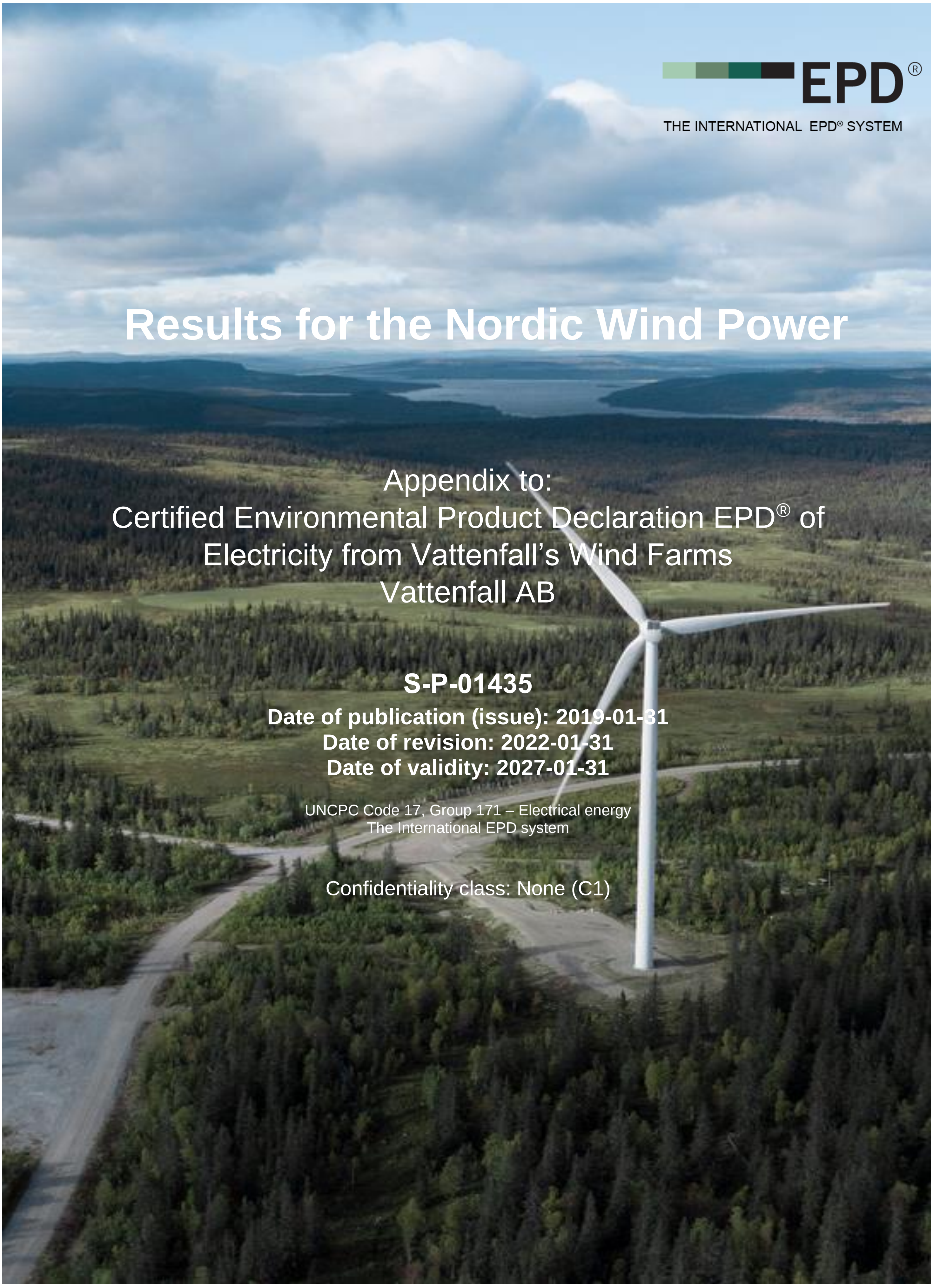

EPD®
THE INTERNATIONAL EPD® SYSTEM

Results for the Nordic Wind Power

Appendix to:
Certified Environmental Product Declaration EPD® of
Electricity from Vattenfall's Wind Farms
Vattenfall AB

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VATTENFALL

Background

This appendix describes the environmental impact from Vattenfall's wind farms in the Nordic countries. The purpose is to describe the environmental impacts related to the EPD-certified products offered for electricity customers in the Nordic countries. The numbers presented in this appendix are calculated based on the Nordic wind farms in the selection for the full EPD.

