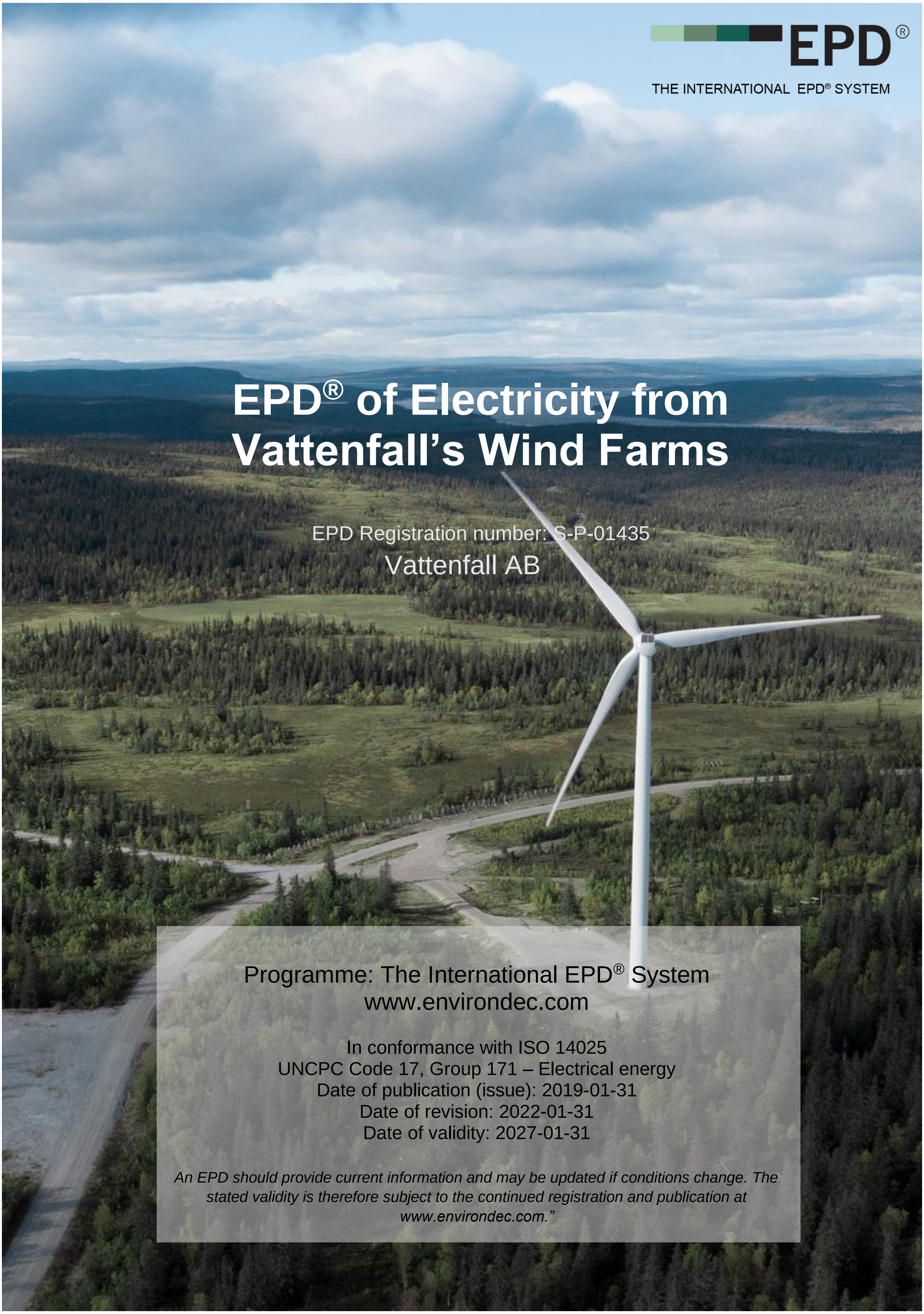

EPD® THE INTERNATIONAL EPD® SYSTEM

EPD® of Electricity from Vattenfall's Wind Farms

EPD Registration number: S-P-01435

Vattenfall AB

Programme: The International EPD® System
www.environdec.com

In conformance with ISO 14025
UNCPC Code 17, Group 171 – Electrical energy
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An EPD should provide current information and may be updated if conditions change. The stated validity is therefore subject to the continued registration and publication at www.environdec.com."

VATTENFALL

Contents

Cover page: Juktan wind farm, Sweden (photo: Jennie Pettersson)

Summary

PRODUCER
Vattenfall Business Area (BA) Wind is responsible for the electricity generation in all Vattenfall's wind farms in Europe. Vattenfall Business Area Wind is part of Vattenfall AB, SE–169 92 Stockholm, telephone +46 8 739 50 00, www.vattenfall.com. Vattenfall BA Wind has a management system for quality, environment and health & safety certified according to ISO 9001:2015, ISO 14001:2015 and OHSAS 18001:2008 implemented.

PRODUCT AND FUNCTIONAL UNIT
Electricity belongs to the product category UNCPC Code 17, Group 171 – Electrical energy. The functional unit is defined as 1 kWh net of electricity generated and thereafter distributed to a customer connected to the medium voltage grid.
Vattenfall's average annual wind power generation is close to 9 TWh of electricity (net).

Country	**Installed capacity 2020 [MW]**		**Net average generation [GWh/year]**		**Total net average generation [GWh/year]**
	Offshore	Onshore	Offshore	Onshore	
Sweden[1]	110	148	327	382	709
Denmark	502	233	1 869	629	2 498
UK	613	391	1 845	1 079	2 924
Germany	294	12	1 307	20	1 327
Netherlands	0	501	0	1 420	1 420
Total[1]	**1 518**	**1 285**	**5 348**	**3 530**	**8 878**

[1] Note that these values do not include the wind farm Blakliden Fäbodberget, since it is being constructed in 2021

THE INTERNATIONAL EPD®SYSTEM
The International EPD® system is administrated by EPD International AB and based on ISO 14025, Type III Environmental Declarations. The relevant governing documents in hierarchical order are: PCR CPC171 version 4.2, General Programme Instructions for an environmental product declaration EPD®, Version 3.01, ISO 14025, ISO 14040, ISO 14044.

ENVIRONMENTAL PERFORMANCE - BASED ON LCA
See section 3 of the complete EPD® documentation.

System boundaries
The EPD® comprises the generation of electricity in the wind farms, upstream processes (production of auxiliary substances) and downstream processes (distribution of electricity). Further, construction and dismantling of the wind farms has been included. The use stage of electricity at the consumer is not included. The technical service life is estimated to 25 years for Horns Rev 3, Blakliden Fäbodberget and Princess Ariane. For the rest of the farms, it is estimated to be 20 years.

The complete certified declaration also contains descriptions of environmental risks, land use and impacts on biodiversity in accordance with the EPD® system instructions.

Environmental information
A short summary of compiled data is presented below per generated and distributed kWh electricity. The results are presented for the following lifecycle modules:

Upstream	Production of oils, and fuels for maintenance and inspection trips.
Core	Operation of wind farm, i.e. emissions from inspection trips. Incineration or deposit of operational waste
Core – infrastructure	Construction and decommissioning of wind farms, including foundation, tower, nacelle, hub, rotor blades etc. Reinvestment of gearbox, generator, transformer and more.
Downstream	Operation of electricity networks, i.e. emissions from inspection trips, production and emissions of oils. Losses in the networks.
Downstream – infrastructure	Construction and decommissioning of the transmission grids and distribution networks.

Distribution of electricity implies grid losses, which is compensated for by increased generation. The losses are different in different countries and often higher in the countryside. The grid loss to an average large industrial customer connected to the regional network is set to 5% of generated electricity. This loss is assumed to be compensated for by increased generation in the wind farms and is included in the downstream column in the table below.

Environmental impact categories		Unit/kWh	Upstream	Core	Core - infra.	Total - generated	Down-stream[1]	Downstream - infra.	Total - distributed
Global warming potential (GWP)	Fossil	g CO_2-eq. (100years)	0.0748	0.419	11.6	**12.1**	0.691	1.34	**14.2**
	Biogenic	g CO_2-eq. (100years)	0.00177	0.00151	0	**0.00329**	0.00173	0.0159	**0.0209**
	Luluc[2] (deforestation)	g CO_2-eq. (100years)	0	0	0.944	**0.944**	0.0472	0.445	**1,44**
	Total	g CO_2-eq. (100years)	0.0766	0.420	12.6	**13.1**	0.739	1.80	**15,6**
Acidification potential (AP)		g SO_2-eq.	2.20E-04	0.00350	0.0361	**0.0398**	0.00217	0.00248	**0.0445**
Eutrophication potential (EP)		g PO_4^{3-}-eq.	2.03E-04	6.85E-04	0.00703	**0.00792**	4.36E-04	0.00272	**0.0111**
Photochemical oxidant formation potential (POFP)		g NMVOC-eq.	6.76E-04	0.00498	0.0310	**0.0367**	0.00231	0.00590	**0.0449**
Particulate matter		g PM2.5-eq.	6.39E-05	5.59E-04	0.00916	**0.00979**	5.40E-04	6.45E-04	**0.0110**
Abiotic depletion potential - Elements		g Sb-eq.	3.23E-07	4.61E-08	1.72E-04	**1.73E-04**	8.66E-06	5.56E-05	**2.37E-04**
Abiotic depletion potential - Fossil fuels		MJ, net cal. value	0.00617	1.40E-04	0.130	**0.136**	0.00744	0.0179	**0.161**
Water scarcity footprint		m^3 H_2O-eq.	1.13E-05	3.79E-06	0.300	**0.300**	0.0150	9.87E-04	**0.316**

[1] Distribution losses of 5% of generated electricity are included in the downstream column.
[2] The indicator GWP Luluc entails emissions of greenhouse gases related to activities leading to land use and land use change.

Resource use and emissions related to handling and treatment of the lifecycle waste through incineration or deposition are included in the Environmental impact i.e., no crediting has been performed.

Conclusions of the LCA

The major environmental impact per kWh from wind power is attributable to the activities in the Core - infrastructure process, i.e., the construction of wind farms. Emissions of greenhouse gases emanate mainly from the combustion of fossil fuels as a part of the energy supply for manufacturing processes, here the majority comes from the production of steel for the turbine towers and foundations. Offshore wind sites require more steel mainly due to the larger towers and underwater construction, in comparison with onshore sites. This causes the lifecycle emissions of greenhouse gases from offshore sites in general to be higher than for onshore sites, although the higher production from offshore sites partly decreases the impact per kWh.

In this version, emissions as a result of deforestation (Luluc) are included, which increases the total global warming potential results compared to the previous version. When excluding GWP-Luluc, the GWP results are however lower than in the previous update of the EPD. This indicates a significant decrease in GWP because new factors have been included in this EPD version that could have increased the GWP. This is mainly related to factors such as the inclusion of demolition of previously modelled substations, the increase in core result due to increased offshore maintenance trips (where emissions from combustion of marine diesel is a dominating contributor) and a decrease in average energy production for Lyngsmose, Horns Rev 1, Bajlum, Kentish Flats and Pen y Cymoedd. Global warming potential (GWP) excluding Luluc has decreased due to Vattenfall's wind farm portfolio's higher ratio of modern wind farms with generally lower GWP per produced kWh and longer lifetime expectancy. See section 0 for more information on this.

In this version of the EPD, water scarcity footprint (AWARE) is a new impact category. The water scarcity footprint is a regionalised approach which quantifies the relative available water remaining per (specified) area after satisfying the demand of aquatic ecosystems and anthropogenic activities. The impact category considers the water scarcity in the region where the water is consumed, so that water which is consumed in a scarce region is weighted higher. The dominating contribution to water scarcity is related to the construction of turbines (Core - infrastructure), approximately 95 %. Water is mainly used in supplier processes and material production. The impact of distribution losses is driven by the impact of core – infrastructure.

ADDITIONAL ENVIRONMENTAL INFORMATION

Land use and impact on biodiversity

Vattenfall's method for land use and biodiversity is used to quantify changes in land use when wind power is built, and to look at impact on biodiversity from those changes as well as from operations of the wind farms. In the table below the identified changes are shown. See section 4.1 for the complete results.

Land cover	Area before (m^2)	Area after (m^2)	Land use change (m^2)
1. Artificial Surfaces	8.93E+05	1.09E+07	9.99E+06
2. Agricultural areas	1.06E+06	7.20E+04	-9.84E+05
3. Forest and seminatural areas	8.46E+07	7.67E+07	-7.94E+06
4. Wetlands	1.44E+07	1.33E+07	-1.06E+06
5. Water bodies	2.79E+08	2.79E+08	0

Environmental risk assessment

The conclusion is that over a longer period of time the environmental risks due to undesired events are considerably smaller than those emanating from normal operation. The main risks are connected to diesel/oil/gasoline leakages. See chapter 4.4 of the complete EPD® documentation.

Noise

Measurements show that Vattenfall's wind farms operate below limits in present regulations.

1. Introduction

1.1. Functional Unit

This document constitutes the certified Environmental Product Declaration EPD® (Environmental Product Declaration) for electricity generated in Vattenfall's wind farms.

The functional unit is 1 kWh net of electricity generated and thereafter distributed to a customer.

The wind farms depend on wind for the generation of electricity and the better the wind conditions are and the availability in the plant, the higher the capacity factor. The capacity factor is determined as follows: (recorded electricity generation, during the average year) / (installed capacity x 8 760 h). The average capacity factor for the wind farms selected in this EPD® to represent Vattenfall's portfolio is 0.35. It is not possible to adapt generation to demand, and complementary generation of electricity is required to keep the power network balance. Additional information regarding delivery of electricity to customers is supplied in section 0.

1.2. The Declaration and the EPD® system

Environmental Product Declaration is recognised as a tool for industry for the communication of the environmental impact of products and services.

This Environmental Product Declaration is compliant with the International EPD® System, administered by EPD International AB (www.environdec.com): Box 210 60, SE-100 31 Stockholm, Sweden, e-mail: info@environdec.com. Environmental Product Declarations within the same product category but from different programmes may not be comparable.

The hierarchical structure of the fundamental documents for the EPD® system is:
- Product Category Rules, CPC 171 Electrical Energy, CPC 173 Steam and Hot Water, version 4.2
- General Programme Instructions (GPI) for an environmental product declaration, EPD®, version 3.01.
- ISO 14025 on Type III environmental declarations.
- ISO 14040 and ISO 14044 on Life Cycle Assessments (LCA)

This EPD® contains an environmental performance declaration based on a lifecycle assessment. Additional environmental information is presented in accordance with the PCR:
- Information on land use:
  - an assessment of impact on biodiversity
  - a categorisation of land use according to Corine Land Cover Classes, land occupation time periods and exploitative activities
  - a description of visual impacts
- An Environmental Risk Inventory (ERI) for potential incidents/accidents with environmental impact that occur less frequent than once every three years from abnormal incidents and accidents.
- Electromagnetic fields, a description of measures to keep fields low and some information on limits and recommendations by different bodies
- Noise

1.3. Vattenfall, LCA and EPD®

Vattenfall has employed LCA for almost 30 years and has accumulated competence and experience in this field. The additional development through the EPD® enhances the ability to inform objectively about the complex environmental issues associated with generation of electricity. Vattenfall AB has the sole ownership, liability and responsibility of this EPD®.

There are multiple reasons to environmentally declare electricity, most significantly:

- Electricity is used in the manufacturing of virtually every product. Information regarding resource use in electricity generation is central to relevant LCA for other products. This has generated an increased interest in the market for this type of information primarily because users need certified and modular life cycle data that are possible to sum up as inputs to their own EPD® and LCA.
- EPD® provides a basis for professional procurement, private as well as public sector, in permitting comparison of different power sources, heat production technologies, and different producers. This creates an incentive for producers to reduce their use of resources and the impact on the environment caused by their systems.
- EPD® is an effective instrument in the continuing environmental efforts within Vattenfall, the objective being constant improvement.
- The Directive 2003/54/EC requires member states to introduce systems for customer information regarding the origin of the electricity and, at a minimum, figures on CO_2 and radioactive waste. The information given in an EPD® is of a high quality and exceeds the requirements in the Directive.
- The demand for Climate Declarations and measures of Carbon footprint. The international EPD®system has issued so-called climate declarations as the first example of a single-issue EPD®. It describes the emissions of greenhouse gases, expressed as CO_2-equivalents for a product's life cycle, based on verified results from LCA information in accordance with ISO 14025.

Vattenfall Business Area (BA) Wind is responsible for the electricity generation in all Vattenfall's wind farms in Europe. Vattenfall Business Area Wind is part of Vattenfall AB, SE–169 92 Stockholm, telephone +46 8 739 50 00.

For questions concerning this EPD® send an e-mail to epd@vattenfall.com.

For additional information about Vattenfall, please visit our web site at www.vattenfall.com.

2. Producer and product

2.1. Vattenfall AB

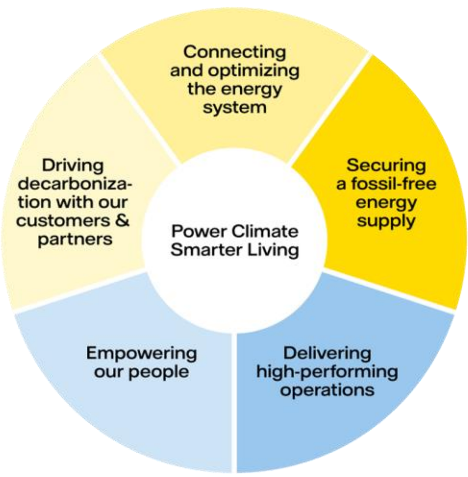
Vattenfall AB is one of Europe's major retailers of electricity and heat and one of the largest producers of electricity and heat. Group sales amounted in 2020 to 158.4 billion SEK (approximately 15 billion EUR). Vattenfall's main markets are Denmark, Finland, Germany, the Netherlands, the UK and Sweden. The Parent Company, Vattenfall AB, is 100 % owned by the Swedish state, and its headquarters are located in Solna, Sweden.

Read more about Vattenfall's environmental work at https://group.vattenfall.com/who-weare/sustainability/environmental-responsibility

Vattenfall's ambition is to enable fossil free living within one generation and an important activity on this journey is to reduce environmental impacts throughout the entire value chain. Life cycle assessments and environmental product declarations are important tools in this work. The goal for the Vattenfall Group is to be net zero by 2040, and to contribute to limiting global warming to 1.5 degrees by reducing its emission intensity with 77 % from 2017 to 2030 (scope 1+2). Vattenfall will also reduce absolute emissions from use of sold products (Scope 3) by 33 % by 2030 compared to 2017. The 2030 emission reduction targets are approved by the Science Based Targets initiative, SBTi, providing external validation that these are in line with climate science and the Paris agreement.

Apart from Vattenfall's environmental work and strategy, social responsibility throughout the value chain is an integrated part of the business. This includes stakeholder engagement, human rights and other social impacts in the supply chain. To read more about how Vattenfall manage social responsibility, visit https://group.vattenfall.com/who-we-are/sustainability/social-responsibility

Vattenfall has five strategic focus areas:



Driving decarbonisation with our customers & partners with focus on increasing customer centricity and promoting electrification and climate smart energy solutions in areas where we have a competitive advantage.

Connecting and optimising the energy system with focus on maximising the value of flexibility and promoting a stable and cost-efficient grid infrastructure.

Securing a fossil-free energy supply with focus on growing in renewables, maximising the value of our existing fossil-free assets, and implementing our CO2 roadmap.

Delivering high-performing operations with focus on being both competitive and cost-effective, leveraging opportunities in digitalisation and taking social and environmental responsibility throughout the value chain.

Empowering our people with focus on securing necessary competence while improving the employee journey and providing a safe working environment.

In 2020 Vattenfall generated 112.8 TWh electricity, of which 22.7 TWh was fossil power, 39.3 TWh nuclear power, 0.3 TWh biomass and waste, 39.7 TWh hydro power and 10.8 TWh wind power. Furthermore, Vattenfall produced 14.2 TWh of heat during 2020.

