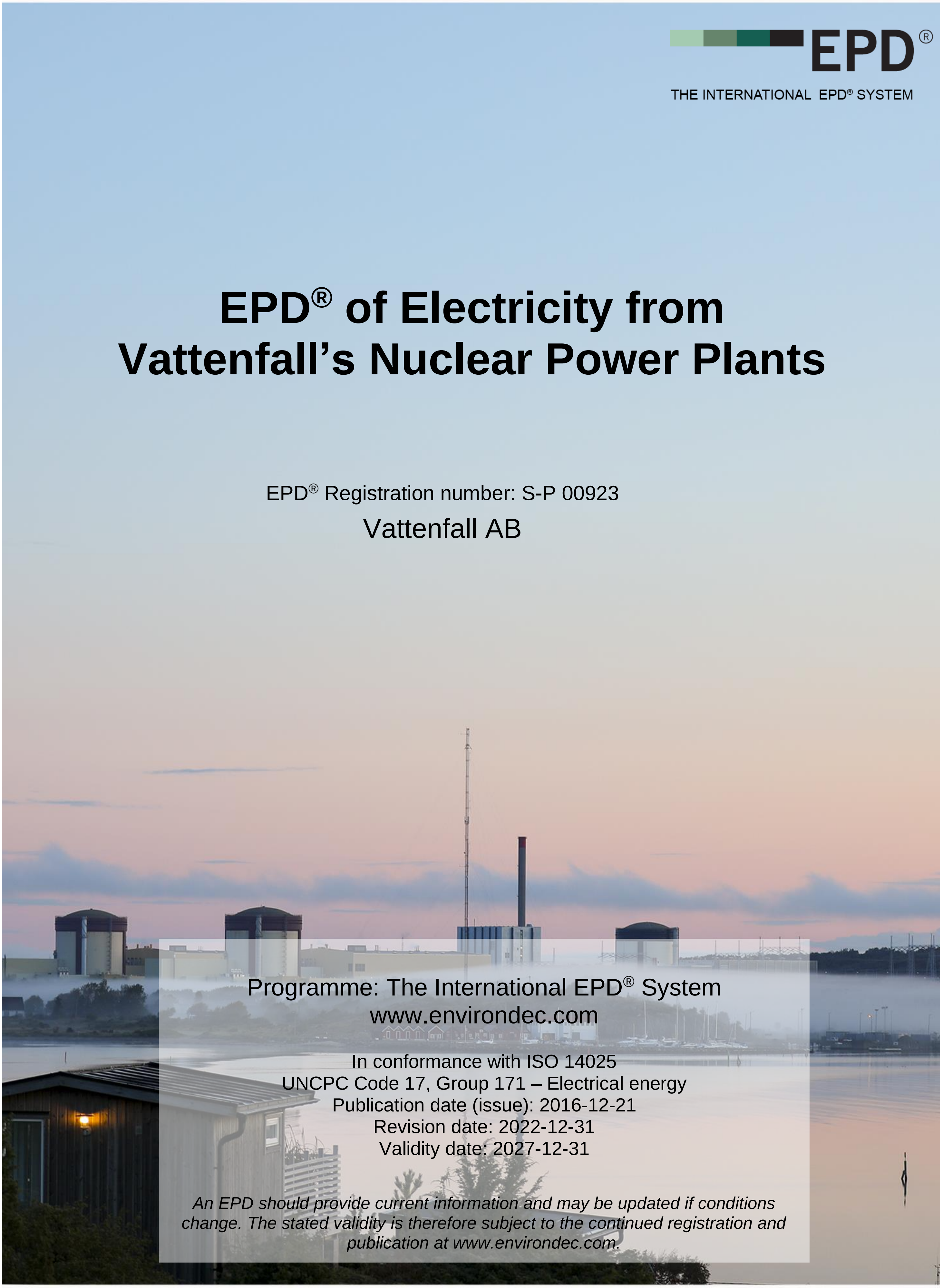

EPD® of Electricity from Vattenfall's Nuclear Power Plants

EPD® Registration number: S-P 00923

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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Validity date: 2027-12-31

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 EPD®

Contents

Front page: Ringhals nuclear power station (cropped image, photo: Malin Arnesson)

Summary

PRODUCER. Forsmarks Kraftgrupp AB (hereafter called Forsmark) and Ringhals AB (hereafter called Ringhals) 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 Forsmark and Ringhals 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 three Boiling Water Reactors (BWR) and two Pressurised-Water Reactors (PWR) with a common generating capacity of about 5500 MW. On an average year they generate approximately 40 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 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 below for a summary of methods and results. For more information, see section 3.

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 have been included in Core – Infrastructure, while the annual operation of all plants is included in Core. The use stage of electricity at the consumer level is not included. 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 are presented below, per generated and distributed kWh electricity. The results are presented for the life cycle modules described in the table below.

Upstream	Mining & milling, refinery and conversion, enrichment and fabrication of nuclear fuel. Production of auxiliary substances and chemicals for nuclear power plant operations and radioactive waste treatment.
Core	Operation of nuclear power plants 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 plants 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 nuclear power plants to compensate for losses in the distribution system.
Downstream – Infrastructure	Construction and decommissioning of the transmission grids and distribution networks.

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) is set to 4 %. The losses

are different for different types of customers and often higher in the countryside. The average loss to a household customer varies between 7-8 %.

