ENVIRONMENTAL PRODUCT DECLARATION

WIND FARM WITH NORDEX DELTA4000 N149/4.0–4.5 WIND TURBINES

NORDEX ENERGY SE&CO. KG
Erich-Schlesinger-Str. 50,
18059 Rostock, Germany
(Nacelle assembly)

Hinrichshaeger Str. 60,
18146 Rostock, Germany
(Blade production)

In compliance with ISO 14025 and ISO 14040/14044

Program Operator: EPDItaly
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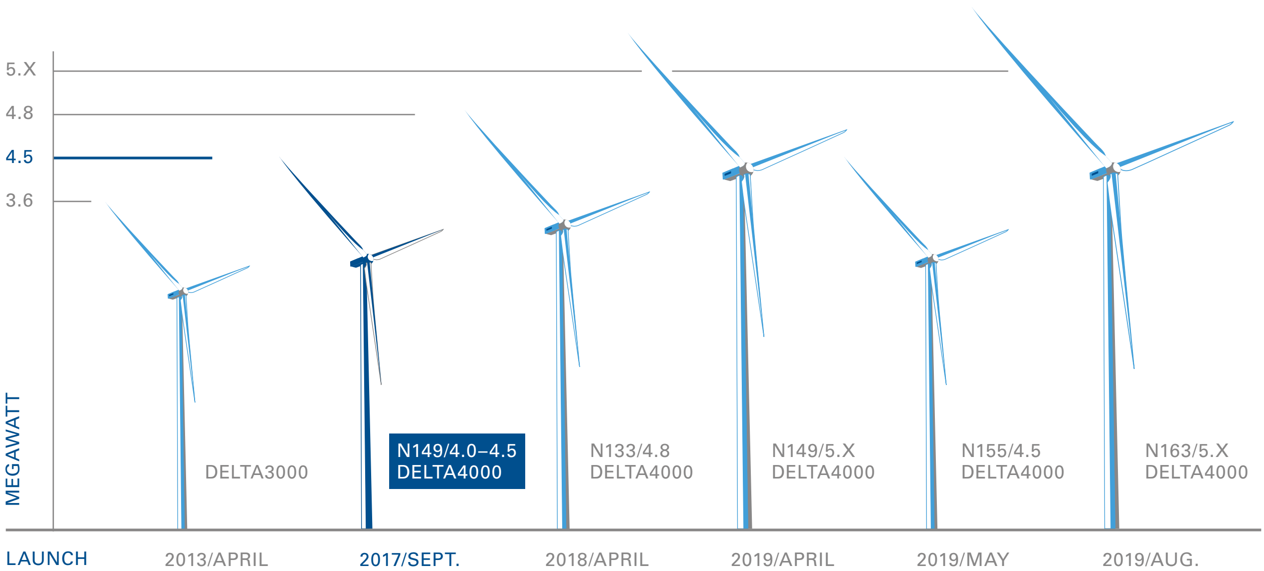
THE DELTA4000 N149/4.0 – 4.5
OPTIMIZED YIELDS FOR LIGHT TO MEDIUM WIND SITES



Based on more than 35 years of experience, the Nordex Group is an expert in connecting proven technology with innovative engineering. For the Delta4000 product series, we took over the Delta Generation's fundamental design and transferred it to the 4 MW class. Depending on investment criteria in the customer's business case the wind park can be optimized with regards to AEP, rating, life time and sound requirements. In addition, this flexibility offers opportunities to optimize the revenues in line with PPA structures and merchant price profiles.

General Information

OWNER OF THE EPD
Nordex SE

MANUFACTURING SITES
Nordex Energy SE & Co. KG.

Nacelles
Erich-Schlesinger-Str. 50
18059 Rostock
Germany

Blades
Hinrichshaeger Str. 60
18146 Rostock
Germany

SCOPE OF THE EPD
According to EPDItaly's program regulations, this is a cradle-to-grave product EPD study on a "Delta4000 N149/4.0–4.5 wind farm" commissioned by the Nordex Group.

PROGRAM OPERATOR
EPDItaly
Via Gaetano De Castillia 10
20124 Milan
Italy

INDEPENDENT VERIFICATION
This Environmental Product Declaration has been developed following the instructions of the EPDItaly Program; further information and the document itself can be found at: www.epditaly.it.

The LCA study has been conducted according to the requirements of ISO 14040/44:2006.

Independent verification of the declaration and data was carried out according to ISO 14025:2010 by ICMQ, Via Gaetano De Castillia 10, 20124 Milan, Italy.

CPC OF REFERENCE
171 "Electrical energy"

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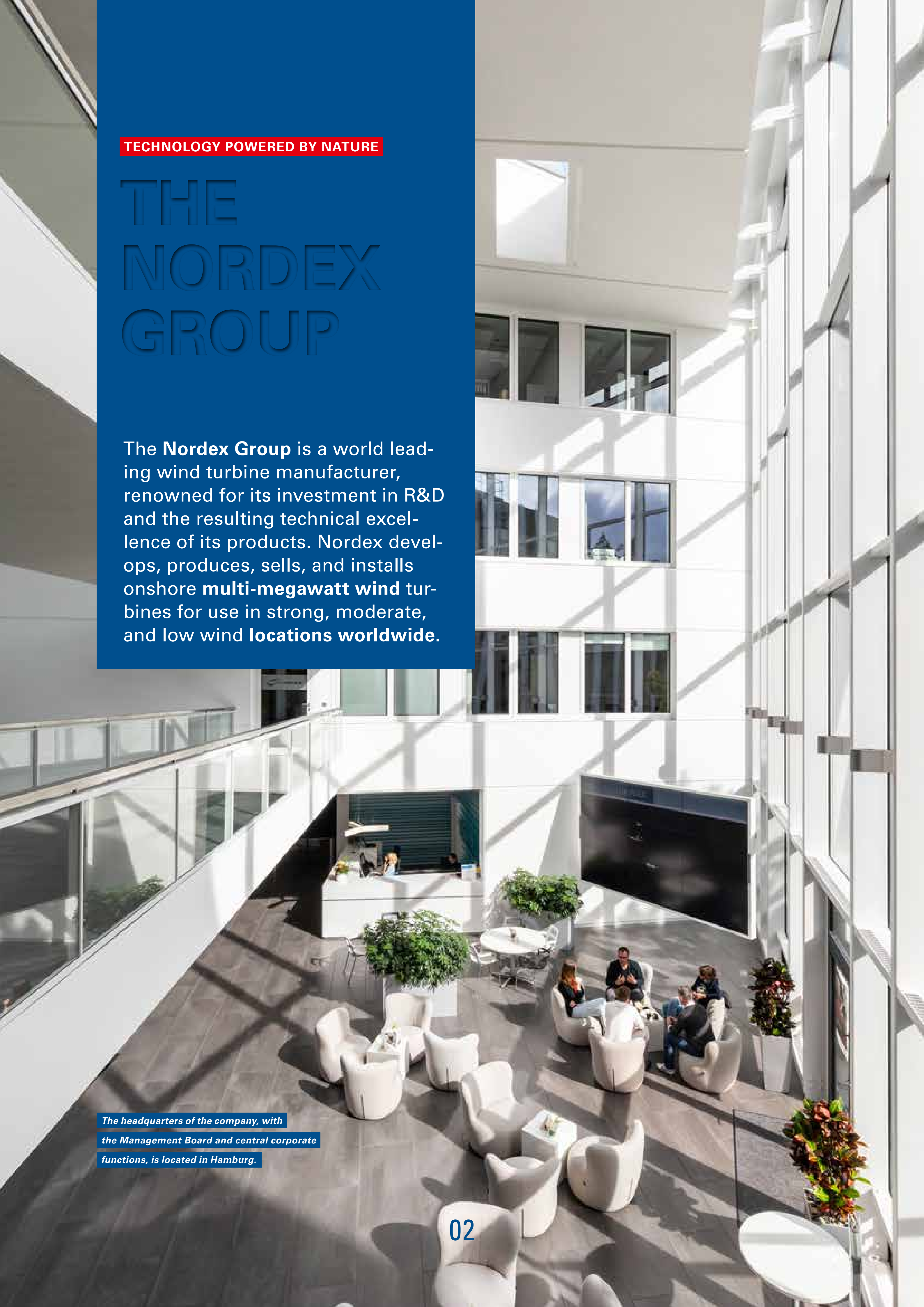
COMPARABILITY
EPDs related to the same category of products but belonging to different programs may not be comparable.