2.2. Vattenfall Business Area Wind

BA Wind is responsible for Vattenfall's onshore and offshore wind. BA Wind currently operate a portfolio of about 1,100 wind power turbines with total installed capacity of 2,751 MW across five countries. Today BA Wind develops, constructs and operates wind generation in Sweden, Denmark, Germany, The Netherlands and the UK. Apart from wind power, BA Wind is also growing in the solar and energy storage sectors.

BA Wind has a strong market position in our different renewable technologies. In onshore wind, Vattenfall is among the leading companies in terms of commissioned capacity in our markets, with leading positions in the Netherlands and Denmark. In offshore wind, Vattenfall is among the strongest European offshore player with 4,6 GW in operation or construction as well as a strong development pipeline across our markets.

2.2.1. Quality, Health & Safety and Environmental Management

Vattenfall BA Wind has a management system for quality, environment and health & safety certified according to ISO 9001:2015, ISO 14001:2015 and OHSAS 18001:2008.

2.3. Product system description

2.3.1. Core process and upstream processes

2.3.1.1. A Wind Turbine Simplified

A wind turbine uses the kinetic energy in the wind to generate electricity. It is not possible to withdraw all energy from the wind, as the wind velocity after the wind turbine cannot be zero.

The assembly of hub and rotor blades is called turbine or rotor. Behind the rotor in the so-called nacelle other electric and machine equipment are found. In order to capture more wind, taller and larger wind turbines with ever-longer rotor blades are being constructed. Onshore wind turbines are fixed to a foundation, normally a heavy concrete foundation. For offshore application there are different types of foundations such as monopile, gravity, and jacket. Most of Vattenfall's offshore farms consist of monopile foundations with steel tubular towers driven or drilled into the seabed. To protect from erosion, the foundations are covered with stone.

2.3.2. Downstream processes – distribution of electricity

2.3.2.1. General

The downstream process comprises the transmission and distribution of the product, electricity, to its end users, via its distribution chain consisting of numerous lines, cables, transformers, and switchgears. The national grid voltage is stepped down to lower voltages for transmission over distribution networks and local networks to consumers. Structure, voltages and terminology differ between countries, but the principles are the same. Large customers, e.g., certain industries, are frequently connected to the high or medium voltage distribution network (6 kV-150 kV), while small users such as single households are connected to low voltage (0.23-0.4 kV) local networks. While large wind farms deliver electricity to the national (or high voltage distribution) grid, single wind turbines and smaller farms often deliver electricity to the medium voltage distribution network. A large industrial customer connected to the high voltage distribution network may purchase wind power electricity and is consequently dependent on the national grid and the high and medium voltage distribution networks.

During the transmission and distribution phases, losses of electricity occur. These losses depend on several factors, such as distance, load, feed voltage, and user connection voltage. The weighted losses for the entire networks in the countries within this EPD® are around 4 % on the distribution networks, and just over 2 % on the transmission networks. In the Environmental Impacts, the result for delivery to an industrial customer is reported with a total distribution loss of 5 % of generated electricity. 5 % is applied provided that the losses to an industrial customer (as assessed in this EPD®) connected to a high or medium voltage distribution network has somewhat lower losses than what the entire networks has.

In the coming sections, the overall grid losses for Sweden, Denmark, the United Kingdom, Germany and the Netherlands for their respective transmission and distribution levels are described, to show that the applied 5 % transmission and distribution loss to an industrial customer is reasonable. Note that the green bars in the following figures present total losses on the entire networks, where the losses are somewhat higher than to an industrial customer connected to the high or medium voltage distribution network.

In the calculations, the loss is compensated through generation in Vattenfall's wind farms.

2.3.2.2. Electricity distribution in Sweden

The Swedish transmission grid has a voltage of 220 kV and 400 kV. The so-called regional network has different voltage levels in different part of the country, 70 kV and 130 kV. Power lines and cables on lower voltage levels is called local network. The regional and local network together comprise the distribution network.

Distribution losses

In Figure 1 below the average distribution losses are shown in % of generated electricity.

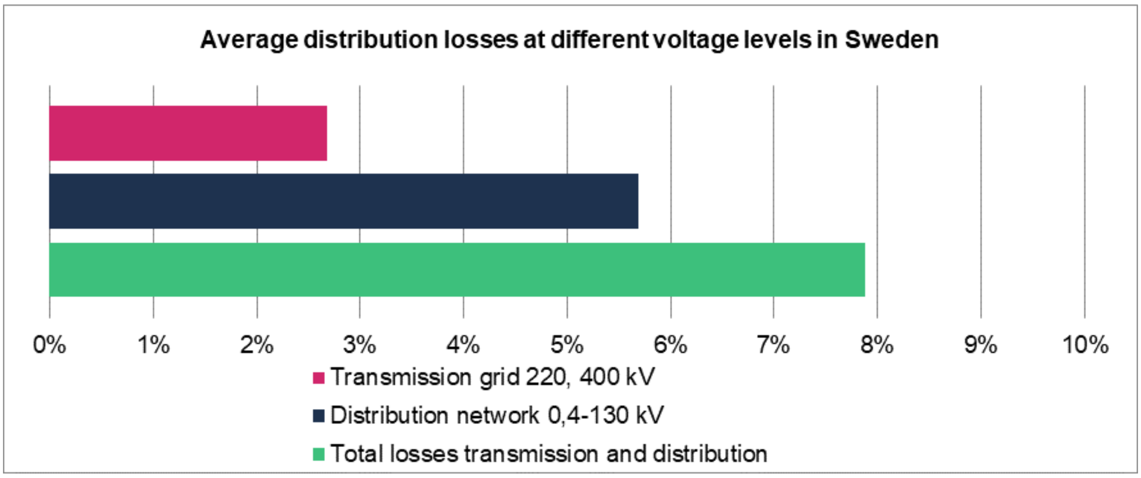


Figure 1 *Distribution losses in Sweden. Data is a 5-year average between 2015 to 2019. Source: Statistics Sweden and Svenska Kraftnät*

2.3.2.3. Electricity distribution in Denmark

The Danish transmission grid has the voltages 132/150 kV and 400 kV. Power lines and cables at lower voltage levels belong to the so-called distribution network. Energinet, owned by the Danish Ministry for Energy, Utilities and Climate, no longer publishes the overall grid losses of the distribution network in Denmark, but instead refer to the various grid companies. Statistics for Denmark has therefore been retrieved from the 2nd CEER Report on Power Losses (CEER, 2020).

Distribution losses

In Figure 2 below, the average distribution losses for Denmark are shown as a 5-year average for the period 2014-2018. In addition, Energinet does advice to use a grid loss of 5% at the distribution level if the specific data from the grid owner is not available. This aligns well with the losses presented in Figure 2 as well as average statistics retrieved earlier for the 5-year period 2010-2014, which showed for lower values on the distribution network than the CEER report and somewhat higher for the transmission grid and total losses.

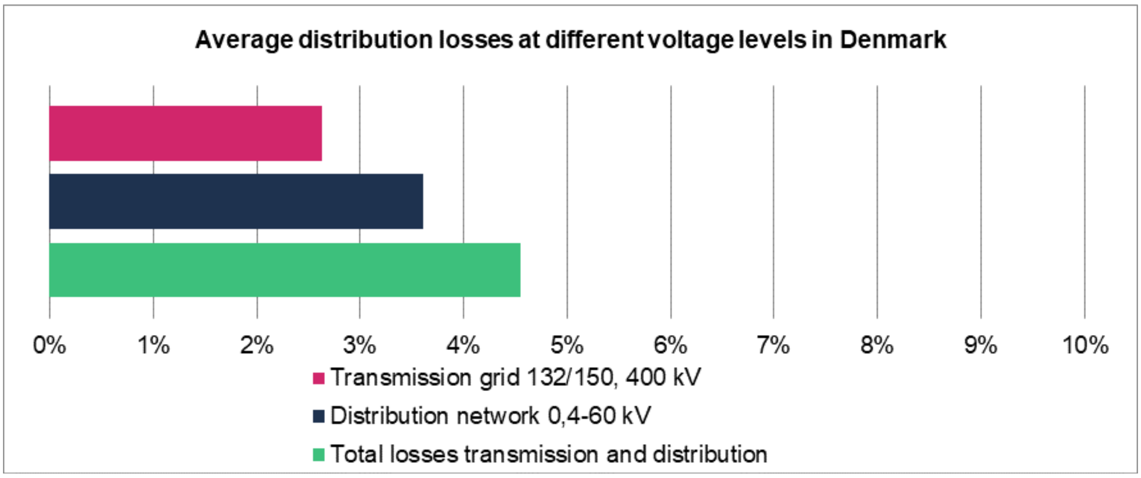


Figure 2 *Distribution losses in Denmark. Data is an average between 2014 to 2018. Source: 2nd CEER Report on Power Losses (CEER, 2020)*

2.3.2.4. Electricity Distribution in the UK

In the UK, the transmission grid has a voltage of 275 kV and 400 kV and there are three levels of distribution grid: LV 0.415 kV, HV 6.6-11 kV and EHV 33-132 kV. Data for these grids are retrieved from National Grid UK in 2009, which is supported by a recent report they published (National Grid ESO, 2019). In regard to the total losses, data is retrieved from GOV.UK (GOV.UK, 2021), which figures too are supported by the previously mentioned report from National Grid.

Distribution losses

Figure 3 below presents the average distribution losses for each of the above mentioned grids, along with total losses.

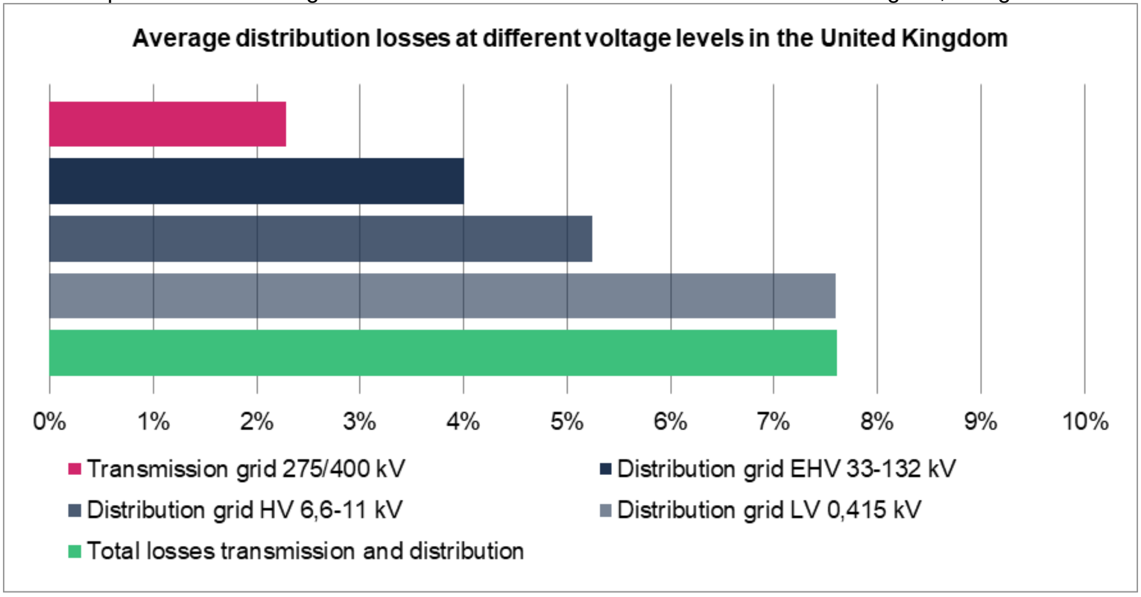


Figure 3 *Average distribution losses, in % of generated electricity, at different voltage levels in the UK. Source: National Grid UK, 2009 and GOV.UK (GOV.UK, 2021)*

2.3.2.5. Electricity Distribution in Germany

The German transmission grid has the voltages 220 kV and 380 kV. The distribution grid consists of the high voltage grid (60-220 kV), medium voltage grid (6-60 kV) and low voltage grid (0.23-0.4 kV). Large customers are commonly connected to the high voltage grid or medium voltage grid.

Distribution losses

In Figure 4 below the average distribution losses are shown for each of the grids, along with total losses.

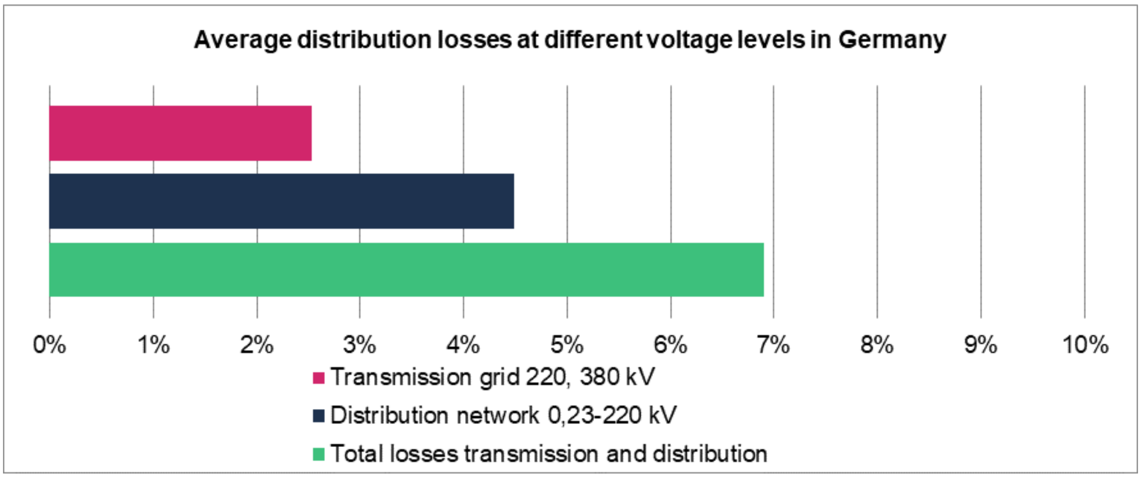


Figure 4 *Distribution losses in Germany Data is an average over 2017 and 2018. Source: Destatis (Statistics Germany) and the European Network of Transmission System Operators for Electricity (ENTSO-E).*

2.3.2.6. Electricity Distribution in the Netherlands

The electricity grid in the Netherlands consists of the national high-voltage transmission grid, which transmits electricity at 110,150, 220 and 380 kV. The regional electricity grids have the voltages 66 kV or less (TenneT, 2021).

Distribution losses

Statistics for the Netherlands are retrieved from the 2nd CEER Report on Power Losses (CEER, 2020) and presented in Figure 5 below. Previously attained statistics from Statistics Netherlands (CBS) and TenneT show for similar values as the CEER report, although somewhat lower on all points – why the conservative approach of using the values from the CEER report is applied.

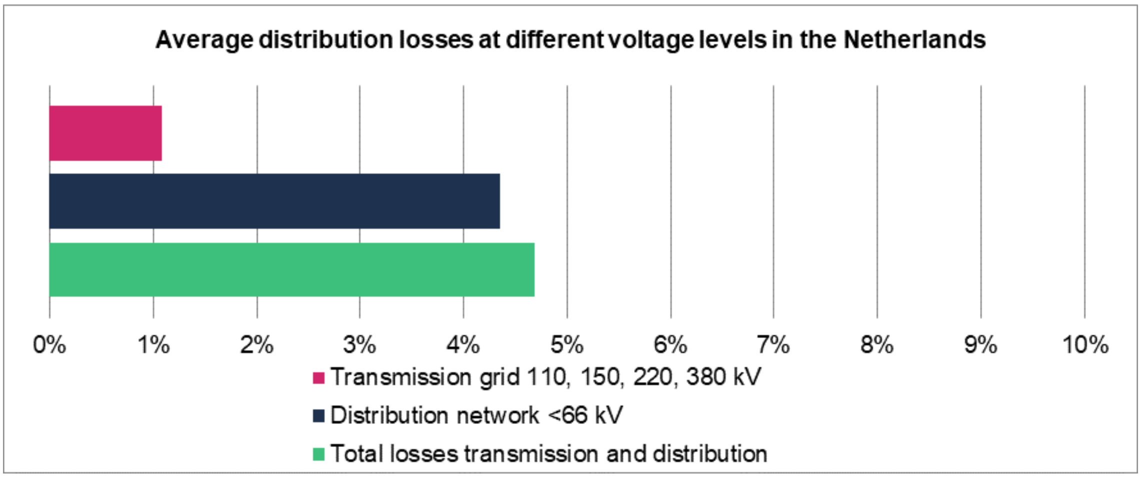


Figure 5 *Distribution losses in the Netherlands. Data is an average over the 5-year period 2014 to 2018. Source: 2nd CEER Report on Power Losses (CEER, 2020)*

2.3.2.7. Environmental Impact in Conjunction with Electricity Distribution

Distribution losses lead to reduced delivery of useful kWh, which must be compensated for by additional generation of electricity and consequently additional resource use and emissions. In this study the losses are estimated to be 5 % of the generated electricity and assumed to be compensated for through additional generation in Vattenfall's wind farms.

Construction, operation and dismantling of power lines has an environmental impact as well, predominantly in the construction stage. Production of metals, concrete and insulation material generates emissions, for example via the consumption of electricity and fuel.

Additional environmental impact stems from salt impregnated and creosote impregnated power poles (no new salt impregnated poles are set up today) and from cables that cause low amounts of emissions of heavy metals. As an example, salt impregnated poles emit arsenic, and galvanized steel emits zinc. Older cables can emit some lead. Such emissions are, however, quite local, within 0.2 meters of source.

Deforestation before the construction of the distribution network is connected to a reduced uptake of CO_2 of the land, resulting in a climate impact due to land-use change.

The power grids also have an impact on biodiversity. Lanes are regularly cleared creating a possible habitat for species normally inhabiting meadows and pastures. In addition, lanes constitute border zones, which are generally considered more bio-diverse than homogenous areas. Wider lanes may constitute barriers that may cause fragmentation for some woodland species. Power grids in areas with dense forest areas require in general more maintenance than power grids located in areas with cultivation landscape. Burying cables, both on land and in the seabed, affects the habitat in a narrow zone along the cable route. Changes to habitats are usually transient, with original biological communities being restored over a number of years.

Power lines above 70 kV can generate corona noise levels of 45 dB(A) at 25 meters, however abating as distance increases. See 4.4 for more information on noise. Electromagnetic fields appear in the vicinity of all electrical equipment and power lines, for more information on electromagnetic fields see 4.3.

2.4. Selected farms and coverage

By the end of 2020 Vattenfall operated approximately 50 wind farms in five European countries, with a total annual generation of close to 9 TWh. More than half of this is generated in offshore farms. The wind farms are owned fully or partly by Vattenfall. There are also wind farms under construction in UK, Sweden and Denmark, of which some have been inaugurated during 2021. This study is however based on the reference year 2020 so numbers below are given for the situation by 31st of December 2020.

In Table 1 below, installed capacity is based on the wind farms in operations by the end of 2020.

Table 1 *Installed capacity and average generation in Vattenfall's portfolio by the end of 2020 (due to rounding, the totals may not fully add up).*

Country	**Installed capacity 2020 [MW]**		**Net average generation [GWh/year]**		**Total net average generation [GWh/year]**
	Offshore	Onshore	Offshore	Onshore	
Sweden[1]	110	148	327	382	709
Denmark	502	233	1 869	629	2 498
UK	613	391	1 845	1 079	2 924
Germany	294	12	1 307	20	1 327
Netherlands	0	501	0	1 420	1 420
Total[1]	**1 518**	**1 285**	**5 348**	**3 530**	**8 878**

[1] Note that these values do not include the wind farm Blakliden Fäbodberget, since it is being constructed in 2021

The farms included in this EPD® were selected in order to be representative of Vattenfall's portfolio of wind power. The selection criteria were: wind conditions, size, configuration, technology, manufacturer and geographic location.