In the table below, the calculated environmental impact per life cycle module is presented. *Total – generated* summarizes the impacts from producing 1 kWh electricity from Vattenfall's nuclear power, while *Total – distributed* presents the entire impacts as per functional unit: *1 kWh distributed to an industrial customer during an average year*. The industrial customer is connected to the regional distribution network.

Environmental impact categories

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)	1.60	0.214	0.433	**2.25**	0.168	1.62	**4.04**
	Biogenic	g CO_2-eq. (100years)	0.0442	0.0811	0.0940	**0.219**	0.0094	0.0188	**0.248**
	Luluc[2] (deforestation)	g CO_2-eq. (100years)	0	0	0.00821	**0.00821**	3.28E-04	1.41	**1.42**
	Total	g CO_2-eq. (100years)	1.65	0.296	0.535	**2.48**	0.177	3.05	**5.71**
Acidification potential (AP)		g SO_2-eq.	0.00511	0.00137	0.00242	**0.00890**	4.46E-04	0.0104	**0.0198**
Eutrophication potential (EP)		g PO_4^{3-}-eq.	0.00327	7.11E-04	4.30E-04	**0.00441**	1.94E-04	0.00533	**0.00993**
Photochemical oxidant formation potential (POFP)		g NMVOC-eq.	0.00731	0.00184	0.00197	**0.0111**	7.59E-04	0.00741	**0.0193**
Particulate matter		g PM2.5-eq.	0.00320	3.58E-04	6.43E-04	**0.00420**	1.86E-04	0.00414	**0.00853**
Abiotic depletion potential - Elements		g Sb-eq.	2.81E-05	5.28E-08	7.24E-06	**3.54E-05**	1.42E-06	2.28E-05	**5.97E-05**
Abiotic depletion potential - Fossil fuels		MJ, net cal. value	0.0267	6.73E-04	0.00408	**0.0314**	0.00190	0.0197	**0.0530**
Water scarcity footprint		m^3 H_2O-eq.	0.0685	0.00562	0.328	**0.402**	0.0161	0.199	**0.618**

[1] Distribution losses of 4 % 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 from nuclear power generation, concerning the herein assessed impact categories, is attributable to the activities in the upstream processes, especially during mining of uranium where the biggest contributions come from the uranium extraction activity and electricity consumption. All in all, upstream processes contribute to about 11-50 % of the impact depending on impact category. When looking at the distribution of electricity as well, 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 about 35-57 % of the total impact, depending on impact category. See section 3.4.8. for a more detailed dominance analysis of the results.

In contrast to the previous version of this EPD®, greenhouse gas emissions as a result of deforestation (GWP Luluc) are now included. The greenhouse gas emissions from generation and distribution of electricity are around 5.7 g CO_2e per kWh delivered to customer, which is somewhat higher compared to last update of the EPD® and much due to the inclusion of GWP Luluc. When excluding GWP Luluc, the GWP results are however somewhat lower than in the previous update of the EPD®. See section for 5.1. for more description of the differences towards the previous EPD®.

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 method for Land use and biodiversity impacts 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 the Corine Land Classes. In the table and figure below the identified biotope changes are shown. See section 4.1 for more information.

Land cover	Before (m^2)	After (m^2)	Land use change (m^2)
1. Artificial Surfaces	1 730 000	90 500 000	88 700 000
2. Agricultural areas	513 000	0	-513 000
3. Forest and seminatural areas	107 000 000	30 100 000	-76 500 000
4. Wetlands	10 200 000	4 050 000	-6 180 000
5. Water bodies	36 100 000	30 600 000	-5 560 000

Safety, Barriers and Radiation

The nuclear power industry is strictly regulated and closely monitored by authorities. The operator of a nuclear power plant 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 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 and to people outside the facility, dose to third party.

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

	Unit	Upstream facilities	Nuclear power plants - operations	Nuclear waste handling
Average annual individual dose	**mSv**	0.02 – 1.9	0.95 – 1.1	0.25 – 1.5

Dose to representative individual is an assessed 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 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 2021 from Forsmark and Ringhals was 0.00012 and 0.00079 mSv respectively. 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 annual dose to people in Sweden 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 4.4 for more information.

1. Introduction

1.1. Declared Unit

This document constitutes the certified Environmental Product Declaration EPD® of electricity from the nuclear power plants Forsmark and Ringhals operated by Vattenfall AB.

The declared unit is 1 kWh net electricity generated and thereafter distributed to an industrial customer connected to 70/130 kV

Forsmark and Ringhals nuclear power plants are base-load plants of the Swedish electricity system meaning that they provide a continuous supply of electricity throughout the year.

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 an EPD® in accordance with the system administered by EPD International AB (www.environdec.com). EPD® is an international application of ISO 14025, Type III environmental declarations. The International EPD® system and its application are described in General Programme Instructions.

The hierarchic structure of the fundamental documents for the EPD® system is:

- Product Category Rules, PCR 2007:08 *Electricity, steam and hot/cold water generation and distribution* (UN CPC 171 AND 173)), version 4.2.
- General Programme Instructions (GPI) for the International EPD® System, version 3.01.
- ISO 14025 on Type III Environmental Declarations.
- ISO 14040 *LCA - Principles and Procedures*, and ISO 14044 *LCA - Requirements and Guidelines*.