RESPONSIBILITY
Nordex relieves EPDItaly from any non-compliance of the environmental legislation self-declared by the manufacturer itself. The holder of the declaration will be responsible for the information and the supporting evidence; EPDItaly declines any responsibility with regard to manufacturer information, data and life cycle assessment results.

REFERENCE DOCUMENTS
This statement has been developed following the regulations of the EPDItaly Program, available at www.epditaly.it.

Further explanatory material about the Delta4000 can be found here:

Nordex Group website
https://www.nordex-online.com/en/sustainability/



TECHNOLOGY POWERED BY NATURE

THE NORDEX GROUP

The **Nordex Group** is a world leading wind turbine manufacturer, renowned for its investment in R&D and the resulting technical excellence of its products. Nordex develops, produces, sells, and installs onshore **multi-megawatt wind** turbines for use in strong, moderate, and low wind **locations worldwide**.

The headquarters of the company, with the Management Board and central corporate functions, is located in Hamburg.

Company

In addition, we offer a complete spectrum of services over the entire operating life of the wind turbines. Since Nordex was founded in 1985 as a wind power pioneer, our Company has consistently driven the development of the sector with highly efficient products.

The wind turbine to be analyzed in this study is the newest turbine developed by Nordex, the Delta4000. The five wind turbine types in the Delta4000 series provide variable solutions for all wind conditions and cover wind power output requirements from 4.0 MW into the 5 MW class. These highly efficient wind turbines with rotor blades spanning up to 163 meters have already been ordered for wind farms in Europe, North and South America, and Australia. Overall, the Nordex Group has already installed combined generating capacity of over 28 GW across a total of 40 countries. At the end of 2019 the Nordex Group's Service organization supported around 7,800 wind turbines worldwide with a combined nominal generating capacity of 19.6 GW.

We focus on the development, production, and installation of complete wind turbine systems, including control software and key components. In particular we assemble turbine nacelles and hubs at our own facilities. We develop the rotor blades in-house, and a significant number of the required blades are manufactured at our own production plants. The remainder are manufactured by contractors according to Nordex specifications. We procure components such as gearboxes, generators, and inverters from external suppliers, the majority of which are long-term partners.

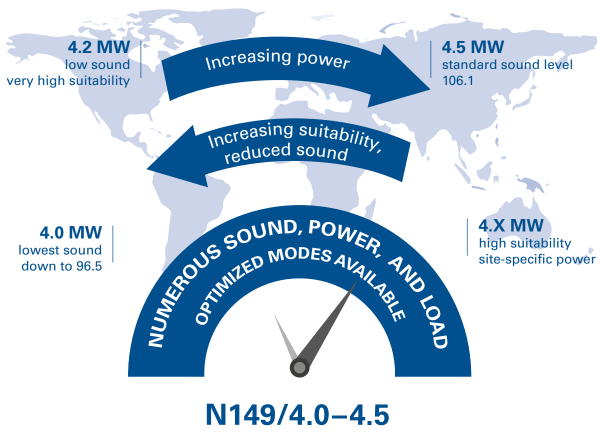
Towers are produced as steel and steel-concrete hybrid constructions by various suppliers. Moreover, the Nordex Group also uses its own concrete tower technology that enables the production of precast concrete towers close to project sites. These production sites are operated partly by Nordex itself and partly by contractors.

We serve our customers in all focus markets through our own Sales organization. The Nordex Group offers installation of the supplied wind turbines and subsequent servicing over the turbines' whole operating life. Our close customer support is provided as part of usually long-term, comprehensive maintenance contracts. Services such as the supply of spare parts and customer training are also offered separately.

Apart from producing technologically leading products, Nordex is also concerned with minimizing its impact on the environment and is seeking to better understand the sustainability performance of its products through a life cycle perspective. Therefore, Nordex has implemented an integrated quality, occupational safety, health protection, and environmental management system, and had it certified to the ISO 14001 standard. Furthermore, our German production sites and office buildings have been ISO 50001-certified since 2014. Finally, Nordex also holds certifications of the ISO 9001 and the OHSAS 18001 standards.

The product system to be assessed in this study is the N149/4.0–4.5, the latest development of the successful Delta4000 series, which is the culmination of over 35 years of experience in the sector.

THE DELTA4000 N149/4.0–4.5 ADAPTABLE TO VARIOUS SITE CONDITIONS



With the N149/4.0–4.5, the Nordex Group was the first company to launch a turbine with a flexible rating as part of its core design philosophy and operation strategy. This design approach, combined with a variety of operating modes, enables the N149/4.0–4.5 to be utilized in a large range of projects – from medium wind projects in Australia to highly complex sites in Germany or Scandinavia.

DELTA4000 N149/4.0–4.5 WIND FARM

ABOUT THIS EPD

According to **EPDItaly's program** regulations, this is a full life cycle product **EPD study** on a **"Delta4000 N149/4.0–4.5 wind farm"**. The study accounts for the **whole product**, including packaging.

Maximum flexibility. Maximum output. The Delta4000 specialist for medium to light wind sites. The features are site-specific performance modes from 4.0 to 4.8 MW, less sound, more power: 103.6 dB(A) at 4.0 MW, performance measured and proven in the field.

Scope and Type of EPD

The full life cycle of the turbine has been considered from cradle-to-grave, i.e., from the point at which raw materials are extracted from the environment through to manufacturing, installation, operation and end-of-life. According to EPDItaly's program regulations, this is a cradle-to-grave product EPD program on a "Delta4000 N149/4.0–4.5 wind farm".

The study accounts for the whole product, including packaging. This includes the extraction and production of raw materials, the manufacturing of these materials into the finished product with packaging, the transportation and distribution of the product for use and end-of-life stages, the use stage and the end-of-life stage including recycling and final disposal.