The wind condition is the single most important parameter for the environmental performance of a wind turbine. All Vattenfall's wind farms have been grouped with respect to wind conditions expressed as the capacity factor[1] and farms from each group have been selected to be representative of their group.

Studied wind farms have been weighted within each group with respect to actual annual average electricity generation. The Environmental Impacts, seeTable 9, have been calculated based on the groups' percentages of total wind power generation.

The selected sites consist of one or more turbines and are located onshore or offshore. The capacities vary between 1,8 MW and 8.3 MW. The studied farms are located from Lapland in the north of Sweden to Wales in the west of UK, to Gotland in the east of Sweden and Kent outside of UK in the south.

All together the selected turbines generate 73 % of Vattenfall's total electricity from wind power during an average year. The selection has been made to cover all countries where Vattenfall is active and as many different types of geography as possible. Through the selection of the sites listed in Table 2 below, the environmental impact of Vattenfall's wind power portfolio is assumed to be mirrored correctly in this EPD®. Note that commissioning has not

1 The capacity factor is determined as follows: (recorded electricity generation, during the year) / (installed capacity x 8 760 h).

yet been performed for Blakliden Fäbodberget, as the wind farm is being constructed at the time of this assessment. Expected generation has therefore been applied

For more information about the selection of sites and the representativity, see Appendix 2 *Selected wind farms*.

Table 2 *Selected wind farms*

Group	Wind farm	No of turbines	Manufacturer	Power per turbine [MW]	Construc-tion year	Average generation per farm [MWh (net)]	Location	Portion of Vattenfall's wind power generation
0	Horns Rev 1[1]	80	Vestas	2	2002	481 068 (288 641)	North Sea West of Jutland	3.3%
	Horns Rev 3	49	Vestas	8.3	2018	1 580 352	North Sea West of Jutland	17.8%
	Lillgrund	48	Siemens	2.3	2006	327 178	South Sweden Öresund	3.7%
	Thanet	100	Vestas	3	2010	887 975	Outer Thames Estuary, east of London	10.0%
	Kentish Flats	30	Vestas	3	2005	238 717	Outer Thames estuary, east of London	2.7%
	DanTysk[1]	80	Siemens	3.6	2014	1 280 974 (653 297)	German North Sea	7.4%
1	Klim[1]	21	Siemens	3.2	2015	223 689226 156 (219 550)	Klim, Denmark	2.5%
	Pen y Cymoedd	76	Siemens	3.0	2017	648 758	South Wales	7.3%
	Blakliden Fäbodberget[1]	84	Vestas	4.2	2021	1 100 000[2] (330 000)	Northern Sweden, Lappland	3.7%
	Princess Ariane	50	Nordex	3.7	2019	672 000[3]	Wieringermeer NL	7.6%
2	Stor-Rotliden	40	Vestas	1.8-2	2010	200 356	Northern Sweden, Lappland	2.3%
	Edinbane	18	Enercon	2.3	2010	106 110	Isle of Skye, Scotland (UK)	1.2%
	Lyngsmose	2	Siemens	2.3	2008	12 242	Central Jutland	0.1%
	Bajlum[1]	5	Siemens	3	2013	42 532 (36 732)	Northwest Jutland	0.4%
3	Princess Alexia	36	Senvion	3.4/3.0	2013	256 030	Flevoland, NL	2.9%

[1] Vattenfall owns 60% of the wind farm Horns Rev 1, 51% of DanTysk, 30% of Blakliden Fäbodberget,87.5% of Bajlum and 21 out of 22 turbines at Klim. Both total generation and Vattenfall's share is shown under average generation per farm, with Vattenfall's generation in brackets.
[2] Approximated production, since commissioning has not yet been performed at the time of assessment
[3] Approximated production, since not fully operated at the time of assessment

Performed studies

Apart from life cycle assessment, some of the plants also have been studied with respect to land-use and biodiversity and environmental risks.

Table 3 *Land-use and impacts on biodiversity has been assessed at 12 windfarms, and so has environmental risks*

Wind farm	Study of land-use and biodiversity	Study of environmental risks	Location
Horns Rev 1*	X	X	North Sea, West of Jutland
Lillgrund	X	X	South Sweden, Öresund
Thanet	-	-	North Sea/ outer Thames Estuary (UK)
Kentish flats	X	X	North Sea/ outer Thames Estuary (UK)
DanTysk*	X	X	German North Sea
Horns Rev 3	X	X	North Sea, West of Jutland
Bajlum	X	X	North West Jutland
Klim*	-	X	Klim, Denmark
Pen Y Cymoedd	X	X	South Wales
Lyngsmose	-	-	Central Jutland
Stor-Rotliden	X	-	North Sweden, Lappland
Blakliden Fäbodberget	X	X	North Sweden, Lappland
Edinbane	X	X	Isle of Skye, Scotland (UK)
Princess Alexia	X	X	Flevoland, NL
Princess Ariane	X	X	Noord-Holland, NL

Location

The locations of Vattenfall's wind farms by the end of 2020 are shown in Figure 3.

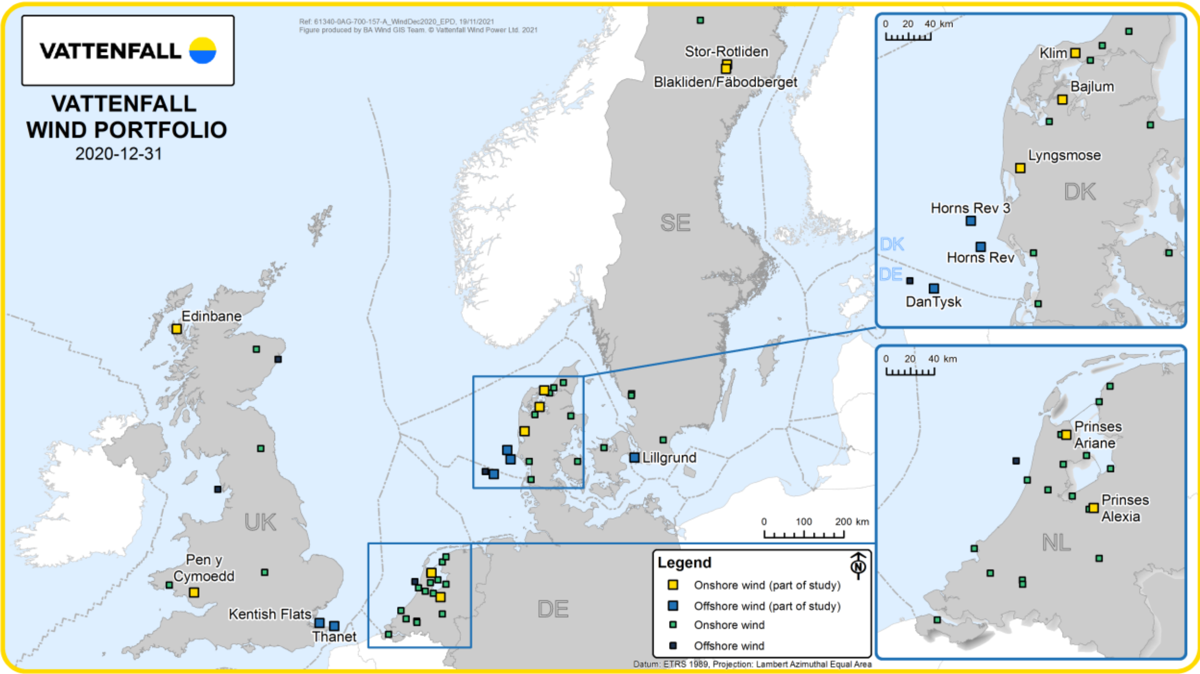
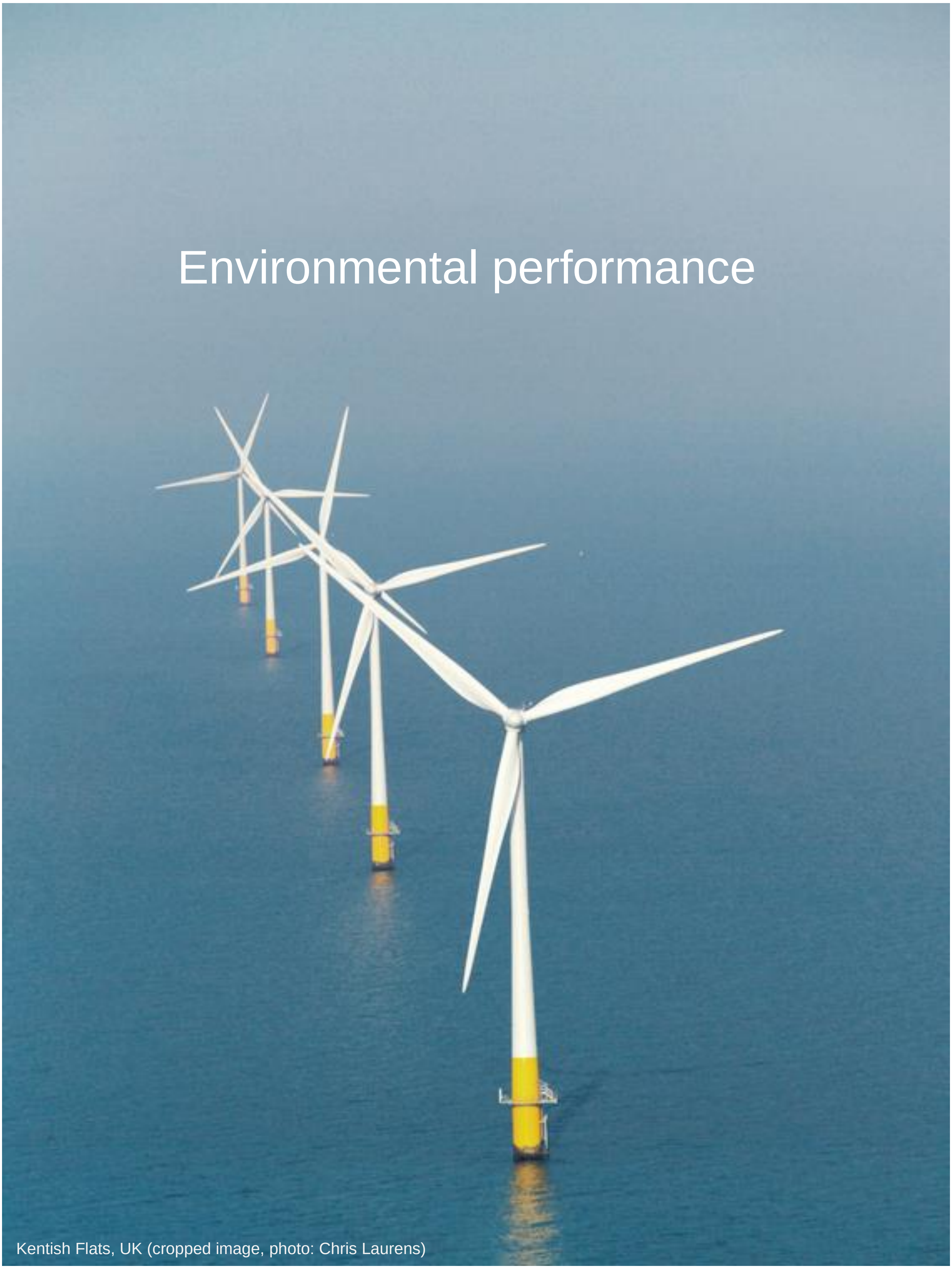


Figure 6 - *The locations of Vattenfall's studied wind farms. Some dots indicate several farms. The farms presented in this EPD® are marked with yellow (onshore) and blue (offshore) boxes. The figure shows the situation by the end of 2020.*

Environmental performance



Kentish Flats, UK (cropped image, photo: Chris Laurens)

3. Environmental Performance Based on LCA

3.1. Life Cycle Assessment Method

This EPD® for electricity from Vattenfall's wind turbines is based on a comprehensive LCA. The declared unit is defined as 1 kWh net of electricity generated and thereafter distributed to a customer connected to the medium voltage grid.

The electricity generation used in the assessment is the average annual net generation, which is calculated as the average net electricity generation over the five-year period 2016-2020 or based on approximated production if built later than 2016. The assessment comprises operation of the wind turbines as well as the construction and decommissioning of the wind farms. The distribution of electricity has been included in terms of distribution losses as well as construction, operation and dismantling of the network.

3.2. System Boundaries, Allocation and Data Sources

3.2.1. System Boundaries

Figure 7 below is a simplified process tree with system boundaries for the LCA on Vattenfall's wind power production. Solid boxes indicate parts that are included, dotted boxes are excluded.

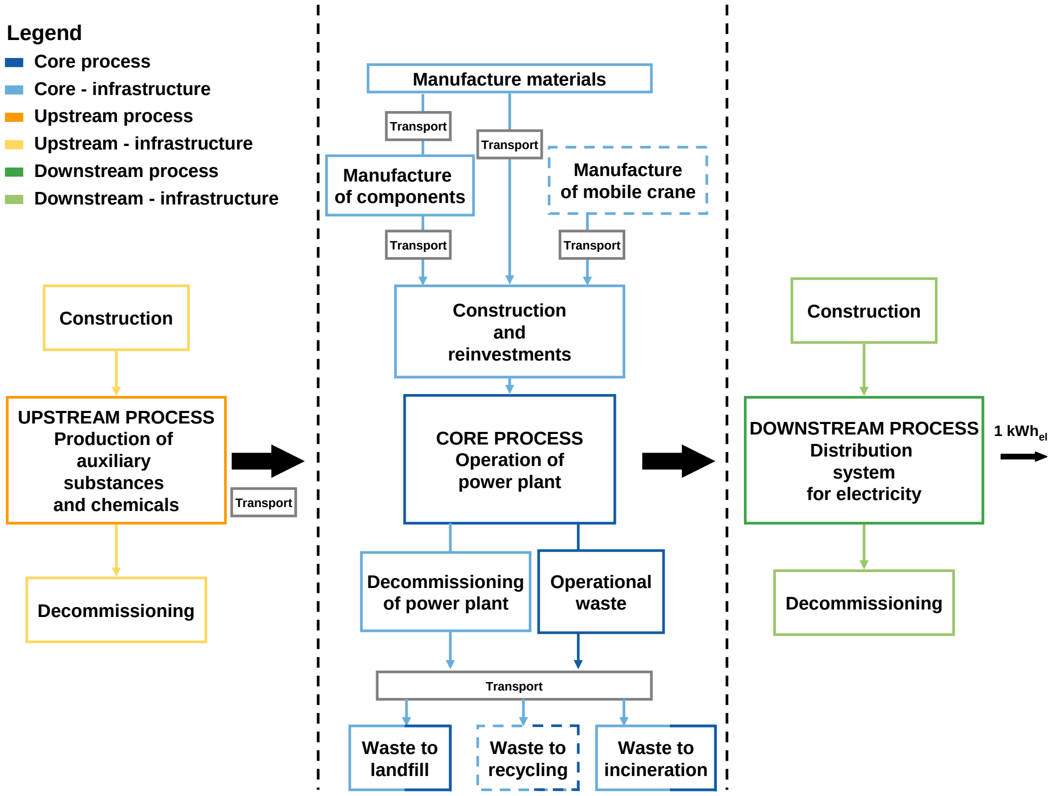


Figure 7 *Simplified process tree and boundaries for the LCA in this EPD®. Boxes with dotted lines are not included. Thick black arrows indicate the life cycle main flow. Conventional waste is handled according to the Polluter Pays Principle within each process step.*

Emissions are aggregated in five life cycle stages, as described in Table 4 below. For the columns *Upstream, Core* and *Core – infrastructure,* the emissions are expressed as per 1 kWh of generated electricity. For the columns *Downstream* and *Downstream – infrastructure*, the emissions are expressed as per 1 kWh of electricity delivered to a customer (distribution loss: 5 % of generated electricity).

Table 4 *Life cycle stages and processes included*

Upstream	Core	Core – infrastructure	Downstream	Downstream – infrastructure
Production and transportation of auxiliary substances and chemicals used during operation (core process) of the wind farms is included in the upstream process. Construction and decommissioning of factories for production of operational chemicals and fuels is included as well, although aggregated with the production processes. Hence is the environmental impact for upstream infrastructure not reported separately.	The core process includes operation of the wind farms, i.e. emissions from inspection trips. Transportation along with production of new auxiliaries as well as incineration and deposit of operational waste.	Construction and decommissioning of the wind farms are included; foundation, tower, nacelle, hub, rotor blades, etc. Reinvestments are also included, as well as construction of internal access roads and cables in the wind farm. Emissions form deforestation before the wind farms where constructed are included as well.	Distribution of electricity, which comprises operation of electricity networks, inspection trips, production and emissions of oils. Generation in Vattenfall's wind power plants to compensate for the losses in the distribution system – 5% of generated electricity.	Construction and decommissioning of electricity networks. Manufacturing of materials for lines, cables, transformers, buildings etc., groundwork, as well as transports and waste handling. Emissions form deforestation before the distribution networks where constructed are included as well.

3.2.2. Technical service lifetime and reference flow

The technical service lifetimes and reference flows used in the assessment are specified in Table 5 below.

Table 5 *Reference flow and service lifetime*

	Wind farm/facility	Technical service life-time [years]	Operational data origin	Year of inventory	Reference flow [GWh]	
					Operation	Infra-structure
Core processes	Horns Rev 1[1]	20	Operational data checked and updated 2021	2006	481 (289)	9 621 (5 772)
	Horns Rev 3	25	Operational data 2021	2021	1 580	39 509
	Lillgrund	20	Operational data checked and updated 2021	2008	327	6 544
	Thanet	20	Operational data checked and verified 2021	2013	888	17 760
	Kentish Flats	20	Operational data checked and updated 2021	2009	239	4 774
	DanTysk[1]	20	Operational data checked and updated 2021	2018	1 281 (653)	25 619 (13 065)

	Klim[1]	20	Operational data checked and verified 2021	2018	224 (220)	4 473 (4 391)
	Pen y Cymoedd	20	Operational data checked and updated 2021	2018	649	12 975
	Blakliden Fäbodberget[1]	25	Operational data 2021	2021	1 100[2] (330)	27 500 (8 250)
	Princess Ariane	25	Operational data 2021	2021	672[3]	16 800
	Stor-Rotliden	20	Operational data checked and updated 2021	2012	200	4 007
	Edinbane	20	Operational data checked and verified 2021	2013	106	2 122
	Lyngsmose	20	Operational data checked and verified 2021	2008	12	244
	Bajlum[1]	20	Operational data checked and verified 2021	2015	43 (37)	851 (735)
	Princess Alexia	20	Operational data checked and updated 2021	2018	256	5 121
Downstream processes	Electricity distribution Sweden (transmission and distribution)	40	Length and losses from operators in Sweden Operational data from Swedish power networks	2019 (operat.)	118 500 (transm.) 69 500 (distr.)	4 624 000 (transm.) 2 780 000 (distr.)
	Electricity distribution Denmark (transmission and distribution)	40	Length and losses from operators in Denmark and CEER report Operational data from Swedish power networks	2019 (operat.)	118 500 (transm.)	1 364 000 (transm.)
	Electricity distribution UK (transmission and distribution)	40	Length and losses from operators in UK Operational data from Swedish power networks	2019 (operat.)	118 500 (transm.) 69 500 (distr.)	12 731 000 (transm. and high voltage distr.)
	Electricity distribution Germany (transmission and distribution)	40	Length and losses from operators in Germany and ENTSO-E Operational data from Swedish power networks	2019 (operat.)	118 500 (transm.) 69 500 (distr.)	22 356 000 (transm.) 21 791 000 (distr.) 154 000 (SylWin1)
	Electricity distribution the Netherlands (transmission and distribution)	40	Length and losses from operators in NL and CEER report Operational data from Swedish power networks	2019 (operat.)	118 500 (transm.)	4 663 000 (transm.)

