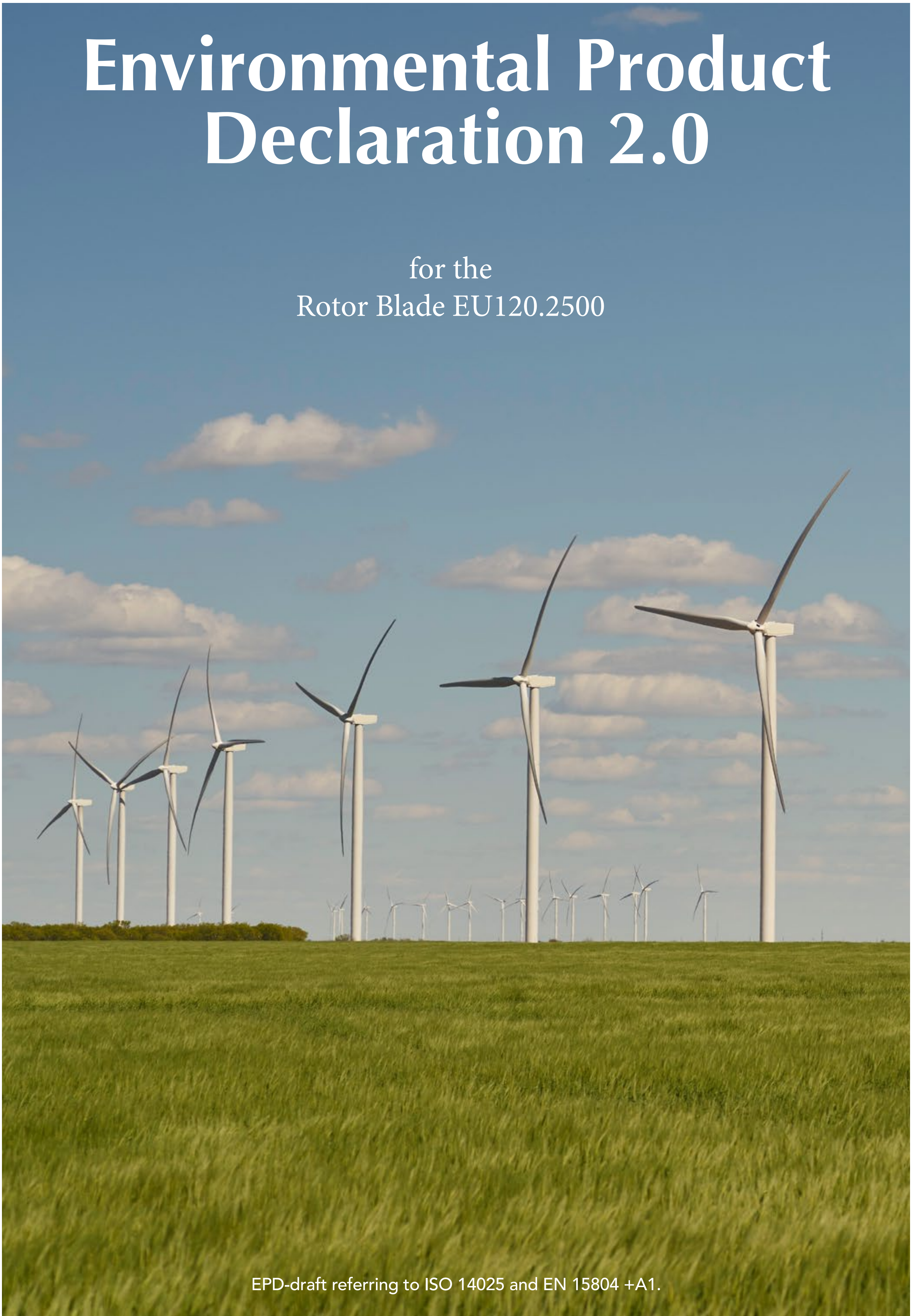
RecycleWind

Environmental Product Declaration 2.0

for the
Rotor Blade EU120.2500



EPD-draft referring to ISO 14025 and EN 15804 +A1.

This EPD draft is product of the research project "RecycleWind", a R&D project to develop a self-learning and resilient recycling network for wind turbines.

In the context of long-life products, such as rotor blades of wind turbines, structured information on the materials and designs used is of enormous importance for recycling efforts at the end of the product's service life. However, due to the long service life, information material, personnel as know-how carriers or even manufacturers themselves might not be available any more.

In the case of dismantling projects for wind turbines, there are clear gaps in the documentation on the specification of the materials used and on the necessary technical data, such as weights. This makes dismantling planning and reliable cost calculation difficult.

For these reasons, environmental product declarations (EPDs) are required for the main components of a wind turbine for an efficient recycling management system with a high level of recycled materials for use in new production.

An EPD is a Type III environmental label, i.e. a comprehensive and externally verified description of the environmental impact without a rating [ISO 14025]. In this document, the environmentally relevant properties of a specific product are presented in the form of neutral and objective data.

Manufacturers of products or consulting service providers have so far been confronted with the task of collecting and evaluating data for LCA modules. The production and use phase (LCA modules A and B) are usually available in good quantity and quality, but for the modules C (deconstruction, disposal) and D (recycling potential/credits) far less data is available. Therefore, these are usually mapped with generic data of common disposal processes. Since there are no tight specifications for the selection of end-of-life scenarios, the assumptions used can vary widely, which makes it very difficult to compare the results.

There is a fundamental need for standardization with regard to essential information on process and material flows during dismantling, disassembly and reprocessing after the end of the product's life, as well as on their supply to recycling or other recovery processes.

Within the framework of RecycleWind 1.0, a draft version for an "EPD Rotor Blade" has been developed in a first partial step on the basis of the previous standardization. In cooperation with the rotor blade company TPI Composites Germany GmbH (formerly EUROS Entwicklungsgesellschaft für Windkraftanlagen mbH), the following new elements have been added:

- Documentation on material composition tailored to the recycling processes.
- Information on the location and installation of materials potentially to be classified as "critical pollutants" for recycling purposes
- Information on the possibility of dismantling individual assemblies and main components relevant for recycling.

The standardization of the EPD with regard to the LCA modules C and D has been completed in the follow-up project RecycleWind 2.0. In particular, additional criteria were developed for the presentation of the recyclability of a product. These include information on the dismantlability of individual main components and assemblies and the material flows generated in the process, as well as the availability of state-of-the-art treatment and recycling processes for these material flows. The present version of the "EPD Rotor Blade 2.0" represents the result from the RecycleWind project.

More information: www.iekrw.de/recyclewind

Project partners

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0 Table of contents

1 General Information

Program Operator	This ist a draft. The program operator still has to be selected.
Declaration owner	TPI Composites Germany GmbH
Underlying PCR	EN 15804 + A1:2013
Product or rotor blade family	EU120.2500*
Place of manufacture	Zory-Warszowice, Poland
Declaration number	This ist a draft. The programm operator will assign the declaration number
Manufacturer	EUROS Polska sp. z o.o
Date of issue	This is a draft. The date has yet to be announced
Valid until	This is a draft. The date has yet to be announced
Year of investigation	2022
Geographical area of validity	Worldwide
Declared unit	1 GWh Energy yield per blade based on lifetime
The study was conducted in accordance with	EN ISO 14025:2010. Environmental labels and declarations – Type lll environmental declarations - Principles and procedures. EN 15804:2012 + A1:2013, Sustainability of construction works - Environmental product declarations
***Intellectual property of declaration owner**	

2 About TPI Composites[1]

We are a leading wind blade manufacturer and the only independent wind blade manufacturer with a global footprint. We accounted for approximately 32% of all onshore wind blades on a MW-basis globally in 2021, excluding China. We reached a record high this year with more than $1.7 billion in net sales and produced more than 9,700 wind blades. We are enabling many of the industry's leading wind turbine original equipment manufacturers (OEMs) to outsource the manufacturing of a larger portion of their wind blades, thus expanding their global wind blade capacity. We manufacture advanced composite products to our customers' exact specifications in facilities designed, built, and strategically located either near our customers' target markets or in low-cost world class locations, to minimize total delivered cost. In addition, we provide global field service maintenance and repairs for wind turbine OEMs and asset owners by leveraging our global footprint and approximately 14,100 capable associates. We are building a growing global team of experienced technicians to provide best-in-class wind blade service capabilities. We also apply our advanced composite technology and innovation to supply unique, high-strength, lightweight and durable composite product solutions for transportation markets, including passenger automotive, bus, truck, and delivery vehicle applications. The wind blades we manufacture support the decarbonization of energy production, provide significant reductions in greenhouse gas (GHG) emissions, and help mitigate climate change. The wind blades that we produced from 2017 to 2021 have the potential to reduce more than 1.5 billion metric tons of CO2 over their average 20-year life span.[2] This is equivalent to the use of over 250 million homes' electricity use for one year in the United States.[3]

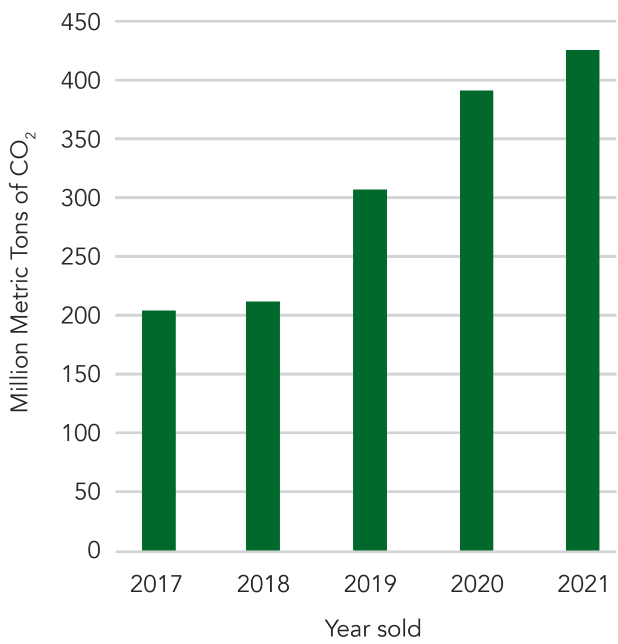


Figure 1: Estimated CO2 reduction from blades produced over entire product life by year produced

[1] Source: www.tpicomposites.com/sustainability/reporting/

[2] TPI Produced Estimated MWs x 1000 x Total Lifetime Hours x Estimated Turbine Capacity Factor (DOE/IRENA) x IEA emissions factor of 475 g CO2/kWh

[3] United States Environmental Protection Agency (EPA). (2020). GHG Equivalencies Calculator

3 Product related information

3.1 Product description and specifications

The technical data must follow the design standards established in IEC 61400-1 and be tested according to IEC 61400-22.

