Environmental Product Declaration

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 is to be consolidated and completed in the further course of the RecycleWind 2.0 project; in particular, additional criteria for the presentation of the recyclability of a product are to be developed. These must 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 previous draft version of the "EPD rotor blade" will be expanded to include these aspects in a separate chapter entitled "Recyclability" and will in future be referred to as the "EPD-plus rotor blade".

More information: www.recyclewind.hs-bremen.de

Project partners

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BAB
Die Förderbank

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	EU120.2500.5-A*
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	2019
Geographical area of validity	Worldwide
Declared unit	1 kWh Energy yield
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 13% of all onshore wind blades on a MW-basis globally in 2020. We reached a record high this year with nearly $1.7 billion in net sales and more than 10,600 wind blades produced. We enable many of the industry's leading wind turbine original equipment manufacturers (OEMs), who have historically relied on in-house production, to outsource the manufacturing of a 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 nearly 15,000 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 2016 to 2020 have the potential to reduce more than 1.2 billion metric tons of CO2 over their average 20-year life span[2]. This is equivalent to the use of over 200 million homes' electricity use for one year in the U.S.[3].

EUROS Polska sp. z o.o was an independent manufacturer of moulds and rotor blades for wind turbines since 1999. The glass/carbon-epoxy blades ranged from 9m to 82m and were produced in hand lamination or vacuum infusion process. The blade design was done by EUROS GmbH in Berlin. In 2019, the EUROS GmbH engineering team was acquired by TPI Composites and renamed as TPI Composites Germany GmbH.

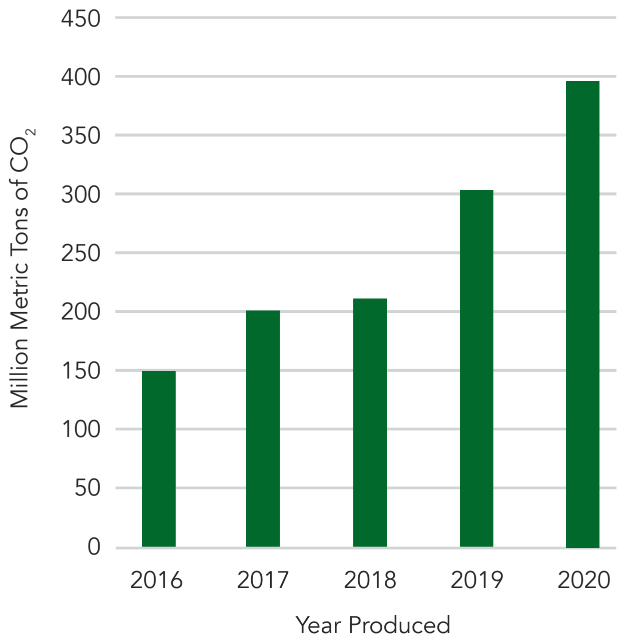


Figure 1: Estimated CO2 reduction from blades produced over entire product life by year produced

[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.

Designation	Type 1 (PMI)	Type 2 (PVC)	Unit
Length of blade (root at L 0.00m)	58.8		m
Total mass	15344	15483	kg
Centre of gravity	17.70	17.80	m
Blade surface	344		m^2
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
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

	58.8m PMI	58.8m PVC	Unit
Glass fibres	8527	8527	kg
Balsa wood	986	986	kg
PVC	0	172	kg
Polymethacrylimide (PMI)	143	0	kg
Epoxy resin	5052	5161	kg
PU-Coating	168	168	kg
Steel bolts	450	450	kg
Aluminium	18	18	kg
Total mass	**15344**	**15483**	**kg**

3.4 Manufacture

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.