[1] Vattenfall owns 60% of the wind farm Horns Rev 1, 51% of DanTysk, 30% of Blakliden Fäbodberget, 87.5% of Bajlum and 21 out of 22 turbines at Klim, where also 2% are co-owned with neighbours. The reference flows in brackets shows Vattenfall's share.

[2] Approximated production, since commissioning has not yet been performed at the time of assessment

[3] Approximated production, since not fully operated at the time of assessment

The technical service life of the wind farms influences the environmental impacts from infrastructure (construction and dismantling). The technical service life of wind turbines is set to 20 years for all wind farms except Horns Rev 3, Blakliden Fäbodberget and Princess Ariane which have been set to 25 years; this is based on expert judgment together with an estimation of the rate of reinvestments.

The selected turbines generate close to 73 % of Vattenfall's wind power during an average year. The Environmental Impacts has been calculated based on the electricity generation during an average year.

3.2.3. Allocation and calculation principles

All environmental impact is allocated to the electricity generation.

Excluded from the LCA:

- Further processing of scrapped material transported to recycling plant (in accordance with PCR 171 version 4.2).
- Construction of roads to the wind farms (except for roads within the site area).
- Impacts due to potential accidents, and breakdowns, and leakages (included in Additional Environmental information, see section 4.2 on Environmental Risk Assessment).
- Impacts due to land use and land use change, apart from emissions from deforestation (included in Additional Environmental Information, see section 4.1).

3.2.4. Specific methodological choices

Environmental impacts have been calculated in accordance with the methodology described in the PCR for electricity (version 4.2).

Emissions from clearing of land has been calculated as a pulse of emissions resulting from a momentane change in carbon stock the year that the land was cleared. The decrease of carbon stock has been recalculated to CO_2 emissions and divided by the total electricity production for core-infrastructure, and total transmitted energy for downstream-infrastructure. All emissions related to the clearing of forest is allocated to the wind power.

3.2.5. Completeness and the 1 %-rule

Core module and upstream module

The International EPD® System requires that less than 1% of the total environmental impact for any impact category is omitted due to data gaps. The rule is related to the inflow and outflow of materials, chemicals, electricity, heat and fuels to studied core process.

All inflows and outflows to the operation of the wind farms is according to interviews with site managers and suppliers and have been included in the LCA. Major inputs and outputs necessary to construct, maintain and dismantle the infrastructure of the wind farms are included.

Production of raw material for nacelle, tower, foundation etc is included in the LCA, as well as manufacturing of components for the wind turbines. The infrastructures of inventoried suppliers (factories etc.) are excluded, which is allowed according to PCR. Infrastructure of other processes where data has been taken from Ecoinvent is included. Production of steel and components for wind turbines are assumed to be made in European factories, if not otherwise specified by supplier. Aluminium, epoxy, copper as well as production of chemicals and other materials are assumed to take place in Europe, if not otherwise specified by supplier.

For included processes (excluding gravel, sand, soil, water, and energy resources) all resource flows from nature aggregate to approximately 28.7 g/kWh electricity. The sum of all identified flows not tracked from the cradle is approximately 0.02 g/kWh electricity, which is less than 1% of aggregated resource flows from nature.

The conclusion is that the known exclusions in the production stage (upstream and core processes) contribute less than 1 % to reported impact categories.

Downstream module
In the distribution stage (downstream processes) construction, operation and dismantling of the power network are included, as well as the distribution losses in terms of the extra generation necessary for compensation. Selected generic data is used to model the construction and dismantling of all national grids.

The Swedish regional grid is modelled with specific data from a Life Cycle Assessment conducted on Vattenfall Eldistribution AB's 36-145 kV grid in 2020. Power lanes in forest areas must be deforested regularly and that is why power lines in forest areas require more maintenance than lines in open landscapes, hence resulting in higher emissions. Operational data for the national grid in Sweden are taken from Svenska Kraftnät (2019) and include inspection trips, consumption of oil and SF6, including waste management. Operational data for the regional grid are taken from Vattenfall Eldistribution (2019) and includes fuels and emission from machines used in maintenance and operation, including clearing of power lanes, from transportation during maintenance and inspections, as well as consumption of oils including waste management.

No operational data has been available for neither the national or regional grids in Denmark, the UK, Germany and the Netherlands. Thus, has the Swedish operational data been applied for these countries as well, as a conservative estimate provided that the Swedish transmission network passes through more forest than the networks in these countries.

For included processes (excluding gravel, sand, soil, water, and energy resources) all resource flows from nature aggregate to approximately 2.87 g/kWh electricity. Selected generic data used for construction of power networks do not include any information on data gaps. The sum of all identified flows not tracked from the cradle (from compensation of losses) is approximately 0.00033 g/kWh, which is less than 1% of aggregated resource flows from nature.

A few onshore substations are excluded due to both lack of data and that they are connected to several wind farms outside the scope of this assessment. Rough calculations have however shown that their potential contribution falls well below 1 %. The conclusion is that the known exclusions in this stage contributes less than 1 % to reported impact categories.

3.2.6. Data Quality and the 10 %-rule
In the Environmental Impacts, the results are given with three significant figures. It should be noted that data quality does not always motivate three significant figures. Values smaller than 0.001 are presented with scientific format.

According to the International EPD® System's General Programme Instructions, section 1, *specific data* shall always be used if available. If *specific data* is lacking generic data may be used. There are two types of generic data: *selected generic data* and *proxy data*. *Selected generic data* are data from commonly available data sources that fulfil prescribed data quality characteristics of *selected generic data. Proxy data* are data from commonly available data sources that do not fulfil all of the data quality characteristics of *selected generic data*.

Upstream module
Selected generic data has been used for production of auxiliary material and chemicals for the wind farms, hence has no *proxy data* been used in the upstream module.

Core module
Core process
Specific data has been used with respect to transport distances and input amounts of auxiliary materials. *Proxy data* has been used for combustion emissions from service transports and maintenance vehicles, apart from Horns Rev 3 where *specific data* has been used.

Core process – infrastructure
Specific data has been used with respect to construction material amounts, excavated amounts etc. whereas data for production of construction materials, vehicle operation, waste treatment, and generation of the electricity supplying the subcontractors are *selected generic data*.

Specific data has been used for the manufacturing processes for the components. Emission data from factories for manufacturing blades, nacelles, towers, control equipment etc. are mainly based on the environmental management systems from the manufacturers and are hence also specific – where specific data has been lacking.

- For **Vestas** turbines in the Nordics (Denmark and Sweden), the factories are chosen either according to specific information from Vestas or assumptions based on earlier data from Vestas. In the case where Vestas's factories have been used as approximation for manufacturing of a turbine from another supplier, conservative assumptions have been made about doubled environmental impact, to not underestimate impacts. For the UK Vestas turbines, no specific factories have been used in the inventory. Information on manufacturing is instead taken from the overall sustainability data, which is presented per MW produced.
- For **Enercon** turbines, information on manufacturing has been provided together with other inventory data from the supplier.
- For **Siemens** (now Siemens Gamesa Renewable Energy), turbines factories chosen are either according to specific information from Siemens or conservative assumptions based on earlier information from Siemens. When specific data has not been available for Bajlum, DanTysk, Pen Y Cymoedd and Klim turbines, emissions have been doubled for the assumed processes not to underestimate impacts.
- For **Senvion** (no longer existing), specific data is given for what seems to be major materials in parts and to some extent energy and water use during production. To not underestimate the resource and energy use, data for other materials given from Siemens has been added. The material data has in those cases been scaled according to the specific data from Senvion, and the energy and water use has been scaled likewise as well as doubled in order to not underestimate the environmental burden.
- For **Nordex** turbines, information on manufacturing has been provided for the main parts of the WTG; such as blades, hub and nacelle. The energy requirements for manufacturing the tower have been approximated based on the other components manufactured by Nordex.

Proxy data have been used for diesel-fired machines, and vehicles used for groundwork such as excavating, transports and handling of masses of stone and soil during construction of e.g. foundations.

Downstream module
Construction/dismantling of the electricity network are either *specific data* or *selected generic data*. There are no operational data available for the networks in Denmark, the UK, Germany and the Netherlands, therefore operational data has been taken from the Swedish Vattenfall power network, which comprise fuels and emissions from clearing of power lanes, and from transportation during maintenance and inspections, consumption of oils, and specific emissions from pylons. These data are categorised as being *proxy data*.

The use of Swedish operational data results in an overestimation; this because Sweden has a larger proportion of dense forest areas compared with the other countries assessed. Power lines in forest areas results in power lanes that must be deforested regularly and require, in general, more maintenance – which results in higher emissions.

The 10 %-rule – in summary
The 10 %-rule implies that less than 10 % of the overall environmental impact should stem from processes where *proxy data* has been used. The 10 %-rule is met in all life cycle stages but the core process, where the proxy data stands for the largest share in all impact categories. However, as Core accounts for a small share in the entire life cycle's impact for most impact categories, this does not affect meeting the 10 %-rule in total. The reason for not meeting the 10 %-rule in Core is that the proxy emanates from the combustion of diesel in service trip vessels for off-shore wind farms, of which Vattenfall does not have direct control over and can hence not provide specific data. See Table 6 below for the entire life cycles use of *proxy data*. Since over 90 % of the environmental impact regarding the mandatory environmental impact categories originate from *specific* and *selected generic data*, the conclusion is that the 10 %-rule is met for all categories.

Table 6 *Summary of use of proxy data in the entire life cycle*

Environmental impact categories	**Portion of the Environmental impact result emanating from *proxy data***
Global Warming Potential, fossil	4.0 %
Global Warming Potential, including biogenic CO2	4.1 %
Acidification Potential	3.3 %
Eutrophication potential	4.8 %
Photochemical Oxidant Formation Potential	7.9 %
Particulate Matter Formation	8.2 %
Abiotic depletion potential - Elements	3.0 %
Abiotic depletion potential - Fossil fuels	3.3 %
Water scarcity footprint	2.9 %

3.2.7. Characterization

Characterization factors have been applied when the impact of various emissions and resource use to the environmental impact indicators was calculated. Calculations and characterizations are in accordance with General Programme Instructions and the latest information on www.environdec.com.

The characterization factors used are:

- CML2001 - Jan. 2016, Acidification Potential (AP) non-baseline
- CML2001 - Jan. 2016, Global Warming Potential (GWP 100 years)
- CML2001 - Jan. 2016, Global Warming Potential (GWP 100 years), excl. biogenic carbon
- CML2001 - Jan. 2016, Eutrophication Potential (EP)
- CML2001 - Jan. 2016, Abiotic Depletion (ADP elements)
- CML2001 - Jan. 2016, Abiotic Depletion (ADP fossil)
- ReCiPe 2008 v1.05 Midpoint (H), Photochemical oxidant formation
- ReCiPe 2016 v1.1 Midpoint (H), Fine Particulate Matter Formation
- Available Water Remaining (AWARE) 2017, OECD+BRIC average for unspecified water

All CML impact indicators are baseline characterization factors except for AP, which is non-baseline. It should be noted that for the water scarcity indicator, AWARE, that the regional characterization method (OECD+BRIC) for unspecified water was selected based on the geographical scope of the study. Furthermore, the selected indicator considers the same water flows and is consistent with the methodology of the other water use indicator, use of net fresh water, which is a reported resource use indicator.

3.2.8. Environmental impact calculation

All Vattenfall's wind power sites were grouped with respect to wind conditions expressed as the capacity factor[2], and each group's percentage of the total annual wind power generation was calculated. The Environmental impact was calculated based on the groups' percentages of total wind power generation, see Figure 8 and Table 7 below. Studied wind farms were weighted within each group with respect to actual annual average electricity generation, see Table 8. Each wind power site is individually assessed regarding construction, operation, and dismantling after an assumed life of 20 or 25 years. Resource use, emissions, transportation, waste from construction, operation, refurbishments, and dismantling of the facilities are included.

[2] The capacity factor is determined as follows: (recorded electricity generation, during the year) / (installed capacity x 8 760 h).

__Table 7__ Grouping of wind farms and each groups' relative contribution to Vattenfall's wind power portfolio by the end of 2020.

	Portion of Vattenfall's wind power [%]
Group 0: Offshore. capacity factor >0.25	60.2 %
Group 1: Onshore. capacity factor >0.32	22.4 %
Group 2: Onshore. capacity factor 0.25-0.32	11.4 %
Group 3: Onshore. capacity factor <0.25	5.9 %

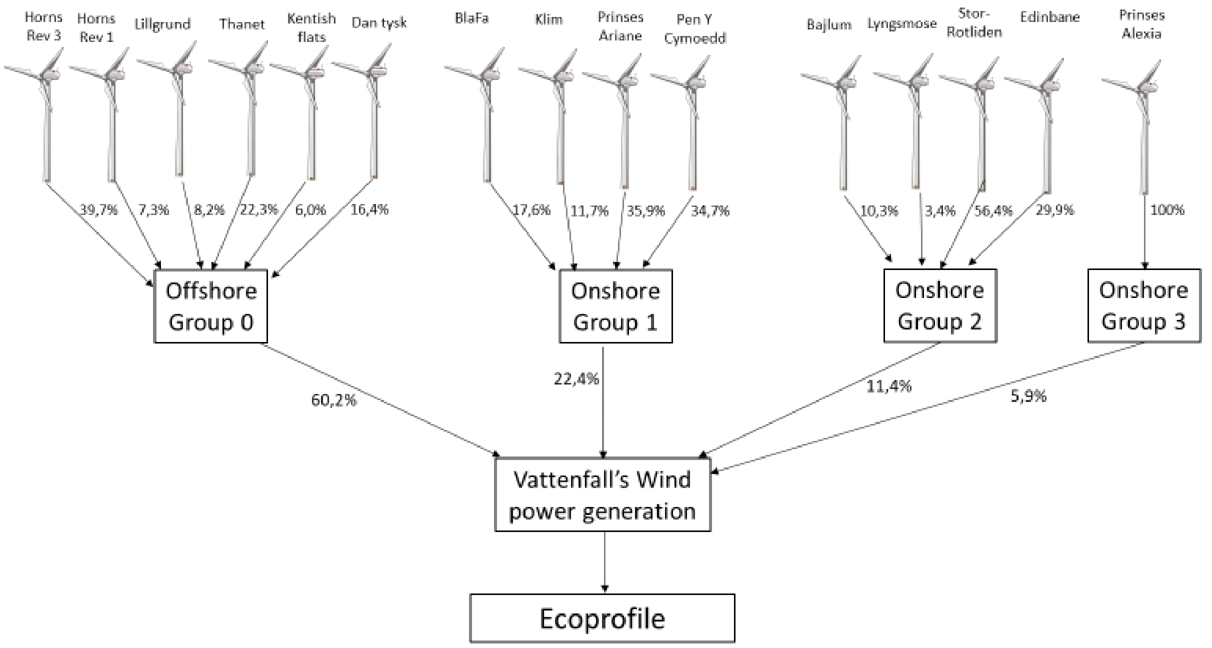


__Figure 8__ Weighting of included facilities in Vattenfall's Environmental impact for wind power

Table 8 *Wind farm and their weighting*

Group	Wind farm	Average capacity factor	Electricity generation 2020 [GWh, net]	Average electricity generation [GWh, net]	Portion of Vattenfall's wind power generation
0	Horns Rev 1[1]	0.44	430 (258)	481 (289)	3.3%
	Horns Rev 3	0.51	1 812	1 580	17.8%
	Lillgrund	0.34	354	327	3.7%
	Thanet	0.34	1 027	888	10.0%
	Kentish Flats	0.30	263	239	2.7%
	DanTysk[1]	0.51	1 229 (627)	1 281 (653)	7.4%
1	Klim[1]	0.41	241 (236)	224 (220)	2.5%
	Pen y Cymoedd	0.32	716	649	7.3%
	Blakliden Fäbodberget[1]	0.36	-	1 100[2] (330)	3.7%
	Princess Ariane	0.42	434	672[3]	7.6%
2	Stor-Rotliden	0.29	231	200	2.3%
	Edinbane	0.29	110	106	1.2%
	Lyngsmose	0.30	13	12	0.1%
	Bajlum[1]	0.32	43 (37)	43 (37)	0.4%
3	Princess Alexia	0.24	276	256	2.9%

[1] Vattenfall owns 60% of the wind farm Horns Rev 1, 51% of DanTysk, 30% of Blakliden Fäbodberget, 87.5% of Bajlum and 21 out of 22 turbines at Klim. Both total generation and Vattenfall's share is shown under average generation per farm, with Vattenfall's generation in brackets.
[2] Approximated production, since not yet commissioned at the time of assessment
[3] Approximated production, since not yet fully operating at the time of assessment

3.3. Environmental Impacts

The assessment results are summarized in Table 9 below and commented in sections 3.3.1-3.3.8.

Quantities are expressed per declared unit:

- For *Upstream, Core, Core - infrastructure*, and *Total generated*, the numbers are expressed per 1 kWh generated electricity.
- For *Downstream, Downstream - infrastructure*, and *Total distributed* the numbers are expressed per 1 kWh electricity delivered to a customer. Distribution losses are set to 5% of generated electricity.

More information on distribution and distribution losses is presented in section 0 on Distribution of Electricity. More comprehensive inventory data has been made available to the Certifier.

Table 9 *Environmental impacts*

Environmental impact categories		Unit/kWh	Upstream	Core	Core - infra.	Total - generated	Down-stream1	Downstream - infra.	Total - distributed
Global warming potential (GWP)	Fossil	g CO_2-eq. (100years)	0.0748	0.419	11.6	**12.1**	0.691	1.34	**14.2**
	Biogenic	g CO_2-eq. (100years)	0.00177	0.00151	0	**0.00329**	0.00173	0.0159	**0.0209**
	Luluc[2] (deforestation)	g CO_2-eq. (100years)	0	0	0.944	**0.944**	0.0472	0.445	**1,44**
	Total	g CO_2-eq. (100years)	0.0766	0.420	12.6	**13.1**	0.739	1.80	**15,6**
Acidification potential (AP)		g SO_2-eq.	2.20E-04	0.00350	0.0361	**0.0398**	0.00217	0.00248	**0.0445**
Eutrophication potential (EP)		g PO_4^{3-}-eq.	2.03E-04	6.85E-04	0.00703	**0.00792**	4.36E-04	0.00272	**0.0111**
Photochemical oxidant formation potential (POFP)		g NMVOC-eq.	6.76E-04	0.00498	0.0310	**0.0367**	0.00231	0.00590	**0.0449**
Particulate matter		g PM2.5-eq.	6.39E-05	5.59E-04	0.00916	**0.00979**	5.40E-04	6.45E-04	**0.0110**
Abiotic depletion potential - Elements		g Sb-eq.	3.23E-07	4.61E-08	1.72E-04	**1.73E-04**	8.66E-06	5.56E-05	**2.37E-04**
Abiotic depletion potential - Fossil fuels		MJ, net cal. value	0.00617	1.40E-04	0.130	**0.136**	0.00744	0.0179	**0.161**
Water scarcity footprint		m^3 H_2O-eq.	1.13E-05	3.79E-06	0.300	**0.300**	0.0150	9.87E-04	**0.316**

[1] Distribution losses of 5% of generated electricity are included in the downstream column.

[2] The indicator GWP Luluc entails emissions of greenhouse gases related to activities leading to land use and land use change.

3.3.1. Global Warming Potential (GWP)

Emissions of greenhouse gases emanate mainly from the combustion of fossil fuels and the major part in this study comes from the production of steel, i.e. from the core – infrastructure module. In total, core - infrastructure contributes with 80% of the emissions of greenhouse gases. The contributions from the life cycle modules, visualized in Figure 9 below, are further described below:

Upstream process contributes with about 0.5%, which emanates mainly from the production of fuels for the core process.

Core process: About 2.7 % of the total emissions, emanating mainly from incineration of operational waste and combustion of fossil fuels in service vehicles.