In the Nordic countries, Vattenfall operates wind farms in Sweden and Denmark, whereof 32 % of the production is located offshore and 68 % onshore. In Table 1 below, installed capacity is based on the wind farms in operation by the end of 2020.

Table 1 *Installed capacity and average generation in Vattenfall's Nordic portfolio (numbers represent Vattenfall's share, pro-rata ownership as per 2020-12-31)*

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
Total[1]	**612**	**381**	**2 196**	**1 011**	**3 207**

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

See locations of the included wind farms in **Figure 1** below.

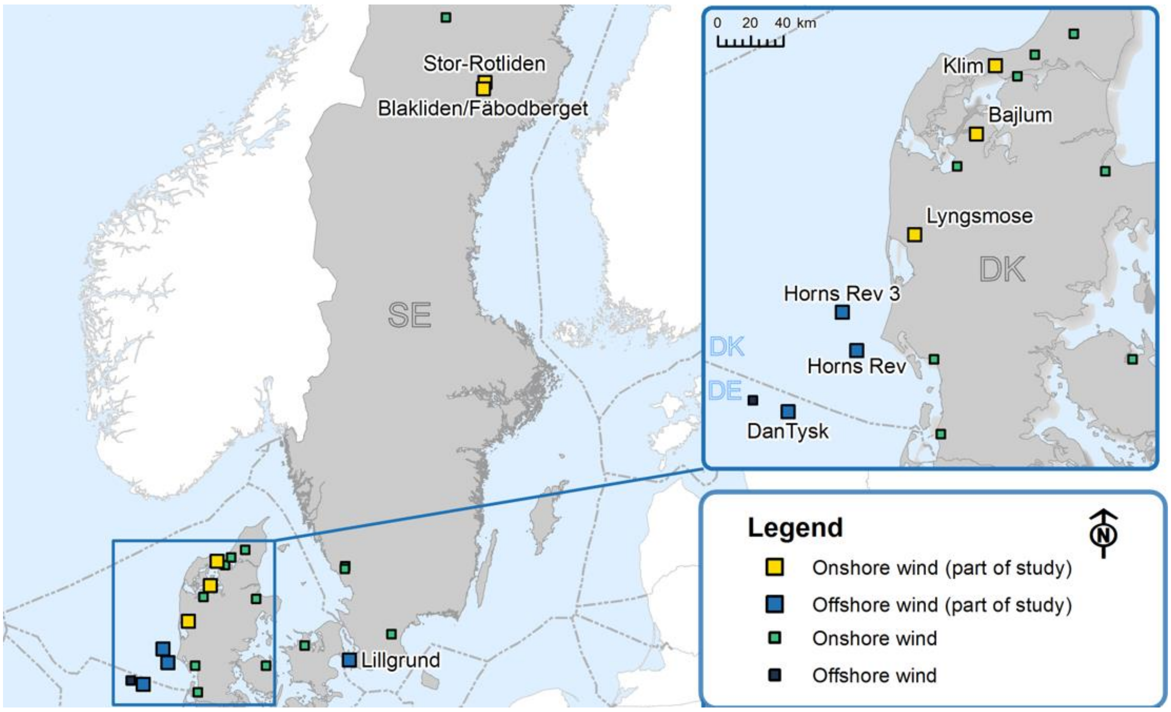


Figure 1 *The locations of Vattenfall's studied wind farms. Some dots indicate several farms. The farms presented in this EPD® are marked with yellow (onshore) and blue (offshore) boxes. The figure shows the situation by the end of 2020.*

Selected sites – Nordic

To describe impacts from electricity generated in Vattenfall's Nordic wind farms the lifecycle inventory data for the farms in the selection located in the Nordic countries have been used. These inventory data have been used together with an allocation based on the average generation in the Nordic countries to calculate the average environmental impact per kWh in the Nordic portfolio. All wind power sites have been grouped with respect to wind conditions expressed as the capacity factor[1], and each group's percentage of the total annual wind power generation was calculated. Studied wind farms were weighted within each group with respect to actual annual average electricity generation. Se Table 2 below for grouping of farms.