The local system boundary for the wind farm ends with the connection to the electricity grid. The turbines in the wind farm are connected via medium voltage (MV) cables to the substation. The substation transforms the electricity to 110kV (high voltage, HV). The HV cable connects the wind farm to the grid.

Transport is included for inbound raw materials to the manufacturing sites and then distribution of the product system from the manufacturing site to the location of the wind farm. Transport was also included from the wind farm to end-of-life processing.

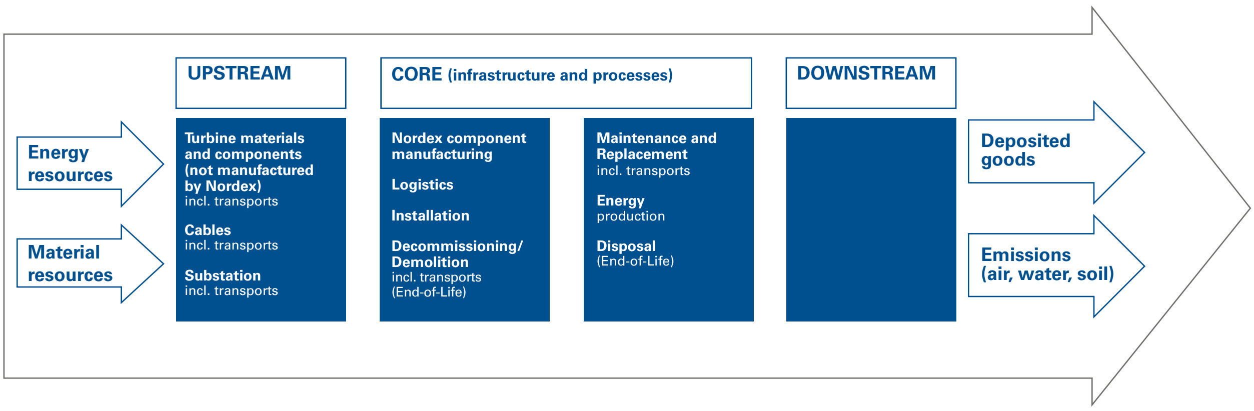
As required by the EPDItaly PCR for wind turbines, the life cycle was split into the upstream, the core (infrastructure and processes) stage and the downstream stage. The different stages are detailed as the following:

Upstream: The upstream module includes all relevant processes of the supply chain including the extraction of raw materials including waste recycling and the production of semi-finished products and auxiliary items, as well as the packaging of products and semi-finishing products and also the transport of raw materials to the manufacturing company (the wind turbine parts manufacturing sites and final manufacturing/assembly site).

Core: There are two components of the core module: core infrastructure and core processes. Core infrastructure represents the construction of the turbine parts and wind farm carried out by Nordex including all auxiliary materials required to construct the wind farm, structural elements, electricity control and conversion infrastructure. This stage also includes the disassembling of the wind farm, the transportation to disposal and the final disposal of the wind turbines. Core processes includes activities associated with the operation and maintenance of the wind farm. The assessed system ends at the connection point with the national electricity grid. The infrastructure and the electrical losses due to the transmission via HV (high voltage) cable between the wind farm and the connection point are considered in the core stage.

Downstream: The downstream module includes all the relevant processes that take place outside the control of Nordex. This includes environmental impacts associated with activities after the connection point with the national electricity grid (associated processes and infrastructure); however, this was not included in the system boundary of this study.

FIGURE 1: OVERVIEW OF SYSTEM BOUNDARIES



The system boundaries have been summarized in Table 1, detailing stages both included and excluded.

TABLE 1: SYSTEM BOUNDARIES

Included		Excluded	
✓	Raw material production	✗	Employee commuting
✓	Fabrication of raw materials into parts and components		
✓	Manufacturing		
✓	Installation		
✓	Associated infrastructure such as roads		
✓	Operation		
✓	End-of-life		

The boundary for the study is at the connection point to the grid. As such, electrical losses due to the voltage elevation in the substation as well as due to the distribution with the MV and HV cables inside and outside the wind farm have been included in the study. The boundary is taken to be the point at which the wind farm produces an equivalent of 1 kWh to be transmitted into the grid.

Impacts associated with employee commuting have been excluded as these are expected to be negligible for a manufactured product. However, all transports associated with the maintenance done by service teams and the replacement of parts during the service life of the turbines have been included.

SOFTWARE AND DATABASE

The LCA model was created using the GaBi 9 Software system for life cycle engineering (software version 9.2), developed by Sphera Solutions Inc. The GaBi 2020 LCI database is the basis for most of the life cycle inventory data for modeling the background system. Datasets from the database version with service pack status SP40 are applied.

DECLARED UNIT

In LCA studies, the **declared unit** quantifies and describes the performance of a product system and is used as the basis for reporting results.

The function of a wind farm is to generate electricity by harnessing wind energy. As such, as defined by the PCR, the **declared unit** for this study is:

The generation of **1 kWh** of electrical energy (net) considering the full life time of the wind farm **(Delta4000 N149/4.0–4.5 turbines)**, located in an exemplary Swedish scenario and operating under low wind conditions **(IEC wind class III)**, and thereafter distributed to a **110kV** electrical grid.

The wind farm design is based on a predefined project landscape. The assessed site is a low wind site (IEC wind class III) which is defined as less than 7.5 m/s average wind speed at hub height (actual value applied in this study: average wind speed at hub height 6.8 m/s). Site-specific parameters for losses and uncertainties are considered using a net annual energy production (AEP) calculation.

Product Description

Major components of a Delta4000 wind turbine are the tower and the foundation as well as the nacelle, main gear and blades.

Overall, the material mix for the Delta4000 N149/4.0–4.5 turbine excluding the mass-dominant foundation is:

- 87.0% steel (carbon steel, stainless steel, cast steel)
- 9.1% glass fiber/carbon fiber reinforced plastics
- 1.5% polymers
- 0.6% operating fluids
- 0.5% electrics/electronics
- 0.5% aluminum
- 0.4% copper
- 0.4% others

PRODUCTION PROCESS

The production process of a Delta4000 turbine can generally be divided into three parts:

- The blades are manufactured at the Nordex blade production facility in Rostock, Germany. The process can be divided into several stages: Initially, components such as root joints and shear webs are prefabricated. Subsequently, these are integrated into the manufacturing process of green bodies and the following completion process of the rotor blade: This includes i.a. the fabrication of the main shell, the shell bonding, trimming and laminating. Finally, the finishing processes such as painting and labeling are carried out before preparing the blades for transportation.
- The nacelle is assembled at the Nordex nacelle facility in Rostock, Germany, in the form of line production. Firstly, the switch cabinet assembly is divided into four production lines for prefabricated units with four to 20 assembly stations. Some of the assembled switch cabinet components are then incorporated into the nacelle assembly and some directly shipped to the project installation site. The nacelle assembly itself is generally divided into three production lines, one for each individual module – machine house, drive train and hub – with nine to 20 assembly stations.
- The steel tower is supplied by a third-party manufacturer.

LCA Results

The following tables detail the life cycle impact potential, resource consumption parameters and waste production parameters for the specified declared unit of the Delta4000 N149/4.0–4.5 wind farm.

