EPD® Nuclear Power

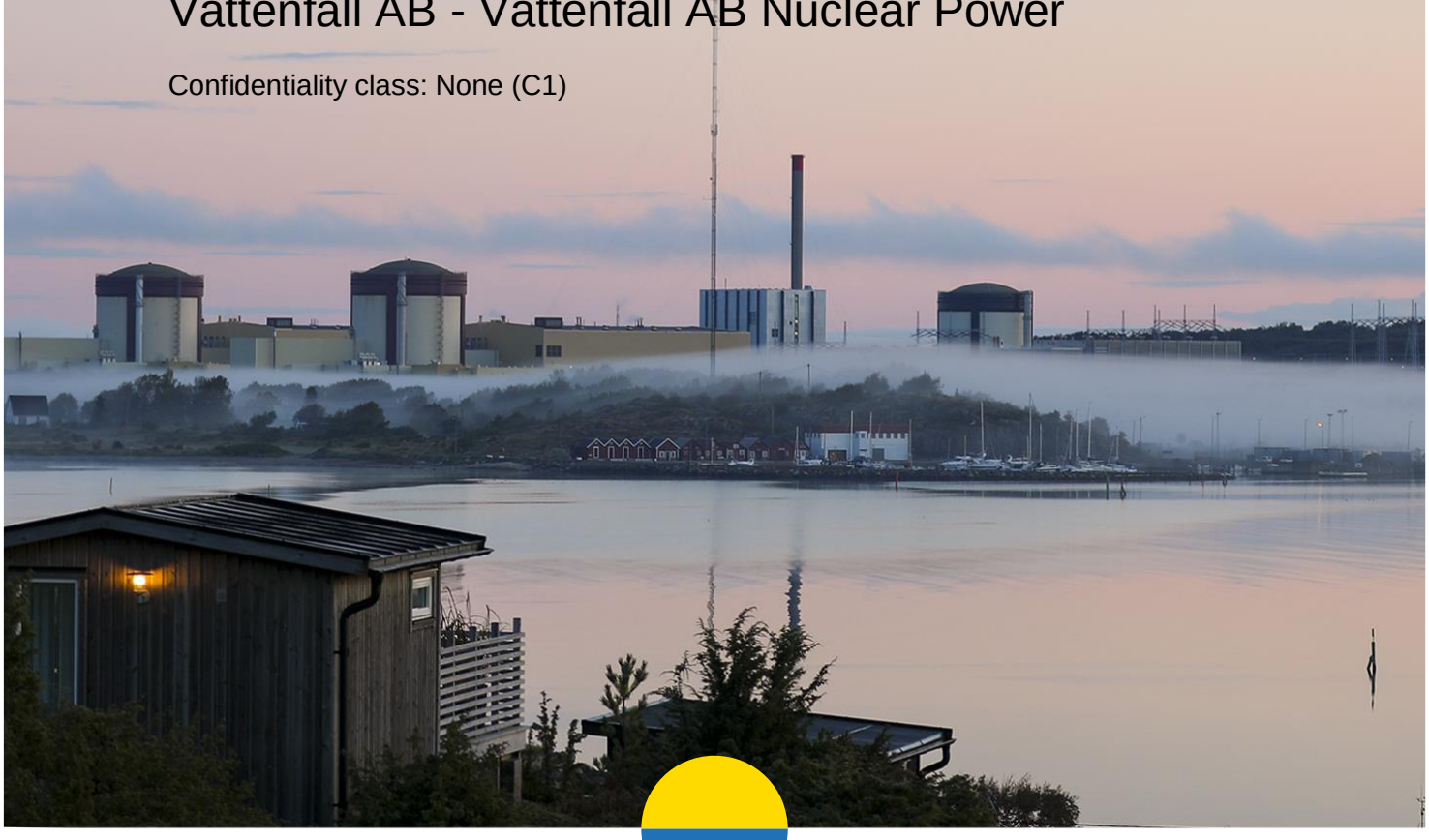
Summary of certified Environmental Product Declaration EPD® of electricity from Vattenfall's Nordic Nuclear power plants

UNCPC Code 17, Group 171 – Electrical energy

The International EPD® system - in line with ISO 14025

S-P 00923
2019-12-31
Vattenfall AB - Vattenfall AB Nuclear Power

Confidentiality class: None (C1)



VATTENFALL

VATTENFALL

EPD®

S-P 00923
environdec.com

2019-12-31

Vattenfall AB

Summary of certified Environmental Product Declaration EPD® of electricity from Vattenfall's Nordic Nuclear power plants

UNCPC Code 17, Group 171 – Electrical energy

The International EPD® system

Summary

PRODUCER. Forsmarks Kraftgrupp AB (FKA) and Ringhals AB (RAB) are responsible for the electricity generation in Vattenfall's nuclear power sites. The sites are located north of Östhammar on the Swedish East coast and north of Varberg on the Swedish West coast. The companies are partly owned by Vattenfall AB SE–162 87 Stockholm, telephone +46 8 739 50 00, www.vattenfall.com. Both FKA and RAB have environmental and health and safety management systems certified and registered according to ISO 14001 and ISO 45001.