Table 2 *Grouping of wind farms*

	Portion of Vattenfall's wind power
Group 0: Offshore, capacity factor >0.25	68.5 %
Group 1: Onshore, capacity factor >0.32	13.1 %
Group 2: Onshore, capacity factor 0.25-0.32	14.0 %
Group 3: Onshore, capacity factor <0.25	4.4 %

Selected sites

In Table 3 below the selected wind farms located in the Nordic countries are shown. The selected sites consist of one or more turbines and are located on- or offshore. The capacities vary between 1.8 MW and 8.3 MW. All together the selected turbines generate 93 % of Vattenfall's total Nordic electricity from wind power during an average year. The selection has been made to cover as many different types of geographies as possible.

In the selection, group 3 (onshore farms with a capacity factor below 0.25) is represented by the Swedish wind farm Stor-Rotliden. There is no Nordic farm in the EPD representing group 3, but since a non-neglectable share of the Nordic generation (4.4 %) comes from this group, a representation is needed. That is why construction data for StorRotliden has been selected to represent generation from group 3 (although it actually belongs to group 2). The reason for choosing Stor-Rotliden is that the technology in this wind farm (i.e. wind mill size and turbine capacity) is considered similar to the typical group 3 wind farms in the Nordic portfolio.

The capacity factor for Stor-Rotliden has been adjusted to be representative for group 3, based on average value for the group 3 wind farms in Sweden and Denmark, and the lifetime production recalculated in accordance. In addition, 5 % of the environmental impact has been added to be conservative. Through the selection of the sites listed in the table below the environmental impact of Vattenfall's wind power portfolio is assumed to be mirrored correctly in this EPD®.

Table 3 *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 Nordic wind power generation
0	Horns Rev 1[1]	80	Vestas	2	2002	481 (289)	North Sea West of Jutland	9.0 %
1	Horns Rev 3	49	Vestas	8.3	2018	1 580	North Sea West of Jutland	49.3 %
	Lillgrund	48	Siemens	2.3	2006	327	South Sweden Öresund	10.2 %
	Klim[1]	22 (21)	Siemens	3.2	2015	224 (220)	Klim, Denmark	6.8 %
	Blakliden Fäbodberget[1]	84	Vestas	4.2	2021	1 100[2] (330)	Northern Sweden, Lappland	10.3 %

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

2	Stor-Rotliden	40	Vestas	1.8-2	2010	200	Northern Sweden, Lappland	6.2 %
	Lyngsmose	2	Siemens	2.3	2008	12	Central Jutland	0.4 %
	Bajlum[1]	5	Siemens	3	2013	43 (37)	Northwest Jutland	1.1 %
3	Stor-Rotliden[2]	40	Vestas	1.8-2	2010	148	North Sweden, Lappland	-

[1] Vattenfall owns 60 % of Horns Rev 1, 30 % of Blakliden Fäbodberget, 87.5% of Bajlum and 21 out of 22 turbines at Klim. The values in brackets shows Vattenfall's share.
[2] Approximated production, since commissioning has not yet been performed at the time of assessment
[3] Stor-Rotliden has been used to represent group 3 as well, but with an adjusted annual production

Data quality

For discussion about methodology and data quality, see the full EPD® report.

Characterization

Calculations and characterizations are in accordance with General Programme Instructions and the latest information on http://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.