The described rotor blade is verified and certified according to the GL-guideline 2010, assuming fatigue loads to represent 20 years of operation/lifetime. Since the availability of PMI-core material is limited, it is also possible to build the blades by using PVC-core material.

A third design option consists in changing the fiber material of the spar caps to carbon fiber (CF) instead of glass fiber (GF), which, due to its superior specific strength/modulus, reduces blade mass and static moment significantly. This leads to decreased edgewise fatigue loads to enable an extended lifetime of 25 years.

The CF-version of the blade is to be considered as a virtual de-sign exercise, that has neither been fully verified nor realized by means of manufacturing or operation on a turbine.

Table 1: Dimensions and other speci ications

Designation	GF-type 1 (PMI)	GF-type 2 (PVC)	CF-type	Unit
Length of blade (root at L 0.00m)	58.8			m
Total mass	15344	15483	12672	kg
Centre of gravity	17.70	17.80	15.92	m
Blade surface	344			m²
Pre-bend	2000			mm
Max. chord (position)	4289 (L14.00m)			mm
Separability (longest section)	one part			m
Bolt circle diameter	2500			mm
Bolts number/ thread	72 x M36			-
Surface coating	PU-topcoat			-
Energy Yield per rotor (per blade)	14.22 (4.74)			GWh/a
Life time	20	20	25	years
Total yield per blade during life time	94.8	94.8	118.5	GWh
IEC class	II (3MW)			-

3.2 Delivery status

The dimensions/quantities of the declared products as delivered must be stated.

3.3 Construction and material composition

Table 2: Material composition

	GF-type 1 (PMI)	GF-type 2 (PVC)	CF-type	Unit
Glass fibers	8527	8527	4922	kg
Carbon fibers	-	-	1186	kg
Balsa wood	986	986	1034	kg
PVC	0	172	169	kg
Polymethacrylimide (PMI)	143	-	-	kg
Epoxy resin	5052	5161	4620	kg
PU-Coating	168	168	168	kg
Steel parts	450	450	467	kg
Cooper	-	-	97	kg
Aluminium	18	18	2	kg
Brass	-	-	7	kg
Total mass	**15344**	**15483**	**12672**	**kg**

3.4 Manufacture

The following description of the manufacturing process is related to the production of GF-blades (option 1/2), whereas most of the steps would occur identically in case of the CF-option.

3.4.1 Manufacturing Process

Main production steps:

1. Cutting and storage of dry glass fabrics and core materials, if not as a kit.
2. Cleaning of/release agent application to the moulds (e.g. "Loctite Frekote 55-NC").
3. For SS/PS-shells: rolling of PU-gelcoat or layup of peel ply as outer layer.
4. Manufacturing of prefabricated parts (root joint, LE/TE/aux. webs, platform).
5. Layup, infusion and precuring of SS/PS shells including and layup of spar cap.
6. Removing of infusion process waste (consumables) and preparation for bonding.
7. Bonding and overlamination of webs to the SS-shell, bonding of TE gluing lip, balancing chamber, LPS-receptors/cable.
8. Test-closing, application of bonding paste resin to LE/TE/webs and bonding of PS- to SS-shell.
9. Curing of the bondlines and post curing of shells.
10. Demoulding and transport to finish area.
11. Cutting of root and drilling of holes for IKEA cross-/length-bolts.
12. Cutting/trimming of root and bonding paste resin along LE/TE edges, overlamination of bondlines inside/outside.
13. Installation, bonding and lamination of platform.
14. Surface preparation (contour putty) and application of topcoat, LEP-foil, daylight markings.

3.4.2 Description of energy-intensive processes

The heating/curing as well as the (test)closing/opening of the moulds are energy-intensive processes.

Due to heavy masses, the use of overhead/indoor cranes and machinery for lifting and transport of tools and blades is energy intensive.

The temperatures and humidity inside the production hall and storage areas need to be controlled in order to guarantee optimal use and reliable/recurrent quality of the blades. Especially the handling and exothermic behavior of mixed epoxy-based materials are heavily influenced by temperatures, meaning that higher temperatures are shortening the open time and pot-life.

For health and safety reasons, production halls are equipped with dust extraction/suction and air filtration to remove cutting/grinding/sanding particles from work environment.

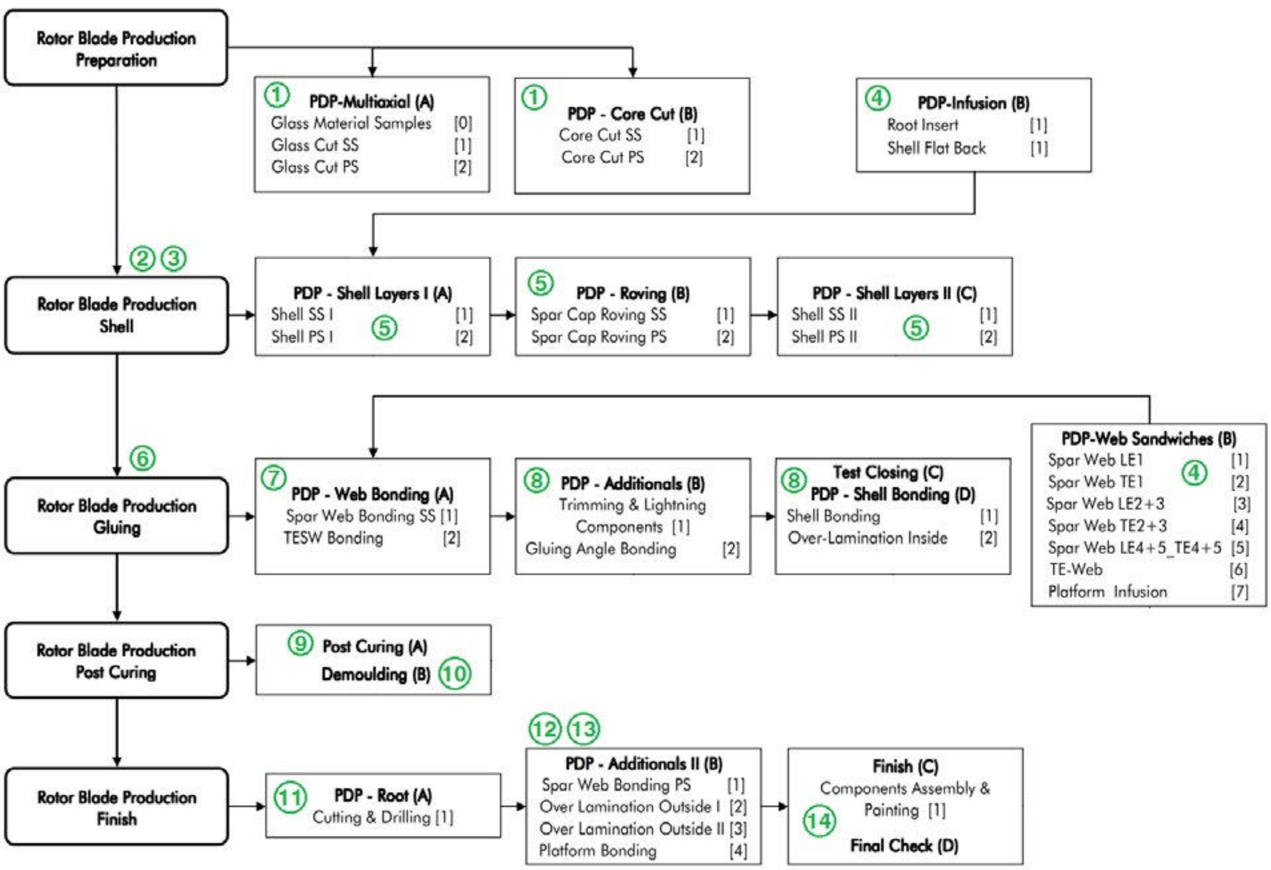


Figure 2: Process instruction for blade production

3.4.3 Information on relevant production waste

Relevant production wastes are in particular excess epoxy resin, blends of glass and carbon fiber mats as well as operating materials such as foils, which are required for the infusion of the resin.

3.5. Environment and health during production

The general health, safety and environmental requirements for working with glass/carbon/epoxy laminates need to be followed. Safety shoes and glasses are mandatory. For some tasks, full-body protective suits are needed. Workers, staff and visitors need to be protected from the following dangers:

- Dust from grinding/cutting (hall suction/extraction, water spray system)
- Glass/carbon fiber particles and resins (long-sleeved clothes is to be used, dust mask)
- Chemicals/epoxy outgassing (dedicated masks to be used, especially hardeners)
- Moving, heavy objects (helmets and safety shoes)
- Small flying parts (safety glasses)

3.6 Installation and commissioning

For lifting and moving of the blade, see "EU120.2500.5-A_InstallationManual_Rev00".

3.7 Transport material and packaging

For the transport of the blade, dedicated belts with a specific minimum width and TE-cover are mandatory to protect the blade structure from handling damages, see "EU-120.2500.5-A_InstallationManual_Rev00".

3.8 Condition of use

There is no known change in the material properties during the period of use.

3.9 Environment & health during use

There are no known interactions between product, environment and health.

3.10 Reference service life

The described rotor blade (GF-options 1 and 2) is verified and certified according to GL-guideline 2010, assuming fatigue loads to represent 20 years of operation/lifetime. The CF-type is assumed to have a lifetime of 25 years.