PRODUCT AND DECLARED UNIT, Electricity belongs to the product category UNCPC Code 17, Group 171 – Electrical energy. The declared unit is defined as 1 kWh net of electricity generated and thereafter distributed to a customer connected to the Swedish regional grid (70/130 kV). The two sites have together four Boiling Water Reactors (BWR) and three Pressurised-Water Reactors (PWR) with a common generating capacity of about 7200 MW. On an average year they generate approximately 47 TWh of electricity. The reactors are of type generation II and once-through fuel cycles are applied, i.e. there is no reprocessing of fuel. Both Forsmark and Ringhals are base load plants.

THE INTERNATIONAL EPD® SYSTEM
The international EPD® system, administrated by EPD International AB, is based on ISO 14025, Type III Environmental Declarations. The relevant governing documents in hierarchical order are: Product Category Rules UN CPC 171 and 173, version 3.1, General Programme Instructions for an environmental product declaration, EPD® version 2.01, ISO 14025, ISO 14040, ISO 14044.

ENVIRONMENTAL PERFORMANCE BASED ON LCA
See below for a summary of methods and results. For more information, see section 3 in the complete EPD® documentation.

System Boundaries. The EPD® comprises the generation of electricity in the nuclear power plant; Upstream processes i.e. uranium fuel production and production of auxiliary supplies; and Downstream processes i.e. distribution of electricity. Further construction and dismantling of the nuclear power plant and the facilities for radioactive waste handling has been included in Core – Infrastructure. The use stage of electricity at the consumer level is not included. The technical lifetime is 60 years. The geographical scope for electricity generation and management of spent nuclear fuel and radioactive waste is within Sweden, whilst the nuclear fuel is produced world-wide.

Environmental Information. A short summary of compiled data is presented below, per generated and distributed kWh electricity.

Upstream	Mining & milling, refinery and conversion, enrichment and fabrication of nuclear fuel. Production of auxiliary substances and chemicals for Nuclear Power Plant (NPP) operation and radioactive waste treatment.
Core	Operation of NPP and facilities for handling radioactive waste and spent nuclear fuel. Incineration or deposit of conventional waste from operations.
Core infrastructure	Construction and decommissioning of the nuclear power plant and radioactive waste facilities, including necessary reinvestments.
Downstream	Operation of electricity networks, i.e. emissions from inspection trips, production and emissions of oils. Extra generation in NPP to compensate for losses in distribution system.
Downstream infrastructure	Includes manufacturing of materials (for lines, cables, pylons, transformers, buildings, and switching stations), ground work and handling of discharge material incl. transportation.

Distribution of electricity implies losses, which must be compensated for by increased generation. The loss to an average large industrial customer connected to the regional distribution network (70/130 kV) amounts to 3% (included in the downstream column below). The losses are different for different types of customers and often higher in the countryside. The average loss to a household customer varies between 7-9%.

