (CH_2O)	g	0.52
(a) Formic Acid (CH_2O_2)	g	0.032
(a) Heptane (C_7H_{16})	g	0.494
(a) Hexane (C_6H_{14})	g	0.482
(a) Isoprene (C_5H_8)	g	1.09
(a) Methane (CH_4)	g	0.006
(a) Methanol (CH_3OH)	g	0.14
(a) Methyl Chloride (CH_3Cl)	g	0.005
(a) Methyl tert Butyl Ether (MTBE, $C_5H_{12}O$)	g	0.175
(a) Methylene Chloride (CH_2Cl_2, HC-130)	g	0.068
(a) Pentane (C_5H_{12})	g	0.395
(a) Propane (C_3H_8)	g	0.176
(a) Propionaldehyde (CH_3CH_2CHO)	g	0.798
(a) Propionic Acid (CH_3CH_2COOH)	g	0.15
(a) Propylene (CH_2CHCH_3)	g	1.12
(a) Styrene ($C_6H_5CHCH_2$)	g	0.14
(a) Tetrachloroethylene (C_2Cl_4)	g	0.029
(a) Toluene ($C_6H_5CH_3$)	g	0.64
(a) Xylene (m-$C_6H_4(CH_3)_2$)	g	1.1
(a) NMVOC (Non Methanic Volatile Organic Compounds)	g	1
(a) VOC (Volatile Organic Compounds)	g	1
(a) Sulphur Oxides (SO_x as SO_2)	g	0.048
(a) Nitrogen Oxides (NO_x as NO_2)	g	0.028
(a) Nitrogen Monoxide (NO)	g	-0.427

Note: the previous report did not consider the influence of SO_x, NO_2 and NO emissions on the formation of photochemical ozone in the troposphere.

3.5 Eutrophication of water

Eutrophication of an aqueous environment is characterized by the introduction, for example, of nutrients in the form of phosphatized and nitrogenous 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.

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

Table 10 : Eutrophication equivalence coefficients (source: CML, University of Leiden, The Netherlands)

Elementary flow		Conversion factor
(w) Ammonia (NH4+, NH3, as N)	g	0.42
(w) COD (Chemical Oxygen Demand)	g	0.022
(w) Nitrate (NO3-)	g	0.095
(w) Nitrite (NO2-)	g	0.13
(w) Nitrogenous Matter (Kjeldahl, as N)	g	0.42
(w) Nitrogenous Matter (unspecified, as N)	g	0.42
(w) Phosphates (PO4 3-, HPO4--, H2PO4-, H3PO4, as P)	g	3.06
(w) Phosphorous Matter (unspecified, as P)	g	3.06
(w) Phosphorus (P)	g	3.06
(w) Phosphorus Pentoxide (P2O5)	g	1.336
(a) Nitrogen Oxides (NOx as NO2)	g	0.13
(a) Ammonia (NH3)	g	0.35
(a) Nitrous Oxide (N2O)	g	0.27
(s) Nitrogen (N)	g	0.42
(s) Phosphorus (P)	g	3.06

Note: the previous report did not consider the influence of air emissions of nitrogen and soil emissions of nitrogen and phosphate on eutrophication of rivers.

3.6 Human toxicity

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 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[9].

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 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 (CTUh in cases/kg emitted) providing the estimated increase in morbidity in the total human population per unit mass of a chemical emitted.

Table 11 – Human toxicity coefficients (source: USEtox 1.0, February 2010)

Elementary flow	Unit	Characterization factor
(a) Mercury (Hg)	g	0.000861765
(w) Arsenic (As3+, As5+)	g	2.77E-05
(w) Barium (Ba++)	g	9.82E-08
(w) Zinc (Zn++)	g	1.28E-06
(w) Chromium (Cr VI)	g	1.07E-05
(a) Zinc (Zn)	g	1.60E-05
(a) Lead (Pb)	g	9.60E-06
(a) Arsenic (As)	g	1.68E-05
(a) Cadmium (Cd)	g	4.67E-05
(w) Antimony (Sb++)	g	3.64E-07
(w) Mercury (Hg+, Hg++)	g	1.43E-05
(w) Nickel (Ni++, Ni3+)	g	4.04E-08
(a) Mercury (Hg)	g	0.000861765