The environmental impact indicators were determined using modeling as specified in EN15804:2012+A2:2019. The global warming potential was determined in accordance with EN15804:2012+A2:2019 as: fossil, biogenic and land use/land use change, according to the Baseline model of 100 years of the IPCC (2013).

TABLE 2: THE ENVIRONMENTAL IMPACT INDICATORS

Impact category	Unit	Total	Upstream	Core	Downstream
GWP	kg CO_2 equivalent	1.59E-02	1.07E-02	5.22E-03	0.00E+00
GWP fossil	kg CO_2 equivalent	1.18E-02	1.07E-02	1.15E-03	0.00E+00
GWP biogenic	kg CO_2 equivalent	0.00E+00	–4.69E-06	4.69E-06	0.00E+00
GWP LULUC	kg CO_2 equivalent	4.08E-03	5.80E-06	4.07E-03	0.00E+00
ODP	kg CFC 11 equivalent	3.58E-14	3.57E-14	1.10E-16	0.00E+00
EP	kg PO4 equivalent	2.04E-08	1.73E-08	3.11E-09	0.00E+00
AP	kg H+ equivalent	4.42E-05	3.73E-05	6.92E-06	0.00E+00
POCP	kg C2H4 equivalent	3.15E-05	2.30E-05	8.51E-06	0.00E+00
ADPE	kg Sb equivalent	1.27E-07	1.27E-07	3.72E-10	0.00E+00
ADPF	MJ, net calorific value	1.40E-01	1.27E-01	1.35E-02	0.00E+00
WSP	m^3 equivalent	9.95E-04	9.02E-04	9.29E-05	0.00E+00

GWP = Global warming potential; ODP = Ozone depletion potential; EP = Eutrophication potential; AP = Acidification potential; POCP = Photochemical ozone creation potential; ADPE = Abiotic depletion potential for non-fossil resources; ADPF = Abiotic depletion potential for fossil resources; WSP = Water scarcity potential

Impact category	Unit	Total	Upstream	Core	Downstream
PENRE	MJ, net calorific value	1.40E-01	1.27E-01	1.35E-02	0.00E+00
PERE	MJ, net calorific value	1.53E-02	1.34E-02	1.88E-03	0.00E+00
PENRM	MJ, net calorific value	1.90E-05	1.80E-05	1.08E-06	0.00E+00
PERM	MJ, net calorific value	0.00E+00	0.00E+00	0.00E+00	0.00E+00
PENRT	MJ, net calorific value	1.40E-01	1.27E-01	1.35E-02	0.00E+00
PERT	MJ, net calorific value	1.53E-02	1.34E-02	1.88E-03	0.00E+00
FW	kg	1.40E-01	1.26E-01	1.41E-02	0.00E+00
SM	kg	5.70E-07	5.63E-07	6.97E-09	0.00E+00
RSF	MJ, net calorific value	0.00E+00	0.00E+00	0.00E+00	0.00E+00
NRSF	MJ, net calorific value	0.00E+00	0.00E+00	0.00E+00	0.00E+00

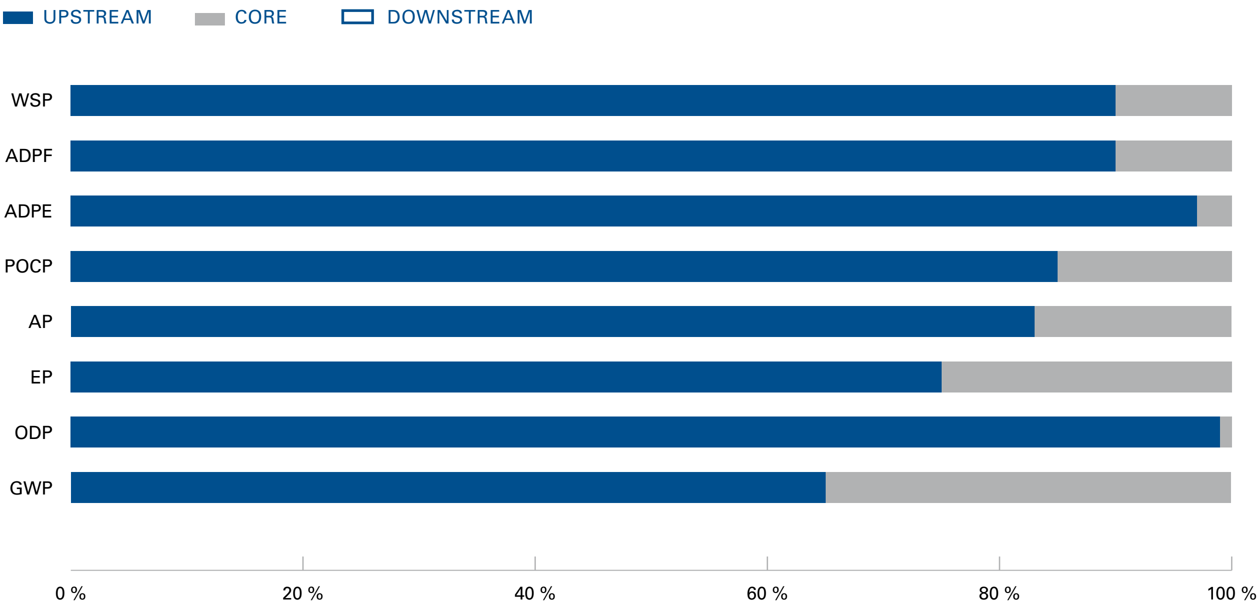
PENRE = Use of non-renewable primary energy excluding non-renewable primary energy resources used as raw materials; PERE = Use of renewable primary energy excluding renewable primary energy resources used as raw materials; PENRM = Use of non-renewable primary energy resources used as raw materials; PERM = Use of renewable primary energy resources used as raw materials; PENRT = Total use of non-renewable primary energy resources; PERT = Total use of renewable primary energy resources; FW = Use of net fresh water; SM = Use of secondary material; RSF = Use of renewable secondary fuels; NRSF = Use of non-renewable secondary fuels

Impact category	Unit	Total	Upstream	Core	Downstream
HWD	kg	2.89E-08	2.71E-08	1.73E-09	0.00E+00
NHWD	kg	2.01E-03	7.27E-04	1.28E-03	0.00E+00
RWD	kg	2.72E-06	2.57E-06	1.54E-07	0.00E+00
MFR	kg	8.22E-03	0.00E+00	8.22E-03	0.00E+00
MER	kg	1.62E-05	0.00E+00	1.62E-05	0.00E+00
CRU	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00
EET	MJ	4.42E-04	0.00E+00	4.42E-04	0.00E+00
EEE	MJ	2.37E-04	0.00E+00	2.37E-04	0.00E+00

HWD = Hazardous waste disposed; NHWD = Non-hazardous waste disposed; RWD = Radioactive waste disposed; MFR = Materials for recycling; MER = Materials for energy recovery; CRU = Components for re-use; EET = Exported thermal energy; EEE = Exported electrical energy

Results Interpretation

FIGURE 2: REPRESENTATION OF RELATIVE CONTRIBUTION



It can be seen from the results, presented per declared unit, that across the majority of impact categories, the upstream module (raw material and manufacturing stages not carried out by Nordex) of the turbine is, by far, the most dominant contributor across the whole life cycle of the windfarm. This is due to the raw material procurement and upstream manufacturing associated with the wind turbine.