Core – infrastructure contributes with approximately 80% of total greenhouse gas emissions. The main contribution is driven by production and waste treatment of materials going into the infrastructure, this by about 92 %. Emissions of greenhouse gases emanate mainly from the combustion of fossil fuels as a part of the energy supply for manufacturing processes, here the majority comes from the production of steel for the turbine towers and foundations. Offshore wind sites require more steel mainly due to larger turbine towers and underwater construction, in comparison with onshore sites. This causes the lifecycle emissions of greenhouse gases from offshore sites in general to be higher than for onshore sites, although the higher production from offshore sites partly decreases the impact per kWh. Deforestation is a contributor to emissions from Core – infrastructure as well, contributing by 7.5 %. GWP from deforestation is a result of removal of the forest before construction, i.e. land transformation from high carbon stock land (forest) to lower carbon stock land.

Downstream process contributes around 0.5 %, caused mainly by inspection trips.

Downstream – infrastructure contributes approximately 11.5 % of total greenhouse gas emissions. The main contribution is driven by production and waste treatment of materials going into the infrastructure, this by about 75 %. The emissions from deforestation contribute 25 % to emissions from Downstream – infrastructure. As in the case of Core – infrastructure, removal of the forest before the construction of the transmission network (powerlines and poles) results in a net effect of carbon emissions.

Downstream distribution losses contribute by 4.2 %

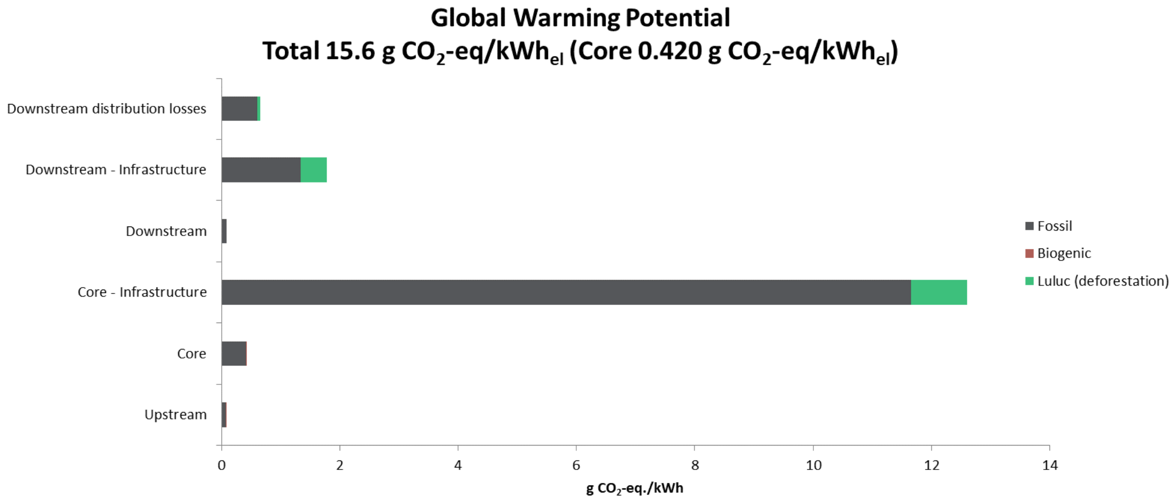


Figure 9 Potential emissions of greenhouse gases

Transportation accounts for about 5 % of the emissions of greenhouse gases. Including biogenic carbon dioxide does not affect the result. Carbon dioxide is the dominating greenhouse gas contributing to Global Warming Potential, this by 87 % of total. Other contributing substances are shown in Table 10 below.

Table 10 Substances contributing to Global Warming Potential (apart from carbon dioxide)

Substance	Contribution	Dominating process
Methane	5 %	Production of epoxy
Sulphur hexafluoride	1.5 %	Production of magnesium-alloy
N_2O	1 %	Production of steel

3.3.2. Acidification Potential (AP)

The dominant contributions to Acidification Potential occur in Core – infrastructure (see Figure 10 below) and are mainly due to emissions of NO_X and SO_2. NO_X contributes with 47 % of the total emissions and SO_2 with 45 %, of which Core – infrastructure contributes to 76 % of total NO_x and 94 % of total SO_2 emissions. Most of the SO_2 and NO_X emissions in Core - infrastructure are related to emissions from the production of steel used in construction of the wind farms, but also minor contributions from the production of concrete used in the construction of the foundations and epoxy used in the blades. The emissions of NO_X in the core module amounts to 17 % of total NO_X emissions and derives mainly from the emissions of service trips to offshore wind farms.

Transportation in all life cycle modules accounts for 16 % of the total emissions of acidifying substances; the main contributing emissions are NO_X and SO_2.

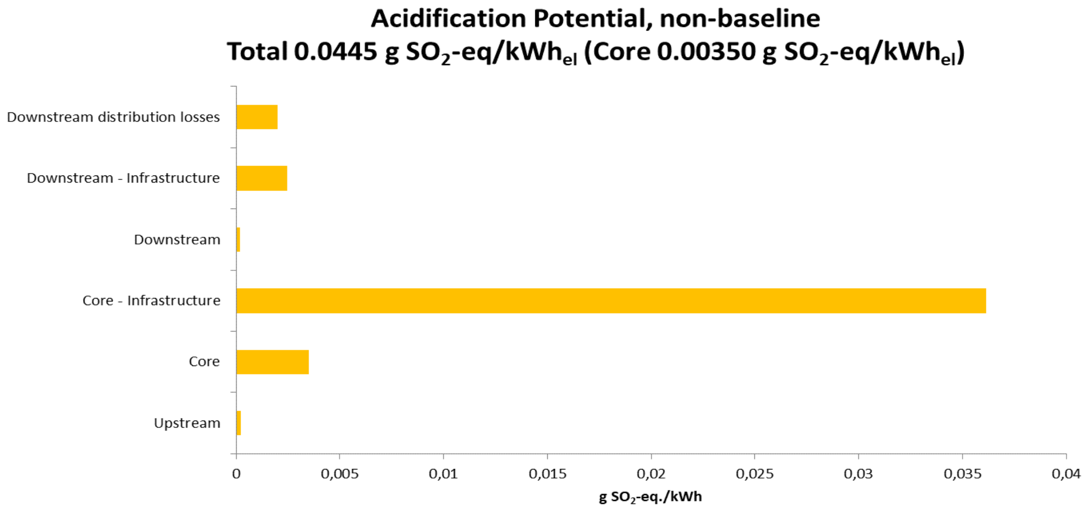


Figure 10 Potential emissions of acidifying substances

3.3.3. Eutrophication Potential (EP)

Oxygen consuming substances like organic matter, and nutrients like nitrogen and phosphorous compounds, cause eutrophication. The dominant substances to Eutrophication Potential are NO_X emitted to air and phosphate emitted to water, which account for about 36 % each. Chemically oxygen demanding substances, expressed as COD, emitted to water stand for 1 % of the total contribution.

The Core – infrastructure module accounts for about 63 % of the emissions of eutrophying substances, see Figure 11 below. In Core – infrastructure, most of the emissions of NO_X to air arises from the production of steel used in the construction of turbines and the foundations. Also, the production of epoxy used in the blades and the production of concrete used in the foundations contribute to this impact category. The emissions of COD to water comes primarily from the production of epoxy.

About 25 % of the emissions of eutrophying substances arises in the Downstream – infrastructure module, which is mainly due to the construction of the long-distance transmission grids.

Transportation accounts for 10 % of the total emissions of eutrophying substances; the main contributing emission is NO_X.

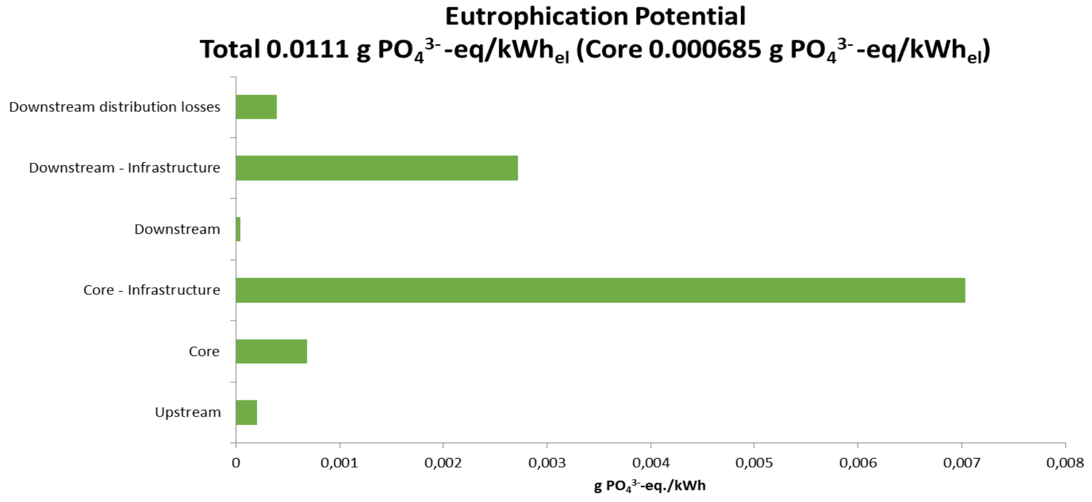


Figure 11 Potential emissions of eutrophying substances

3.3.4. Photochemical Oxidant Formation Potential (POFP)

In the presence of nitrogen oxides and sunlight various types of hydrocarbons in the air may give rise to photochemical oxidants, primarily ozone. The main contribution is related to the Core - infrastructure, approximately 69 %, where the production of steel and electronics dominates. Other large contributions are related to the Core module (by approximately 11 %) where the combustion of fuel for transportation is the largest contributor, and Downstream – infrastructure (about 13 %) where the materials for distribution grids dominates. See Figure 12 below.

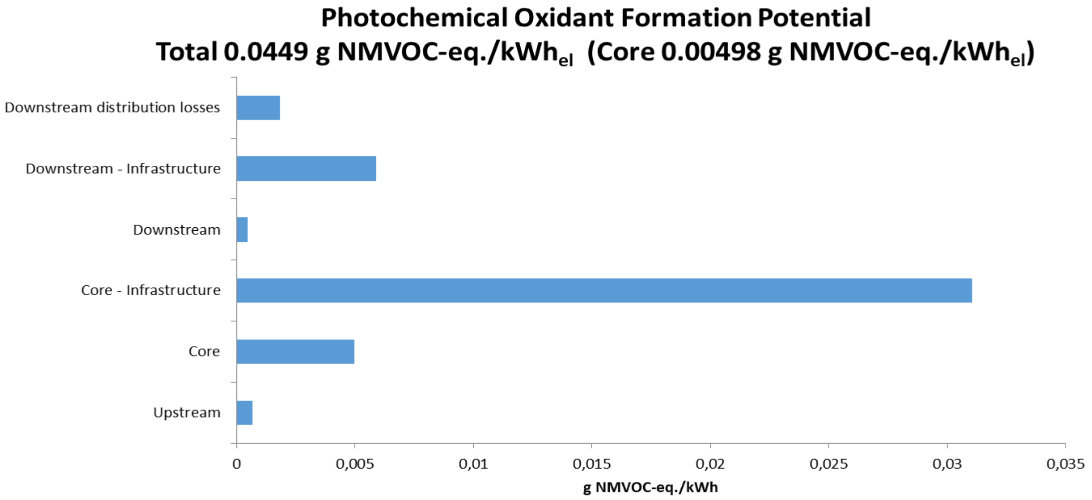


Figure 12 *Potential emissions of substances contributing to ground-level ozone*

3.3.5. Formation of fine particular matter

Fine particulate matter can be harmful to human health. Emissions of particulate matter emanate mainly from production of metals (mining) and digging (as during construction of distribution systems) but also from combustion of fuels. Emissions of particulate matter emanate mainly from the core - infrastructure module (84 % of the total emission of particles), and somewhat from core (5 %) and downstream - infrastructure (6 %). See

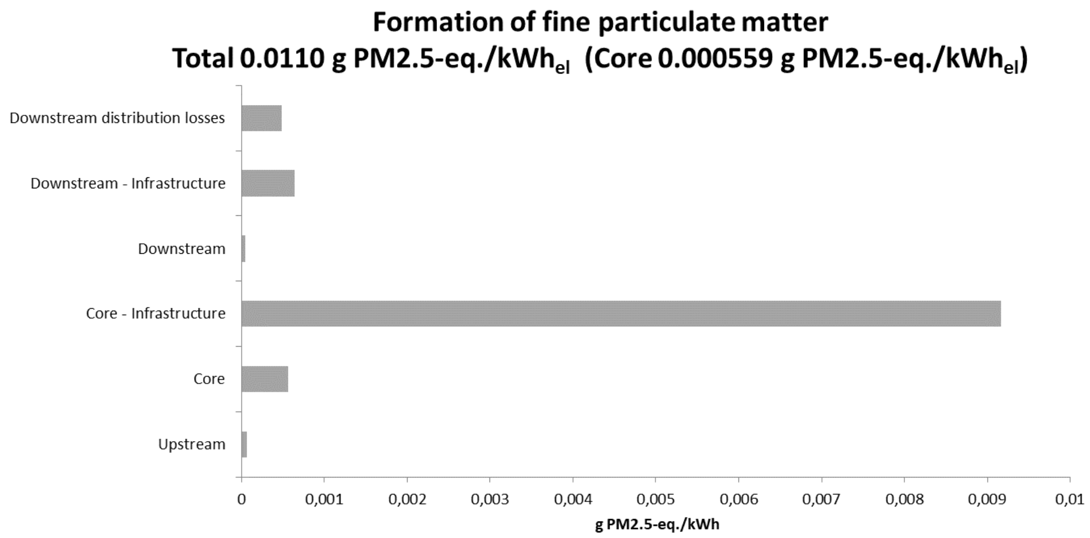


Figure **13** below. The emissions emanate mainly from the production of steel and epoxy used in the construction of the turbines and the foundations. Dust emissions whirling around in the air or water during construction and decommissioning of the wind farms have not been considered.

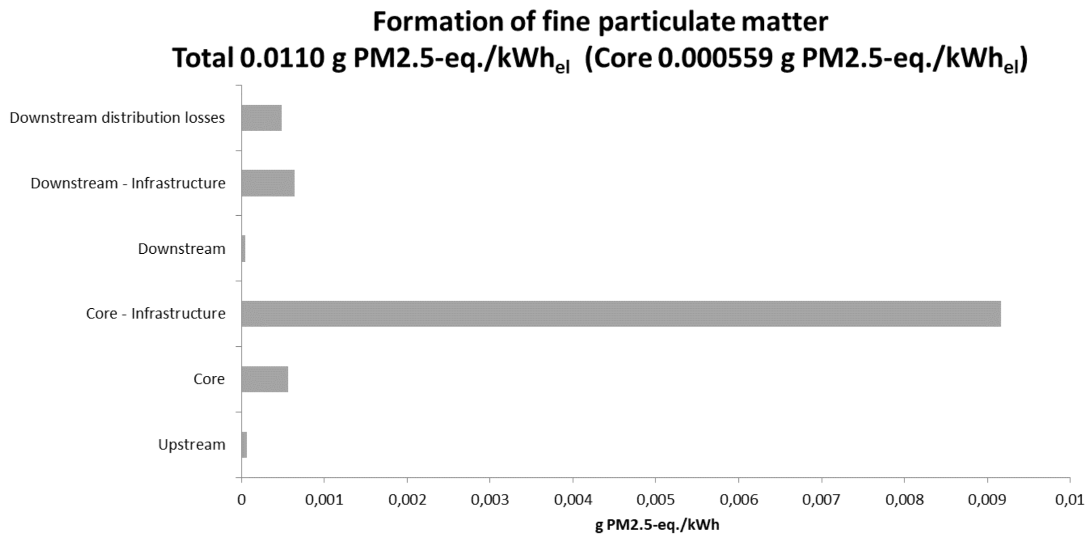


Figure 13 *Potential emissions of particulate matter*

3.3.7. Abiotic Depletion Potential (ADP) – elements and fossil fuels
Abiotic depletion refers to the depletion of non-living (abiotic) natural resources (including energy resources).

Abiotic depletion potential (elements) is a measurement of the non-renewable abiotic depletion of elements, such as metals, minerals etc. The impact category considers the size of the reserves and rate of extraction, so a metal or mineral that is rare is rated higher. The material use is accounted as a depletion even if the metal is recycled and used in another life cycle in the end of life, as the impact category measured the depletion of reserves.

Abiotic depletion potential (fossil fuels) is a measurement of non-renewable abiotic depletion of fossil fuels. As for elements, the impact category considers the size of the reserves and rate of extraction, so a fossil fuel that is rare is rated higher.

The main contribution to both these indicators is related to the Core - infrastructure module, approximately 73% (elements) and 80 % (fossil fuels), as shown in Figure 14 and Figure 15 below. Other large contributions are related to the construction of power distribution networks, approximately 23 % (elements) and 11 % (fossil fuels).

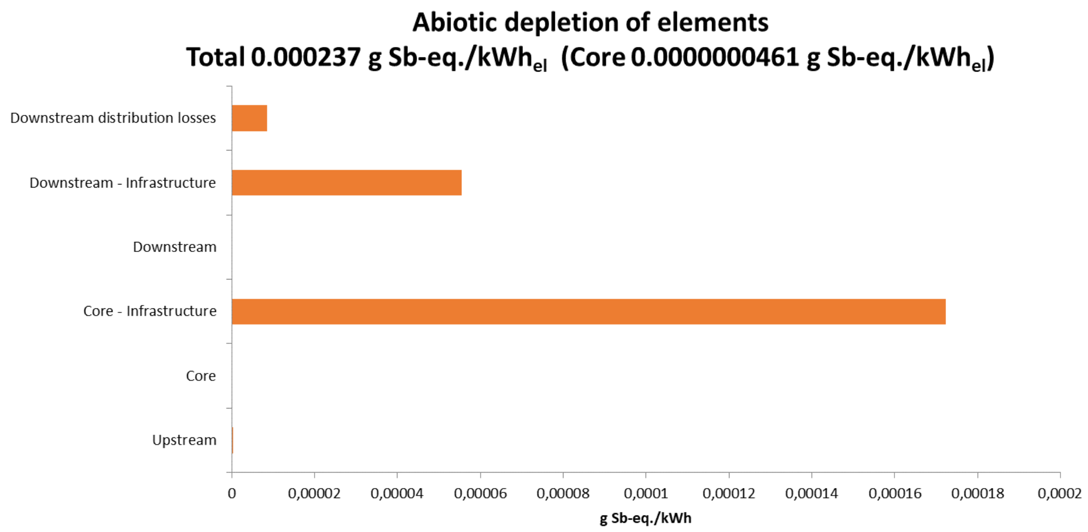


Figure 14 *Potential abiotic depletion of elements*

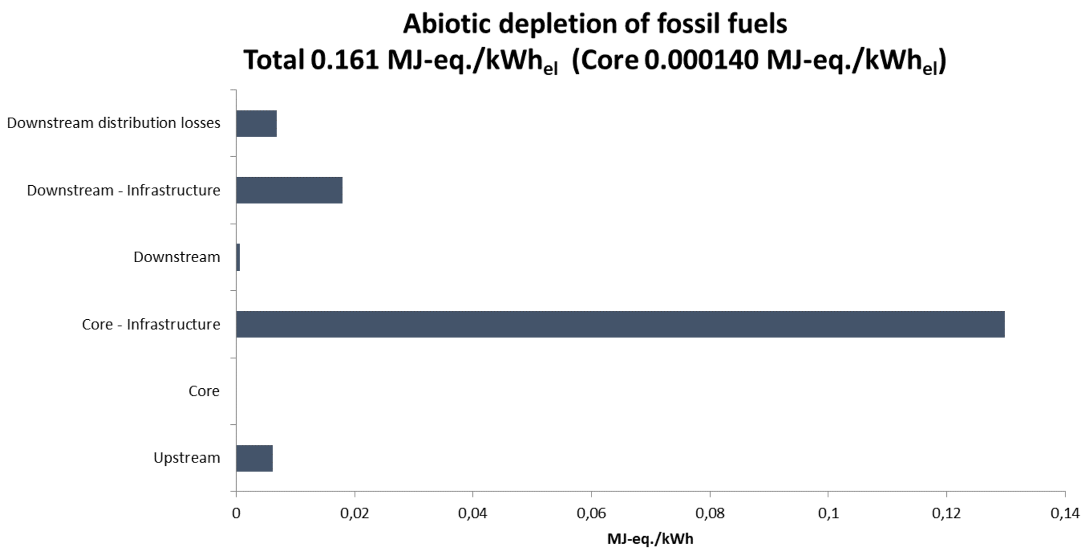


Figure 15 *Potential abiotic depletion of fossil fuels*

3.3.8. Water scarcity footprint (AWARE)

The water scarcity footprint is a regionalised approach which quantifies the relative available water remaining per (specified) area after satisfying the demand of aquatic ecosystems and anthropogenic activities. The impact category considers the water scarcity in the region where the water is consumed, so that water which is consumed in a scarce region is weighted higher.