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

[9] 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	2015

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										*Please provide dry weight for other products*
% humidity	% (0-100)		14.0	0.0	9.0	0.0	0.0				*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
Default values	Maximum load	30%	0.38	24		

UPSTREAM (Batch house + Furnace) — TOTAL site

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

		TOTAL site
Silicious sand (SiO_2)	t	
Kaoline	t	
Borax	t	
Colemanite	t	
Boric acid	t	
Limestone ($CaCO_3$)	t	
Quick lime (CaO)	t	
Fluorspar	t	
<please specify>	t	
	t	
	t	

Raw materials transport

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
Silanes	t								
Filmformers	t								
Lubricants	t								
Defoamers	t								
Surfactants	t								
PH-modifiers	t								
<please specify>	t								
	t								
	t								

Raw materials transport

PACKAGING

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

Raw materials transport

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	2015

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		

Energy transport

General annual energy consumption

		TOTAL site
Electricity (from the grid)	MWh	0.0
Natural Gas	MWh (LCV)	
Light fuel	MWh (LCV)	
Heavy fuel oil	MWh (LCV)	
Propane	MWh (LCV)	
Oxygen	m3	
Hot water (purchased)	MWh	
Steam (purchased)	MWh	

Select Origin

Conversion factor	HCV/LCV	HCV/LCV
Natural gas	1,110	0,901
Diesel / Light fuel oil	1,070	0,935
Heavy fuel oil	1,055	0,948
Propane	1,088	0,917

Detailed energy consumption

UPSTREAM (Batch house)		TOTAL site
Electricity (from the grid)	MWh	

UPSTREAM (Furnace + Forehearth)		TOTAL site
Electricity (from the grid)	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 (from the grid)	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 (from the grid)	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 (from the grid)	MWh								
<please specify>	MWh								

BINDER COATING		TOTAL site	Chopped strand mats	Continuous filament mats
Electricity (from the grid)	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 (from the grid)	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 (from the grid)	MWh								
<please specify>	MWh								

INDUSTRIAL WATER TREATMENT		TOTAL site
Electricity (from the grid)	MWh	
<please specify>	MWh	

e.g. Treatment of water from river

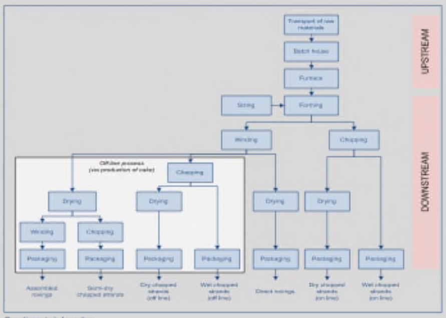
WASTE WATER TREATMENT		TOTAL site
Electricity (from the grid)	MWh	
<please specify>	MWh	

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	m3								
<please specify>	MWh								
	MWh								