Ecoprofile **Input**

Resources	Unit/kWh	Upstream	Core	Core - infrastructure	Total - generated	Down-stream[1]	Downstream - infrastructure	Total - distributed
Copper in ore	**g**	2,02E-03	3,65E-06	1,64E-03	**3,66E-03**	1,11E-04	6,79E-03	**1,06E-02**
Fossil energy resources	**MJ**	2,04E-02	3,74E-04	3,73E-03	**2,45E-02**	1,57E-03	1,61E-02	**4,21E-02**
Gravel, stone & sand	**g**	3,29E+00	5,58E-02	6,34E+00	**9,69E+00**	2,91E-01	1,08E+00	**1,11E+01**
Iron in ore	**g**	3,34E-02	0	5,54E-02	**8,88E-02**	2,80E-03	5,76E-01	**6,67E-01**
Limestone	**g**	2,12E-01	2,34E-03	7,43E-01	**9,57E-01**	2,89E-02	2,38E-01	**1,22E+00**
Potential energy through hydro turbines[2]	**MJ**	2,80E-03	1,50E-03	1,31E-03	**5,61E-03**	1,70E-04	7,12E-04	**6,49E-03**
Renewable fuel (biomass)	**MJ**	1,04E-04	1,58E-06	1,32E-03	**1,42E-03**	4,38E-05	2,65E-04	**1,73E-03**
Soil	**g**	1,04E-01	1,50E-02	8,20E-01	**9,38E-01**	2,81E-02	0	**9,66E-01**
Uranium in ore	**g**	1,88E-02	4,15E-06	6,27E-06	**1,88E-02**	5,65E-04	8,77E-07	**1,94E-02**
Zirconium sand	**g**	5,77E-04	1,39E-07	2,04E-05	**5,98E-04**	1,80E-05	4,51E-06	**6,20E-04**
Electricity use in the power plant[3]	**MJ**	0	1,36E-01	0	**1,36E-01**	4,09E-03	0	**1,40E-01**
Water, different sources	**g**	2,99E+04	1,05E+04	2,98E+03	**4,34E+04**	1,25E+04	1,61E+01	**5,59E+04**
Other input (agg. of remaining substances)	**g**	5,46E-02	3,82E-04	3,11E-02	**8,60E-02**	2,68E-03	5,11E-02	**1,40E-01**

Output: emissions

Pollutant emissions	Unit/kWh	Upstream	Core	Core - infrastructure	Total - generated	Down-stream[1]	Downstream - infrastructure	Total - distributed
Global Warming Potential	**g CO_2-eq. (100years)**	1,87E+00	1,76E-01	4,30E-01	**2,48E+00**	2,17E-01	1,44E+00	**4,13E+00**
Global Warming Potential incl. biogenic CO_2	**g CO_2-eq. (100years)**	2,01E+00	2,32E-01	5,21E-01	**2,76E+00**	2,26E-01	1,45E+00	**4,44E+00**
Acidification Potential	**g SO_2-eq.**	4,97E-03	1,28E-03	2,36E-03	**8,61E-03**	4,12E-04	9,43E-03	**1,85E-02**
Photochem. Ozone Creation Potential	**g Ethene-eq.**	4,88E-04	9,76E-05	1,77E-04	**7,63E-04**	5,45E-05	1,32E-03	**2,14E-03**
Eutrophication Potential	**g Phosphate-eq.**	2,85E-03	2,93E-04	4,05E-04	**3,55E-03**	1,45E-04	4,87E-03	**8,56E-03**
C-14 to air	**kBq**	5,13E-05	6,46E-02	1,43E-05	**6,47E-02**	1,94E-03	2,05E-06	**6,66E-02**
Kr-85 to air	**kBq**	2,88E-02	4,71E-02	1,23E-04	**7,59E-02**	2,28E-03	4,87E-07	**7,82E-02**
Rn-222 to air	**kBq**	1,18E-02	2,71E-03	5,50E-03	**2,01E-02**	6,09E-04	4,68E-04	**2,11E-02**
Particulate matter to air	**g**	3,27E-03	1,52E-04	4,71E-04	**3,89E-03**	1,31E-04	7,24E-03	**1,13E-02**
Polyaromatic hydrocarbons	**g**	3,42E-07	1,09E-07	1,93E-07	**6,45E-07**	2,02E-08	2,93E-06	**3,60E-06**