The foundation of the turbine by mass is 73% of the turbine, however, as it is composed of approximately 93% concrete, the impact potential across all impact categories is significantly lower than that of the components that are mainly composed of metals and other higher impact materials. The foundation contributes to approximately 11% of the total GWP over the full life cycle. The tower accounts for 13% of the mass of the turbine, however, due to the large amount of steel that contributes to the infrastructure, the GWP is approximately 23% of the full life cycle, showing it to be much more significant than the foundation by mass. Similarly, despite the blades only contributing 3% of the mass of the turbine, they are significant contributors in several impact categories and represent 13% of the total GWP. Freshwater eutrophication potential is the highest for the blades. This is largely due to the polymer parts, resin glass fibres and electricity required to manufacture the blades. The E-module is the most significant contributor to resource use, metals and minerals which is due to the electronics present in the top-box and pitch-box (dataset proxy for electronics contains gold).

The core module is the dominant contributor to the life cycle impact potential for global warming potential biogenic and land use change. The negative biogenic carbon in the upstream module is due to the uptake of carbon by renewable materials. This is predominantly the wood in the blades which is then released during the core stage due to incineration during manufacturing and disposal at end of life. The explanation for the significant contribution to GWP for land use change in the core module can be found in the following section.

LAND USE AND LAND USE CHANGE (GWP LULUC)

The analyzed Nordex wind farm comprises 47 wind turbines of the specification Delta4000 N149/4.0–4.5. Since this wind farm is based on an exemplary project, no real data on some aspects is available. Therefore, data from a comparable Swedish wind farm situated in similar conditions has been chosen.

The underlying data for GWP LULUC effects refers to the wind farm of "Nysäter – Björnlandhöjden". Please find more information on that in the section "Additional Environmental Information/Land Use".

The resulting affected area per turbine is 3.6 ha. The calculation of the GWP LULUC effects are done based on (IPCC, 2019). The main assumptions for the calculations are:

- removed above-ground biomass and dead organic matter is considered (complete modified area is deforested prior to installation), changes in soil organic carbon (SOC) stocks is not considered
- for all modified area the respective amount is lost for biomass and dead organic matter considering the share of forest and woodland shrub (about 80% forest and 20% shrub)
- classification for the forest: secondary, 50% older than 20 years and 50% younger than 20 years
- conditions for above-ground biomass: temperate/continental/Europe (compare Table 4.12 in (IPCC, 2019))
- conditions for dead wood C stocks and grassland: cold temperate, wet/moist Europe (compare Tables 2.2 and 6.4 in (IPCC, 2019))
- carbon content of biomass: 50%

Due to these circumstances, the GWP LULUC alone accounts for 26% of the total GWP. Moreover, this relatively high GWP LULUC contribution to the overall GWP result is not necessarily representative for any wind farm. It is rather related to the specific and conservative assumptions of the exemplary wind farm site applied as basis for this LULUC assessment in the EPD.

The N149 turbines are also well designed in terms of acoustics for increasing citizen acceptance, with a sound emission level of less than 106.1 dB(A) even when operating at full load.

Calculation Rules

ASSUMPTIONS

The wind farm design is based on a predefined project landscape. The assessed site is a low wind site (IEC wind class III) which is defined as less than 7.5 m/s average wind speed at hub height (actual value applied in this study: average wind speed at hub height 6.8 m/s). Site-specific parameters for losses and uncertainties are considered using a net annual energy production (AEP) calculation.

The certified standard life time of Delta4000 turbines is 20 years. In principle, the life time of those turbines can be extended by 10 years to a total life time of 30 years, according to the method of life time extensions and the related advisory opinions by TÜV Nord and TÜV Süd (TÜV Nord CERT, 2018 and TÜV Süd Industrie Service, 2019). The applied life time of turbines in a wind farm follows site-specific conditions. For the assessed wind farm of this study, the CoE landscape for Sweden defines a life time of 25 years applying the method of life time extension by 5 years. Thus, this declared unit allows for an average energy production to be determined based on-site-specific parameters for a location in Sweden.

However, the baseline assumption for this EPD is a wind farm life time of 20 years as specified by the PCR. In LCAs on onshore wind turbines, the life time is often defined with 20 years as base case.

CUT-OFF RULES

No cut-off criteria have been defined for this study. The system boundary was defined based on relevance to the goal of the study. For the processes within the system boundary, as much available energy and material flow data have been included in the model as possible. In cases where no matching life cycle inventories are available to represent a flow, proxy data have been applied based on conservative assumptions regarding environmental impacts.

DATA QUALITY

Inventory data quality is judged by its precision (measured, calculated or estimated), completeness (e.g., unreported emissions), consistency (degree of uniformity of the methodology applied) and representativeness (geographical, temporal, and technological).

To cover these requirements and to ensure reliable results, first-hand industry data in combination with consistent background LCA information from the GaBi 2019 database were used. The LCI datasets from the GaBi 2019 database are widely distributed and used with the GaBi 9 Software. The datasets have been used in LCA models worldwide in industrial and scientific applications in internal as well as in many critically reviewed and published studies. In the process of providing these datasets they are cross-checked with other databases and values from industry and science.

PRECISION AND COMPLETENESS

- ✓ **Precision:** As the majority of the relevant foreground data are measured data or calculated based on primary information sources provided by the Nordex Group, precision is considered to be high. Seasonal variations/variations across different manufacturers were balanced out by using yearly averages. Most background data are sourced from GaBi databases with the documented precision.
- ✓ **Completeness:** Each foreground process was checked for mass balance and completeness of the emission inventory. Some data points were omitted as documented earlier in this report. Nevertheless, completeness of foreground unit process data is considered to be high. Most background data are sourced from GaBi databases with the documented completeness.

CONSISTENCY AND REPRODUCIBILITY

- ✓ **Consistency:** To ensure data consistency, all primary data were collected with the same level of detail, while most background data were sourced from the GaBi databases.
- ✓ **Reproducibility:** Reproducibility is supported as much as possible through the disclosure of input-output data, dataset choices, and modeling approaches in this report. Based on this information, any third party should be able to approximate the results of this study using the same data and modeling approaches.

REPRESENTATIVENESS

- ✓ **Temporal:** All primary data were collected for the year 2019. Most secondary data come from the GaBi 2019 databases and are representative of the years 2012–2019 (although one dataset has a reference year of 2005). As the study intended to compare the product systems for the reference year 2019, temporal representativeness is considered to be moderate/high.
- ✓ **Geographical:** All primary and secondary data were collected specific to the countries under study. Where country-specific data were unavailable, proxy data were used. Geographical representativeness is considered to be high.
- ✓ **Technological:** All primary and secondary data were modelled to be specific to the technologies or technology mixes under study. Where technology-specific data were unavailable, proxy data were used. Technological representativeness is considered to be high.

ALLOCATION

End-of-life allocation
(cut-off approach/baseline scenario)

The cut-off approach was utilized in this study as required by the PCR and Regulations of EPDItaly. The following details a short description of the cut-off approach that has been modelled for this study:

Material recycling (cut-off approach): Any open scrap inputs into manufacturing remain unconnected. The system boundary at end-of-life is drawn after scrap collection to account for the collection rate, which generates an open scrap output for the product system. The processing and recycling of the scrap is associated with the subsequent product system and is not considered in this study.