The dominating contribution to water scarcity is related to the construction of turbines (Core - infrastructure), approximately 95 %, as shown in Figure 16 below. Water is mainly used in supplier processes and material production. The impact of distribution losses is driven by the impact of core – infrastructure.

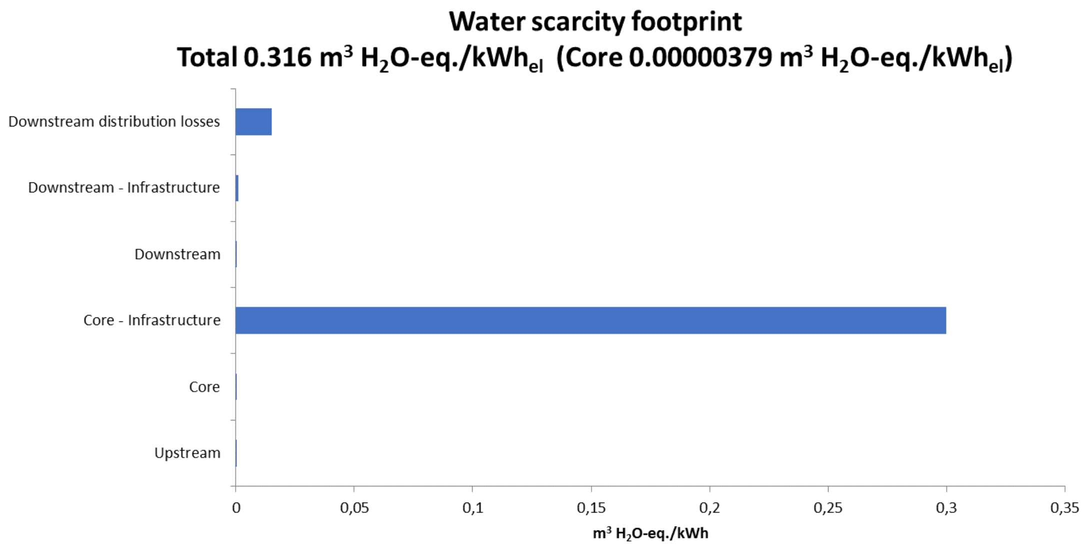


Figure 16 *Water scarcity footprint*

3.3.9. Dominance Analysis and Conclusions

Contributions to the studied environmental impact categories distributed between the different life cycle stages are shown in Table 11 below.

Table 11 *Dominance analysis for selected impact categories*

>50%	>25%	>5%	≤5%

Environmental impact categories		Unit/kWh	Upstream	Core	Core - infra.	Down-stream	Downstream - infra.	Distribution losses	Total - distributed
Global warming potential (GWP)	Fossil	g CO_2-eq. (100years)	0,5%	3,0%	82,2%	0,6%	9,5%	4,3%	**100%**
	Biogenic	g CO_2-eq. (100years)	8,5%	7,2%	0,0%	7,5%	76,0%	0,8%	**100%**
	Luluc (deforestation)	g CO_2-eq. (100years)	0,0%	0,0%	65,7%	0,0%	31,0%	3,3%	**100%**
	Total	g CO_2-eq. (100years)	0,5%	2,7%	80,5%	0,5%	11,5%	4,2%	**100%**
Acidification potential (AP)		g SO_2-eq.	0,5%	7,9%	81,2%	0,4%	5,6%	4,5%	**100%**
Eutrophication potential (EP)		g PO_4^{3-}-eq.	1,8%	6,2%	63,5%	0,4%	24,6%	3,6%	**100%**
Photochemical oxidant formation potential (POFP)		g NMVOC-eq.	1,5%	11,1%	69,1%	1,1%	13,1%	4,1%	**100%**
Particulate matter		g PM2.5-eq.	0,6%	5,1%	83,5%	0,5%	5,9%	4,5%	**100%**
Abiotic depletion potential - Elements		g Sb-eq.	0,1%	0,0%	72,7%	0,0%	23,5%	3,6%	**100%**
Abiotic depletion potential - Fossil fuels		MJ, net cal. value	3,8%	0,1%	80,4%	0,4%	11,1%	4,2%	**100%**
Water scarcity footprint		m^3 H_2O-eq.	0,0%	0,0%	94,9%	0,0%	0,3%	4,7%	**100%**

Core - infrastructure (construction, reinvestments and decommissioning of the wind farm) dominates within all reported environmental impact categories apart from biogenic CO_2 emissions. It is mainly the production of steel, concrete and composite material that causes these emissions but also the wind turbine suppliers' factories and transportation. Core – infrastructure contributes with 65.7% of total Luluc emissions, due to the clearing of forest for the wind farm areas.

Downstream - infrastructure (construction, reinvestments and decommissioning of the electricity network) contributes with around or less than 10% to most of the reported impact categories, apart from Eutrophication and Abiotic depletion potential (elements), where the contribution is around 24%. As well for biogenic CO_2 emissions, where the contribution is 76%, originating from aggregated processes for transmission network construction. The electricity network is mostly made up by steel constructions and hence emissions emanate mostly from steel production. Downstream – infrastructure contributes with about 31% of total Luluc emissions, due to the clearing of forest for transmissions networks.

The environmental impact from compensation for distribution losses in the table above is due to the generation of electricity needed to make up for the assumed transmission and distribution losses of 5 %.

A comparison of the results compared to previous version of this EPD® can be found in chapter 5.1.

3.3.10. Resource use

The LCA results regarding use of resources are summarized in Table 12 below. Resources are divided in renewable and non-renewable primary energy resources, use of secondary materials along with net use of freshwater. Primary energy resources classified as raw material are wood, plastics, lubricating oil and paper in components the power station and grid infrastructure. Secondary materials are found in metal (aluminium, steel and copper) parts, which contain shares of recycled scrap.

Table 12 *Resource use*

Resources		Unit/kWh	Upstream	Core	Core - infra.	Total - generated	Down-stream1	Downstream - infra.	Total - distributed
Primary energy resources - Renewable	**Used as energy carrier**	**MJ, net cal. value**	3.96E-05	5.86E-06	0.00885	**0.00890**	4.69E-04	0.00112	**0.0105**
	Used as raw material	**MJ, net cal. value**	1.86E-08	1.72E-09	1.22E-06	**1.24E-06**	6.20E-08	1.42E-07	**1.44E-06**
	Total	**MJ, net cal. value**	3.96E-05	5.86E-06	0.00885	**0.00890**	4.69E-04	0.00112	**0.0105**
Primary energy resources - Non-renewable	**Used as energy carrier**	**MJ, net cal. value**	0.00622	1.48E-04	0.136	**0.142**	0.00774	0.0186	**0.168**
	Used as raw material	**MJ, net cal. value**	0	0	2.77E-05	**2.77E-05**	1.91E-06	2.82E-06	**3.24E-05**
	Total	**MJ, net cal. value**	0.00622	1.48E-04	0.136	**0.142**	0.00774	0.0186	**0.168**
Secondary material		**g**	0	0	1.96E-04	**1.96E-04**	9.78E-06	0	**2.05E-04**
Renewable secondary fuels		**MJ, net cal. value**	0	0	3.19E-05	**3.19E-05**	1.60E-06	1.89E-06	**3.54E-05**
Non-renewable secondary fuels		**MJ, net cal. value**	1,08E-08	0	3.18E-05	**3.18E-05**	1.59E-06	1.88E-06	**3.53E-05**
Net use of fresh water		**m^3**	3,31E-07	1.10E-07	0.00875	**0.00875**	4.38E-04	2.89E-05	**0.00922**

[1] Distribution losses of 5 % of generated electricity are included in the downstream column.

3.3.11. Waste and output flows

Only waste amounts and output flows that are not treated within the system boundaries are reported in Table 13 - Table 15 below, in accordance with the PCR. Impacts related to incineration and deposition of waste which is treated within the system boundaries are included in the environmental impact results. All waste and residues from operation (core) of the windfarm to landfill or incineration have been followed to the grave and residues for recycling have been followed to collection sites, thus these categories are reported as 0 in Table 13 below.

Table 13 *Waste production for core processes*

Waste	Unit/kWh	Core	Core - infra.	Total
Hazardous waste disposed	**g**	**0**	**0.0249**	**0.0249**
Non-Hazardous waste disposed	**g**	**0**	**17.7**	**17.7**
Radioactive waste disposed	**g**	**0**	**3.52E-04**	**3.52E-04**

Table 14 *Waste production for upstream and downstream processes*

Waste	Unit/kWh	Upstream	Down-stream1	Downstream - infra.	Total - distributed
Hazardous waste disposed	g	3.12E-07	0.00124	3.12E-07	0.00124
Non-Hazardous waste disposed	g	2.51E-04	0.886	0.171	1.06
Ash	g	0	8.38E-04	1.01E-04	9.39E-04
Inert (rock, sand etc.)	g	0	0.103	0.00324	0.106
Radioactive waste disposed	g	1.01E-08	1.84E-05	6.28E-05	8.12E-05

[1] Distribution losses of 5 % of generated electricity are included in the downstream column

Reported hazardous waste consists mainly of chemicals and sludge from subcontractors' processes.

Reported non-hazardous waste emanates from mainly from the disposal of inert waste. The largest amount of waste comes from decommissioning of the farms. When decommissioned, 90% of the metal waste is assumed to go to recycling and the remaining 10% to landfill. Composite goes to landfill and polymers are assumed to go to waste incineration. Another source of waste is the reinvestment of the wind farms and consists mainly of metal that is recycled.

The construction of national power networks (transmission grid) in the downstream process has been calculated with selected generic data, where waste flows are not reported. The regional distribution network is calculated with specific data from Vattenfall Eldistribution AB, where all known waste flows that are not treated within the system boundaries are reported.

Table 15 *Output flows; materials for reuse, recycling or energy recovery*

Output flows	Unit/kWh	Upstream	Core	Core - infra.	Total - generated	Down-stream1	Downstream - infra.	Total - distributed
Components for reuse	g	0	0	0	0	0	0	0
Material for recycling	g	5.11E-06	0.00166	1.88	1.89	0.0943	5.07E-04	1.98
Materials for energy recovery	g	0	0.0127	0.355	0.368	0.0184	0	0.386

[1] Distribution losses of 5 % of generated electricity are included in the downstream column

Waste to recycling consists of metal scrap emanating from the manufacturing of generators and turbines and from scrapped components, which are assumed to be stripped down and recycled to 90 %. Other waste to recycling consists of plastic and chemicals.

Waste for energy recovery (incineration) consists mainly of waste flows of plastic from scrapped components, which are not treated within the system boundaries.

4. Additional Environmental Information

4.1. Land Use Change and Impact on Biodiversity

4.1.1. System boundaries and methodology
Land use change and impact on biodiversity is only described for the core processes.

From this year on, Vattenfall has developed a new method, meeting the basic requirements of the Product Category Rules. It is based on the Corine Land Cover classes (CLC), which form the basis of the requirements in the Product Category Rules. While the previous method categorized biotopes depending on their actual or potential value, the new method uses only the CLC classes within the project area to categorize biotopes and calculate land use change. In addition, the new method uses information found in Environment Impact Assessments (EIA) and survey reports to describe impacts on biodiversity qualitatively.

4.1.2. Land use change
Generally, land use data for the Before state has been received from Corine Land Cover (CLC)[3] data from before the onset of the wind farm, and land use data for the After state by using the latest (year 2018) Corine Land Cover data. For sites in Sweden, Sweden Land Cover Data from 2000 and CadasterENV Sweden data from 2018 have been used, which have a higher resolution than Corine Land Cover data. When CadasterENV data has been used, the categories have been transferred to Corine Land Cover classes according to a translation key in the developed method. For some sites, manual adjustments or calculations have been made to either the Before or After state to represent the real situation more accurately. A problem with using CLC-data and CadasterENV- data is that both these data are based on satellite images, which does not reflect land use changes on the seabed. In the calculations of land use change for offshore wind farms are shown as 0. This is of course not true since foundations of turbines, substations, and weather stations as well as cables both within the area of the wind farm as well as from the offshore site to land cover parts of the seabed. Results of land use change per site according to Corine Land Cover classes at level one, are given in table 16 below.

Comparisons made between onshore and offshore wind farms show that the number of artificial surfaces is larger for onshore installations, which is mainly due to the need for access to the wind turbines by roads. Land-use change in offshore wind farms is poorly shown by CLC, since the CLC data is based on satellite images, which only mirrors the sea surface. For this reason, the relevant information on impact is given in the qualitative description of each offshore wind farm. For Kentish flats GIS-data was available for its onshore constructions, why the CLC data provides information on land-use change regarding terrestrial land.

For onshore sites, the roads and cables are the main reason for land-use change. For the Danish onshore wind farm Bajlum located on agricultural land, the cables have been located by the roadside and have not affected the area of exploited land. In Princess Ariane and Princess Alexia, which are also situated on agricultural land, the cables have caused a larger area of both agricultural land and forest to be exploited. Stor-Rotliden, Blakliden-Fäbodberget (all in Sweden) and Pen y Cymoedd (UK) are located in woodland. The roads and cables in these sites have contributed to a larger area of exploited land.

[3] In the tables in chapter 4.1, the Corine Land Cover classes are shown together with their respective number used in the CLC-standard.

*Table **16** Land use change in the project area of each site, summarized to Corine Land Cover class 1.*

Wind farm	Land cover	Area before (m²)	Area after (m²)	Land use change (m²)
Offshore				
DanTysk	5. Water bodies	8.93E+07	8.93E+07	0[1]
Horns Rev 1	5. Water bodies	1.96E+07	1.96E+07	0 [1]
Horns Rev 3	5. Water bodies	1.44E+08	1.44E+08	0[1]
Kentish flats	1. Artificial Surfaces	2.23E+04	1.92E+04	-3.13E+03
	2. Agricultural areas	2.28E+04	2.28E+04	0
	4. Wetlands	0	3.13E+03	3.13E+03
	5. Water bodies	1.82E+07	1.82E+07	0[1]
Lillgrund	5. Water bodies	6.88E+06	6.88E+06	0[1]
Onshore				
Bajlum	1. Artificial Surfaces	0	1.44E+04	1.44E+04
	2. Agricultural areas	1.44E+04	0	-1.44E+04
Blakliden Fäbodberget	1. Artificial Surfaces	2.58E+05	5.92E+05	3.34E+05
	3. Forest and seminatural areas	2.75E+07	2.72E+07	-3.25E+05
	4. Wetlands	4.82E+06	4.81E+06	-9,24E+03
	5. Water bodies	6.54E+05	6.54E+05	0
Edinbane	1. Artificial Surfaces	0	1.11E+06	1.11E+06
	3. Forest and seminatural areas	3.99E+05	3.56E+05	-4.27E+04
	4. Wetlands	8.16E+06	7.10E+06	-1.06E+06
Pen Y Cymoedd	1. Artificial Surfaces	6.12E+05	7.79E+06	7.18E+06
	2. Agricultural areas	4.81E+04	4.92E+04	1.12E+03
	3. Forest and seminatural areas	4.62E+07	3.90E+07	-7.18E+06
Princess Alexia	1. Artificial Surfaces	0	1.52E+05	1.52E+05
	2. Agricultural areas	1.52E+05	0	-1.52E+05
Princess Ariane	1. Artificial Surfaces	8.48E+02	8.64E+05	8.63E+05
	2. Agricultural areas	8.19E+05	0	-8.19E+05
	3. Forest and seminatural areas	4.49E+04	0	-4.49E+04
Stor-Rotliden	1. Artificial Surfaces	0	3.40E+05	3.40E+05
	3. Forest and seminatural areas	1.05E+07	1.01E+07	-3.50E+05
	4. Wetlands	1.41E+06	1.42E+06	6.63E+03

[1] Since the land use change i based on CLC-data, changes of land use on the seabed are not shown. However, wind turbine foundations, cables, substations and weather station occupy areas on the seabed.

Fel! Hittar inte referenskälla. below is a summary of the land-use change of all sites together according to Corine Land Cover classes at level one.

***Table* 17** *Land use change – summary for all sites*

Land cover	Area before (m²)	Area after (m²)	Land use change (m²)
1. Artificial Surfaces	8.93E+05	1.09E+07	9.99E+06
2. Agricultural areas	1.06E+06	7.20E+04	-9.84E+05
3. Forest and seminatural areas	8.46E+07	7.67E+07	-7.94E+06
4. Wetlands	1.44E+07	1.33E+07	-1.06E+06
5. Water bodies	2.79E+08	2.79E+08	0[1]

[1] Since the land use change i based on CLC-data, changes of land use on the seabed are not shown. However, wind turbine foundations, cables, substations and weather station occupy areas on the seabed.

Fel! Hittar inte referenskälla. shows the total area occupied per year of operation by each wind farm. The figures are based on the increase of artificial surfaces in the After state compared to Before.

Table 18 *Total area occupied per year of operation by each wind farm.*

Site	Area occupied (m2)	Estimated years of operation	Area occupied / year of operation (m2)
Dan Tysk	0[1]	20	0[1]
Horns rev 1	0[1]	20	0[1]
Horns rev 3	0[1]	25	0[1]
Kentish flats	0[1]	20	0[1]
Lillgrund	0[1]	20	0[1]
Bajlum	14 400	20	719
Blakliden Fäbodberget	334 000	25	13 400
Edinbane	1 110 000	20	55 400
Pen y Cymoedd	7 180 000	20	359 000
Princess Alexia	152 000	20	7 600
Princess Ariane	863 000	25	34 500
Stor-Rotliden	340 000	20	17 000
Total	**9 990 000**	**280**	**488 000**

[1] Since the land use change i based on CLC-data, changes of land use on the seabed are not shown. However, wind turbine foundations, cables, substations and weather station occupy areas on the seabed.

4.1.3. Description of impact on biodiversity

The following is a brief general description of the effects, positively and negatively, of offshore wind farms on biota. The most adverse effects of offshore wind farms are the noise pollution and turbid water when pile driving for building foundations (Naturvårdsverket 2012[4]). The noise can scare biota, both bottom fauna, fish, birds and mammals off and in worst case cause damage or even be lethal to some species. Also, when establishing the cables, water turbidity increases, which can cause adverse effects on several smaller biota. Since especially noise disturbance is an increasing problem in marine environment, numerous turbines and several wind farms within the same region can cause severe barrier effects and fragmentation for both fish and marine mammals. Also, for birds both these effects can cause severe disturbance since some bird species avoid wind farms when migrating, but also for feeding. However, there might also be positive effects wind offshore windfarms. The foundations as well as stones and gravel beds formed around the foundations constitute hard surfaces that cause so called reef effects. For foundations built for wind turbines, it is unique that these so called reefs reach from the seabed all the way up to the water surface. There are indications that fish can be attracted to these so called reefs, where they may find food more easily, find shelter and some fish predators can hunt without being hunted themselves.