Results

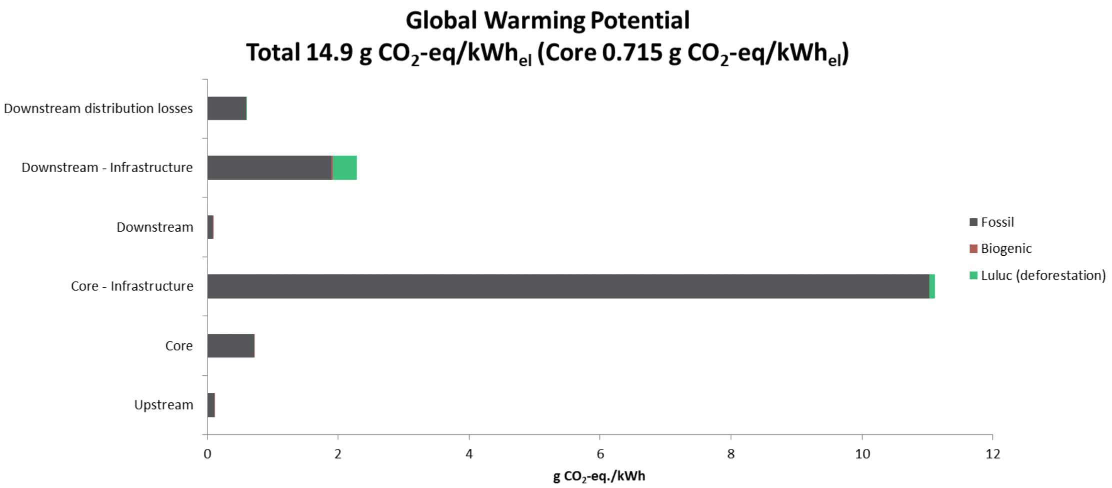
In **Table 4** below, the results for Vattenfall's Nordic wind power are shown, together with environmental impacts related to the Swedish and Danish electricity distribution grids. The grid loss used in all calculations is set to 5 % of generated electricity and is assumed to be compensated for by increased generation in the wind farms.

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.

Table 4 *Environmental impact*

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)	0.112	0.714	11.0	**11.9**	0.676	1.90	**14.4**
	Biogenic	g CO_2-eq. (100years)	0.00150	6.16E-04	0	**0.00211**	0.00167	0.0234	**0.0272**
	Luluc[2] (deforestation)	g CO_2-eq. (100years)	0	0	0.0887	**0.0887**	0.00443	0.363	**0.456**
	Total	g CO_2-eq. (100years)	0.114	0.715	11.1	**11.9**	0.683	2.28	**14.9**
Acidification potential (AP)		g SO_2-eq.	3.49E-04	0.00558	0.0358	**0.0417**	0.00227	0.00327	**0.0473**
Eutrophication potential (EP)		g PO_4^{3-}-eq.	3.12E-04	0.00107	0.00738	**0.00876**	4.78E-04	0.00375	**0.0130**
Photochemical oxidant formation potential (POFP)		g NMVOC-eq.	9.29E-04	0.00797	0.0298	**0.0387**	0.00241	0.00835	**0.0494**
Particulate matter		g PM2.5-eq.	1.03E-04	8.87E-04	0.00926	**0.0103**	5.63E-04	8.61E-04	**0.0117**
Abiotic depletion potential - Elements		g Sb-eq.	3.61E-07	4.89E-08	2.80E-04	**2.80E-04**	1.40E-05	6.55E-05	**3.60E-04**
Abiotic depletion potential - Fossil fuels		MJ, net cal. value	0.00994	1.46E-04	0.127	**0.137**	0.00750	0.0256	**0.170**
Water scarcity footprint		m^3 H_2O-eq.	9.58E-06	3.92E-06	0.377	**0.377**	0.0189	3.97E-04	**0.397**

[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.



See
Figure 2 below for illustration of impacts per lifecycle stage for Global Warming Potential.