This EPD® contains an environmental performance declaration based on a life cycle assessment. Additional environmental information is presented in accordance with the Product Category Rules (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,
- Information on radiology, doses to personnel, doses to third party.
- An Environmental Risk Assessment (ERA) for the potentially environmentally or human toxicologically harmful emissions that may result 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 applied LCA for several 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 the generation of electricity. Vattenfall AB has the sole ownership, liability and responsibility of this EPD®.

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

- Electricity is used in the manufacturing of virtually every product. Information regarding the environmental footprint in electricity production is essential to LCAs 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 allowing 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 and being in line with ISO14001.
- The Directive 2009/72/EC requires member states to introduce systems for customer information regarding the origin of the electricity and, at a minimum, provide 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 Carbon Footprint. The International EPD® system has issued so-called climate declarations as the first example of single-issue EPDs. It describes the emissions of greenhouse gases, expressed as CO_2-equivalents for a product's life cycle, based on verified results from an LCA in accordance with ISO 14025.

Nuclear power differs from other power technologies e.g. in that:

- The nuclear fuel cycle and the technology are complex, and fuel is produced and refined in various locations.
- Radioactive substances are formed during the process.
- Ionizing radiation can neither be seen, heard nor felt.
- The general public worries about accidents and long-lived radioactive waste.

Vattenfall Business Area Generation is responsible for the electricity generation in all Vattenfall's nuclear power plants in Sweden. Vattenfall Business Area Generation is part of Vattenfall AB, SE-169 92 Stockholm, telephone +46-87395000.

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. Net sales amounted in 2021 to 180 billion SEK (approximately 18 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.

In 2021 Vattenfall generated 111.4 TWh electricity, of which 40.4 TWh was nuclear power, 40.9 TWh hydro power 11.2 TWh wind power, 0.5 TWh power from biomass and waste, and 18.4 TWh was fossil power. Furthermore, Vattenfall sold 15.6 TWh of heat and 56.0 TWh of gas during 2021.

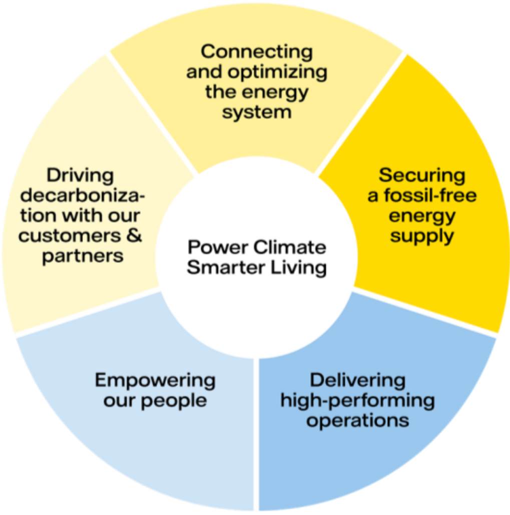
Read more about Vattenfall's environmental work at https://group.vattenfall.com/who-weare/sustainability/environmental-responsibility

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 reach net zero by 2040, and to contribute to limiting global warming to 1.5 °C by reducing its emission intensity (per kWh) with 77 % from 2017 to 2030 (scope 1+2). Vattenfall will also reduce the 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 industry 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.

2.2. Vattenfall Nuclear Power Plants

The product (electricity) described in this EPD is generated in the nuclear power plants Forsmark and Ringhals. They are two of the largest power plants in Sweden and important base load plants of the Swedish electricity system, contributing to approximately 24 % of the annual production in the country in 2021. Forsmark power plant is situated on the east coast of Sweden, in the region of Uppland, some 70 km northeast of the city of Uppsala. Ringhals power plant is situated on the west coast of Sweden, close to Varberg in in the region of Halland, some 60 km south of Gothenburg, see map in Figure 4.

Forsmark power plant is owned and operated by Vattenfall AB (66 %) and a number of private and public energy utilities under the name of Forsmarks Kraftgrupp AB. The company was formed in 1973. Ringhals power plant is owned and operated by Vattenfall AB (70.4 %) and Sydkraft Nuclear Power (29.6 %) and goes under the name of Ringhals AB.

Forsmark and Ringhals have a partly common organisation and one CEO. The CEO of Forsmark and Ringhals carries the ultimate responsibility for operations. Environmental supervisory and controlling support, including reactor safety and radiological protection, is managed by internal functions at the power plants. Monitoring of environmental work and reporting to authorities is managed by the environmental departments. Forsmark and Ringhals, as plant owners, are by Swedish law responsible for paying for any radiological damage in case of an accident with releases to the environment.[1]

Procurement of nuclear fuel requires a permit issued by the Swedish Government in accordance with present legislation (Kärntekniklagen). Permits are only granted to operators of nuclear power plants. The Operators Ringhals AB and Forsmark Kraftgrupp AB as well as Vattenfall Nuclear Fuel AB have received such permits and are the owners of the uranium from cradle to grave, i.e. from natural uranium to final repository of nuclear waste. SKB (Swedish Nuclear Fuel and Waste Management Company) has a permit to operate the waste facilities on behalf of Vattenfall.

2.2.1. Forsmark and Ringhals Nuclear Power Plants – Technical information

Forsmark consists of three boiling-water reactors (BWR) of the light-water type (LWR). Two of the reactors, Forsmark 1 and Forsmark 2, are practically identical and Forsmark 3 is of a more recent model. Ringhals has two pressurised-water reactors (PWR) of the light-water type (LWR), Ringhals 3 and Ringhals 4 that are practically identical. The reactors Ringhals 1 and Ringhals 2 were taken out of operation after 2020 and 2019 respectively and are not included in this EPD.