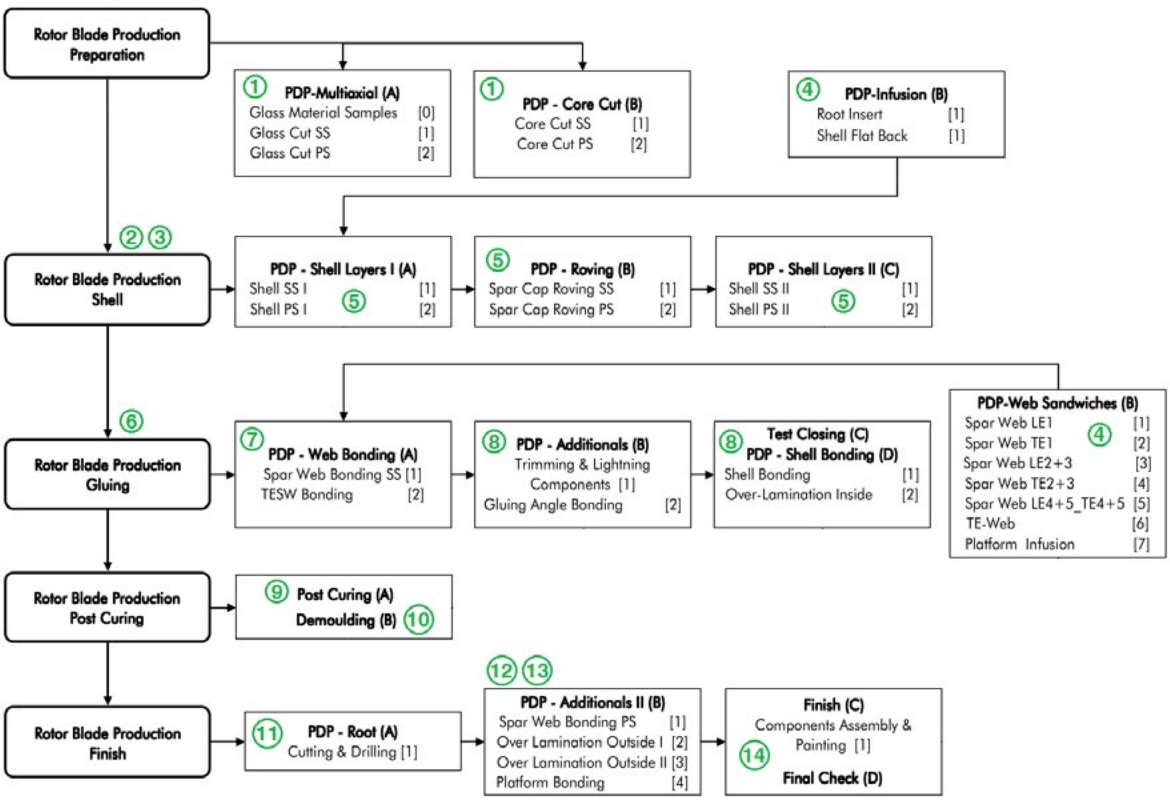
The temperatures and humidity inside the production hall and storage areas need to be controlled in order to guarantee optimal use and reliable/recurrent quality of the blades. Especially the handling and exothermic behavior of mixed epoxy-based materials are heavily influenced by temperatures, meaning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

3.4.3 Information on relevant production waste

Relevant production wastes are in particular excess epoxy resin, blends of glass fibre mats as well as operating materials such as foils, which are required for

Process instruction for blade production



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 fibre 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 "EU120.2500.5-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 is verified and certified according to GL-guideline 2010, assuming fatigue loads to represent 20 years of operation/lifetime.

3.11 Extraordinary effects

Fire

Glass-fibre-epoxy structures are flammable, depending on the existent temperatures. Since cured epoxy-resins do not show a liquid phase and glass-fibres have a high melting point, the risk of dripping is low. Formation of smoke is likely.

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-structures, respirable and harmful dust is generated.