Process diagram



Questionnaire's boundary

pwc

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	2015

Person in charge of the data collection

Name	
Position	
Phone	
Email	

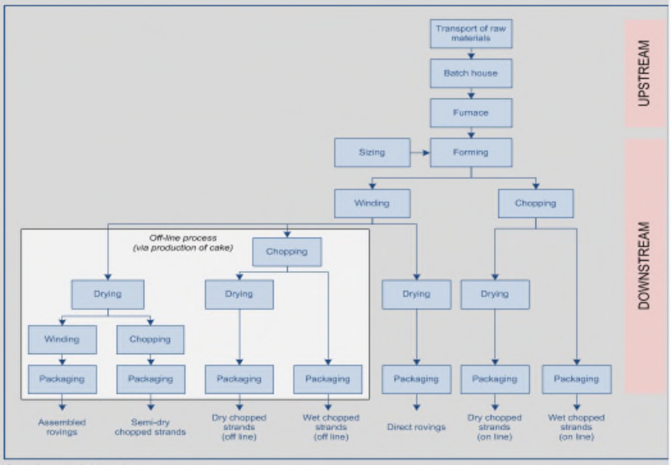
Comments on air emissions

General annual emissions

		TOTAL site
CO2 (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 NO2)	kg	
SOx (as SO2)	kg	
Dust / particulates	kg	
CO	kg	
CO2 (from fuel combustion and process emissions)	kg	
VOCs	kg	
HCl	kg	
HF	kg	
NH3	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	Semi-dry chopped	Direct rovings	Assembled rovings	Chopped strand	Continuous filament
VOCs total	kg								
Ethanol	kg								
Methanol	kg								
Formaldehyde	kg								
Ammonia	kg								
<please specify other main emissions>	kg								
	kg								
	kg								

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

		TOTAL site
NOx (as NO2)	kg	
SOx (as SO2)	kg	
CO	kg	
CO2	kg	
VOCs	kg	
Dust	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	

UTILITIES (e.g. combustion of boilers)

		TOTAL site
NOx (as NO2)	kg	
SOx (as SO2)	kg	
CO	kg	
CO2	kg	
VOCs	kg	
Dust	kg	
<please specify>	kg	

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	2015

Person in charge of the data collection

Name	
Position	
Phone	
Email	

Comments on water consumption & discharge

General annual water consumption

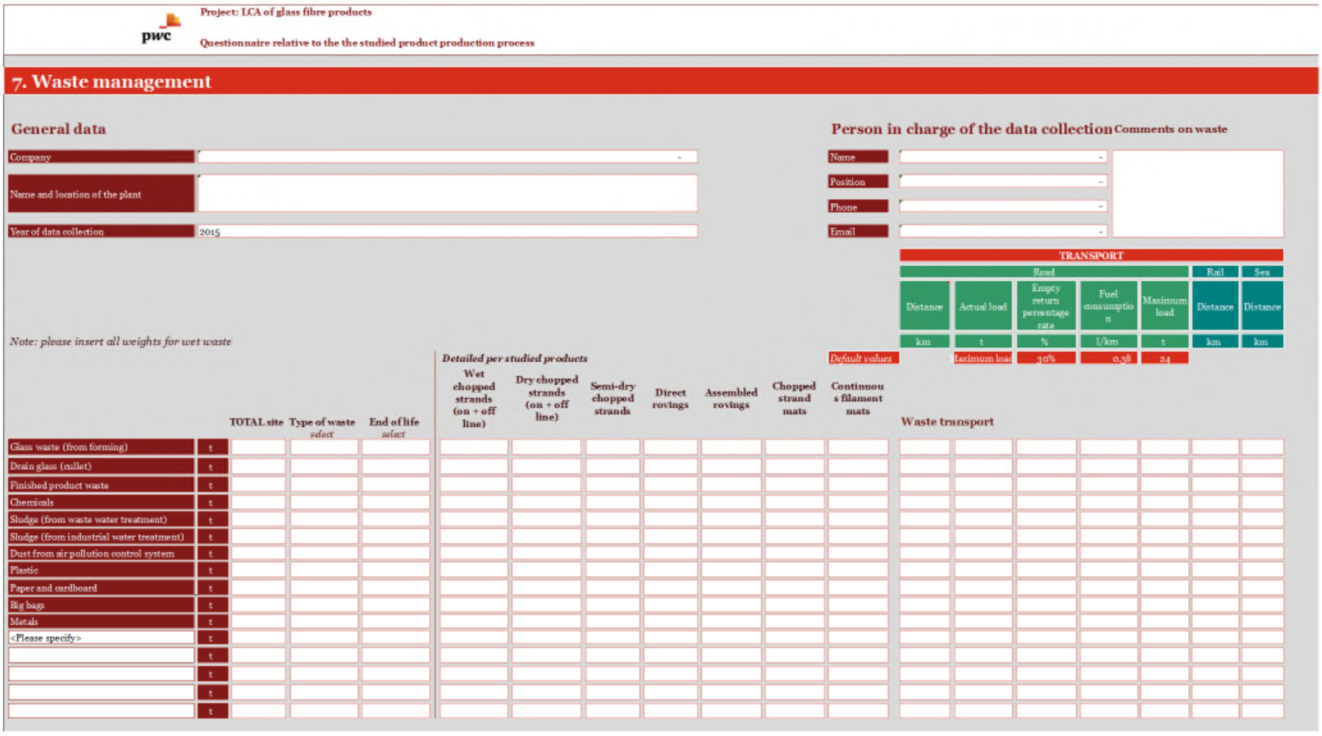
		TOTAL site	Wet chopped strands	Dry chopped strands	Semi-dry chopped strands	Direct rovings	Assembled rovings	Chopped strand mats	Continuous filament mats
Water consumption from public network (potable	m3								
Water consumption from industrial network	m3								
Water consumption from underground (well)	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 municipal 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		12
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		