3.11 Extraordinary effects

Fire

Glass/Carbon fiber-epoxy structures are flammable, depending on the existent temperatures. Since cured epoxy-resins do not show a liquid phase and glass-fibers have a high melting point, the risk of dripping is low. Formation of smoke and toxic gases is likely. While carbon- & glass fibers themselves are not flammable, the decomposition of carbonfibers under the influence of high and persistent temperatures can produce micron-scale fiber fragments that are considered pulmonary by the WHO.

Water

In case of water inside the blade, which cannot leave the blade through the drainage hole, the danger of entering into the laminate (swelling) or bondlines through micro cracks is present. It harms the structure and in combination with temperatures below 0 °C, it is critical due to the expansion during formation of ice.

Mechanical Destruction

During grinding and cutting of GFRP- and CFRP structures, respirable and harmful dust is generated. Appropriate protective measures need to be taken.

3.12 Maintenance, servicing, repair and replacement

For the regular maintenance requirements, see "EU-120.2500.5-A_ServiceManual_Rev01". The necessary works include:

- Lightning protection functionality check
- Check for foreign materials inside the blade
- Condition/check of leading edge protection
- Check for cracks at the trailing edge (TE)
- Outer cover, corrosion and tightening of bolts of IKEA-connection
- Water drainage hole check
- Check for balancing masses on the webs

Most of the parts and medium scale areas of the blade can be repaired and/or replaced. Since the blade structure is complex and varies in different areas of the blade, decisions and repair instructions have to be made for each individual case. Trained and certified service teams are able to perform on-site repairs with the blade on the ground. In many cases, inspections and small repairs are done by rope or external platform with the blades mounted to the turbine.

3.13 Disassembly

Information to enable high value recycling of materials or reuse of entire structures/parts:

Figure 3 shows the general architecture of this rotorblade-family (GFRP and CFRP). In Table 3 the specific direct and unrolled distances are given to locate relevant parts of the blade and to develop an efficient cutting plan. The scheme and table are showing the circumferential distances from the leading edge (LE) to the LE and TE SparCap centre axes on SS and PS (a_SCLE & a_SCTE). It is also showing direct distances from LE/TE to LE/TE-Webs (B_LE & B_TESW), in between SparWebs (S) and from TE SparWeb to TE-Web (T).

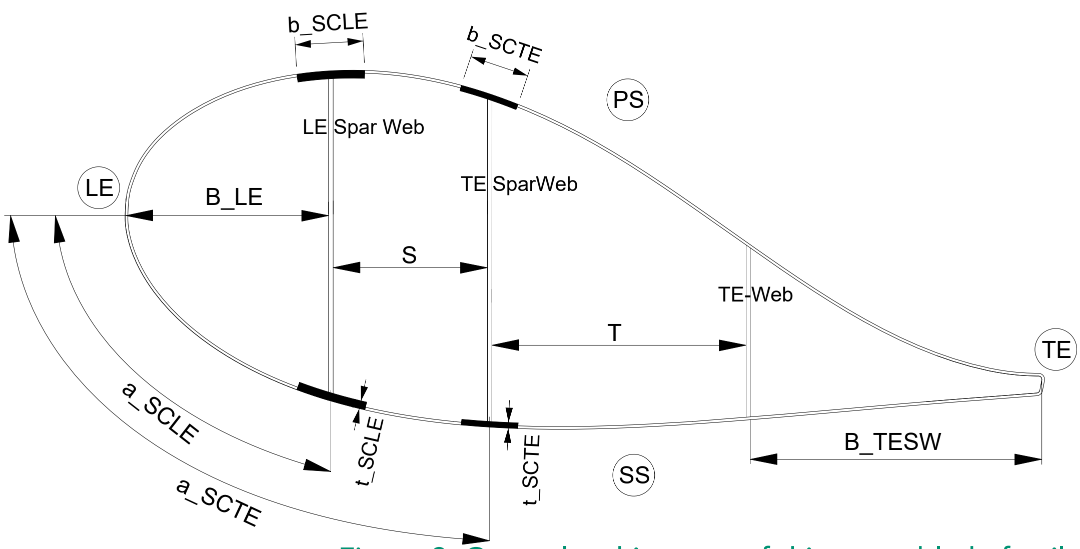


Figure 3: General architecture of this rotor blade-family (GFRP- and CFRP-types)

Table 3: Circumferential distances for this rotor blade-family (GFRP- and CFRP-types)

L	a_SCTE (SS)	a_SCTE (PS)	a_SCLE (SS)	a_SCLE (PS)	B_LE	S	T	B_TESW
/m	/mm	/mm	/mm	/mm	/mm	/mm	/mm	/mm
0.00	-	-	-	-	-	-	-	-
1.00	2381	2381	1810	1810	1011	581	-	-
6.00	2372	2290	1802	1720	1068	564	762	647
11.00	2256	2125	1686	1555	1137	549	1035	1283
15.00	2094	1994	1524	1424	1116	535	1253	1232
21.00	1783	1759	1213	1189	972	520	1140	900
25.00	1609	1593	1039	1023	847	506	1063	661
31.00	1374	1363	811	800	672	490	-	-
37.00	1164	1155	640	630	534	470	-	-
43.00	995	985	509	499	428	449	-	-
50.00	820	807	380	367	319	425	-	-
54.00	-	-	295	283	247	-	-	-
57.00	-	-	188	177	153	-	-	-
58.80	-	-	-	-	-	-	-	-

Width (b_SCLE & b_SCTE) and thickness (t_SCLE & t_SCTE) information of the SparCaps are given in Table 4 and 5 (see below “dismantling options”.)

There is at least one balancing chamber at the tip (L57.00-57.80) and one optional from L50.25 to L50.75. These chambers might be loaded with a mixture of epoxy-steel/lead-shot. They are not marked from the outside. Additional balancing masses can be fixed to the SparWebs, close to the centre of gravity (see Table 1) (L17.75).

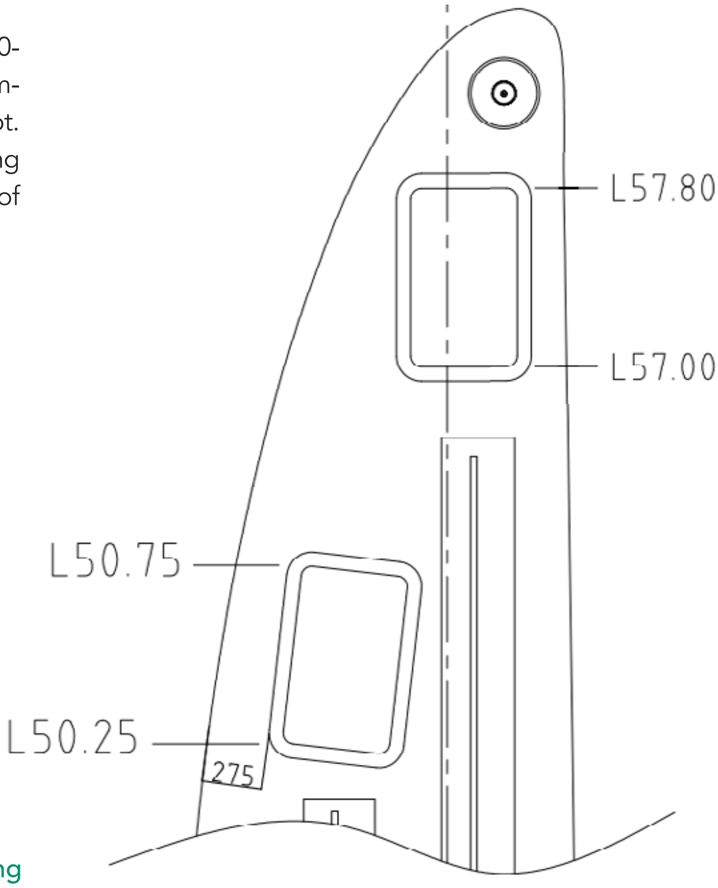


Figure 4: Balancing chamber positions

The trailing edge (TE) part of the GFRP Types contains the LPS (Lightning Protection System) -aluminium receptor parts (plates and bolts) at radius positions L25.50m, L42.00m, L51.20m and L58.50m. Once the TE part is removed, the LPS-cable (aluminium, 70mm²) is accessible.

It is overlaminated with glass patches on the TE side of the TE-SparWeb. Since the TE-Web ends at L25.00, all receptor parts are accessible after separation of TE-panels from the blade. They are mounted as shown below:

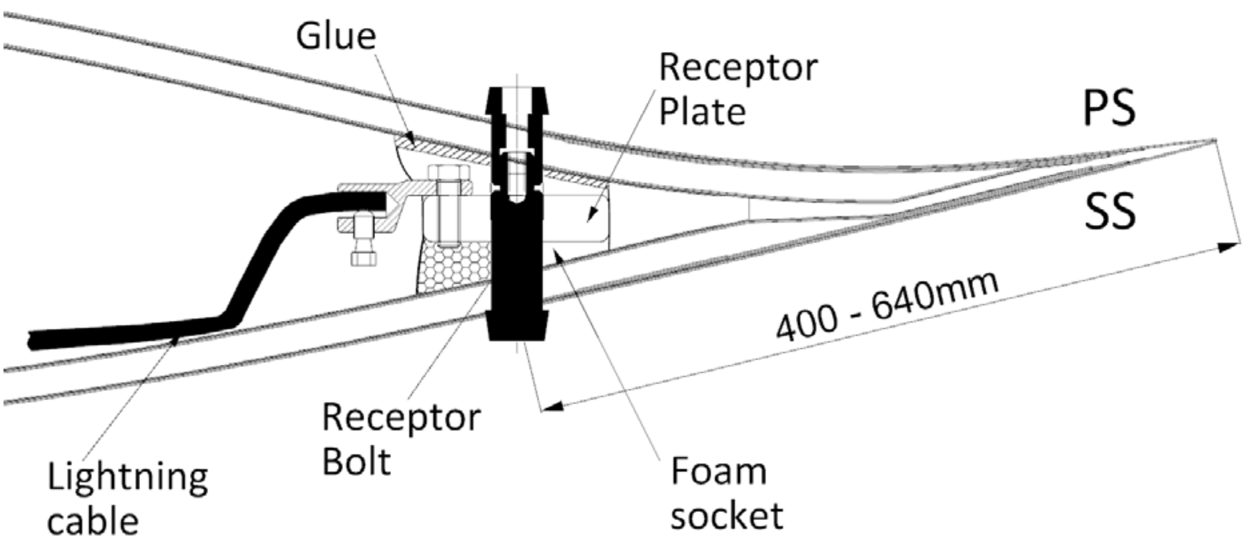


Figure 5: Mounted receptor plate

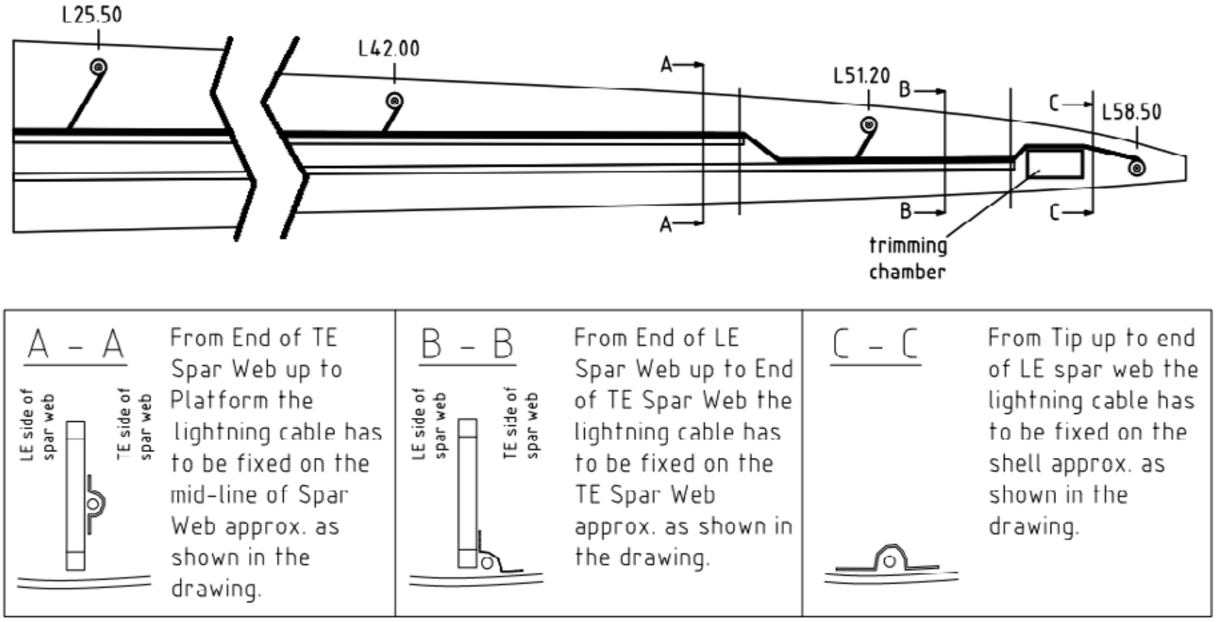


Figure 6: Positions of LPS - receptors and – cable

For the lightning protection of the CFRP blade type, several trailing edge receptors (steel/brass) are located in the area from L54.00-L58.00. The receptor bolts are not coated and thereby visible from the outside. From L5.00 to L54.50, the outside of the CFRP spar caps are covered by copper meshes, according to the related patent nr. "EP2649690". These copper meshes are not visible due to being covered/painted. Copper cables are connecting the aluminum tip receptor with the TE-receptors (brass-bodies/steel-bolts) and the copper meshes at their tip ends. At the root end of the copper meshes they are connected with copper cables to a discharge ring (steel).

Root Part:

Due to its relative material-homogeneity, the massive GFRP-root part (first 1.5m, see also Figure 7) of the blade shall be separated from the balsa/foam core sandwich panels.

The blade connecting cross- and length bolts (steel) forming the IKEA-connection can be removed by unscrewing the length bolts from the cross bolts, which might fall out of their hole, because they are not glued to the blade. From the outside (and sometimes inside), the cross bolts are covered/sealed by an aluminium/butyl tape.

Spar Caps:

Also the Spar Caps shall be extracted from the blade structure separately and preferably in long pieces of high and constant thickness (see table 4 (GFRP-Type) and table 5 (CFRP-Typ). Due to its increased material value and special recycling requirements, the isolation of CFRP-spar caps is notably important.

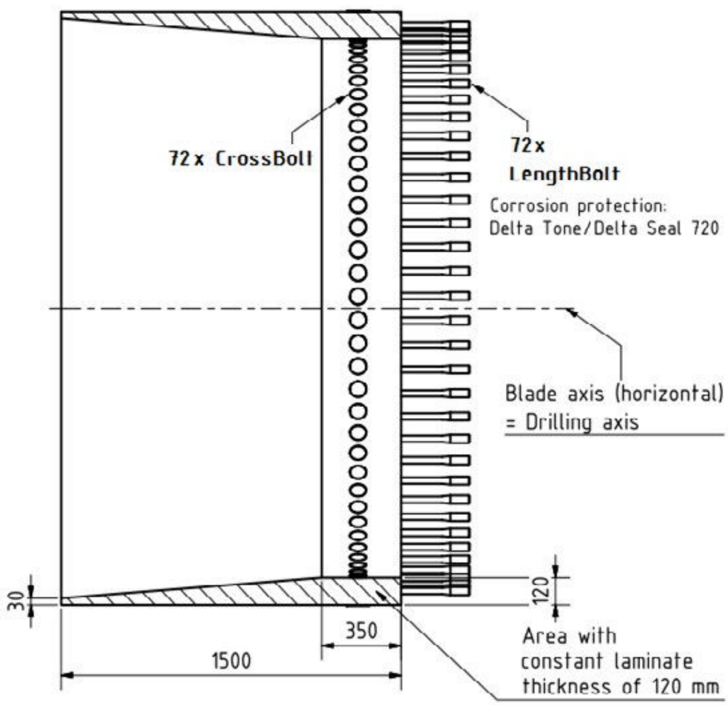


Figure 7: Blade connection

GF-SparCaps: Detailed width and thickness information related to the GFRP LE- and TE-SparCaps are given in table 4. All four SparCaps (SCLE/SCTE on SS/PS) start at L1.50 m. The LE-sided SparCaps (SCLE SS/PS) are ending at L57.00m, the TE-sided SparCaps (SCTE SS/PS) are ending at L50.00 m. All four SparCaps show large areas of constant width (SCLE/380 mm from L1.50-50.00, SCTE/380 mm from L1.50-L30.00) and smaller areas of constant/maximum thickness (SCLE from L20.00-32.00, SCTE from L7.50-L30.00). GF-SparCaps are identical on SS and PS.

Table 4: Width and thickness for the SparCaps of the GFRP-type

L	b_SCLE_GF (SS/PS))	t_SCLE_GF (SS/PS)	b_SCTE_GF (SS/PS)	t_SCTE_GF (SS/PS)
/m	/mm	/mm	/mm	/mm
0.00	0	0	0	0
1.40	0	0	0	0
1.50	380	4	380	4
4.00	380	24	380	18
5.00	380	31	380	23
7.60	380	43	380	33
9.00	380	49	380	33
10.00	380	53	380	33
15.00	380	54	380	33
17.50	380	54	380	33
20.00	380	55	380	33
25.00	380	55	380	33
28.00	380	55	380	33
30.00	380	55	380	33
32.00	380	55	354	32
35.00	380	51	315	30
40.00	380	45	250	27
45.00	380	30	185	20
49.50	380	19	127	9
50.00	380	18	120	0
56.80	127	7	0	0
57.00	120	0	0	0
58.80	0	0	0	0

CF-SparCaps: Detailed width and thickness information related to the CFRP LE- and TE-SparCaps are given in table 5. All four SparCaps (SCLE/SCTE on SS/PS) start at L1.50 m. The LE-sided SparCaps (SCLE SS/PS) are ending at L54.00 m, the TE-sided SparCaps (SCTE SS/PS) are ending at L50.00 m. All four SparCaps show large areas of constant width (SCLE/300 mm from L1.50-50.00, SCTE/250 mm from L1.50-L30.00) and smaller areas of constant/maximum thickness (SCLE from L17.50-28.00, SCTE from L7.50-L30.00). CF-SparCaps are identical on SS and PS.

Table 5: Width and thickness for the SparCaps of the CFRP-type

L	b_SCLE_CF (SS/PS)	t_SCLE_CF (SS/PS)	b_SCTE_CF (SS/PS)	t_SCTE_CF (SS/PS)
/m	/mm	/mm	/mm	/mm
0.00	0	0	0	0
1.40	0	0	0	0
1.50	300	3	250	3
4.00	300	18	250	11
5.00	300	21	250	15
7.50	300	27	250	21
9.00	300	31	250	21
10.00	300	32	250	21
15.00	300	37	250	21
17.50	300	39	250	21
20.00	300	39	250	21
25.00	300	39	250	21
28.00	300	39	250	21
30.00	300	37	250	21
35.00	300	32	218	18
40.00	300	26	185	16
45.00	300	16	153	11
48.00	300	12	133	8
50.00	300	10	120	0
54.00	200	0	76	0
58.80	0	0	59	0

Sandwich material

From L9.00 to the tip, the SS/PS-LE/TE panels consist of sandwich material made from core (Balsa/PMI/ PVC) and only two layers of glass fabrics on each side. The thickness of GFRP on each side of the panels is below 2 mm.

Figure 8 shows the positioning of the different core materials, to enable a matched cutting. This might be relevant to separate sandwich parts made from balsawood and PMI/PVC.