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

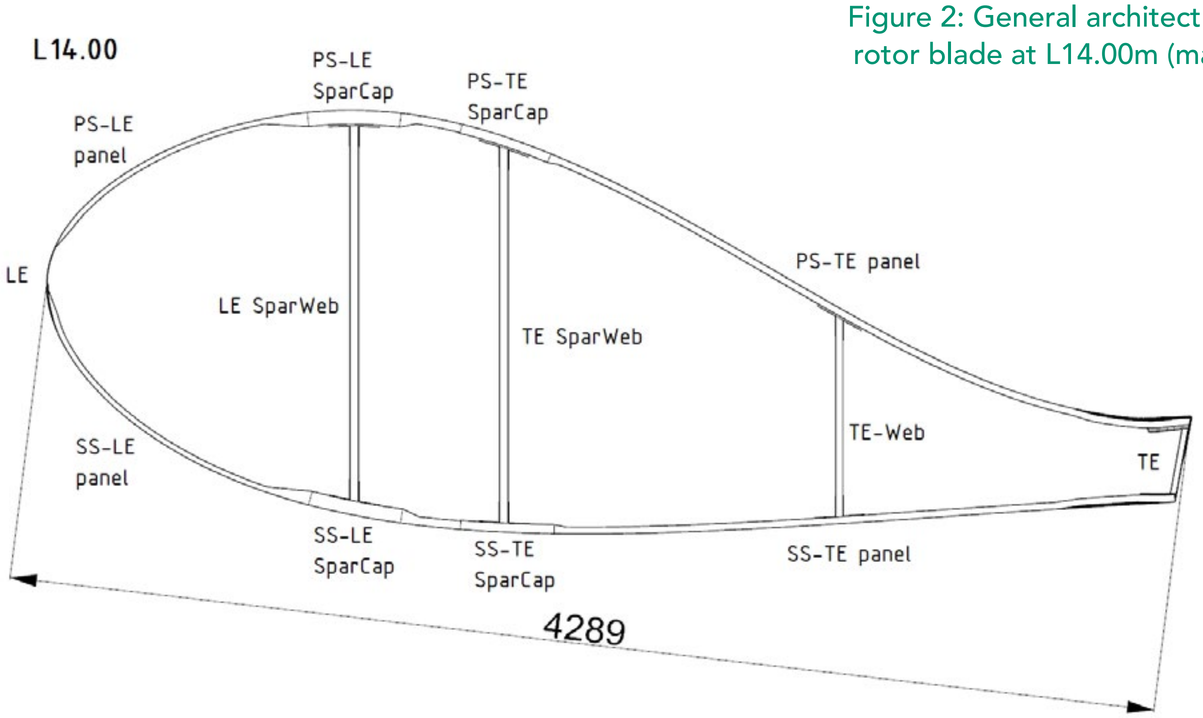
Most of the parts and medium scale areas of the blade can be repaired and/or replaced. Since the blade structure is complex and varies in different areas of the blade, decisions and repair instructions have to be made for each individual case. Trained and certified service teams are able to perform on-site 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

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

The Spar Caps shall be extracted from the blade structure separately and preferably in one piece. The massive root part (first 1.5m, see also Figure 5) of the blade shall also be removed separately. The leading and trailing edge parts (mostly sandwich structure) are to be removed first.

Figure 2: General architecture of the rotor blade at L14.00m (max. chord)



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 2mm which allows the separation of GFRP and core by simply pulling/ peeling off the GFRP from the core. The same method is feasible for all webs on the whole length.