The following is a brief general description of the negative effects of onshore wind farms on biota. No positive effects of onshore wind farms on biota are described in the literature. The main negative effects concern birds and bats (Naturvårdsverket 2017[5]). Regarding birds it is known that the number of birds killed increases with the physical size of the wind turbine. However, since larger wind turbines produces more electricity, the mortality decreases with increasing installed effect and produced electricity. All kinds of birds are killed by wind farms and birds are probably killed at all existing wind farms. In relation to their population size, raptors, gulls and game birds are killed at higher rates than expected based on their population sizes. Bats are also frequently killed by wind farms. However, the mortality is limited to only those species flying and feeding in the open air above the tree canopies. Since wind farms causes collisions and especially some birds avoid flying through wind farms, the wind farms cause barrier effects as well as fragmentation of the landscape. If there are numerous turbines and several wind farms within the same region it can cause profound effects on bird migration and decrease the populations of both birds and bats.

The above general description of effects of wind farms on biota is relevant for all offshore and onshore wind farms respectively. The magnitude of the problems is specific to the site in question. Regarding the wind farms owned by Vattenfall, the general picture is that in recent years, inventories regarding all relevant organism groups are conducted in the planning phase. Based on the results of the inventories the wind farms are placed so that collisions and other damages on biota to a large extent are avoided. However, it is important to point out that especially birds but also bats, in areas where they exist, still are killed at all onshore wind farms (Naturvårdsverket 2017[5]). Also, several mitigation measures have been developed both for on- and offshore wind farms. For example, so called bat mode is used for onshore wind farms. This means that wind farms are stopped during some summer nights when temperature is high and wind speed low, which are nights when bats hunt at high altitudes. For offshore windfarms, for example mitigation measures such as “ramp-up procedure”, where loudness of noise slowly is increased or creating a curtain of bubbles around foundations are used. Both measures are used to scare animals off to avoid damage by very high noise disturbance. For older, especially offshore wind farms mitigation measures were not developed. However, long term studies are necessary to measure the impact effect of wind farms on biota, since there have been some indications on that birds and fish return to the wind farm areas after some years after the onset.
Below, site specific effects on biota is described. The information content varies somewhat depending on which information could be retrieved from EIAs (new wind farms) or the previous EPD from 2019 and the Biotope report from the same year.

4.1.3.1. Offshore windfarms

DanTysk

The DanTysk windfarm is located approximately 70 kilometres west of the North Sea Island of Sylt in the German EEZ (exclusive economic zone) adjacent to the Danish border. The site is situated within an important area for roosting birds (Important Bird Area), as well as inside a defined potential marine protection area. Three biotopes of habitat type ‘reefs’ (code 1170)” are found in the project area and there are further eight areas with possible reefs. The site is a part of an important wintering ground for divers (Red-throated Diver and Black-throated Diver) and has been graded in the highest classification as of international importance. The site is also important wintering ground for Little Gulls,

[4] Naturvårdsverket 2012. Vindkraftens effekter på marint liv. En syntesrapport. Naturvårdsverket, Rapport 6488.

[5] Naturvårdsverket 2017. Vindkraftens påverkan på fåglar och fladdermöss. Uppdaterad syntesrapport 2017. Naturvårdsverket. Rapport 6740.

which are roosting and passing through the area. The location is within the wintering ground IBA eastern German Bight, which is of international importance for this species. The air space above the proposed area was also ranked as being in the highest classification due to the migrating Divers and Pink-footed Geese (Spitzbergen population) that fly through the area.

There is an intermediate risk of negative effects for wintering divers. As divers are sensitive to disturbance from ships it was assumed that divers will be completely displaced from the wind park. Only some migratory bird species in small sections of their distribution area or migration route will be negatively affected. It is assessed that this only will cause low adverse effects on the populations concerned. It has been established that there is a small to intermediate adverse risk for Harbour Porpoises during the period of construction of the wind farm. During the time of operation of the wind park, Danish investigations indicate only very limited disturbance to marine mammals.

Horns Rev 1

Horns Rev 1 is situated at the west coast of Jutland in Denmark. A portion of the 19,5 km long cable from the wind farm to the shore passes an area protected by the Ramsar Convention, EU's Bird Directive and EU's Habitat Directive. This area is considered to be a rare biotope. The site is situated on sandy seabed and the benthic fauna is dominated by *Ophelia borealis* – society, typical for sandy substrates in the North Sea. The cable between the wind farm and land crosses an area where the sand is mixed with more silt and here the benthic fauna is characterized by *Abra*-society. Close to the coast the cable crosses an area where the substrate is mainly silt with clay, where the *Lanice conchilega*-society dominates. Studies before the onset of the wind farm showed that the number of fish species was low, and the population sizes of fish varied a lot between years. The site of the wind farm is not important for seals. An area northeast of the wind farm is used by the harbour porpoise. Studies before the onset of the wind farm shows in general a relatively low frequency of bird species within 2-3 km from the site. However, in summer and winter, there are high numbers of common scoter in areas close to the wind farm.

At Horns Rev 1 several investigations of flora and fauna has been made since the onset of the site. The wind farm turns out to have had several positive effects on marine biota. The introduction of hard surfaces through foundations and gravel beds has created opportunities for new forms of life. Vegetation is scarce and mainly limited to the zone just beneath the waterline on the monopiles. 11 species of seaweed (macro algae) have been registered. 70 species of invertebrates have been registered. Common blue mussel is found on the foundations down to a couple of metres below the surface of the water. Two red-listed species of the peacock worm *Sabellaria* and the colony-forming hydroid *Sertularia cupressina* have been observed. The new hard grounds offer a 60 times larger supply of food for fish and other organisms compared to the conditions in the Before situation. Many species e.g. pouting and shoals of codfish seek food close to the hard surfaces. The occurrence of herring gull, little gull, common scoter, and artic tern is increasing at Horns Rev and in 2004 common scoter and herring gull were the most common bird species. Red-throated diver, black-throated diver, gannet, and razorbill belong to the species avoiding the wind farm. It is not known why certain species avoid the wind farm. Disturbances from turbines is a possible reason and the increased human activity in the area another. The risk of collision for birds with wind turbines was studied during three periods in 2004. No collisions were observed. There is an ongoing research project regarding impacts on seals and porpoises.

Horns rev 3

Horns reef and the Horns rev 3 project area is located in an area of the North Sea that is rich in bird life of both resting seabirds and migratory birds including a large part of Europe's total population of waterfowl. Because of the importance for several seabirds and waders, Horns reef and the Wadden Sea area in the south, are of national and international significance. Furthermore, the area is due to good conditions for various fish species of great importance to harbour porpoise as well as to grey and harbour seals.

The main risk for impact on seals and porpoise was assessed to come from noise emissions from pile driving during the construction of the wind farm. The noise was calculated to reach levels which could cause permanent damage to the animals, and the EIA concluded that noise mitigation measures were needed. The wind farm was not assessed to cause any major impact on marine mammals during operation. Risk for bat collisions was estimated to be low. Degree of impact for some bird species was classified very high, while it was classified as high, medium, or low for other species. It was considered unlikely that annual mortality caused by collisions with wind turbines will exceed 1 % of the individuals in flyway populations of bird species detected in the Horns Rev region. The impact assessment on resting birds concluded with mostly low impacts to resting birds.

Kentish flats

The Kentish flats offshore wind farm is situated in the Thames Estuary, 8 to 10 km from the North Kent Coast, north of Herne Bay and Whitstable. A lot of different bird species were recorded within the area of the wind farm during monitoring investigations for the EIA. Two species of terns, sandwich tern (*Sterna sandvicensis*) and common tern (*Sterna hirundo*), are nesting within foraging distance of the wind farm. Migratory species that have been recorded in the wind farm area include divers, geese, ducks, waders, and guillemots. All of these are of potential conservation concern. The export cable reaches land at the western end of a Special Protection Area (Natura 2000) called Thanet Coast and Sandwich Bay SPA. This SPA is primarily of value for the population of turnstone, especially during wintertime. The area is also used by many migratory birds, some notable ones (with conservation value) being, golden plover, sanderling, ringed plover, and grey plover. The impact on the SPA is considered to be of little importance since no trenching of the landfall cable was carried out. The cable was instead buried by directional drilling below the coastal line.

Ornithological monitoring indicates that the SPA species red-throated diver (*Gavia stellata*) is avoiding the windfarm. There has been little other change in bird life or migration routes for birds through the Kentish Flats area during the monitoring period. No significant effects on the flight lines or behaviour of SPA species, have been recorded. Collision risks for SPA species remain very low due to the low numbers of birds recorded and the generally low flight heights.

Lillgrund

Lillgrund is located on three shallow areas in Öresund (between Denmark and Sweden) with a varying water depth of 1-12 m. The seabed is dominated by sand or gravel, but there are also areas with stones and hence red algae. There are some colonies of blue mussel. Öresund is an important migratory route for many fish species such as eel and Atlantic herring, although the number of eels has decreased during the last decades, Areas with eelgrass (*Zostera marina*) and shallow, sandy areas are important reproduction sites for flatfish. In general, the areas around Lillgrund were assumed to be important reproduction areas for fish, but there was not information on which fish species that reproduced around Lillgrund. The conducted inventories of resting and wintering birds in the Öresund area show that the area has a rich and varying fauna of waterfowl, gulls, and terns. The highest number of birds are measured in the autumn when more than 40 000 individuals has been noted during the investigations along the Swedish coast from Lernacken to Falsterbo. The baseline studies showed that there is a low risk for bats to collide with the wind farm and that possible losses are negligible compared to the size of population for the species studied.

Monitoring programs include for example birds, fish, marine flora and fauna. To assess the impact on flora and fauna, the biological key species eelgrass and common blue mussels were chosen for special monitoring studies. A method with video screening was applied. After the first year of operation there no negative effects from the construction work were found. There were also no negative effects on fish that could be related to the wind farm. Regarding birds, inventories after one year of operation clearly shows that long-tailed duck, common eider and red-breasted merganser are avoiding the wind farm and not using Lillgrund as they did before the establishment of the wind farm. It was also seen that the proportion of flocks passing Lillgrund was only ¼ of the amount flocks passing before the start of the wind farm.

4.1.3.2. Onshore windfarms

Bajlum

Bajlum wind farm is located in Skive, in northern Jutland, Denmark. The surroundings of the wind farm are dominated by agricultural land, however there is some nature with conservation values in the adjacent area. One of the windmills is located nearby a water stream which is included in the Nature Protection Act in Denmark (naturbeskyttelseloven §3). Furthermore, there is a bird protection area approximately 10 km away which is also part of a Natura 2000 area.

The establishment of the wind farm mainly decreased the area of agricultural land in the project area. According to the EIA the project is not expected to have any negative impact on protected areas or habitats of species covered by international conservation. Before the establishment of the wind farm there was some deciduous forest with low conservation value. This forest was removed when establishing the windfarm.

Blakliden Fäbodberget
The wind farm consists of two areas. Both are dominated by coniferous forest used for forestry. In Blakliden there are two protected areas that could be negatively affected by the wind farm. These protected areas are both national nature reserves as well as Natura 2000 areas and called Bäckmyrkullen and Blakliden (Pöyry SwedPower AB, 2011a). In Fäbodberget there are also two protected areas that could be negatively affected by the wind farm; the nature reserve Vargen and the Natura 2000 area called Lögdeälven (Lögde river, Pöyry SwedPower AB, 2011b).

The establishment of the wind farm mainly decreased the area of coniferous, broad-leaved, and mixed forests in the project area. The exact position of wind turbines and roads was adjusted to avoid any negative impact on areas with high natural value, and mitigation measures were implemented to avoid any damage to Natura 2000 areas. Overall, the effect on the bird fauna was assessed to be small. An area where golden eagles had been observed to pass through the project area was left without turbines to avoid any impact. Some negative impact on the densities of more common forest-dwelling bird species may be the case in the long run, but this impact is expected to be limited and local. The project area was assessed to be of no importance for resting or overwintering birds and the project area was assumed to not affect any major migratory routes. There were no indications of presence of any particularly endangered bird species. With implemented protective measures, the wind farm was assessed to not adversely affect the conditions for the golden eagle's further establishment in the county. The project area was assessed to be of low risk for bat collision with wind turbines.

Edinbane
The wind farm is located in the south of the village of Edinbane on the Isle of Skye, UK. The landform of the site is very diverse. The landscape is greatly influenced by the presence of areas of seascape, which can be seen as linear open spaces of water extending as sounds and narrows into the surrounding landform. Most of the farm is located in the smooth stepped moorland, but a small portion is located in coniferous woodland plantation. The moorland is mainly used for agricultural purposes and is typical of the northern sector of Skye. The acid grasslands within the project boundary appear to be typical of this area within the Isle of Skye and elsewhere in the western Highlands. No part of the Edinbane site is subject to national or local ecological designation. A noticeable feature is the lack of confirmed breeding by birds of prey within the survey boundary which may reflect the smooth terrain, lack of suitable breeding sites and prey resource. However, the merlin (*Falco columbarius*) and hen harrier (*Circus cyaneus*), both red-listed are seen in the area. Also, both the white-tailed sea eagle and even more the golden eagle are known to frequent the application site and surrounding area.

The establishment of the wind farm reduced some of the moorland and acid grassland. No other effects of the establishment of the wind farm are described.

Pen y Cymoedd
The windfarm is located on land in southern Wales, United Kingdom. Most of the project area covers coniferous forest, but there are also moors and heath.

The establishment of the wind farm reduced the area of coniferous woodland and peat land with coniferous trees. The peat land with coniferous trees is assessed to important bog habitat. As a mitigation measure, around 300 000 cubic metres of peat was removed and relocated to restoration areas. This measure was assessed to more than compensate for the impact of the wind farm. No protected areas were assessed to be impacted by the wind farm. The bat monitoring program survey reports have reported findings of at least seven different species of bat and some mortalities from collision with the turbines. It was considered unlikely that collision risk would be a significant threat to local bird populations. Monitoring programs of nightjar and honey buzzard report presence of the species in the area despite the presence of the wind turbines.

Figure 17. Overview Pen y Cymoedd

Princess Alexia

The windfarm is located in Zeewolde (Flevoland), the Netherlands. The area consists of agricultural land. Within the system boundaries there are no areas that constitute valuable biotopes. Nearby the windfarm there are three Natura 2000 areas named Arkenheem, Eemmeer and Gooimeer south bank. The Natura 2000 areas include valuable biotopes for the Bewick's swan (*Cygnus columbianus bewickii*), Grebe sp*.,* grey goose (*Anser anser*), widgeons sp., pochard, tufted duck (*Aythya fuligula*) and common tern (*Sterna hirundo*). There are also areas included in national ecological networks, called EHS, nearby and within the windfarm. The EHS is a network of areas in the Netherlands where nature takes precedence over other interests. Gruttoveld, Gorzenveld and Rassenbeekt are located within the windfarm area. These EHS-areas include valuable biotopes for grey goose (*Anser anser*), harrier and bittern (*Botaurus stellaris*). Outside the windfarm area the EHS area Horsterwold is located in the east, Hulkenstein in the south and Stichtse putten in the north. From inventories it has been shown that the windfarm mainly has a function as a foraging area for many bat species.

The establishment of the wind farm decreased the area of agricultural land in the project area. It was assessed that the wind farm will have no effects on the Natura 2000-habitats or the birds the areas are designated to. The conclusions regarding the effects on the EHS areas are that the windfarm has some effect on these values due to fragmentation and disturbance. Effects on bats are not expected since current bat species fly on lower altitude than where effects on those could be expected. The Rosy bat is an exception and are known to fly on higher altitude. The impact on the Rosy bat from the wind park is not known, but the risk of collision cannot be ignored and the function and quality of the area as a foraging area for bats, especially the Rosy bat, is decreased due to the windfarm.

Princess Ariane

It I situated in the municipality of Hollands Kroon, in the Northwest of the Netherlands. It consists mainly of agricultural land and small areas of broad-leaved and coniferous forest. The wind farm is located close to two Natura 2000 areas. These Natura 2000-areas are among other species designated to protect the Bewick's swan and tundra bean goose. A few windmills are placed inside the Robbenoordbos EHS area,

The establishment of the wind farm mainly decreased the area of agricultural land in the project area. Small areas of coniferous, broad-leaved, and mixed forest were also turned into artificial surfaces. The wind farm was assessed to have a negative effect on the conservation objectives of the Bewick's swan and tundra bean goose and concluded that mitigating measures were necessary. For all other designated species, effects were assessed to be negligible. A few windmills were planned to be placed inside the Robbenoordbos EHS area. This was assessed to cause change in land use of an area up to 2 ha, which was considered significant damage. Establishment of the Princess Ariane wind farm was calculated to lead to an increase in the total number of bird collisions by up to 1,650 birds per year. Significant numbers of collisions were not expected among locally, regionally, or nationally scarce or rare bird species. It could not be ruled out that the wind farm would have an effect on the conservation status of the two bat species Nathusius' pipistrelle and common pipistrelles, without implementing mitigation measures.

Stor-Rotliden
The wind farm is situated in Åsele, Västerbotten, in the north of Sweden. Spruce forest used for forestry dominates the hilly landscape. The area also includes old spruce forest with nature conservation values such as dead wood and pendulous lichens. The project area has been utilized for forestry. A number of areas of valuable forest occurred and do occur in the area. The wind farm is adjacent to a Natura 2000 area in the east. This Natura 2000 area consists of very old forest. Within the project area there are a number of streams, which are protected by Natura 2000. In the south, there is an area considered to be of national interest for nature conservation, outdoor recreation, and reindeer.

The establishment of the wind farm reduced the area of broad-leaved and mixed forest, as well as the area of transitional woodland. The project's environmental impact assessment (EIA) has not considered those interests to be affected by the wind farm. Some forest areas of high value have been lost due to the establishment of the wind farm (Sweco 2019).

4.1.4. Land use, downstream processes – electricity distribution
The power grid also has an impact on biodiversity, both positive and negative, but the impact on biodiversity from the distribution of electricity is not included in this study.

Lanes are regularly cleared, which removes trees but also creating possible habitats for species normally inhabiting heathlands, meadows, and pastures. In addition, lanes constitute border zones, which are generally considered more biodiverse than homogenous areas. Wider lanes may constitute barriers that may cause fragmentation for some woodland species. In an agricultural landscape the lanes do not have any particular impact on biodiversity, positive or negative.

4.2. Environmental Risk Assessment

4.2.1. System boundaries
In this EPD®, risk is identified as the probability of an undesired event multiplied by the consequence of the event. The purpose of environmental risk inventory (ERI) is to give complementary information to the overall picture given in the LCA concerning environmental risks. While the LCA is to describe emissions etc. during normal operation of a power plant, the aim of the ERI is to describe more unexpected and rare mishaps that occur or have occurred during operation, also referred to as "abnormal operation". In relation to the Land use and Biodiversity section of the EPD, the Environmental risk inventory covers abnormal events and includes mainly effects on emissions and effluents. The Land use and biodiversity part includes effects on flora and fauna as a result of exploitation of land and water, for example collision between birds and wind turbines and disturbances to marine mammals during construction of offshore wind farms due to noise.

The ERI includes incidents that occur less frequent than once every third year.

For this study, 12 European plants, both onshore and offshore, have been assessed regarding environmental risks; see **Fel! Hittar inte referenskälla.**.

The environmental risk inventory includes undesired events in conjunction with:
- Transportation of material for construction, operation, and dismantling of the wind farm.
- Construction of the wind farm.
- Operation and maintenance of the wind farm.
- Dismantling of the wind farm.