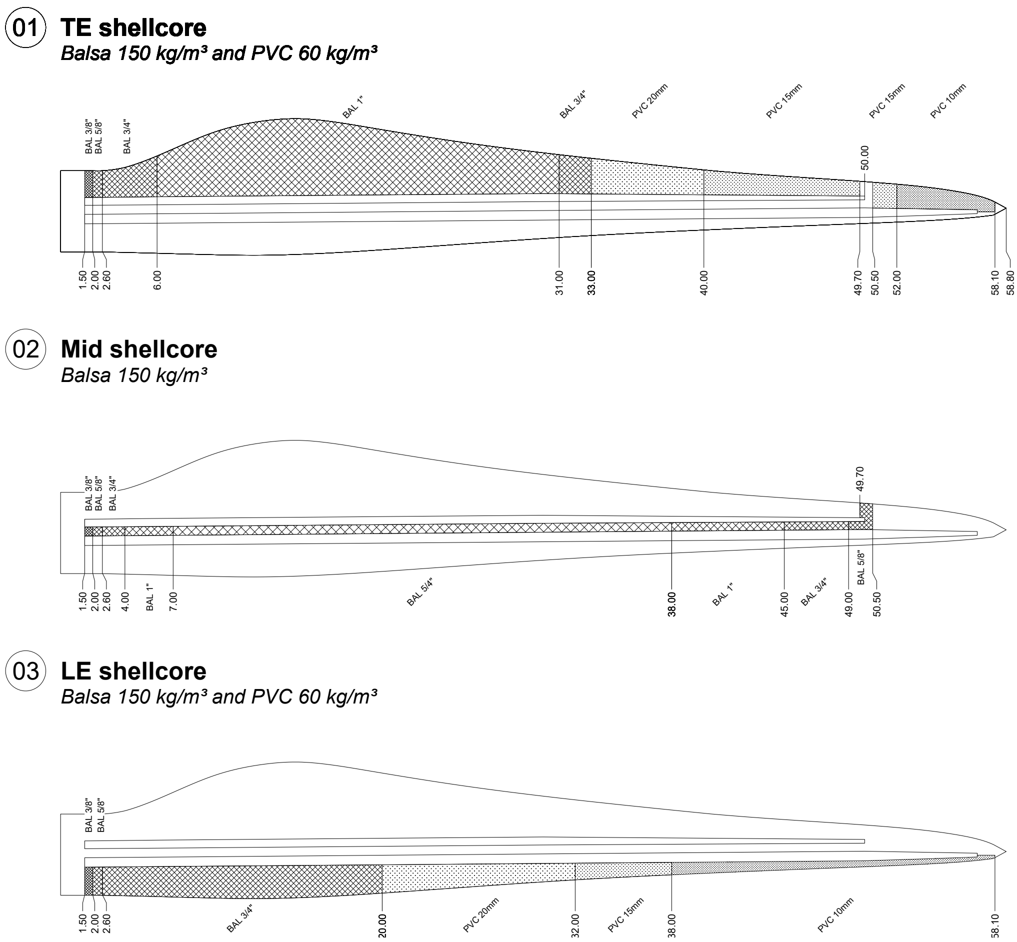


Figure 8: Position of the different core materials (GFRP- and CFRP-types)

3.14 Re-use phase

The entire wind turbine can be supplied to a second life by dismantling and rebuilding it at another location. In this case, the rotor blades are dismantled and loaded as part of the dismantling of the entire wind turbine. Alternatively, well preserved rotor blades can also be used as replacement material for identical rotor blades of other turbines.

3.15 Recyclability, circularity, recovery and disposal

3.15.1 Disposal of production waste

The relevant production wastes presented in section 3.4.3 are all recycled. In the case of the glass fiber or carbon fiber mats, recycling takes place in the new production of fiber composites. The consumables such as peel ply or vacuum films and cured epoxy resin or coating residues, as well as residues of the core kit materials are incinerated for energy recovery. Any aluminum, copper or brass waste generated will be sent for metal recycling.

3.15.2 Potential recycling and recovery routes for the overall product (state of the art)

Based on the current state of the art, the rotor blades generated as EoL materials can be fed to the following recycling and recovery routes:

- GFRP materials as secondary raw material and fuel to a cement plant with substitution to limestone, sand, clay and coal.
- GFRP materials as a secondary raw material for the production of mineral plastic compounds (MPC) planks or cladding or of stones, with substitution of limestone and proportionally plastic (including polypropylene or polyester)
- GFRP materials as secondary raw materials for the production of public furniture, building elements while retaining the existing structure
- Steel materials as secondary raw materials in the electric steel furnace with substitution of primary iron and primary alloying components, including molybdenum and chromium
- Non-ferrous materials as secondary raw material in copper or aluminum smelters with substitution of primary copper or aluminum raw materials
- CFRP materials as secondary fuel for pyrolysis and secondary carbon fiber raw material after pyrolysis for substitution of primary energy (pyrolysis) and primary glass and/or carbon fibers.

To ensure effective recycling, the EoL rotor blades are disassembled on site in transport units and divided according to flange segments, GFRP and CFRP materials, while copper and aluminum components (including lightning protection) are separated by hand. The collected segments are individually fed to the further treatment processes.

The previously described recycling routes are not always established markets. The following processes are developing markets:

- Public furniture
- MPC panels, stones
- Pyrolysis of CFRP

Low capacities, ranging from 1000-5000 Mg/year, are available in Europe for these options. For the cement plant recycling route, sufficient licensed capacities of up to 40,000 Mg/a are currently available.

3.15.3 Potential recycling, circularity, reuse and recovery rate for the total product (state of the art)

On the subject of recyclability and the implementation of related statements and data in EPDs, additional indicators and criteria were created to extend the scope of the classic EPD according to DIN EN 15804.

To support an assessment of the recyclability of materials used in the product, the output indicators defined in the existing DIN EN 15804 + A2 are used.

- "Material for Recycling (MFR)": material recycling (in the case of rotor blades: glass fibers as material for new production of cement, MPC panels, paving stones; use of recycled carbon fibers (rCF)) in injection moulding/fleece, metal recycling)
- "Material for Energy Recovery (MER)": energy recovery as qualified fuel with defined quality requirements (in the case of rotor blades: plastic content (epoxy matrix, rigid foams), balsa wood in the cement plant)

Supplemented by the following indicators:

- Material for Circularity (MFC) = Material is kept in the cycle (in the case of the rotor blade: GRP/sandwich matrix as (new) furniture, new fabric from rCF, metals)
- Material for energetic utilisation (MEU) = energetic utilisation as non-qualified fuel without defined quality requirements (in the case of rotor blades: combustion of balsa wood in waste wood power plants in the utilisation path of paving stones)

These evaluations are based on the potential recycling, circularity, reuse and recovery rates, which are summarised in tabular form for each rotor blade type (see Tables 6 and 7). A distinction is made between established and developing markets for the potential recycling paths with regard to market access for the individual materials.

CFRP rotor blade

Based on the composition of CFRP rotor blades from this product family with non-ferrous metals, steel, CF, and GF, and a loss of 5% applied across all treatment steps, the potential recycling rate is 59.2%, of which 32.1% goes into pathways established in the market. For the 9,4 Mass-% of carbon fibers, a market is under development for secondary carbon fibers (rCF).

Table 6: Summary of potential recycling, circularity and recovery rates for CFRP composites; state of the art practices and market situation 2021

Disposal type	Material depending on disposal route	Quote*%		Indicator
Recycling		59.2		
Only recyclable once	Glass fiber in the cement plant	27.8	46.4	MFR
	Recycled carbon fiber (rCF) for injection moulding application	*6.7*		MFR
	GFRP/sandwich material for MPC panels, paving stones	*12.6*		MFR
Supporting Circular economy	Non-ferrous metals, steel	4.3	12.8	MFC
	rCF for thermoplastic textile fabric	*2.2[1]*		MFC
	GFRP/sandwich material as furniture	*6.3[2]*		MFC
Energy recovery		35.9		
	Epoxy/ sandwich in the cement plant	30.8		MER
	Balsa wood for burning from paving stone route, Epoxy from CFRP pyrolysis	5.1		MEU
Loss		5		
Utilisation$_{total}$		**95**		

Italic = developing markets

* = Basis wt.% composition of rotor blade minus a general 5% loss due to reprocessing

1 = Assumption: 25% of rCF is used for thermoplastic textile fabrics, but majority of rCF is used as regrind <0,5 mm in injection moulding (not assessed here as supporting the circular economy).

2 = according to percentage share of GFRP/ sandwich share in relation to capacity GFRP treatment furniture as a proportion of total recycling capacity of cement, MPC boards, furniture, here 9.5%

GFRP rotor blade

For the GFRP blades, the resulting potential for recycling, circularity, and recovery rates are summarized below. Recycling is currently done through a cement plant, where components of the fiberglass can be recycled materially and the epoxy resin fraction is used thermally. Furthermore, metals and GFRP material can be recycled as furniture in a circular manner.

Table 7: Summary of potential recycling, circularity and recovery rates GFRP composites; state of the art practices and market situation 2021

Disposal type	Material depending on disposal route	Quote*%		Indicator
Recycling		65.2		
Only recyclable once	Glass fiber in the cement plant	39.7	54.5	MFR
	GFRP/sandwich material for MPC panels, paving stones	*14.8*		MFR
Supporting Circular economy	Non-ferrous metals, steel	2.9	10.7	MFC
	GFRP/sandwich material as furniture	*7.8*[1]		MFC
Energy recovery		29.9		
	Epoxy/ sandwich in the cement plant	29.6		MER
	Balsa wood for burning from paving stone route, Epoxy from CFRP pyrolysis	0.3		MEU
Loss		5		
Utilisation$_{total}$		**95**		

Italic = developing markets

* = Basis wt.% composition of rotor blade minus a general 5% loss due to reprocessing

1 = according to percentage share of GFRP/ sandwich share in relation to capacity GFRP treatment furniture as a proportion of total recycling capacity of cement, MPC boards, furniture, here 9.5%

3.15.4 Relevant critical, hazardous and climate-relevant substances

- Critical raw materials: carbon fibers, aluminum and glass fibers
- Climate-relevant substances: carbon fibers and epoxy resin
- Hazardous substances: not present

When considering the recyclability of a product, in addition to the evaluation of recycling rates for the overall product, in this case the rotor blade, differentiated material-specific rates are to be used for the most relevant materials and substances with regard to resource and climate protection; i.e. for the "critical" and particularly CO2 or energy-intensive substances according to the EU definition, insofar as these are used in mass proportions relevant in terms of quantity. For this purpose, used (raw) materials, semi-finished products and products are listed with regard to their classification as critical raw materials and with regard to their Global Warming Potential (GWP) or Primary Energy Demand (PED) value.