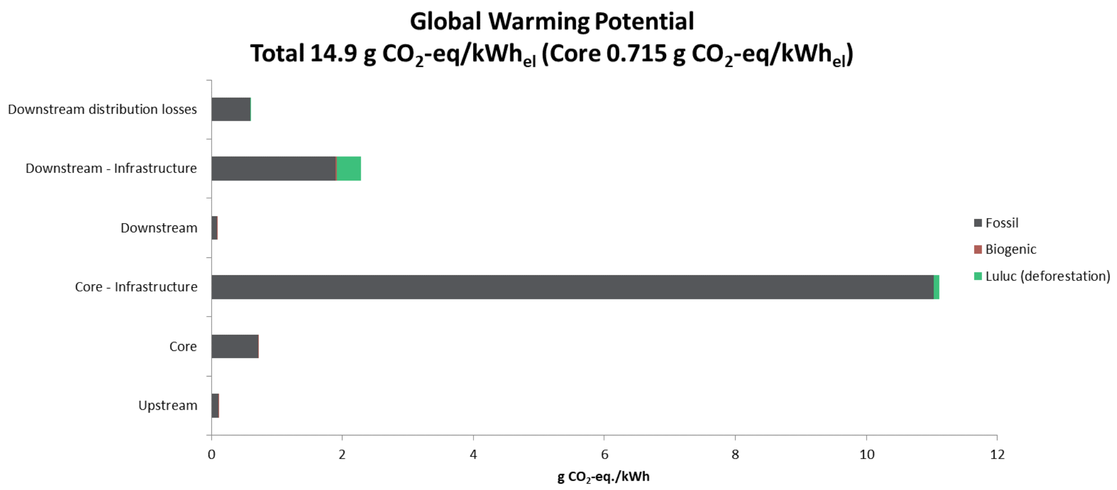


Figure 2 *Emissions of greenhouse gases, expressed in grams of CO_2-equivalents per kWh*

Resource use and emissions related to handling and treatment of the lifecycle waste through incineration or deposition are included in the results, i.e. no crediting has been performed. See **Table 5**-**Table 8** below for resources, wastes and other output flows.

Table 5 *Resource use*

Resources		Unit/kWh	Upstream	Core	Core - infra.	Total - generated	Down-stream[1]	Downstream - infra.	Total - distributed
Primary energy resources - Renewable	**Use as energy carrier**	**MJ, net cal. value**	3.76E-05	6.18E-06	0.00917	**0.00921**	4.84E-04	0.00161	**0.0113**
	Use as raw material	**MJ, net cal. value**	1.01E-08	1.88E-09	8.27E-07	**8.39E-07**	4.22E-08	1.86E-07	**1.07E-06**
	Total	**MJ, net cal. value**	3.76E-05	6.18E-06	0.00917	**0.00921**	4.84E-04	0.00161	**0.0113**
Primary energy resources - Non-renewable	**Use as energy carrier**	**MJ, net cal. value**	0.0100	1.54E-04	0.133	**0.143**	0.00781	0.0264	**0.178**
	Use as raw material	**MJ, net cal. value**	0	0	2.68E-05	**2.68E-05**	1.86E-06	4.00E-06	**3.26E-05**
	Total	**MJ, net cal. value**	0.0100	1.54E-04	0.133	**0.143**	0.00781	0.0264	**0.178**
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	2.72E-06	**2.72E-06**	1.36E-07	1.25E-10	**2.86E-06**
Non-renewable secondary fuels		**MJ, net cal. value**	4,71E-10	0	2.72E-06	**2.72E-06**	1.36E-07	1.25E-10	**2.86E-06**
Net use of fresh water		**m³**	2.80E-07	1.14E-07	0.0110	**0.0110**	5.50E-04	1.19E-05	**0.0116**

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

Table 6 *Waste production for core processes*

Waste	Unit/kWh	Core	Core - infra.	Total
Hazardous waste disposed	**g**	0	0.0284	**0.0284**
Non-Hazardous waste disposed	**g**	0	20.3	**20.3**
Radioactive waste disposed	**g**	0	1.66E-04	**1.66E-04**

Table 7 *Waste production for upstream and downstream processes*

Waste	Unit/kWh	Upstream	Down-stream[1]	Downstream - infra.	Total - distributed
Hazardous waste disposed	**g**	1.39E-07	0.00142	1.39E-07	**0.00142**
Non-Hazardous waste disposed	**g**	2.03E-04	1.01	0.28	**1.29**
Ash	**g**	0	1.78E-04	0	**1.78E-04**
Inert (rock, sand etc.)	**g**	0	0.148	0.00146	**0.149**
Radioactive waste disposed	**g**	2.02E-8	9.10E-06	9.70E-05	**1.06E-04**

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

Table 8 *Output flows; materials for reuse, recycling or energy recovery*

Output flows	Unit/kWh	Upstream	Core	Core - infra.	Total - generated	Down-stream[1]	Downstream - infra.	Total - distributed
Components for reuse	**g**	0	0	0	**0**	0	0	**0**
Material for recycling	**g**	2.28E-06	0	1.76	**1.76**	0.0879	7.73E-06	**1.85**
Materials for energy recovery	**g**	0	0.0100	0.256	**0.266**	0.0133	0	**0.279**

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

Dominance analysis

For all impact categories, the major part of the environmental impact is related to the construction of the wind farms (Core – infrastructure), followed by the construction of the grid (Downstream – infrastructure) and/or maintenance (Core). Emissions emanate mainly from the production of steel and other metals used for construction. See **Table 9** below for dominance analysis regarding the assessed environmental impact categories.