Output: waste

Waste and material subject to recycling	Unit/kWh	Upstream	Core	Core - infrastructure	Total - generated	Down-stream[1]	Downstream - infrastructure[7]	Total - distributed
Hazardous waste								
Hazardous waste to disposal	**g**	2,35E-03	8,45E-04	7,78E-06	**3,20E-03**	9,59E-05	0	**3,29E-03**
Hazardous waste to Incineration	**g**	5,79E-03	1,83E-03	0	**7,62E-03**	2,29E-04	0	**7,85E-03**
Radioactive waste								
Volume of deposit for high-level radioactive waste[4]	**m³**	6,05E-13	2,26E-09	7,06E-15	**2,26E-09**	6,78E-11	0	**2,33E-09**
Volume of deposit for low/medium-level radioactive waste	**m³**	3,57E-11	4,21E-08	5,03E-08	**9,25E-08**	2,77E-09	0	**9,52E-08**
Low-level radioactive waste without further treatment	**g**	1,92E-02	9,02E-04	3,69E-05	**2,02E-02**	6,06E-04	0	**2,08E-02**
Spent fuel[5]	**g**	0	3,08E-03	0	**3,08E-03**	9,24E-05	0	**3,17E-03**
Uranium in spent fuel	**g**	0	2,72E-03	0	**2,72E-03**	8,15E-05	0	**2,80E-03**
Waste to recycling[6]								
Aluminium	**g**	0	0	2,45E-04	**2,45E-04**	7,35E-06	0	**2,53E-04**
Crushed concrete	**g**	0	0	6,75E-01	**6,75E-01**	2,03E-02	0	**6,96E-01**
Copper scrap	**g**	0	1,82E-06	2,32E-03	**2,32E-03**	6,97E-05	0	**2,39E-03**
Lead scrap	**g**	0	0	1,25E-03	**1,25E-03**	3,75E-05	0	**1,29E-03**
Steel scrap	**g**	1,41E-04	5,98E-05	7,12E-02	**7,14E-02**	2,14E-03	0	**7,35E-02**
Other waste to recycling	**g**	1,99E-02	1,22E-01	2,74E-03	**1,44E-01**	4,33E-03	0	**1,49E-01**
Other waste								
Waste to disposal	**g**	1,25E+01	6,27E-02	1,57E+00	**1,42E+01**	4,25E-01	0	**1,46E+01**
Waste to incineration	**g**	2,53E-04	1,08E-02	3,42E-02	**4,52E-02**	1,36E-03	0	**4,66E-02**
Waste water	**g**	6,16E+03	7,45E+00	1,10E+04	**1,72E+04**	5,31E+02	5,21E+03	**2,29E+04**

[1] Distribution losses of 3% of generated electricity are included in the Downstream column.
[2] Hydropower is reported as used potential energy (1 kWh hydroelectricity = 1,14 kWh potential energy).
[3] It is assumed that this electricity is generated by the NPP itself. The environmental impact is accounted for since this amount of electricity has been subtracted from the reference flow.
[4] High-level radioactive waste from electricity generation in upstream processes is assumed to be further processed and is not classified as waste in the generic data.
[5] Spent fuel includes the entire uranium fuel in g UO_2. The fuel assemblies (steel, zircalloy and Inconel components) are included in the volume deposit categories above.
[6] Use of recycled material is classified as secondary resources according to GPI.
[7] All waste flows are transformed into resource use and emissions through appropriate waste management processes. Thus, no waste amounts reported from Downstream infrastructure.

Conclusions of the LCA

The major environmental impact from nuclear power, in terms of emissions such as greenhouse gases, eutrophying and acidifying substances and potentially ground-level ozone creating substances, is attributable to the activities in the upstream processes, especially during mining of uranium and enrichment processes. The biggest contribution to emissions in the uranium extraction and milling phase comes from the uranium extraction activity and electricity consumption, while it in the enrichment phase derives from the electricity consumption. All in all, upstream processes contribute to 23-45% of the impact depending on impact category.

If the distribution of electricity is also included, the environmental impact from nuclear power is mainly caused by construction and decommissioning of the grid for distribution of the electricity generated. The downstream processes contribute to 38-64% of the total impact, depending on impact category. See section 3.4.5 for a dominance analysis of the results

The greenhouse gas emissions from generation and distribution of electricity are just above 4 g CO_2e per kWh which is slightly lower than compared to last update of the EPD. See section for 3.4.6 in the complete EPD® documentation for a description of the largest contributions to this difference.

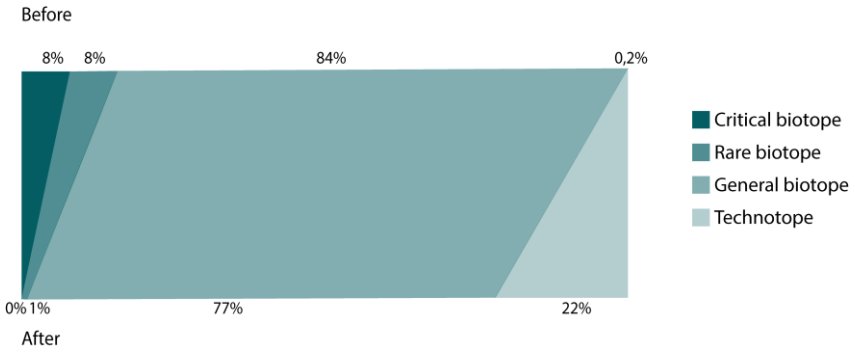
ADDITIONAL ENVIRONMENTAL INFORMATION

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

Land use and Impact on Biodiversity
Vattenfall's Biotope Method is used to quantify impacts on biodiversity as a direct consequence of the utilisation of land and water for economic activities. Affected areas are categorised into Critical biotope, Rare biotope, General biotope and Technotope. In the table and figure below the identified biotope changes are shown. See section 4.1 in the complete EPD® documentation for more information.