Energy recovery & landfilling (cut-off approach): Any open scrap inputs into manufacturing remain unconnected. The system boundary includes the waste incineration and landfilling processes following the polluter-pays-principle. In cases where materials are sent to waste incineration, they are linked to an inventory that accounts for waste composition and heating value as well as for regional efficiencies and heat-to-power output ratios. In cases where materials are sent to landfills, they are linked to an inventory that accounts for waste composition, regional leakage rates, landfill gas capture as well as utilization rates (flaring vs. power production). No credits for power or heat production are assigned.

End-of-life allocation (substitution approach)

The cut-off approach from the base case of the LCA and EPD is replaced by the substitution approach which is typically applied for products including recyclable metals. A short description of the substitution approach (net-scrap calculation) follows:

Material recycling (substitution approach): Open scrap inputs from the production stage are subtracted from scrap to be recycled at end-of-life to result in the net scrap output from the product life cycle. This remaining net scrap is sent to material recycling. The original burden of the primary material input is allocated between the current and subsequent life cycle using the mass of recovered secondary material to scale the substituted primary material, i.e., applying a credit for the substitution of primary material so as to distribute burdens appropriately among the different product life cycles. These subsequent process steps are modelled using industry average inventories.

Energy recovery (substitution approach): In cases where materials are sent to waste incineration, they are linked to an incineration inventory dataset that accounts for waste composition and heating value as well as for regional efficiencies and heat-to-power output ratios. Credits are assigned for power and heat outputs using the regional grid mix and thermal energy from natural gas. The latter represents the cleanest fossil fuel and therefore results in a conservative estimate of the avoided burden.

Landfilling (substitution approach): In cases where materials are sent to landfills, they are linked to an inventory that accounts for waste composition, regional leakage rates, landfill gas capture as well as utilization rates (flaring vs. power production). A credit is assigned for power output using the regional grid mix.

DELTA4000 N149/4.0 – 4.5 WIND FARM

MORE FACTS

With the **Delta4000 platform**, the Nordex Group took the Delta Generation's fundamental design and transferred it over to the 4 and 5 megawatt classes, with the help of performance-enhancing concept adaptations. At the same time, electricity generation costs are consequently reduced.

The technical concept of the Delta4000 series minimizes service requirements over the entire service life of the turbine. Each component was rigorously designed to ensure lower maintenance effort. Additionally, this product series can be maintained with a mobile crane solution.

Additional Environmental Information

The analyzed Nordex wind farm comprises 47 wind turbines of the specification Delta4000 N149/4.0–4.5. Since this wind farm is based on an exemplary project, no real data on some of the following aspects is available. Therefore, data from a comparable Swedish wind farm situated in similar conditions has been chosen to complement the additional information: While the underlying exemplary wind farm "Tvinnesheda" serves as basis for discussion on "Impact on Biodiversity" and "Visual impact", "Land use" and "Noise" refer to the wind farm of "Nysäter – Björnlandhöjden". "Environmental risks" and "Electromagnetic fields" are applicable to all Nordex Delta4000 wind farms.

RETURN ON ENERGY (ROE)

The RoE parameter is an estimation of energy efficiency of the wind farm compared to the energy required to produce the wind farm. It is measured in years and represents the running time required for the turbine to produce the amount of energy consumed for its complete life cycle.

There are no specific standards about how to calculate this indicator. RoE can be expressed in various units; the unit adopted in this study is an amount of time expressed in years. Computation occurs as follows:

RoE = E_invested/E_produced, year

E_invested = Total amount of total primary energy (thermal and electric; total non-renewable + total renewable energy) required to manufacture the wind turbine starting from primary components and including all the necessary fuels.

E_produced, year = Total amount of net electricity generated per year by the wind turbine

The result for RoE is 0.86 years, which equals to 10.3 months.

RESULTS FOR SUBSTITUTION APPROACH

These results reflect the life cycle impact of the wind farm with the implementation of the substitution approach with material credits for the net amounts of recyclable material instead of the cut-off approach. The results are the following:

- **GWP total – upstream, core, downstream:** 13.0g CO_2eq / kWh
- **GWP fossil – upstream, core, downstream:** 8.49g CO_2eq / kWh
- **RoE – upstream, core, downstream:** 0.67 years (8.1 months)

For those two key result indicators, it is demonstrated that the high amount of potentially recyclable materials has a significant influence on the overall results. Especially, the high amount of recycled steel makes a relatively big contribution on EoL material credits.

The cut-off and substitution approaches are detailed in the allocation section of this EPD.

RESULTS FOR LIFE TIME EXTENSION OF 25 YEARS

According to the technical design of the Delta4000 N149/4.0–4.5, the life time is defined as 25 years. For the sake of comparability and to follow the requirements of the PCR, the base case in this LCA takes 20 years life time as a basis. This sensitivity analysis checks the influence of the extended life time on three result parameters. 25% longer life time results in 25% more energy produced. The result parameters related to AEP are reduced accordingly, namely GWP. The RoE indicator is based on the primary energy required for the infrastructure and all activities during life time but is independent from the AEP. So, the RoE value is not different compared to the base case.

- **GWP total – upstream, core, downstream:** 12.7g CO_2eq / kWh
- **GWP fossil – upstream, core, downstream:** 9.44g CO_2eq / kWh
- **RoE – upstream, core, downstream:** 0.86 years (10.4 months)

A 25% longer life time results in a 20% lower GWP value.

IMPACTS ON BIODIVERSITY

By implementing highly efficient wind power solutions, the Nordex Group can make an important contribution to mitigate climate change and, hence, far-reaching changes in nature. Nevertheless, the installation of wind farms may have impacts on the local flora and fauna. In order to protect the surrounding environment by avoiding these affects or minimizing them as much as possible, any potential impacts are analyzed prior to installation. Therefore, upon request of the local public administration, an Environmental Aspects and Impacts Assessment is performed for the different stages of a project including construction and operation in accordance with the standards set by ISO 14001.

NATURE RESERVES, NATURA2000 AND NATIONAL INTEREST IN NATURE CONSERVATION

A first part of the assessment is the analysis of existing nature reserves and thus the identification of areas where wind power is not suitable, hence driving location selection from a macro level. These areas include national parks, the majority of nature reserves and so called Natura2000 sites, animal protection sites, unbroken mountains, in particular valuable and unexploited coastal areas as well as offshore banks designated by the Swedish Environmental Protection Agency with very high biological value. The analysis shows that six Natura2000 sites, four nature reserves and seven sites of national interest in nature conservation are located in the vicinity of the establishment area. These areas thus remain unaffected by the installation of the wind farm.