The reactors are cooled with seawater (Forsmark reactors with 150 m^3 per second and Ringhals reactors with 95 m^3/second) and the temperature of the outlet water is 10°C higher when it is released to the Bay of Bothnia and Kattegatt, North Sea respectively. In the BWR type reactors, 20 % of the fuel is replaced during revision every summer and in the PWR type reactors 25 % is replaced.

The power output, annual average generation, average efficiency and total fuel loads are listed for each reactor in Table 1. Also, the commissioned year and the planned closing-down year are listed for each reactor.

Table 1 Forsmark and Ringhals technical data

Reactor unit	Power output (MWel.)	Yearly average generation[1] (TWh)	Average efficiency[2] (%)	Total fuel load (tonne UO_2)	Commissioned (year)	Planned close down
Forsmark 1	990	7.5	34	134	1980	2040
Forsmark 2	1 121	8.3	34	134	1981	2041
Forsmark 3	1 172	8.9	35	138	1985	2045
Ringhals 3	1 074	7.3	34	82	1981	2041
Ringhals 4	1 130	7.9	33	82	1983	2043
Total	**7 120**					

[1] Forsmark 1-3 and Ringhals 3-4 average from 2017-2021
[2] Net generation/thermal generation.

[1] Law (2010:950) on responsibility and compensation for radiological damage. (Swedish: Lag (2010:950) om ansvar och ersättning vid radiologiska olyckor)

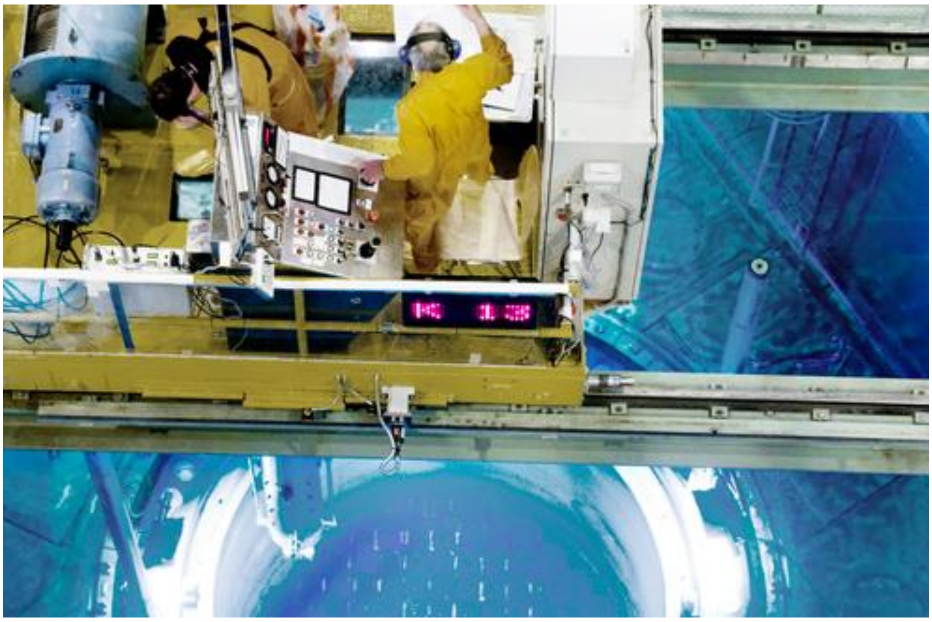


Figure 1 Fuel exchange at Ringhals (cropped image, photo: Börje Försäter)

2.2.2. Environmental Management System

Since 1998 Ringhals and Forsmark have certified environmental management systems according to ISO 14001. Both power plants are also certified according to ISO 45001 for occupational health and safety.
The environmental and health and safety management systems are an integral part of the facilities' management systems, which comprises the whole organization, planning, accountability, routines, and processes.

2.3. Product System Description

2.3.1. The Nuclear Life Cycle

The nuclear fuel cycle describes all the different steps and activities that are undertaken when uranium is used for the generation of electricity. All the stages from "cradle to grave" are included in this life cycle inventory (in accordance with the PCR), hence the full path from mining of natural uranium, through production of uranium fuel and generation of electricity at the nuclear power plants, to final repository of the spent fuel and distribution of the electricity to an average industry customer. These steps can be aggregated into three major processes: Upstream, Core and Downstream, and are briefly described below.