	Biotope Change (ha)	Biotope Change Allocated (ha)	Allocated areas (m^2/kWh el)		Biotope Change per kWh electricity (m^2/kWh el)
			Before	After	
Critical Biotopes	-44 310	-6	8%	0%	$-2 \cdot 10^{-6}$
Rare Biotopes	-2890	-5	8%	1%	$-2 \cdot 10^{-6}$
General Biotopes	-770	4	80%	80%	$3 \cdot 10^{-7}$
Technotopes	8090	7	0,2%	20%	$4 \cdot 10^{-6}$

Biotopes allocated to Vattenfall production (m^2/kWh el)



Safety, Barriers and Radiation
The nuclear power industry is strictly regulated and closely monitored by authorities. The operator of a NPP is the owner of and responsible for the nuclear fuel from mining to final repository. In addition to strict design criteria including redundant control systems there are safety considerations at three levels. See section 4.2 in the complete EPD® documentation for more information.

Radioactive substances in various forms are handled during normal operation by facilities in the nuclear fuel cycle. These substances emit ionizing radiation that may result in doses to the people working in the facility (dose-to-personnel), and to people outside the facility (dose-to-third party).

Dose to personnel. The table below show the average dose to personnel at the different facilities in the nuclear fuel life cycle.

	Unit	Upstream facilities	NPP-operation	Nuclear waste handling
Average individual dose	**mSv**	0,07 – 1,8	0,96 – 0,98	0,1 – 1,5

Dose to critical group/dose to representative individual is an assessed effective dose (mSv) that is received by an individual living in the vicinity of the facility. This is commonly a hypothetical individual that is assumed to represent a person that is more exposed due to its habits and consumption pattern, the critical group /representative individual may be defined differently between countries due to the type of facility, the emissions as well as the surrounding environment.

Maximum calculated annual effective dose 2018 from FKA and RAB was 0,00014 respectively 0,00029 mSv to a 7-12-year individual in the critical group. For comparison, if you live in Sweden the annual radiation dose is about 0,6 mSv from naturally occurring radioactive substances in soil and building materials. The total dose varies, but the average is about 4 mSv including for instance medical radiation and radon in homes.

Environmental Risk Assessment
The conclusion is that environmental risks in the nuclear fuel chain have low probability according to acceptance criteria set by the regulatory body. See chapter 4.5 in the complete EPD® documentation for more information.

Noise
Noise has been measured in the surroundings of the NPPs. Beside the level of noise generated at the original source, the noise level at a specific measuring point is also dependent on external circumstances such as for example wind direction and temperature. Maximum noise levels have been measured to be kept within the environmental permits for the nearest households in the vicinity of the power plant, which are 40 dB(A) (night) and 50 dB(A) (daytime) for Forsmark, and for Ringhals 43 dB(A) (night) and 50 dB(A) (daytime).

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

Information on the Independent Verification of this EPD®

This EPD® has been verified within Vattenfall's EPD® Management Process. The independent verifiers Caroline Setterwall, ABB, and Lasse Kyläkorpi, Vattenfall AB, 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 International EPD® system managed by EPD International AB (General Programme Instructions (GPI), version 2.01, 2013-09-18, and Product Category Rules (PCR) CPC 171 version 3.1, 2015-02-05). This certification is valid until 2022-12-31.

Verification of Vattenfall's EPD® Management Process

Vattenfall's EPD® management process is third party verified on annual bases, the last review was made 2019-10-17. 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 in the GPI and the Process Certification Clarification (PCC) for the International EPD® system.

Mandatory Statements

General
To be noted: EPD®s within the same product category but 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.

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.

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.

Information on Verification

EPD® programme: The International EPD® system managed by EPD International AB, Box 210 60, SE-100 31 Stockholm, Sweden. E-mail: info@environdec.com, www.environdec.com

Product Category Rules: Product Category Rules, CPC 171 Electrical Energy, version 3.1

PCR review was conducted by: The Technical Committee of the International EPD® system. Chair: Massimo Marine. EPD International AB. Full list of TC members available on www.environdec.com/TC

Independent verification of the declaration and data, according to ISO 14025, has been performed within Vattenfall's certified EPD® Management process.

X Internal (EPD process certification)

Internal and external verifiers: Lasse Kyläkorpi, Vattenfall AB, and Caroline Setterwall, ABB

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:** 2022-12-31