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

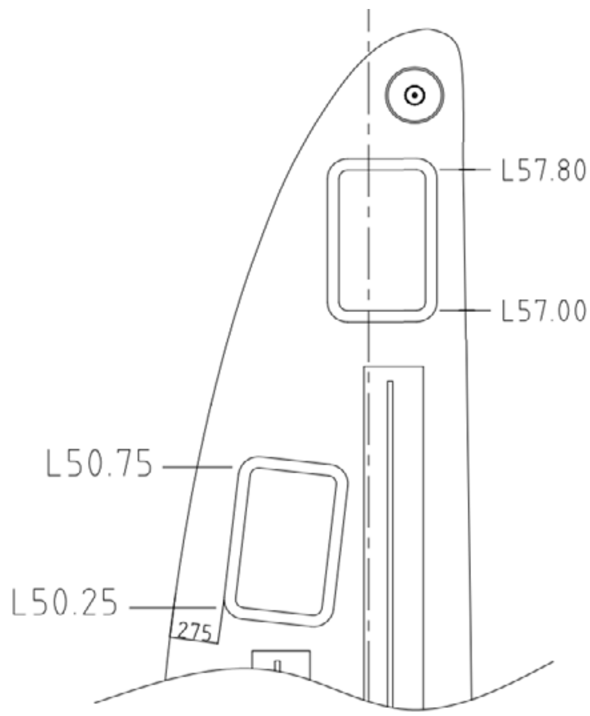


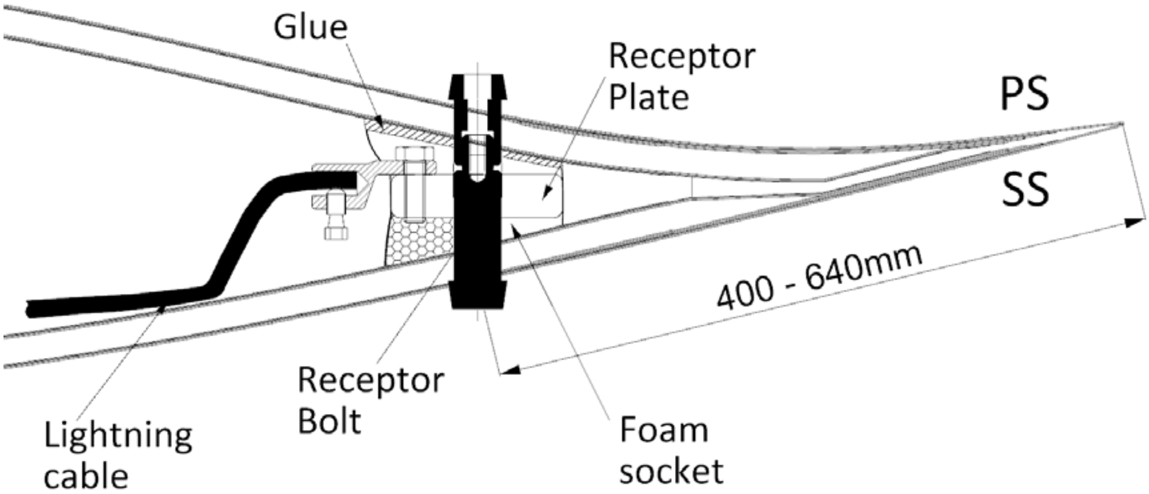
Figure 3: Balancing chamber positions

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 (L17.75).

The trailing edge (TE) part 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

Figure 4: Mounted receptor plate



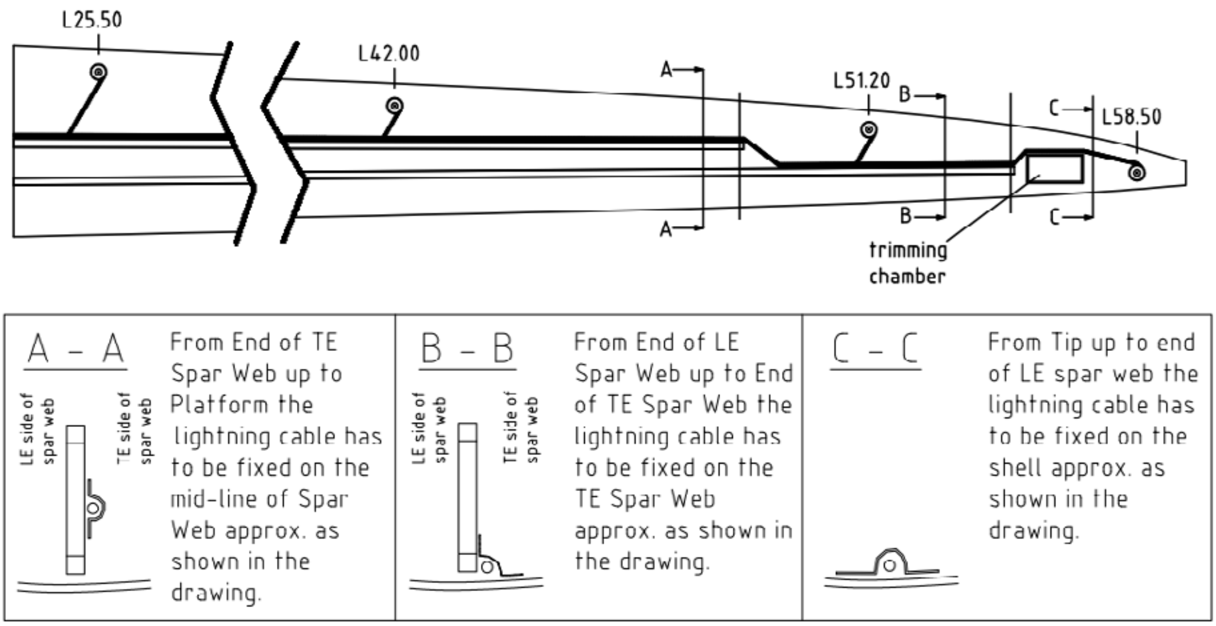


Figure 5: Positions of LPS - receptors and – cable

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:

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.