In the case of classification as a critical raw material, attention must also be paid to indirect classification, e.g. aluminium due to the classification of bauxite as a critical raw material or, in the case of semi-finished products and products, to their compositions and the critical raw materials involved, e.g. e-glass fiber due to a 5-10% share of boric oxide (i.e. borate classified here as a critical raw material). However, not all E-glass contains boron, which makes it even more important for manufacturers to provide this information to reprocessors or recyclers.

In the case of "critical raw materials", it is suggested that this separate consideration be carried out irrespective of the weight percentages of these substances used. This procedure also applies to hazardous substances used, insofar as these are still contained in their original state/mechanisms of action in the materials used.

In the case of energy-intensive substances, it is proposed to additionally consider them separately in case the PED value exceeds two times the calorific value for crude oil of 42 MJ/kg. With the 2-fold of the calorific value for crude oil, an energy-intensive refinement into plastic that exceeds the energy content of the material is to be taken into account, in order to only then be considered as a highly energy-intensive material with regard to the questions on the recyclability of a product. To estimate the quantitative relevance of the latter materials in a real product, the PED values are multiplied by the weight proportions in the product itself. If this sum, which describes the PED proportion in the finished product, exceeds a value of 20% of the sum of all specific PED values of the product. This is classified as proportionally relevant and an additional separate consideration is carried out for these substances.

In addition to these two separate, material-specific considerations on recycling, the declaration of hazardous substances residuing in the EoL material is necessary. Knowledge on the existence of hazardous substances is relevant due to their potentially problematic recycling or elimination options during the dismantling and disposal process and therefore affecting recyclability. Furthermore, indication of substances harmful to the environment helps preventing ubiquitous distribution.

Exemplarily, Table 8 summarizes the evaluation and classification of the CFRP rotor blade.

Table 8: Characteristic data on GWP/PED of installed materials, exemplary for the carbon sheet

Primary products used (Rotor blade)	GWP (kg CO2-eq./kg)	$PED_{total.}$ (MJ/kg)	Classification as a critical raw material*	Mass in rotor blade (Weight-%)	Energy index of materials used (MJ/ kg Rotor blade)**
Carbon fiber	30,2	635,8	indirectly coking coal	9,4	59,8
E-glass fiber	1,7	31,0	due to boron content	38,8	12,0
Epoxy resin, incl. hardener	5,85	130,7		36,4	47,6
Rigid foam/ PVC	2,17	59,42		1,3	0,8
Coating PU	4,59	95,7		1,3	1,2
Al lightning protection Sheet metal	9,56	169,93	indirectly bauxite	0,02	0,03
Cu-lightning protection					
Cu cable 3-wire	2,86	55,57			
Mesh, copper wire	0,82	11,75		0,8	0,1
Brass- lightning protection					
Sheet metal	0,59	8,58		0,05	0,004
Steel (bolt)	2,03	27,5		3,7	1,0
Balsa wood	-1,53	24,7		8,2	2,0

* = EU classification, status 2/2021, Communication from the EU Commission: EU resilience in critical raw materials: Charting a path towards greater security and sustainability; Brussels 3.9.2020.

** = Total PED MJ/kg *Wt% share of material used.

red = relevant energy-intensive (input) materials or energy-intensive product component.

As a result of the evaluation of the materials to be considered in particular, for this blade type presented here

- with regard to climate relevance, carbon fibres and epoxy resin
- and with regard to classification as "critical raw materials", the carbon fibres, aluminium and glass fibres are then to be considered in detail. The EoL materials do not contain any hazardous substances that are relevant.

The recycling routes of these substances classified as relevant are examined and described in detail in the following chapters.

3.15.4.1 Potential recyclability of particularly climate-relevant materials used (high carbon footprint)

According to the classification in table 6 special consideration must be given to the climate relevance of the materials used, carbon fibers and epoxy resin.

Carbon fibers

Carbon fibers are incorporated in the CFRP SparCaps of the rotor blades. By selectively separating these SparCaps, they can be further processed. The state of the art process is the pyrolysis of these materials, where the fibers are recovered as rCF. After pyrolysis, the fibers have to be cut to a homogeneous length distribution to be used in new textile fabrics. Here, longer fiber lengths (up to 30 mm) have advantages over shorter ones (e.g. 6 mm) with regard to a uniform length distribution. Above 30 mm in length, there is no longer any increase in strength during subsequent use in the fabrics.

The fibers can be processed into new CF textiles as fabrics for thermoplastic composites (primarily in wet-laid nonwoven production due to the short lengths) and used as lightweight construction elements. The fibers do not require longitudinal orientation in advance in nonwoven production, since this takes place in the pile formation process in the card itself (anisotropic semi-finished products). Percentages of 10-15% by weight of glass fibers do not interfere with nonwoven production from carbon fibers. On the other hand, an absolute absence of metal (Fe/non-ferrous) must be ensured, as this leads to massive interference in the carding process, including flying sparks. A sizing on the fibers is not absolutely necessary in textile production; this is more a question of the desired overall approach.

In the case of nonwovens, about 20 % by volume of carbon fibers are usually sufficient with regard to the material properties (stiffness/strength), i.e. cheaper fibers (e.g. hemp fibers for 0.5 Euro/kg) are often mixed in for filling (PA fibers cost about 1-1.5 Euro/kg).

In addition, the electrical conductivity of carbon fibers can be used for specific applications, for example for its antistatic capacity and shielding of electromagnetic radiation. The fibers can also be recovered from these fabrics a second time, thus ensuring recyclability.

Another type of use is to grind the fibers to < 0.5 mm, pelletize these dusts and incorporate them into thermoplastic injection molded elements, including sporting goods and automotive parts. Today, injection molded elements are often produced using the so-called organo-sheet process, i.e. thermoplastic compound sheets are formed and back-injected. In the case of flat components, these can in principle also be deformed again at the end of their service life and used again as covers, for example. In this application, too, the electrical properties of the carbon fibers can be specifically utilized. The use of carbon fibers in injection molding is not evaluated in terms of supporting the recyclability for the original continuous fibers in the rotor blade due to the grinding to < 0.5 mm.

As a rule, tensile strength no longer plays a major role for these reuse-cases; the priority is their use in non-structural components due to their low density and, in some cases, their electrical properties. Unlike strength, the stiffness of the fibers is not lost during shredding. About 80% of the lightweight components used do not have high strength requirements. Carbon fibers are preferred over glass fibers for medical technology applications, because of the undisturbed radiation permeability, which for glass fibers can become scattered radiation. With regard to the substitution of other materials by the use of secondary carbon fibers (rCF) and the associated credit in terms of GWP potential, a transparent analysis is necessary. Depending on whether primary glass fibers, primary carbon fibers, CF nonwovens or organic sheet elements are substituted for aluminum sheets, completely different GWP-credits result.

Epoxy resin

Epoxy resin is used as alternative fuel in the current state-of-the-art recycling methods via the cement plant for energy recovery. This is also currently credited in the LCA evaluations in Module D.

Material recycling has not been implemented at present. However, basic approaches are available in the chemical industry to recover basic materials for the chemical industry through chemical recycling by solvolysis or gasification, pyrolysis. These processes would then also support recyclability.

3.15.4.2 Potential recyclability of “critical raw materials“

According to the classification in table 8, special consideration must be given to the materials classified as “critical raw material”, namely carbon fibers, aluminum and glass fibers.

Carbon fibers

See section 3.15.4.1

Glass fibers

The glass fibers in the rotor blades to be discussed here are composed of so-called E-glass and have been indirectly classified as a critical raw material here due to the 5-10% boron oxide content. With the current state of the art recycling methods, the glass fibers are used materially via the cement plant to replace clay, limestone as well as siliceous sand.

There are research approaches to pyrolyze the thick-laminates of the root areas in particular, in order to separate the steel bolts or the laminated metal sleeves from the GFRP matrix without massive shredding effort on the one hand, and on the other hand to be able to reuse the recovered glass fibers as secondary material. This would also support the recyclability of the material.

Aluminum

Aluminum (possibly also copper) can be recovered by separating the cables and lightning protection elements from the rotor blade during dismantling and can be fed into the targeted recycling of new aluminum production. This material has a potential recycling rate of 95% (5% losses over the entire recycling path).

3.15.4.3 Hazardous substances

Substances to be classified as “hazardous” are not present in the potential EoL materials of this rotor blade family.

3.16 Further information

Additional information can be found at:

www.tpicomposites.com

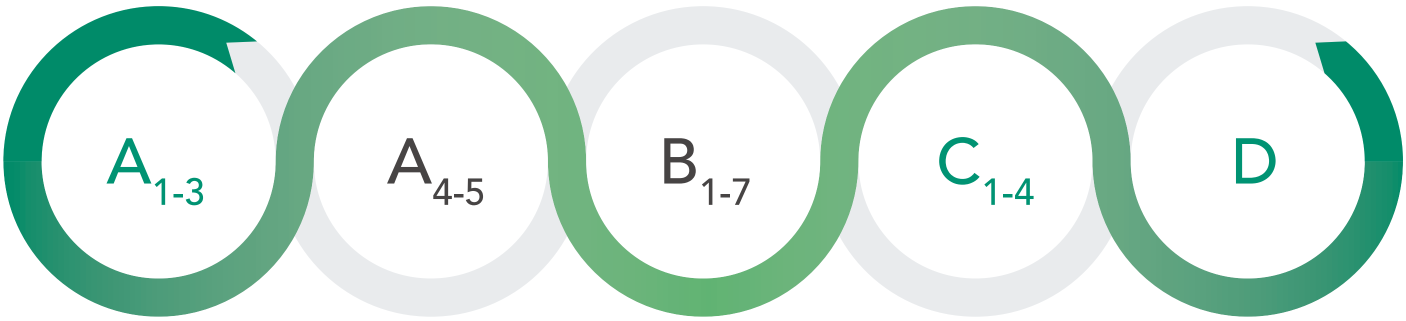
4 LCA calculation rules

4.1 Declared unit

1 GWh energy yield (basis: manufacturer's specification is the energy yield in GWh during life time)

4.2 System boundary

Cradle to factory gate with options (A1-A3, C1, C2, C3; D)



Production	Installation	Utilisation	End-of-Life (EoL)	Next product system
A_1 Raw material supply (extraction, processing, recycling)	A_4 Transport	B_1 Use/Application	C_1 Dismantling/ Demolition	D_1 Reuse, recovery or recycling opportunities
A_2 Transport to the manufacturer	A_5 Installation	B_2 Maintenance	C_2 Transport to EoL	
A_3 Manufacture		B_3 Repair	C_3 Waste processing for re-use, recovery or recycling	
		B_4 Replacement	C_4 Disposal	
		B_5 Renewal		
		B_6 Operational energy consumption		
		B_7 Operative water consumption		

X_x = Declared module

X_x = Module not declared

4.3 Estimations and assumptions

Due to a missing data set for the co-combustion of rotor blades in a cement factory, an energy recovery plant was used in this EPD draft.