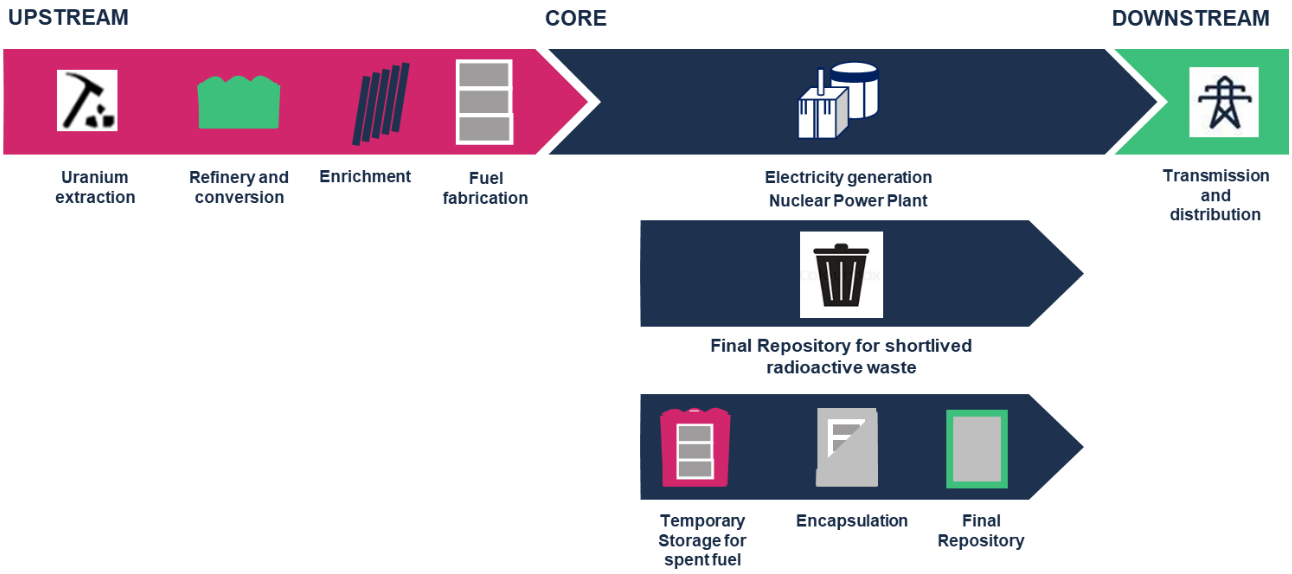


Figure 2 The nuclear value chain from mining of uranium ore to final repository and electricity distribution. Infrastructure for core processes and downstream processes are included.

Upstream Processes:

- **Uranium Extraction**
  The natural uranium ore is extracted via mining (in underground mine or open pit mine) and milling. Uranium oxide (U_3O_8) is produced, so called "yellow cake".
- **Refinery and Conversion**
  The "yellow cake" is converted (via a wet or dry process) into uranium hexafluoride UF_6. The content of the radioactive isotope uranium U_{235} is then less than 1 %.
- **Enrichment**
  Through an enrichment processes (such as the centrifuge method) the content of U_{235} in the UF_6 is increased to 3-5 %.
- **Fuel Fabrication**
  The enriched UF_6 is used for production of fuel pellets, consisting of uranium dioxide (UO_2), which are gathered in fuel assemblies, ready to use in nuclear power plants.
- **Reprocessed uranium**
  In some cases, one or more of the steps above can be replaced by reprocessing uranium. Vattenfall is, during the years of validity of this EPD not procuring reprocessed material.,.

Core Processes:

- **Electricity Generation**
  Via fission processes in the nuclear power plant the nuclear energy in the fuel is converted into heat, which is then converted into electricity. Each fuel assembly can be used for approximately 4-5 years before it is removed from the reactor and stored as spent fuel at on-site storage pools at Forsmark and Ringhals for about 12-18 months.
- **Final Repository for Short-lived radioactive waste**
  The short-lived operational waste is transported to the rock vault repository in Forsmark, a facility called SFR. In the future, short-lived radioactive waste from decommissioning is also planned to be finally disposed of there.
- **Long lived radioactive waste** from dismantling and decommissioning of the nuclear power plants will be finally disposed of in SFL, a final repository not yet built, however planned to be established after 2040[2].

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[2] As this facility is yet in the planning phase, the environmental data are not sufficient to evaluate land use and radiology impacts, and has hence been excluded from chapter 4.1-3. The facility is however assessed from a risk and LCA perspective.

- **Temporary Storage for spent fuel**
  The spent fuel is transported to the central interim storage facility for spent nuclear fuel (Clab). At Clab the fuel is temporary stored in water pools for approximately 30 years. The purpose is to reduce the generation of heat from the spent fuel to a level necessary for disposal in a final repository.
- **Encapsulation**
  After interim storage the spent fuel will then be placed in copper canisters at an encapsulation plant adjacent to Clab (not yet built).
- **Final Repository**
  The canisters with the spent fuel will be transported to the final repository where they will be deposited at about 500 meters depth, in the bedrock close to Forsmark's power plant (not yet built). They will be covered by bentonite clay.

Downstream processes

- **Transmission and distribution**
  The electricity produced at the nuclear power plants is transmitted to the consumers/end users via the transmission and distribution grid.

2.3.2. Upstream Processes – Selected Suppliers

Vattenfall Nuclear Fuel, owned by Vattenfall AB, procures the uranium fuel for Vattenfall's nuclear power plants. There are several suppliers in the different stages in the uranium processing chain and the suppliers selected for this EPD® cover 91-100 % of the uranium fuel used. Suppliers have been selected to cover the different technologies used in the different uranium processing steps, and different geographic locations.

The supplier selection in this EPD® is based on existing contracts for purchase during 2021-2024 including uranium in stock end of 2020. Included suppliers and their representativeness are presented in the map and text below.

Figure 3 Upstream process facilities location worldwide.

The selected suppliers for the different process steps are listed with their representativeness and respective techniques below.

Uranium extraction (Mining & milling)
The selected suppliers represent 91 % of the uranium extracted for fuel used.

- Cameco, Cigar Lake underground mine/McClean Lake milling, Canada
- BHP, Olympic Dam, underground mine, Australia
- China National Uranium Corporation (CNUC), Rössing, open pit mining, Namibia

Refining & Conversion
The selected suppliers represent 100 % of the refining & conversion service needed. Cameco and Orano both use the wet process where the uranium oxide is dissolved in nitric acid, and ConverDyn uses a dry process.