FLORA

Despite aiming to avoid causing impacts on the environment, the vegetation of the designated area might be affected and degraded as a result of land preparation for wind farm installation as well as the set-up of foundations, roads, general building works and other artificial elements on site. With the goal of keeping these impacts at a minimum, the following steps were taken in order to exclude areas of high natural value from the installation process:

- A nature conservation assessment of biotopes has been carried out in the establishment area. The inventory area consists mainly of forest land and wetlands. Estimated about 15-20% of the surface is peatland.
- In the study, areas that house natural values have been delimited and described with respect on habitat type, value species, other natural values and natural value class. Value types refer to red-listed species, signal species or other species of local conservation interest.
- The natural value of the sub-areas has been classified on a five-point scale where class 1 is the highest protection class denoting the area with very high natural values and class 5 the lowest protection class where values are missing or insignificant. Within the inventory area, no sub-areas with very high nature values were noted (class 1), however, two sub-areas with high nature values were identified (class 2) and seven sub-areas with certain natural values (class 3). Furthermore, 44 sub-areas with low nature values were distinguished (class 4). Other sub-areas, a total of 173, lack or have only insignificant natural values (class 5). More than 80% of the surface consists of biotopes where natural values are missing or insignificant.

To minimize the environmental impact as a result of the wind farm installation, the developer applies the so-called placement principles at the development of a park layout. These principles involve i.a. the exclusion of construction work in areas classified as nature value class 1, 2 or 3 as well as the avoidance of construction works in class 4 areas. Thereby, the impact on protected areas, known natural values and cultural environments, etc. will be limited as much as possible.

Once the wind farm is decommissioned after 20–30 years of life time, the foundations are partially removed and revegetation and reforestation activities are carried out.

FAUNA

The area includes forest land and existing wildlife and corresponds to what can be considered normal for the type of environment.

- **Birds:** It is mainly the nesting, heavier birds of prey that are most at risk of colliding with wind turbines. A bird inventory was carried out during the period February to August. The behavior and movement of birds of prey was observed and documented. Furthermore, their approximate flight altitude has been noted. All observations have been documented, e.g. presence of couples (pair formation), flight behavior (mating flight) and recurring flight over certain areas. Interviews with people living in the area have to some extent contributed to increased knowledge about the occurrence of birds in the inventory area. In total, only two species of nesting birds of prey were noted within the inventory area, namely merlins and buzzards.
- **Bats:** The presence of bats is generally intimately linked to the cultural landscape. In the forest landscape they are, however, often less numerous. An inventory of bats at night was carried out in the area during the period March to August with the primary aim to investigate whether there are populations of bats in the inventory area. Since that was the case, it was also studied whether there were unusual or red-listed species. A total of five bat species were observed within the current establishment area. The inventory identified no rare or red-listed species within the area as well as no evidence of any migration routes of bats through the area.

All in all, it can be stated that the current establishment area is generally classified as suitable for a wind power establishment by the Swedish National Board of Housing, Building and Planning (Boverket): The above precautions and the establishment as such, based on the Boverket's criteria, do not involve conflict with the interests of nature conservation. Hence, the impact on the natural environment caused by the current wind power establishment is considered to be limited.

LAND USE

Description of land use – CORINE Land Cover classification

Wind turbines, like any man-made structure, represent an intervention in the natural landscape. Prior to the construction of a wind farm, Nordex conducts an analysis of the prevailing land cover categories before and after exploitation through installed turbines.

The affected area mainly consists of mixed and coniferous forest as well as a small share of transitional woodland and shrub. The following table illustrates land use before and after the installation of the wind farm in more detail:

TABLE 3: LAND USE BEFORE AND AFTER INSTALLATION

CORINE land cover classes	Before (m²)	After (m²)
1 Artificial surfaces		
1.2 Industrial, commercial and transport units		
1.2.1 Industrial, commercial and public units	0	458,207
1.2.2 Road and rail networks and associated land	68,780	1,306,829
2 Agricultural areas		
3 Forests and semi-natural areas		
3.1 Forests		
3.1.2 Coniferous forest	8,046,130	7,480,711
3.1.3 Mixed forest	12,069,195	11,221,067
3.2 Shrub and/or herbaceous vegetation		
3.2.4 Transitional woodland shrub	4,023,065	3,740,356
4 Wetlands		
5 Water bodies		
Total	**24,207,171**	**24,207,171**

A total of 169.6 ha and, thus, 7.01% of the overall area have been affected and modified by the installation and operation of the wind farm. The occupied areas are mainly used for:

- Foundations
- Streets/Tracks
- Crane pads
- Cable trenches
- Substation/Control building
- Storage area

ENVIRONMENTAL RISKS

The occurrence of high-risk environmental events is quite unlikely with a frequency lower than once in three years. However, a general overview of the possible undesirable events, their corresponding environmental impact and the measures taken to prevent, combat and respond to them are discussed.

The following table illustrates the potential risk and environmental emissions caused by environmental incidents:

TABLE 4: ENVIRONMENTAL RISKS

Potential risks	Substances	Air emissions	Soil emissions	Water emissions
Fires	smoke, ash or other burnt debris, CO_2	✗	✗	✗
Spills of fuels	diesel, gas	✗	✗	✗
Spills of hazardous substances	lubricants, coolants, electrical insulators	✗	✗	✗
Spills of oils	oil		✗	✗
Spills of concrete	concrete		✗	✗
Uncontrolled waste generation	sewage, solid-waste		✗	✗

FIRE

A fire results in carbon emissions to the air and in non-carbon contaminants into the water supply and soil due to the combustion of various components and the run-off of fire-fighting.

The Nordex Group has clear operational and monitoring measures to prevent fires by storing flammable units in labelled containers in demarcated areas on site and by ensuring avoidance of potential ignition sources in their vicinity. In the event of a fire, fire-fighting equipment and spill-kits are available on site for immediate response and emergency services are contacted. A clear protocol has been established to assess, report and correct the incident to prevent future reoccurrences.

SPILLS

Spills of hazardous materials, concrete, fuels and oils are possible accidents.

The Nordex Group has spill management systems in place including a clear process of reporting and communication in the HSE management and technical control units such as spill trays, clearly demarcated areas for storage of chemicals and fuels and protection of the water network. In the event of a spill, protocols have been established for emergency response measures to detect, report and respond with immediate corrective clean-up measures with the objective to effectively manage the spill and prevent future reoccurrences.

RADIOLOGY

Radioactive emissions by the Nordex Group are generally very low through the life cycle of the product. Furthermore, high standards for operation and controls are maintained during all life stages of the turbines to prevent environmental hazards.

The only possible source is a very low amount of radioactivity that could be released by the destruction of the smoke detector under emergency conditions. However, this is excluded from normal service tasks, turbine installation and general operations. Furthermore, due to the highly safe design of the smoke detector and the very low radiation energy, there is no possibility of a critical contamination. Alternatives are being looked into for the future.

ELECTROMAGNETIC FIELDS

As with every electrical device, wind turbines also emit electromagnetic radiation. However, since wind turbines are normally located several hundred meters away from dwellings and the electric field decreases exponentially with the distance, impacts on the vicinity are not expected.

Nonetheless, electromagnetic fields above a certain limit can lead to health problems. The EMF Directive (Directive 2013/35/EU of the European Parliament and of the Council of 26 June 2013 on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (electromagnetic fields)) defines limits for electromagnetic fields, which are based on the guidelines of the International Commission on Non-Ionizing Radiation Protection (ICNIRP). According to these regulations, magnetic fields should not exceed 1 mT at 50 Hz for the working environment. Measurements on Delta4000 turbines have shown compliance with these limits.