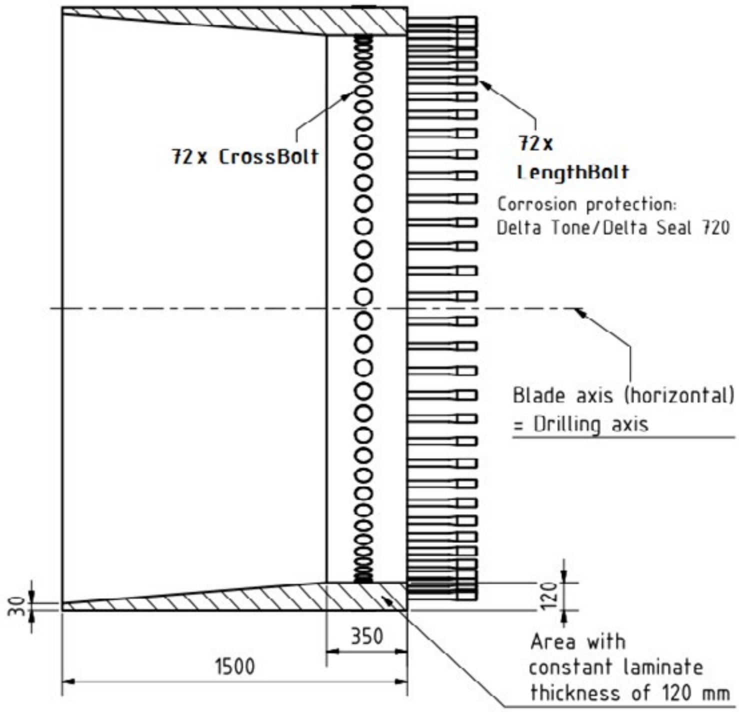


Figure 6: Blade connection

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 Recycling and disposal

The rotor blades are dismantled as part of the dismantling of the entire wind turbine or during replacement. On site, they are divided into transportable segments by special saws which collect the sawdust. This is followed by pretreatment in the form of metal separation, delamination and further comminution, including separation of non-ferrous metals. Thereafter, the GFRP composites can be recycled in the cement plant for the material recycling of the glass content and for the energetic use of the other components. Alternatively, after fine grinding, use as a filler in the plastics industry can be considered.

3.16 Further information

Optional data, indication of the source of further information, e.g. website, source of supply for safety data sheet, etc.

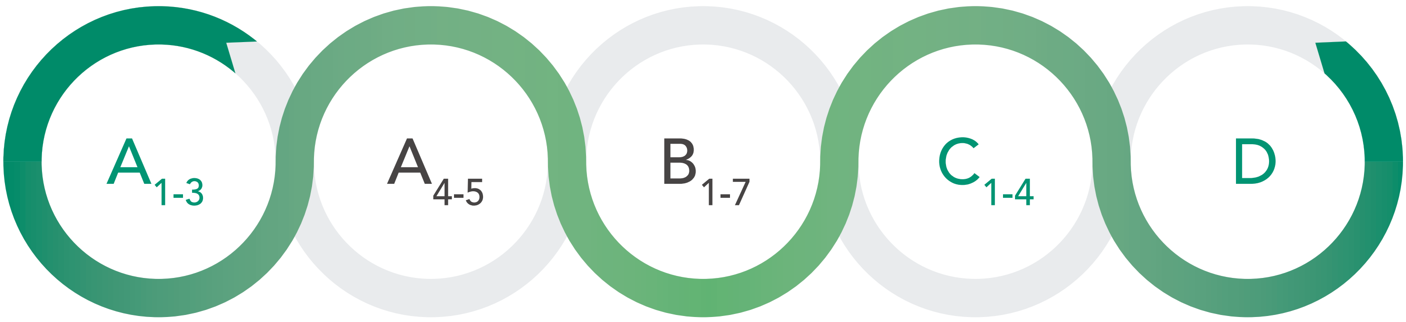
4 LCA calculation rules

4.1 Declared unit

1 kWh energy yield (basis: manufacturer's specification is the energy yield in kWh/a per rotor blade)