- Cameco, Blind River & Port Hope, Canada
- Orano, Malvési & Philippe Coste, France
- ConverDyn, USA

Enrichment
The selected suppliers represent 100 % of the enrichment service needed. They use the centrifuge process for enrichment.

- Orano, George Besse II, France
- Urenco, Great Britain

Fuel Fabrication
The selected suppliers represent 100 % of the service needed. The process is similar for all suppliers.

- Framatome, Lingen, Germany
- Westinghouse, Västerås, Sweden
- GNF, Wilmington, USA (chemical conversion) & Enusa, Juzbado, Spain (fuel fabrication)

2.3.3. Core Process – Nuclear power plants and Management of Conventional and Radioactive Waste
The nuclear power plants and the facilities for management of radioactive wastes included in this EPD® are presented and locations shown in the map below.

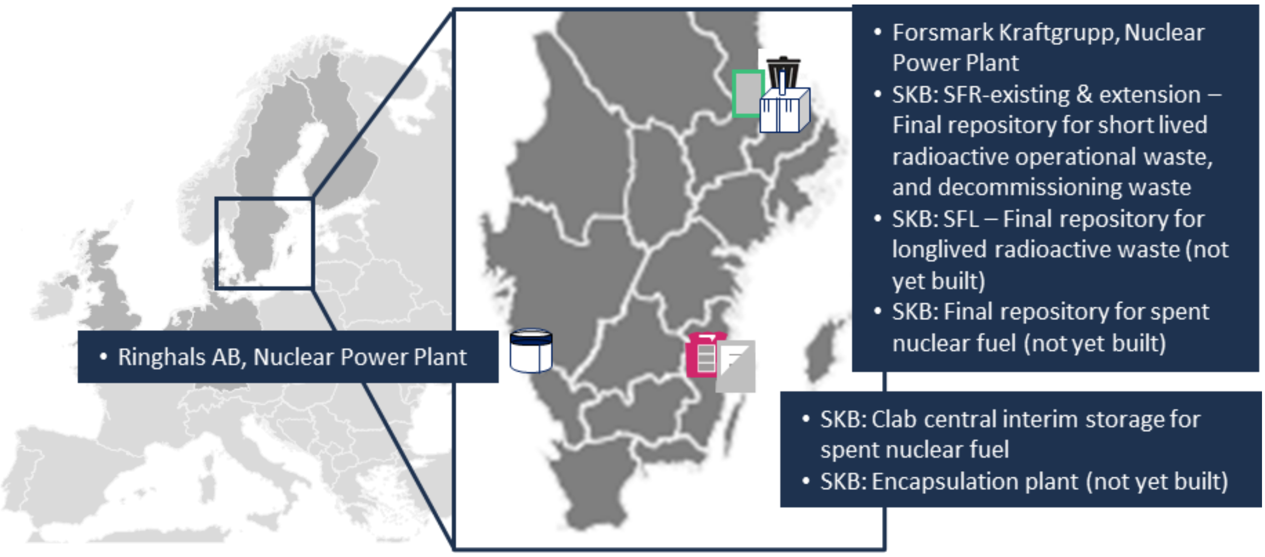


Figure 4 Core process facilities' locations

Included in this EPD® are the facilities for central interim storage (Clab), encapsulation and final disposal of spent nuclear fuel, the final repositories for short-lived radioactive waste (SFR-existing) and long-lived radioactive waste (SFL, future facility), and the nuclear power plants. Operational waste from the nuclear power plants is transported to SFR and waste from dismantling is planned to be disposed at both SFR and SFL. The responsibility for developing and operating the system of facilities used to handle all waste from all the Swedish nuclear power plants lies within SKB.

2.3.4. Downstream Process – Distribution of Electricity

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 converted to lower voltages for transmission over distribution networks and low voltage local networks to consumers. Large customers, e.g. certain industries, are frequently connected to the high or medium voltage distribution network, while small users such as single households are connected to low voltage local 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. In general, the higher the voltage, the lower the losses. To an industrial customer connected to the regional network, the average distribution loss is around 4 % whereas the loss to a household customer in the countryside is around 7-8 %. See Figure 5 below for distribution statistics.