Besides the health and safety aspect, electromagnetic emission also falls under the scope of the EMC Directive (Directive 2014/30/EU of the European Parliament and of the Council of 26 February 2014 on the harmonization of the laws of the Member States relating to electromagnetic compatibility), under which CISPR11 (Industrial, scientific and medical equipment – Radio-frequency disturbance characteristics – Limits and methods of measurement) is listed. Measurements on Delta4000 turbines have shown compliance with the limits of CISPR11, Class A, Group 1, so it can be stated, that there is no increased electromagnetic emission produced by Nordex Delta4000 wind turbines.

Besides the fulfillment of the international directives, Nordex is able on a project-specific basis to reduce the electromagnetic radiation much further. For example for the Dutch project De Drentse Monden en Oostermoer (DMO), Nordex developed a low-electromagnetic interference (EMI) turbine. This was necessary to not disturb the measurements of a nearby central antenna field of a low-frequency array (LOFAR) for astronomical research. The implemented measures reduced the previous EMI limits of EN 55011 by at least 35dB. Therefore, the emitted interference is 56.2 times lower than required by the norm over the entire frequency range.

OPTIMIZED TECHNICAL DETAILS OF N149/4.0–4.5

› Optimized power transfer
Unlike the Delta Generation, the converter and transformer are no longer located in the tower base, but in the nacelle. This minimizes electrical losses and reduces installation efforts in the field.

› Measurements confirm performance
Since the N149/4.0–4.5 prototype was already installed in summer 2018, main warranted performance figures like e.g. the power curve and the most relevant sound power modes have been already confirmed by certified third party measurements.

› Grid compatibility guaranteed
The turbines of the Delta4000 product series meet the grid requirements of international markets. In addition, they provide grid stabilizing system services.

› Larger rotor dimensions
The aerodynamic profile of the N149 rotor blade reflects the enhanced requirements, although its structure is largely unchanged.

NOISE

Throughout their entire life cycle, wind turbines cause two types of noise: mechanical and aerodynamic noise. While the first is caused by machinery inside the nacelle and can easily be kept at a minimum by conventional techniques so that it is almost unnoticeable at ground level, the latter results from the air flow of the rotor blades moving in the wind and may increase depending on the blade rotation speed and individual wind conditions.

BASED ON PROVEN ARCHITECTURE

With the Delta4000 series, the Nordex Group relies on tried-and-tested series-production technology, based on the experience of the Delta Generation.

› Electrical system maintained
Already the first Nordex multi-megawatt system was equipped with a double-fed asynchronous generator and a partial converter in the year 2000. With the Delta4000 series, the Nordex Group has remained faithful to this proven and highly economical electrical system.

› Reliable drivetrain concept
The drivetrain concept is based on a modular system with three-point suspension and a high speed gearbox – an architecture continuously further developed with proven suppliers to reach new performance levels.

› Reduced service effort
The technical concept of the Delta4000 series minimizes the service effort over the whole life of the product. Every component was consequently designed to cater for optimized operation and maintenance. The latest crane and lifting technologies lower the maintenance effort and reduce downtimes.

› Tapping into colder locations
The proven Nordex Cold Climate Package enables wind farm development even in some of the coldest locations. Turbines of the cold climate variant (CCV) can operate in outside temperatures as low as minus 30 degrees Celsius. The proven rotor blade anti-icing system is also available.

Nordex manages the noise emissions of a wind turbine from the very beginning of the turbine design. The noise experts are involved from the beginning of every new product engineering process, from initial acoustic design of main and sub-components until the final verification of measurements in the field.

The wind farm is situated in an uninhabited area with the closest dwelling situated at 1,065 m distance. This distance entails a significantly lower and virtually unnoticeable noise level in the settlements nearby. Moreover, the perceptibility is influenced by the local topography (e.g. presence of trees).

Furthermore, extensive noise calculations following the international standards of IEC 61400-11 (Ed. 3 2012) and IEC 61400-14 (Ed. 2005) showed that the noise limit of 40 dB(A) set by the permitting authority is kept at all times.

VISUAL IMPACT

The Nordex Group acknowledges that the perceived visual impact of a wind farm differs among individuals and is subject to the location of the installed turbines: People experience a landscape differently, e.g. depending on background, knowledge, interests and expectations, and associate it with certain feelings such as a sense of home. To illustrate how a wind farm can be experienced from the surrounding area, a number of photomontages are produced based on the main layout that is reported in the Environmental Aspects and Impacts Assessment. To be able to compare how the experience may change depending on the height and type of the wind turbine that is established, photomontages have been developed based on tubular towers of different heights.

The area of the analyzed wind farm is of flat to slightly hilly topography. Due to the relatively homogeneous landscape of primarily highly durable forest land used for forestry, lines of sight in the landscape are expected to be limited. In order to further reduce the visual impact on the landscape, the grid connection of the wind power establishment is, as far as possible, carried out with ground cables instead of overhead lines.

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Produced by Nordex itself, the single-piece rotor blade of the N149/4.0–4.5 measures almost 73 meters in length. The rotor diameter of 149 meters contributes significantly to the very low cost of energy and the high turbine yield.

Acronyms and Abbreviations

ADPE
Abiotic Depletion Potential for Non-Fossil Resources

ADPF
Abiotic Depletion Potential for Fossil Resources

AEP
Annual Energy Production

AP
Acidification Potential

CoE
Cost of Energy

CRU
Components for Re-Use

EEE
Exported Electrical Energy

EoL
End-of-Life

EP
Eutrophication Potential

EPD
Environmental Product Declaration

ETE
Exported Thermal Energy

FW
Use of Net Fresh Water

GW
Gigawatt

GWP
Global Warming Potential

GWP LULUC
Global Warming Potential Land Use/Land Use Change

HV
High voltage

HWD
Hazardous Waste Disposed

IEC
International Electrotechnical Commission

ISO
International Organization for Standardization

LCA
Life Cycle Assessment

LCI
Life Cycle Inventory

MER
Materials for Energy Recovery

MFR
Materials for Recycling

MV
Medium voltage

MW
Megawatt

NHWS
Non-Hazardous Waste Disposed

NRSF
Use of Non-Renewable Secondary Fuels

ODP
Ozone Depletion Potential

OHSAS
Occupational Health and Safety Assessment Series

PCR
Product Category Rules

PENRE
Use of Non-Renewable Primary Energy excl. Non-Renewable Primary Energy Resources used as Raw Materials

PENRM
Use of Non-Renewable Primary Energy Resources used as Raw Materials

PENRT
Total Use of Non-Renewable Primary Energy Resources

PERE
Use of Renewable Primary Energy excl. Renewable Primary Energy Resources used as Raw Materials

PERM
Use of Renewable Primary Energy Resources used as Raw Materials

PERT
Total Use of Renewable Primary Energy Resources

POCP
Photochemical Ozone Creation Potential

RoE
Return on Energy

RSF
Use of Renewable Secondary Material

RWD
Radioactive Waste Disposed

SM
Use of Secondary Material

WSP
Water Scarcity Potential

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