4.2 System boundary

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



Production

A_1
Raw material supply (extraction, processing, recycling)

A_2
Transport to the manufacturer

A_3
Manufacture

Installation

A_4
Transport

A_5
Installation

Utilisation

B_1
Use/Application

B_2
Maintenance

B_3
Repair

B_4
Replacement

B_5
Renewal

B_6
Operational energy consumption

B_7
Operative water consumption

End-of-Life (EoL)

C_1
Dismantling/ Demolition

C_2
Transport to EoL

C_3
Waste processing for re-use, recovery or recycling

C_4
Disposal

Next product system

D_1
Reuse, recovery or recycling opportunities

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 2019.

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 two pages the results of the LCA will be shown.

Type 1

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

Type 2

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

5.1 TYPE 1 (PMI)

Environmental Impact

Parameter	Unit	A_1 -A_3	C_3	D_3
Global Warming Potential (GWP)	[kg CO2-eq.]	1,24E-02	6,03E-03	-2,49E-03
Stratospheric ozone depletion potential (ODP)	[kg CFC11-eq.]	1,51E-13	1,06E-14	-2,05E-17
Acidification potential of soil and water (AP)	[kg SO2-eq.]	3,65E-05	1,44E-06	-2,00E-06
Eutrophication potential (EP)	[kg PO43--eq.]	3,42E-06	1,19E-07	-3,50E-07
Formation potential for tropospheric ozone (POCP)	[kg Ethene-eq.]	2,89E-06	6,58E-08	-2,36E-07
Potential for abiotic depletion of non-fossil resources (ADPE)	[kg Sb-eq.]	2,26E-07	8,73E-10	-3,02E-10
Potential for abiotic depletion of fossil fuels (ADPF)	[MJ]	2,05E-01	2,41E-03	-3,95E-02

Use of resources

Parameter	Unit	A_1 -A_3	C_3	D_3
Renewable primary energy as an energy carrier (PERE)	[MJ]	3,02E-02	4,14E-04	-3,42E-03
Renewable primary energy for material use (PERM)	[MJ]	0,00E+00	0,00E+00	0,00E+00
Total renewable primary energy (PERT)	[MJ]	3,02E-02	4,14E-04	-3,42E-03
Non-renewable primary energy as an energy carrier (PENRE)	[MJ]	2,15E-01	2,78E-03	-4,09E-02
Non-renewable primary energy for material use (PENRM)	[MJ]	IND	IND	IND
Total non-renewable primary energy (PENRT)	[MJ]	2,15E-01	2,78E-03	-4,09E-02
Use of secondary materials (SM)	[kg]	0,00E+00	0,00E+00	0,00E+00
Renewable secondary fuels (RSF)	[MJ]	0,00E+00	0,00E+00	0,00E+00
Non-renewable secondary fuels (NRSF)	[MJ]	0,00E+00	0,00E+00	0,00E+00
Use of freshwater resources (FW)	[m^3]	5,00E-05	1,49E-05	-1,90E-06

Output flows and waste categories

Parameter	Unit	A_1 -A_3	C_3	D_3
Hazardous waste to landfill (HWD)	[kg]	2,01E-10	1,59E-09	-2,43E-11
Non-hazardous waste disposed (NHWD)	[kg]	7,15E-04	6,10E-04	-1,07E-04
Disposed radioactive waste (RWD)	[kg]	3,97E-06	1,49E-07	-5,95E-07
Components for Reuse (CRU)	[kg]	0,00E+00	0,00E+00	0,00E+00
Materials for recycling (MFR)	[kg]	IND	IND	IND
Substances for energy recovery (MER)	[kg]	IND	IND	IND
Exported Energy [Electricity]	[MJ]	IND	IND	IND
Exported Energy [Thermal Energy]	[MJ]	IND	IND	IND