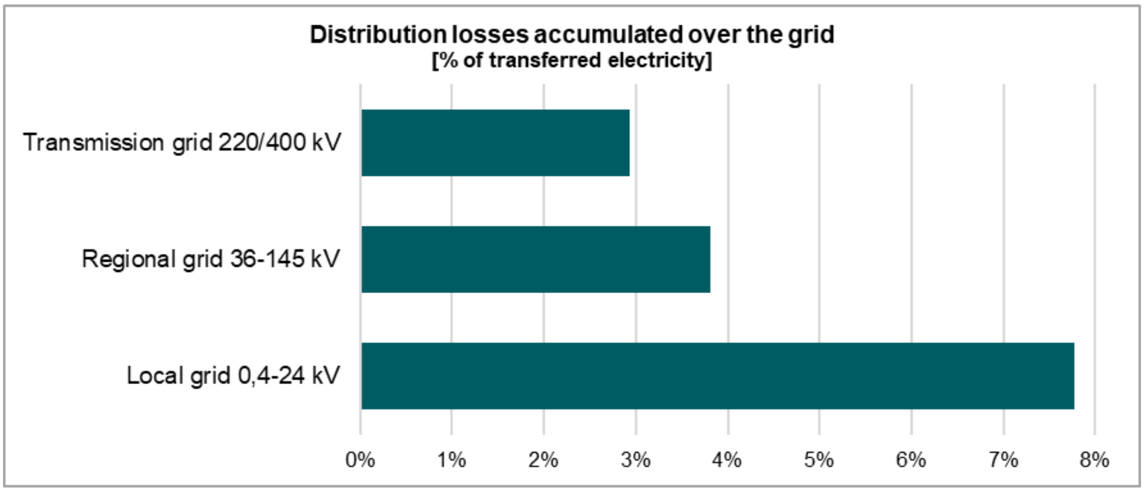
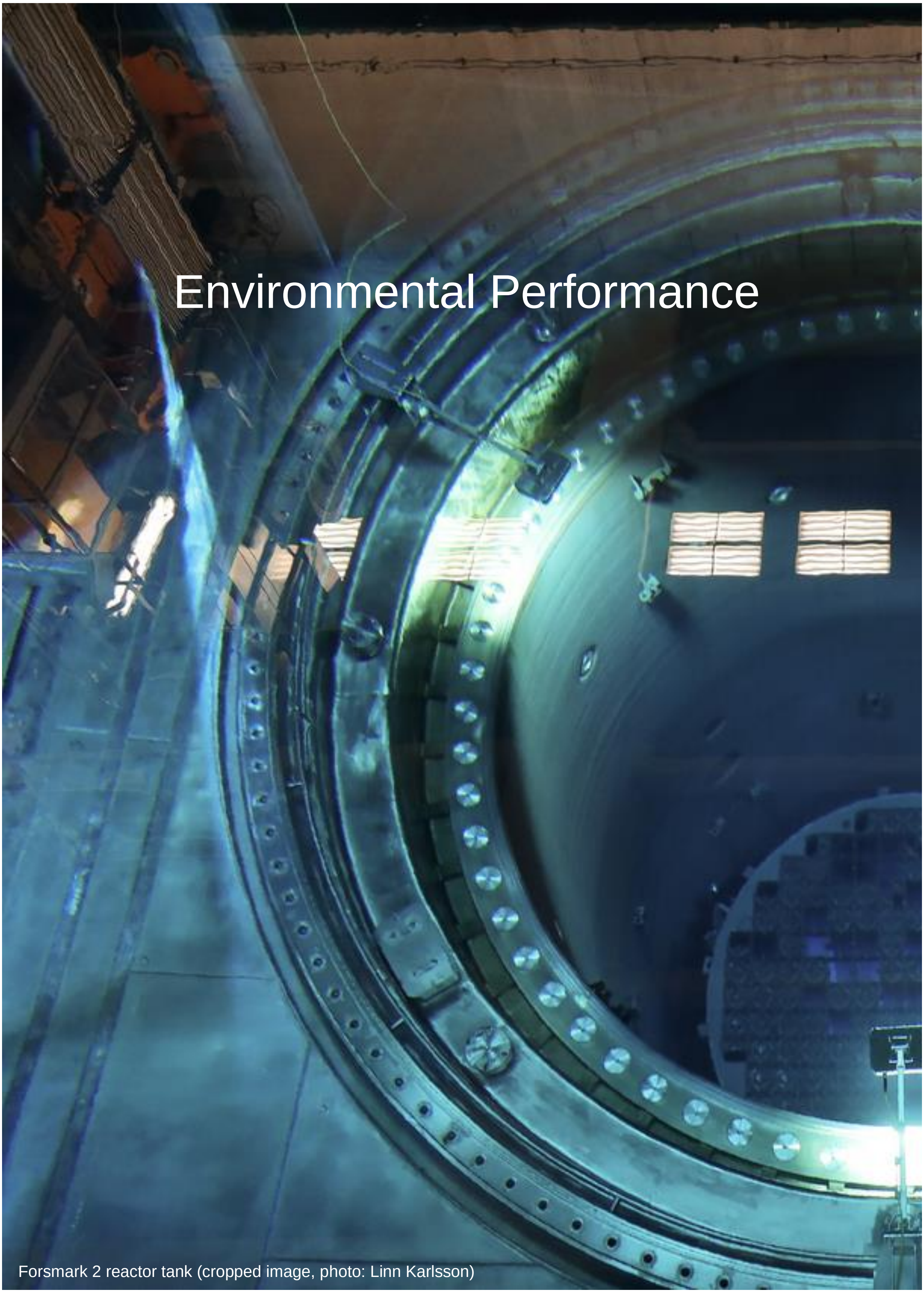


Figure 5 Distribution losses to customers at various voltage levels accumulated over the grid in Sweden. Data are a 5-year averages between 2017 to 2021. Source: Svenska Kraftnät and Vattenfall Eldistribution AB.

Distribution losses lead to reduced delivery of useful electricity, which must be compensated for by additional generation in the power plant and consequently additional resource use and emissions. In this study, the losses are compensated for through additional generation in Forsmark and Ringhals' nuclear power plants. In the downstream calculations, losses of 4 % have been applied, representing a typical industrial customer connected to the 70-130 kV distribution network.