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	2015

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)	Detailed per studied products: 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																	

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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. Life cycle inventory data are proposed in this database under three allocation rules principles. The modules used were generated under the "Default allocation" principle of Ecoinvent 3: "Allocation at the point of substitution. This system model subdivides multi-output activities by physical properties, economic, mass or other properties allocation. By-products of treatment processes are considered to be part of the waste-producing system and are allocated together. Markets in this model include all activities in proportion to their current production volume" www.ecoinvent.org

ETH. ETH Zurich and PSI together from 1992 to 1996 established a Life cycle inventory (LCI) database including data on current energy supply systems, on transport and waste treatment services, and on material supply (the Ökoinventare von Energiesystemen). www.ethz.ch/

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Benchmarking methodology and sector rule book for Continuous Filament Glass Fibre (CFGF) products under EU-ETS. June, 2010, GlassFibre*Europe*

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), GlassFibre*Europe*

Previous LCA report. Life cycle assessment of CFGF – Continuous Filament Glass Fibre Products, February 2012, Report prepared by PwC for GlassFibre*Europe* and based on 2010 CFGF industry data.

6. Peer review report

Review Statement

The subject of this critical review is the updated version (October 2016) of the study „Life cycle assessment of CFGF – Continuous Filament Glass Fibre Products" (first version February 2012).

The report was peer reviewed in October 2016, according to the requirements of ISO 14040/44. The review is based on the final report accompanied by a telephone conference for clarifying open questions and comments of the reviewer.

The study provides life cycle impact assessment results for five products: Dry chopped strands, wet chopped strands, direct rovings, assembled rovings and mats. Typical and current impact categories of CML and UseTox are chosen, integrating updated aspects compared to the previous assessment.

The study follows the structure of the previous project and includes new foreground data as well as updated life cycle inventories for upstream processes (background data). The structure is clear and transparent.
The collection of the data was carried out using the same questionnaires; a direct comparison and plausibility check was possible for the consultants. 11 companies, who also delivered data for the previous study, have taken part and show a representative amount of Glass Fibre Products of the European market. Background data are taken from an updated database version (ecoinvent 3), supplemented by LCI data for national specific electrical energy mixes, generated by PWC.
The methodological approaches for waste management, transport, allocation and recycling follows the previous study.

The recommendations of the reviewer have been followed to clarify certain aspects. Water flow nomenclature are refined according to common water footprint terminology; the recycling approach is supplemented by a graphics to improve understandability; more detailed information on sizing materials increases the transparency of the study. An additional table showing the difference of the applied impact categories explains the operational changes.
Further comparative evaluations on the data collection and results of the current study to the previous one would give a better picture of the technological developments. A deeper interpretation of the results may support the continuous improvement process of the production lines.

The review did not result in significant changes of the results. Revision of data in the review-phase lead to slight corrections of figures. The critical review confirms that this study adheres to the requirements of ISO 14040/44.

Salem, October 2016

Angela Schindler