The following aspects are beyond the scope of this study:
- Manufacturing of the wind turbine and associated machinery
- Environmental risks associated with possible sabotage or war.
- Traffic accidents of private cars on the way to and from work.
- Production of additional raw materials and related transportation in conjunction with losses due to undesired events
- Regional risks connected to impact on biodiversity, such as barrier effects for species, noise disturbances (offshore)
- An abnormal discharge or an accident that might lead to production of more material in order to replace lost parts or reconstruction, which may lead to additional impact on the environment

4.2.2. Method
The method used implies an inventory of undesired events, which can occur and impact the surrounding environment. The probability and consequence for these events are assessed and scored to identify the largest risks.

This assessment has been conducted by picking out relevant information from existing risk assessments, from site visits and staff dialogues. Regarding transportation and construction/dismantling the same amounts have been presupposed as in the LCI part of the EPD®. General statistics on traffic accidents have been used to compile probabilities of different events.

Probability forecasts are always impaired by uncertainties. The degree of uncertainty is greatest for infrequent events, and for events caused by human error. Assessments of potential consequences may also be uncertain.
The results are based on several conservative assumptions to ensure a not too optimistic picture.

Data obtained has been assessed quantitively by using a risk matrix. The risk scenario of the identified mishap/undesired events have been assessed by multiplying two factors: the probable frequency for the mishap to occur (probability) and the environmental impact if it occurs (consequence) according to the five point probability and consequence scales stated in the method. The probability is based on Swedish statistics from authorities such as the Swedish Transport Agency and Swedish Civil Contingencies Agency.

The highest score in the risk matrix is presented by the colour red. Yellow represent moderate risk and green small risk, see Table 19.

Table **19** *Matrix used to score risks scenarios.*

Probability	5	5	10	15	20	25
	4	4	8	12	16	20
	3	3	6	9	12	15
	2	2	4	6	8	10
	1	1	2	3	4	5
		1	2	3	4	5
	Consequence					

Probability

5	Every 3-10 years
4	Every 10-100 years
3	Every 100-1000 years
2	Every 1000-10 000 years
1	Less than 10 000 years

Consequence

5	Extreme – Catastrophic an irreversible environmental impact at a regional level. Loss of ecosystem functionality. No prospect of recovery within foreseeable time.
4	Major – Large environmental impact at local and regional level. Significant impact on ecosystem functionality, protected species or areas. Long-term effects with expectation on moderate recovery, not necessarily to pre-impact conditions.
3	Significant – Environmental impact at local level, including impact on ecosystem functionality, and protected species or areas. Expectations of good recovery to pre-impact conditions after several years or reproduction periods/generations.
2	Mild – Environmental effects at local level. No impact on ecosystem functionality, protected species or areas. Reversible effects – recovery within one year or reproduction period/generation.
1	Minor – Limited environmental effects at local level. No impact on ecosystem functionality, protected species or areas. Quickly reversible – recovery within one season/vegetation period.

After the quantitative assessment described above, a meeting was held together with the Environmental & Sustainability team within BA Wind, as to verify the assessment and obtain any supplementary information on environmental risks in accordance with the PCR and that is of relevance for the ERI.

4.2.3. Summary of risks

All accidents evaluated with the new methodology of the matrix in Table 19 have been scored a six or lower, presented in descending order below. There are no accidents identified for wind power that would have high or very high impact but low or minute probability (e.g., nuclear reactor meltdown, dam bursts). The highest consequence identified from an accident is of significant impact meaning that the environmental impact is at local level, including impacts on ecosystem functionality and protected species or areas. There are also expectations of good recovery to pre-impact conditions after several years or reproduction periods/generations.

Identified risk type scored in descending order, with the largest risk first:

- Ship
- Gearbox
- Tank
- Transformer
- Vehicle

There are however uncertainties within the results and the quantitative values must be read as an indication of magnitude rather than exact statements. The uncertainties are larger for events that occur rarely and events where manual intervention or human errors are the causes of the accident. For some incidents where the failure statistics, or the size of emission/leakage does not exist or is inadequate, data is estimated based on experiences and/or discussions with experts. In these cases, worse case scenarios have been assumed.

The scores for vehicle, tank and transformer accidents are small, within the green area in the matrix. Offshore wind farms have a higher score on tank and transformer accidents compared to onshore wind farms, depending on the larger volume of stored oil, diesel and gasoline.

Ship and gearbox accidents are in some cases within the yellow area of the matrix. For ships, it depends on the large fuel tanks. To be conservative all ships have been assumed to be in the size of a cargo ship. The higher scores for gearboxes depend on the number of wind turbines. If the site is large e.g. a large number of wind turbines, the probability of an accident increases.

It is fairly common with objects accidentally being dropped during construction, and to some extent also during maintenance, of offshore wind farms. The type of object varies, and the consequence depends on the size and content of the object. The most common environmental impact is littering, which can also impact the seabed structure and habitat for aquatic life depending on the object.

An uncommon accident is loss of rotor or rotor blades. This kind of accident would cause littering and possibly oil leakage as well as damage to the biodiversity. If the site is located near a settlement, harm could come to humans and habitation.

During the construction of a wind farm a permit has been issued. If the permit is not followed the surrounding environment might get harmed. Identified risks caused by not following the permit are noise, water pollution, drainage of wetlands, peat slides and machinery driven in areas not included in the permit. Loud noise might disturb species living in the area and vehicles driving in areas not included in the permit might harm soil and fauna. Water pollution and drainage of wetland can affect the biodiversity in the local area. If the water is polluted with hazardous chemicals or redirected it might affect nearby creeks and rivers. Peat slides might cause damage to infrastructure in the areas as well as water courses and biodiversity.

The overall conclusion is that risks connected to construction and operation of wind farms can impact the environment on a local level. The main risks relate to leakages of fuel during construction, and to a smaller degree also during maintenance. The consequences resulting from the main risks, would mainly impact flora and fauna in the local area around the wind farm. The severity of impact depends on both the amount of leakage and the characteristics of the environment around the site.

4.3. Electromagnetic fields

EMF (Electromagnetic Fields, or for power frequency, Electric and Magnetic Fields) appear in the vicinity of all electrical equipment and power lines. There are no binding limits regarding exposure to EMF. The International Commission on Non-Ionizing Radiation Protection (ICNIRP), an independent body, has however published recommendations[6] regarding acute health problems. The recommendations are based on knowledge about acute health problems due to changing magnetic fields and propose a limit of 1000 μT for working environment and for the general public a limit of 200 μT at 50 Hz. The EU Council of Ministers recommends a restriction of exposure to electro-magnetic fields in accordance with the ICNIRP´s recommendations.

According to ICNIRP available research results on lesions due to long-range exposure, for example raised risk of cancer, do not suffice to establish limits. Vattenfall follows ICNIRP's, WHO's and OECD's work and recommendations in the area. At Vattenfall the precautionary principle is also followed, which implies reducing fields that deviate considerably from normality in each specific case.

4.4. Noise

Sound propagation depends on several factors such as medium, frequency, amplitude, temperature, humidity, wind, and geography. Consequently, noise levels from one and the same source may vary from day to day. It also means that two identical sources of noise in different locations may give rise to completely different noise levels and propagation patterns and may be experienced differently. The World Health Organisation (WHO) have recently updated their recommendations for noise, including windfarm noise, where noise levels produced by wind turbines are recommended to be kept below 45 dB.

At wind velocities of more than 8 m/s wind farm noises are drowned out by the sounds of the wind itself, of leaves, and of waves. Most of the noise is from mechanical noise and from modern wind farms this is considerably decreased due to technical improvements and soundproofed nacelles. Measurements show that Vattenfall's wind farms operate below limits in present regulations. The limits differ between countries and permits.

Modern wind turbines are developed to generate less noise in relation to size and capacity. Blade profiles are improved, and rotation speed can be regulated to make the rotor move more slowly with less noise at low wind velocities when the background sounds are low. Many modern wind turbines can also be regulated automatically to lower noise levels on specific occasions, for example at certain times of the day or at certain wind directions. Such regulations of the noise levels however imply a lower electricity generation.

Power lines over 70 kV may give rise to noise (corona noise). Sound levels are moderate: 45 dB(A)[7] at 25 meters decreasing rapidly.
The environmental impacts from low-frequent noise are currently not considered as a critical impact. The environmental effects are however not completely clear in relation to displacement of birds, where multiple explanations can cause birds to partly or completely abandon areas surrounding turbines. The contribution of low-frequency noise s is poorly understood today, but currently displacements or stress-impacts are usually not found beyond some hundreds of meters from the wind turbines. Impact distances are as always highly species and site-specific.

[6] Guidelines for Limiting Exposure to Time-Varying Electric, Magnetic, and Electromagnetic Fields (1 Hz – 100 kHz), Health Physics Vol. 99, No 6, pp 818-836, 2010.
[7] dB(A) indicates that a standard method of measurement has been used where the value has been corrected with respect to the sensitivity of the human ear at different frequencies

4.5. Visual Impacts

Wind turbines always mean a change in the landscape image, mainly because the turbine hight, that they are placed on higher altitude, that the rotor blades move, and that the turbines are equipped with aviation lights. As a result, wind turbines become visible from a far distance. Vattenfall has a routine to analyse the visual landscape impact in the permit process.

How a new wind farm takes place in and changes the landscape image depends on factors such as the size and number of wind turbines, the distance between the wind turbines, distance to the viewer, visibility and how the plant harmonises with the landscape. The concepts of dominance and contrast can be used to explain the interaction with the landscape. Wind turbines that are visible up close in a landscape with small landscape elements, for example with small houses or lower topography, may dominate the landscape picture. Wind turbines from longer distances in a more large-scale landscape may be perceived as less dominant. Contrast is about the facility's ability to blend into the environment. In a landscape with, for example, old settlement structure, the contrast to a wind turbine becomes larger than, for example, in connection to a harbour.

To avoid light pollution by aviation lights, there have been technology developments on triggered aviation lights which only light up when planes are approaching. Triggers can be based on radar detection or transponder signals send-out by the aircrafts. Triggered aviation lights have the potential to decrease light disturbance for humans in connection to onshore and nearshore windfarms. From a biodiversity perspective, migrating birds can be attracted by lights from offshore wind farms during bad weather, which can lead to collisions when approaching the wind farms. Triggered lights have the potential to decrease such collision risks. In the countries Vattenfall operates, only Germany has so far formulated regulations for new wind farms to install triggered lights whereas in all other countries, regulations are still pending due to military and safety considerations.

The environmental impacts from shadowing/flickering are today not considered as a critical impact. The effects are however difficult to single-out from other activities, such as simply the presence of the moving blades, changed landscape or maintenance activities around the sites etc. There can therefore be multiple explanations causing birds to partly or completely abandon areas surrounding turbines. The contribution of each of these parameters is not fully understood today, but currently displacements or stress-impacts are usually not found beyond some hundreds of meters from the wind turbines. Impact distances are as always very species and site-specific.

5. Differences vs. the Earlier Version of Vattenfall's EPD® for Wind Power

5.1. Differences in Life Cycle Assessment

Vattenfall's EPD® for electricity from Wind power has been published in a couple of different constellations (for the Nordics, for the UK and on a European scope). This EPD® is an update of the most recent version, with a European scope. In Table 20 below a comparison between the results of this EPD® and the EPD® for Vattenfall's wind power certified 2019 are shown. Construction of distribution networks is included in this EPD® (and the previous versions) and has been separated in the table to make the values more comparable.

The inventoried farms in this EPD® have been assessed in 2021 or in previous years (2002, 2006, 2008, 2012, 2015, 2018). This means that the construction of the wind farms that were inventoried before 2021 have not been recalculated but only updated with new generation and operational data. This is in accordance with the PCR guidelines for updating an existing EPD®.

The new inclusion of emissions as a result of deforestation (Luluc) is the main contributor to the rise in GWP, as can be seen in
Table **20**, where the GWP result excluding Luluc is lower than the previous version of the EPD.
Several factors could have risked increasing the GWP, such as the inclusion of demolition of previously modelled substations, the increase in core result due to increased offshore maintenance trips (where emissions from combustion of marine diesel is a dominating contributor) and a decrease in average energy production for Lyngsmose, Horns Rev 1, Bajlum, Kentish Flats and Pen y Cymoedd. However, GWP excluding Luluc has decreased, which is mainly due to Vattenfall's wind farm portfolio now containing a higher ratio of modern wind farms with generally lower GWP per produced kWh and longer lifetime expectancy.

The requirements of the updated PCR and GPI has resulted in an increased number of reported environmental impact indicators in the EPD, as can be seen in Table 20 below, limiting the comparability with 2019.

***Table 20** Differences versus earlier version*

		Vattenfall's EPD® for Electricity from Wind power					
		2022		2022 (excl. Luluc)		2019 (excl. Luluc[1])	
Environmental impact categories	**Unit/kWh**	**Excl. Distribution**	**Incl. Distribution**	**Excl. Distribution**	**Incl. Distribution**	**Excl. Distribution**	**Incl. Distribution**
Global warming potential	**g CO_2-eq. (100years)**	13.1	15.6	12.2	14.2	12.8	14.7
Acidification potential	**g SO_2-eq.**	0.0398	0.0445	0.0398	0.0445	0.0428	0.0510
Eutrophication potential	**g PO_4^{3-}-eq.**	0.00792	0.0111	0.00792	0.0111	0.00720	0.0100
Photochemical oxidant formation potential	**g NMVOC-eq.**	0.0367	0.0449	0.0367	0.0449	NR	NR
Particulate matter	**g PM2.5-eq.**	0.00979	0.0110	0.00979	0.0110	NR	NR
Abiotic depletion potential - Elements	**g Sb-eq.**	1.73E-04	2.37E-04	1.73E-04	2.37E-04	NR	NR
Abiotic depletion potential - Fossil fuels	**MJ, net cal. value**	0.136	0.161	0.136	0.161	NR	NR
Water scarcity footprint	**m^3 H_2O-eq.**	0.300	0.316	0.300	0.316	NR	NR

NR = Not reported
[1] In 2019, Luluc was not part of the calculations

5.2. Differences in Land Use and Impact on Biodiversity

It is not possible to compare data from the previous EPD report on wind power with this year's EPD report. The methodology for assessing changes in land use and impacts on biodiversity has been renewed.

While the previous method categorized biotopes depending on their assessed natural value, the new method uses the Corine Land Cover classes within the project area to categorize biotopes. In addition, the new method uses information found in Environment Impact Assessments and survey reports to qualitatively describe impacts on biodiversity.

5.3. Differences in Environmental Risk Assessment

The model is simplified compared to previous years and has been made more conservative. Tanks of oil, diesel and gasoline are for example always assumed to be filled up and during the accident is the entire content of the tank assumed to leak out.

Earlier versions calculated emissions of different substances, for example g CO_2/kWh. This year the matrix presented in Table 19 has been used. The environmental impact of the different accident scenarios has however been assessed similarly in both methodologies. Ship and gearbox accidents are ranked as the largest risks for the environment. In previous versions of Vattenfall's EPD for wind power, truck accidents have been identified as the main risk. In this version all types of accidents involving the same vehicle have been clustered and presented as a worst-case scenario. In this version the fuel tank of a ship has been assumed to always be in the size of a cargo ship resulting in a higher score for ship accidents compared to trucks.

Jacket foundation at Ormonde offshore windfarm (photo: Tony West)

6. Information from the independent verification, the Certification Body and Mandatory Statements

6.1. Information on the independent verification and certification of this EPD

This EPD® has been verified within Vattenfall's EPD® Management Process. The independent verifiers Caroline Setterwall (Hitachi Energy Sweden AB),Lasse Kyläkorpi (Vattenfall AB) and confirm that the product fulfils relevant process- and product-related laws and regulations and certify that this EPD® follows and fulfils all rules and requirements of the EPD® system managed by EPD International AB, General Programme Instructions, version 3.01 (GPI) and Product Category Rules CPC 171 version 4.2. This certification is valid until 2027-01-31.

6.2. Information from the Certification Body on the verification of Vattenfall's EPD® Management Process

Vattenfall's EPD® management process is third party verified annually, last review was made 2021-11-25. Bureau Veritas Certification, accredited by SWEDAC, the Swedish Board for Accreditation and Conformity Assessment, hereby confirms that Vattenfall's EPD® Management Process follows the requirements of EPD® International expressed in GPI and the Process Certification Clarification (PCC) for the International EPD® system

6.3. Mandatory Statements

6.3.1. General

To be noted: EPD®s from different EPD® programmes may not be comparable. When comparisons are made between different products in this product category it should be noted that energy can be supplied through different energy carriers like heat/steam or electricity, but the amount of kWh needed will differ with different energy carriers due to different energy quality and conversion/distribution efficiencies.

6.3.2. Omissions of life cycle stages

The use stage of produced electricity has been omitted in accordance with the PCR since the use of electricity fulfils various functions in different contexts.

6.3.3. Means of obtaining explanatory materials

ISO 14025 prescribes that explanatory material must be available if the EPD® is communicated to final consumers. This EPD® is aimed for industrial customers and not meant for private customer communication.

7.3.4. Information on verification

EPD® programme: **The International EPD®system is managed by EPD International AB , www.environdec.com**
Product Category Rules: **Product Category Rules, CPC 171 Electrical Energy, CPC 173 Steam and Hot Water, version 4.2**
PCR review, was conducted by: **The Technical Committee of the International EPD®system. Chair: Claudia A. Peña. Contact via info@environdec.com**
Independent third-party verification of the declaration and data, according to ISO 14025:2006 **EPD® Process Certification** **has been performed within Vattenfall's certified EPD® Management process.**
Third party verification of Vattenfall´s EPD Management process has been conducted by the accredited Certification body: Bureau Veritas Certification External verifier: **Camilla Landén** **This EPD® is valid until: 2027-01-31** Internal and external verifiers**: Caroline Setterwall, Hitachi Energy Sweden AB, Lasse Kyläkorpi, Vattenfall AB** Procedure for follow-up of data during EPD validity involves third-party verifier **No**

7. Links and references

Reports

The following reports support this EPD® and can be downloaded at www.environdec.com

- Selected wind farms
- Nordic LCA results

Guidelines

- Product Category Rules, CPC 171 Electrical Energy, version 4.2.
- General Programme Instructions (GPI) for an environmental product declaration, EPD®, version 3.01.
- ISO 14025 on Type III environmental declarations.
- ISO 14040 and ISO 14044 on Life Cycle Assessments (LCA).

For programme information and supporting documents: www.environdec.com

Databases

- Generic data mainly stem from the database Ecoinvent and the GaBi Professional database (Thinkstep 2020)
- Data for production of steel has been retrieved from IISI: www.worldsteel.org
- Data for plastics has been retrieved from Plastics Europe: http://www.plasticseurope.org and GaBi Professional database (Thinkstep 2020)
- Data for production of copper and semi fabrication originate from Deutsches Kupferinstitut and the European Copper Institute (ECI).

Other links

www.energinet.dk Energinet is the owner of the overall electricity and gas infrastructure and maintain and ensure the smooth operation of these systems.
www.danskenergi.dk Danish Energy Association, a commercial and professional organization for Danish energy companies.
www.svk.se Svenska Kraftnät, the owner of the electricity infrastructure in Sweden and responsible for maintenance and operation of these systems.
https://www.entsoe.eu/ – the European Network of Transmission System Operators for Electricity (ENTSO-E) represents 43 electricity transmission system operators (TSOs) from 36 countries across Europe
www.scb.se – Statistics Sweden publish statistics on Swedish power grid based on information from Svenska Kraftnät and the Swedish Energy Agency
www.nationalgridet.com – National grid for electricity transmission in the UK, who owns the electricity transmission network in England and Wales

Contact information

For more information about Vattenfall: www.vattenfall.com

More information about sustainability in Vattenfall: corporate.vattenfall.com/sustainability/

For questions concerning this EPD® and for general information on Vattenfall's work with EPD®, contact Vattenfall at epd@vattenfall.com

Specific questions regarding environmental issues in Vattenfall's Wind power should be directed to Eva Philipp, Head of Environment and Sustainability BA Wind, e-mail: eva.philipp@vattenfall.de