Table 9 *Dominance analysis for assessed environmental 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)**	0,8%	5,0%	76,4%	0,6%	13,2%	4,1%	**100%**
	Biogenic	**g CO_2-eq. (100years)**	5,5%	2,3%	0,0%	5,8%	86,1%	0,4%	**100%**
	Luluc (deforestation)	**g CO_2-eq. (100years)**	0,0%	0,0%	19,5%	0,0%	79,6%	1,0%	**100%**
	Total	**g CO_2-eq. (100years)**	0,8%	4,8%	74,5%	0,6%	15,3%	4,0%	**100%**
Acidification potential (AP)		**g SO_2-eq.**	0,7%	11,8%	75,7%	0,4%	6,9%	4,4%	**100%**
Eutrophication potential (EP)		**g PO_4^{3-}-eq.**	2,4%	8,3%	56,8%	0,3%	28,9%	3,4%	**100%**
Photochemical oxidant formation potential (POFP)		**g NMVOC-eq.**	1,9%	16,1%	60,2%	1,0%	16,9%	3,9%	**100%**
Particulate matter		**g PM2.5-eq.**	0,9%	7,6%	79,3%	0,4%	7,4%	4,4%	**100%**
Abiotic depletion potential - Elements		**g Sb-eq.**	0,1%	0,0%	77,8%	0,0%	18,2%	3,9%	**100%**
Abiotic depletion potential - Fossil fuels		**MJ, net cal. value**	5,8%	0,1%	74,6%	0,4%	15,0%	4,0%	**100%**

Water scarcity footprint	**m^3 H_2O-eq.**	0,0%	0,0%	95,1%	0,0%	0,1%	4,8%	**100%**

Differences in the results between Nordic and European wind

The environmental profile for the Nordic part of Vattenfall's wind power are similar to the profile for Vattenfall's European wind power portfolio. In Table 10 below the results are presented side by side to allow for comparison. Results are shown both including and excluding distribution.

Table 10 *Differences between the European and Nordic results 2022*

		Vattenfall's EPD® for Electricity from Wind power			
Environmental impact categories	Unit/kWh	2022 Nordic incl. Luluc		2022 European incl. Luluc	
		Excl. Distribution	Incl. Distribution	Excl. Distribution	Incl. Distribution
Global warming potential	**g CO_2-eq. (100years)**	11.9	14.9	13.1	15.6
Acidification potential	**g SO_2-eq.**	0.0417	0.0473	0.0398	0.0445
Eutrophication potential	**g PO_4^{3-}-eq.**	0.00876	0.0130	0.00792	0.0111
Photochemical oxidant formation potential	**g NMVOC-eq.**	0.0387	0.0494	0.0367	0.0449
Particulate matter	**g PM2.5-eq.**	0.0103	0.0117	0.00979	0.0110
Abiotic depletion potential - Elements	**g Sb-eq.**	2.80E-04	3.60E-04	1.73E-04	2.37E-04
Abiotic depletion potential - Fossil fuels	**MJ, net cal. value**	0.137	0.170	0.136	0.161
Water scarcity footprint	**m^3 H_2O-eq.**	0.377	0.397	0.300	0.316

When comparing the results per generated kWh (without distribution), the GWP results are slightly lower for Nordic. The reason for this is due to technical as well as geographical differences in the different countries, as well as the different impact from deforestation in Core - infrastructure, which is significantly lower for the Nordic portfolio. Other aspects such as differences in inventory data type and quality also affect the results. GWP impact is also lower due to the larger share of modern wind farms in Vattenfall's wind farm portfolio, with longer lifetimes and lower impact per produced kWh - which as well affects the difference in the European EPD towards its predecessors. Two out of three newly constructed and modelled wind farms are part of the Nordic portfolio, which stand for a larger share of average Nordic production compared to the European portfolio. PM and POFP results are slightly higher due to the larger share of electricity generation from Horns Rev 3, which affects core results due to its use of marine diesel for inspection trips.

The differences are smaller when including distribution. This is mainly due to higher impact from deforestation in Sweden in Downstream - Infrastructure, i.e. during the construction of the transmission grids.