4.4 Cut-off criteria

No Cut- Off rule applied.

4.5 Background data

The manufacturing process was modelled based on manufacturer-specific data. However, generic background datasets were used for the upstream and downstream processes. The back ground datasets used were taken from the current versions of various GaBi databases.

The datasets contained in the databases are documented online. All necessary processes within the defined system boundaries were considered.

The background datasets used for accounting purposes should not be older than 10 years. In this study, no datasets older than 10 years were used.

4.6 Data quality

The collected data were checked for plausibility and consistency. Good data quality can be assumed.

4.7 Period under review

Period under review was 2022.

4.8 Allocations

No allocations were made for the modelling of production processes, as the available data do not concern other products manufactured in the plant and there are no coupling processes.

Allocations in the LCA datasets used are documented accordingly in the datasets themselves.

Potential credits and avoided burdens resulting from the recycling and disposal Module C3 are assigned to module D.

4.9 Comparability

EPDs within the same product category but from different programmes may not be comparable.

EPDs of construction products may not be comparable if they do not comply with EN 15804.

5 LCA results

On the next following three pages the results of the LCA will be shown.

GF-type (PMI)

Length: 58,8 m / Blade surface: 344m² / Mass: 15344 kg

GF-type (PVC)

Length: 58,8 m / Blade surface: 344m² / Mass: 15483 kg

CF-type (PVC)

Length: 58,8 m / Blade surface: 344m² / Mass: 12672 kg

5.1 GF-type 1 (PMI)

Environmental Impact

Parameter	Unit	A_1 -A_3	C_1	C_2	C_3	D
Global Warming Potential (GWP)	[kg CO2-eq.]	6,02E+02	1,72E+01	5,56E+00	5,56E+00	-2,49E+02
Stratospheric ozone depletion potential (ODP)	[kg CFC11-eq.]	1,29E-07	4,63E-15	2,63E-15	2,63E-15	-3,12E-13
Acidification potential of soil and water (AP)	[kg SO2-eq.]	1,66E+00	6,15E-02	1,21E-02	1,21E-02	-3,95E-01
Eutrophication potential (EP)	[kg PO43--eq.]	1,72E-01	1,48E-02	3,03E-03	3,03E-03	-4,34E-02
Formation potential for tropospheric ozone (POCP)	[kg Ethene-eq.]	1,40E-01	5,96E-03	-4,45E-03	-4,45E-03	-3,72E-02
Potential for abiotic depletion of non-fossil resources (ADPE)	[kg Sb-eq.]	9,80E-03	1,72E-06	5,56E-07	5,56E-07	-1,84E-04
Potential for abiotic depletion of fossil fuels (ADPF)	[MJ]	1,08E+04	2,34E+02	7,34E+01	7,34E+01	-2,94E+03

Use of resources

Parameter	Unit	A_1 -A_3	C_1	C_2	C_3	D
Renewable primary energy as an energy carrier (PERE)	[MJ]	1,29E+03	1,35E+01	4,40E+00	2,56E+02	-6,46E+01
Renewable primary energy for material use (PERM)	[MJ]	2,09E+02	0,00E+00	0,00E+00	-2,09E+02	0,00E+00
Total renewable primary energy (PERT)	[MJ]	1,50E+03	1,35E+01	4,40E+00	4,70E+01	-6,46E+01
Non-renewable primary energy as an energy carrier (PENRE)	[MJ]	9,12E+03	2,35E+02	7,36E+01	6,97E+03	-2,97E+03
Non-renewable primary energy for material use (PENRM)	[MJ]	2,06E+03	0,00E+00	0,00E+00	-2,06E+03	0,00E+00
Total non-renewable primary energy (PENRT)	[MJ]	1,12E+04	2,35E+02	7,36E+01	4,91E+03	-2,97E+03
Use of secondary materials (SM)	[kg]	9,64E-01	0,00E+00	0,00E+00	0,00E+00	9,59E+01
Renewable secondary fuels (RSF)	[MJ]	0,00E+00	0,00E+00	0,00E+00	0,00E+00	-1,24E+02
Non-renewable secondary fuels (NRSF)	[MJ]	-1,85E+02	0,00E+00	0,00E+00	0,00E+00	-1,65E+03
Use of freshwater resources (FW)	[m^3]	5,19E+00	1,54E-02	3,85E-03	2,33E-02	-5,96E-01

Output flows and waste categories

Parameter	Unit	A_1 -A_3	C_1	C_2	C_3	D
Hazardous waste to landfill (HWD)	[kg]	2,16E-06	1,24E-08	3,11E-09	2,65E-08	-1,77E-07
Non-hazardous waste disposed (NHWD)	[kg]	3,15E+01	3,69E-02	1,24E-02	6,01E-02	-2,45E+00
Disposed radioactive waste (RWD)	[kg]	1,53E-01	4,27E-04	9,02E-05	5,63E-03	-1,15E-02
Materials for Circularity (MFC)	[kg]	7,29E+00	0,00E+00	0,00E+00	9,32E+00	0,00E+00
Materials for recycling (MFR)	[kg]	0,00E+00	0,00E+00	0,00E+00	8,82E+01	0,00E+00
Substances for energy recovery (MER)	[kg]	0,00E+00	0,00E+00	0,00E+00	5,45E+01	0,00E+00
Exported Energy [Electricity]	[MJ]	8,02E+01	0,00E+00	0,00E+00	2,87E-01	0,00E+00
Exported Energy [Thermal Energy]	[MJ]	1,85E+02	0,00E+00	0,00E+00	6,72E-01	0,00E+00
Material for energetic utilisation (MEU)	[kg]	1,68E+01	0,00E+00	0,00E+00	1,30E-01	0,00E+00

5.2 GF-type 2 (PVC)

Environmental Impact

Parameter	Unit	A_1 -A_3	C_1	C_2	C_3	D
Global Warming Potential (GWP)	[kg CO2-eq.]	6,03E+02	1,73E+01	5,61E+00	1,58E+02	-2,51E+02
Stratospheric ozone depletion potential (ODP)	[kg CFC11-eq.]	1,41E-07	4,67E-15	2,66E-15	2,54E-13	-3,15E-13
Acidification potential of soil and water (AP)	[kg SO2-eq.]	1,65E+00	6,20E-02	1,22E-02	1,03E+00	-3,99E-01
Eutrophication potential (EP)	[kg PO43--eq.]	1,70E-01	1,50E-02	3,05E-03	3,28E-02	-4,38E-02
Formation potential for tropospheric ozone (POCP)	[kg Ethene-eq.]	1,41E-01	6,01E-03	-4,49E-03	4,62E-02	-3,76E-02
Potential for abiotic depletion of non-fossil resources (ADPE)	[kg Sb-eq.]	9,84E-03	1,74E-06	5,61E-07	2,66E-06	-1,85E-04
Potential for abiotic depletion of fossil fuels (ADPF)	[MJ]	1,07E+04	2,36E+02	7,41E+01	4,93E+03	-2,97E+03

Use of resources

Parameter	Unit	A_1 -A_3	C_1	C_2	C_3	D
Renewable primary energy as an energy carrier (PERE)	[MJ]	1,29E+03	1,36E+01	4,44E+00	2,56E+02	-6,51E+01
Renewable primary energy for material use (PERM)	[MJ]	2,09E+02	0,00E+00	0,00E+00	-2,09E+02	0,00E+00
Total renewable primary energy (PERT)	[MJ]	1,50E+03	1,36E+01	4,44E+00	4,75E+01	-6,51E+01
Non-renewable primary energy as an energy carrier (PENRE)	[MJ]	9,08E+03	2,37E+02	7,44E+01	7,05E+03	-3,00E+03
Non-renewable primary energy for material use (PENRM)	[MJ]	2,10E+03	0,00E+00	0,00E+00	-2,10E+03	0,00E+00
Total non-renewable primary energy (PENRT)	[MJ]	1,12E+04	2,37E+02	7,44E+01	4,95E+03	-3,00E+03
Use of secondary materials (SM)	[kg]	9,64E-01	0,00E+00	0,00E+00	0,00E+00	9,67E+01
Renewable secondary fuels (RSF)	[MJ]	0,00E+00	0,00E+00	0,00E+00	0,00E+00	-1,26E+02
Non-renewable secondary fuels (NRSF)	[MJ]	-1,88E+02	0,00E+00	0,00E+00	0,00E+00	-1,66E+03
Use of freshwater resources (FW)	[m³]	5,19E+00	1,56E-02	3,89E-03	2,35E-02	-5,97E-01