5.2 TYPE 2 (PVC)

Environmental Impact

Parameter	Unit	A_1 -A_3	C_3	D_3
Global Warming Potential (GWP)	[kg CO2-eq.]	1,26E-02	6,27E-03	-2,59E-03
Stratospheric ozone depletion potential (ODP)	[kg CFC11-eq.]	1,58E-13	1,10E-14	-2,13E-17
Acidification potential of soil and water (AP)	[kg SO2-eq.]	3,69E-05	1,49E-06	-2,08E-06
Eutrophication potential (EP)	[kg PO43--eq.]	3,48E-06	1,23E-07	-3,63E-07
Formation potential for tropospheric ozone (POCP)	[kg Ethene-eq.]	2,95E-06	6,81E-08	-2,45E-07
Potential for abiotic depletion of non-fossil resources (ADPE)	[kg Sb-eq.]	2,26E-07	9,07E-10	-3,12E-10
Potential for abiotic depletion of fossil fuels (ADPF)	[MJ]	2,10E-01	2,49E-03	-4,09E-02

Use of resources

Parameter	Unit	A_1 -A_3	C_3	D_3
Renewable primary energy as an energy carrier (PERE)	[MJ]	3,08E-02	4,30E-04	-3,57E-03
Renewable primary energy for material use (PERM)	[MJ]	0,00E+00	0,00E+00	0,00E+00
Total renewable primary energy (PERT)	[MJ]	3,08E-02	4,30E-04	-3,57E-03
Non-renewable primary energy as an energy carrier (PENRE)	[MJ]	2,19E-01	2,89E-03	-4,24E-02
Non-renewable primary energy for material use (PENRM)	[MJ]	IND	IND	IND
Total non-renewable primary energy (PENRT)	[MJ]	2,19E-01	2,78E-03	-4,24E-02
Use of secondary materials (SM)	[kg]	0,00E+00	0,00E+00	0,00E+00
Renewable secondary fuels (RSF)	[MJ]	0,00E+00	0,00E+00	0,00E+00
Non-renewable secondary fuels (NRSF)	[MJ]	0,00E+00	0,00E+00	0,00E+00
Use of freshwater resources (FW)	[m³]	5,08E-05	1,54E-05	-1,97E-06

Output flows and waste categories

Parameter	Unit	A_1 -A_3	C_3	D_3
Hazardous waste to landfill (HWD)	[kg]	2,45E-10	1,65E-09	-2,51E-11
Non-hazardous waste disposed (NHWD)	[kg]	7,19E-04	6,33E-04	-1,11E-04
Disposed radioactive waste (RWD)	[kg]	4,05E-06	1,54E-07	-6,18E-07
Components for Reuse (CRU)	[kg]	0,00E+00	0,00E+00	0,00E+00
Materials for recycling (MFR)	[kg]	IND	IND	IND
Substances for energy recovery (MER)	[kg]	IND	IND	IND
Exported Energy [Electricity]	[MJ]	IND	IND	IND
Exported Energy [Thermal Energy]	[MJ]	IND	IND	IND

6 Glossar

Abbreviation	Explanation
CO_2	Carbon Dioxide
DOE	Department of Energy
EoL	End of Life
EPA	Environmental Protection Agency
GFRP	Glass fiber-reinforced polymer
GHG	Greenhouse gas
GL	Germanischer Lloyd
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

Abbreviation	Explanation
kWh	Kilowatt hour
LCA	Life cycle assessment
LE	Leading edge
LEP	Leading edge protection
LPS	Lightning Protection System
MW	Megawatt
OEM	Original equipment manufacturer
PDP	Product development process
PMI	Polymethacrylimide
PS	Pressure side
PU	Polyurethane
PVC	Polyvinylchloride
SS	Suction side
TE	Trailing edge
EMEA	Europe, Middle East, Africa

7 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
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Owner of the declaration tpi COMPOSITES.	TPI Composites Germany GmbH Falkenberger Str. 146 A/B, 13088 Berlin Germany +49 30 3119-2090
Commissioner of the Life Cycle brands & values® sustainability consultants	brands & values GmbH Altenwall 14, 28195 Bremen Germany www.brandsandvalues.com info@brandsandvalues.com +49 421 70 90 84- 33