Output flows and waste categories

Parameter	Unit	A_1 -A_3	C_1	C_2	C_3	D
Hazardous waste to landfill (HWD)	[kg]	4,11E-06	1,26E-08	3,14E-09	2,67E-08	-1,79E-07
Non-hazardous waste disposed (NHWD)	[kg]	3,16E+01	3,72E-02	1,26E-02	6,07E-02	-2,48E+00
Disposed radioactive waste (RWD)	[kg]	1,57E-01	4,30E-04	9,09E-05	5,69E-03	-1,16E-02
Materials for Circularity (MFC)	[kg]	7,29E+00	0,00E+00	0,00E+00	9,37E+00	0,00E+00
Materials for recycling (MFR)	[kg]	0,00E+00	0,00E+00	0,00E+00	8,90E+01	0,00E+00
Substances for energy recovery (MER)	[kg]	0,00E+00	0,00E+00	0,00E+00	5,51E+01	0,00E+00
Exported Energy [Electricity]	[MJ]	8,15E+01	0,00E+00	0,00E+00	2,89E-01	0,00E+00
Exported Energy [Thermal Energy]	[MJ]	1,88E+02	0,00E+00	0,00E+00	6,78E-01	0,00E+00
Material for energetic utilisation (MEU)	[kg]	1,71E+01	0,00E+00	0,00E+00	1,31E-01	0,00E+00

5.3 CF-type (PVC)

Environmental Impact

Parameter	Unit	A_1 -A_3	C_1	C_2	C_3	D
Global Warming Potential (GWP)	[kg CO2-eq.]	6,99E+02	1,14E+01	3,29E+00	1,19E+02	-3,05E+02
Stratospheric ozone depletion potential (ODP)	[kg CFC11-eq.]	1,62E-07	3,06E-15	1,55E-15	1,74E-13	-3,19E-12
Acidification potential of soil and water (AP)	[kg SO2-eq.]	1,32E+00	4,06E-02	7,20E-03	6,75E-01	-5,87E-01
Eutrophication potential (EP)	[kg PO43--eq.]	1,93E-01	9,79E-03	1,79E-03	2,27E-02	-6,97E-02
Formation potential for tropospheric ozone (POCP)	[kg Ethene-eq.]	1,29E-01	3,94E-03	-2,63E-03	3,07E-02	-4,89E-02
Potential for abiotic depletion of non-fossil resources (ADPE)	[kg Sb-eq.]	5,18E-03	1,14E-06	3,29E-07	3,46E-06	-7,82E-03
Potential for abiotic depletion of fossil fuels (ADPF)	[MJ]	1,22E+04	1,54E+02	4,35E+01	2,78E+03	-4,17E+03

Use of resources

Parameter	Unit	A_1 -A_3	C_1	C_2	C_3	D
Renewable primary energy as an energy carrier (PERE)	[MJ]	1,98E+03	8,95E+00	2,61E+00	2,09E+02	-5,92E+02
Renewable primary energy for material use (PERM)	[MJ]	1,75E+02	0,00E+00	0,00E+00	-1,75E+02	0,00E+00
Total renewable primary energy (PERT)	[MJ]	2,15E+03	8,95E+00	2,61E+00	3,36E+01	-5,92E+02
Non-renewable primary energy as an energy carrier (PENRE)	[MJ]	1,13E+04	1,55E+02	4,36E+01	4,30E+03	-4,35E+03
Non-renewable primary energy for material use (PENRM)	[MJ]	1,51E+03	0,00E+00	0,00E+00	-1,51E+03	0,00E+00
Total non-renewable primary energy (PENRT)	[MJ]	1,28E+04	1,55E+02	4,36E+01	2,78E+03	-4,35E+03
Use of secondary materials (SM)	[kg]	8,61E-01	0,00E+00	0,00E+00	0,00E+00	5,79E+01
Renewable secondary fuels (RSF)	[MJ]	0,00E+00	0,00E+00	0,00E+00	0,00E+00	-1,11E+02
Non-renewable secondary fuels (NRSF)	[MJ]	-1,38E+02	0,00E+00	0,00E+00	0,00E+00	-1,08E+03
Use of freshwater resources (FW)	[m³]	4,73E+00	1,02E-02	2,28E-03	4,66E-02	-9,20E-01

Output flows and waste categories

Parameter	Unit	A_1 -A_3	C_1	C_2	C_3	D
Hazardous waste to landfill (HWD)	[kg]	4,26E-06	8,19E-09	1,84E-09	2,02E-08	-7,32E-07
Non-hazardous waste disposed (NHWD)	[kg]	2,01E+01	2,44E-02	7,36E-03	1,26E+00	-5,87E+00
Disposed radioactive waste (RWD)	[kg]	2,43E-01	2,82E-04	5,33E-05	4,94E-03	-7,45E-02
Materials for Circularity (MFC)	[kg]	5,14E+00	0,00E+00	0,00E+00	1,39E+01	0,00E+00
Materials for recycling (MFR)	[kg]	0,00E+00	0,00E+00	0,00E+00	4,62E+01	0,00E+00
Substances for energy recovery (MER)	[kg]	0,00E+00	0,00E+00	0,00E+00	3,77E+01	0,00E+00
Exported Energy [Electricity]	[MJ]	5,98E+01	0,00E+00	0,00E+00	1,62E-01	0,00E+00
Exported Energy [Thermal Energy]	[MJ]	1,38E+02	0,00E+00	0,00E+00	3,80E-01	0,00E+00
Material for energetic utilisation (MEU)	[kg]	1,26E+01	0,00E+00	0,00E+00	7,32E-02	0,00E+00

6 LCA interpretation

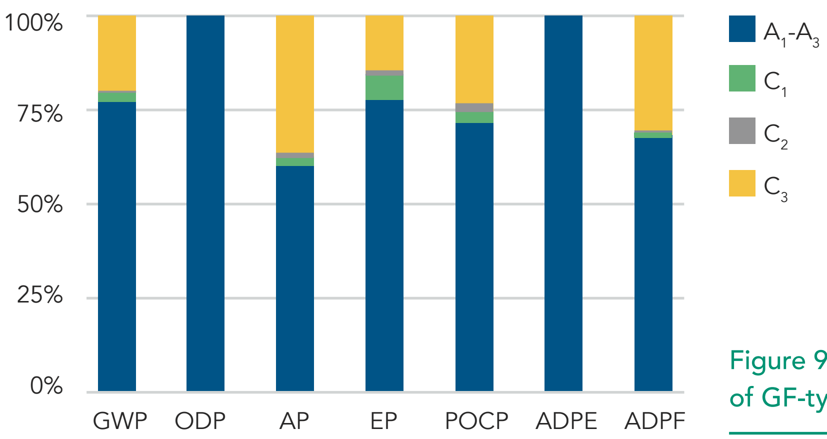


Figure 9: Dominance analysis of GF-type 1 (PVC) and 2 (PMI)

The dominance analysis of GF-type 1 and 2 are quite similar. The graphic shows the analysis of GF-type 2 (PMI) (Figure 9). The production stage (module A1-A3) has the greatest influence. The Epoxy resin has the greatest impact of the GWP (63%), followed by the glass fibers (27%). The second most part is the treatment of the waste at the end of the life cycle (C3). The demolition and the disposal transports do only show minor impacts. Similar distribution is found for the CF-type (Figure 2), but the production stage has an even higher influence on GWP. This is due to the use of carbon fibers, they contribute with 44% within module A1-A3.

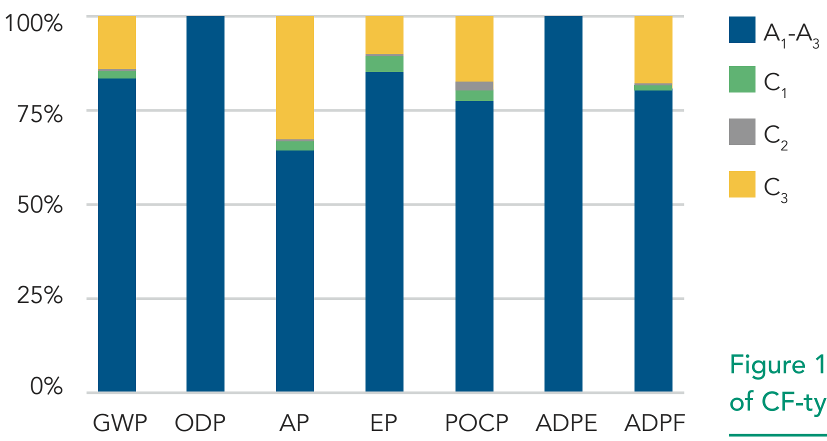


Figure 10: Dominance analysis of CF-type (PVC)

7 Glossar

Abbreviation	Explanation
AEP	Annual Energy Production
CF	Carbon fiber
CFRP	Carbon fiber-reinforced polymer
CO2	Carbon Dioxide
DOE	Department of Energy
EMEA	Europe, Middle East, Africa
EoL	End of Life
EPA	Environmental Protection Agency
GF	wGlass fiber
GFRP	Glass fiber-reinforced polymer
GHG	Greenhouse gas
GL	Germanischer Lloyd
GWP	Global Warming Potential
HSE	Health, safety and environment
IEA	International Energy Agency
IEC	International Electrotechnical Commission
IKEA	A certain type of connection (T-bolt)
IND	Indicator not determined
IRENA	International Renewable Energy Agency
kWh	Kilowatt hour
LCA	Life cycle assessment
LE	Leading edge
LEP	Leading edge protection
LPS	Lightning Protection System
MER	Material for energy recovery
MEU	Material for energetic utilization
MFC	Material for circularity
MFR	Material for recycling
MPC	Mineral plastic compound
MW	Megawatt
OEM	Original equipment manufacturer
PA	Polyamide
PED	Primary energy demand
PDP	Product development process
PMI	Polymethacrylimide
PS	Pressure side
PU	Polyurethane
PVC	Polyvinylchloride
rCF	Recycled carbon fiber
SC	Spar Cab
SS	Suction side
SW	Spar Web
TE	Trailing edge
WHO	World Health Organisation

8 General information

PCR	The EPD draft follows the core rules for the product category of construction products EN 15804 + A1: 2013
Independent verification of the declaration and data, according to ISO 14025	· EPD process certification · EPD verification
Third party verifier:	This is a draft. The verifier can only be disclosed after verification
Accredited and approved by:	This is a draft. The accreditation and approval of the verifier can only be disclosed after selection of the verifier
Owner of the declaration	TPI Composites Germany GmbH Falkenberger Str. 146 A/B, 13088 Berlin Germany +49 30 3119-2090
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