Environmental Performance



Forsmark 2 reactor tank (cropped image, photo: Linn Karlsson)

3. Environmental Performance Based on LCA

3.1. Life Cycle Assessment Method

This EPD® for electricity from Forsmark and Ringhals nuclear power plants is based on a comprehensive LCA. The declared unit is defined as 1 kWh net electricity generated and thereafter distributed to an industrial customer connected to the regional distribution network (70-130 kV).

The used net electricity generation is calculated as the net electricity generation for the year 2021.The assessment comprises operation of all facilities in the nuclear fuel cycle. Construction and decommissioning of the nuclear power plant as well as waste facilities for radioactive waste. The distribution of electricity has been included in terms of distribution losses as well as construction, operation and dismantling.

In summary, the environmental performance has been determined as follows:

- The nuclear power plants' share of the supplier in question has been calculated based on the average annual need for fuel.
- The nuclear power plants' operations have been inventoried with respect to use of electricity, fuels, auxiliary materials and chemicals, emissions and handling of conventional waste, as well as on-site transports and test operation of reserve power.
- The nuclear power plants' share of the different facilities for management of radioactive wastes have been calculated, and the facilities have been inventoried individually along with necessary transportation of the waste.
- Environmental impact per kWh of non-infrastructure processes is the sum of the portions of the environmental impact of suppliers and radioactive waste management facilities allocated to the nuclear power plants, and of the nuclear power plants themselves (including necessary reserve power testing), divided by the annual average electricity net generation.
- Environmental impact per kWh of infrastructure processes (construction and decommissioning) is divided by the annual average electricity net generation during the reference period and the technical service life, i.e. the assumed electricity net generation during the technical service life of the constructions.

3.2. Technical Service Life, Reference Flow, Reference Year

The technical service lifetime is different for different facilities in the nuclear power plants' life cycles and the technical service lifetime of them, as for all Swedish nuclear power plants, influences the environmental impacts from infrastructure (construction and dismantling) and operation of the different facilities in the core process. Furthermore, the technical service lifetime of suppliers' facilities varies. Since construction and decommissioning of suppliers' facilities are excluded, their technical service lifetime has no relevance for the LCA results, only on biotope impact, see chapter 4.1.

Table 2 Overview or reference flows within the life cycle.

Description of reference flows used in the LCA	TWh
Average electricity generation in Forsmark and Ringhals nuclear power plants (Vattenfall share)	26.9
Electricity generation in Forsmark and Ringhals reactors during their technical service lifetime (Vattenfall share)	1 824
Estimated total electricity generation in all Swedish reactors during their technical service lifetimes	3 689
Electricity transfer during the technical service lifetime of the transmission grid 220/400 kV	4 736
Electricity transfer during the technical service lifetime of the regional network 70/130 kV	2 887

Table 3 Reference flow, technical service lifetime and reference year within the process modules

Process module	Facility	Technical service life [years]	Infrastructure: Reference flow [TWh]	Operation: Environmental data	Operation: Reference flow [TWh]
Upstream	Mines Refinery & Conversion Enrichment Fuel fabrication	Not applicable	Not applicable	Operational data mainly from 2021[1]	39.7[2]
Core	Ringhals 3, 4 Forsmark 1, 2, 3	60	2 679[3]	Operational data from 2021	39.7[3]
	CLAB	84	3 689[6]	Operational data from 2021	3 689[6]
	Encapsulation	33		Estimated operational data for encapsulation of total spent fuel from all Swedish reactors during their technical service lifetimes. The lifetime requirement of canisters and total lifetime production provides operating data per kWh	
	SFR-existing[4]	85		Operational data from 2021	
	SFR-expansion[4,5]	45		No operation data available, data estimated from SFR-existing[4] and SKB estimations[7]	
	SFL[5]	10		No operation data available, data estimated from SFR-existing[4]	
	Final repository[5]	43		Estimated operational data for the deposition of total spent fuel from all Swedish reactors during their technical service lifetimes. Estimated operating data for encapsulation is reported per canister.	
Downstream	Transmission grid	40	4 736	Operational data from Svenska Kraftnät for 2021 Length and transferred electricity from Svenska Kraftnät for 2021	118.4
	Regional network	40	2 887	Operational data from Vattenfall Eldistribution AB for 2021 Length and transferred electricity from Vattenfall Eldistribution AB for 2021/2022	72.2

[1] The supplier selection is based on existing contracts for purchase during 2021-2024 including uranium in stock end of 2020. For sites that could not provide sufficient data for the operational year of 2021, provided data from a previous production year has been applied.
[2] Converted to the needed amount of uranium, see Figure 6.
[3] The entire production at Forsmark and Ringhals (including Ringhals 1 and 2 for infrastructure, and only active units Ringhals 3 and 4 for operation)
[4] In previous versions of the EPD (2016 and earlier), SFR-existing was called SFR1 and SFR-expansion was called SFR3
[5] Not yet built. Technical service lifetime for these facilities have been estimated by SKB. For the final repository for spent fuels it represents the time after which all spent fuel has been deposited and the repository has been sealed. After sealing, the surface area can be used for other purposes.
[6] Vattenfall's share emanates to about 41 %
[7] Estimations provided by SKB which was originally used for a climate- and energy mapping for current and future facilities conducted in 2020. Only predicted energy use in operation was applied as operational data, remaining data were estimated from SFR-existing.

3.3. System Boundaries, Allocation and Data Sources

3.3.1. System Boundaries

Figure 6 below presents a simplified process tree with system boundaries for the LCA on Vattenfall's nuclear power production.

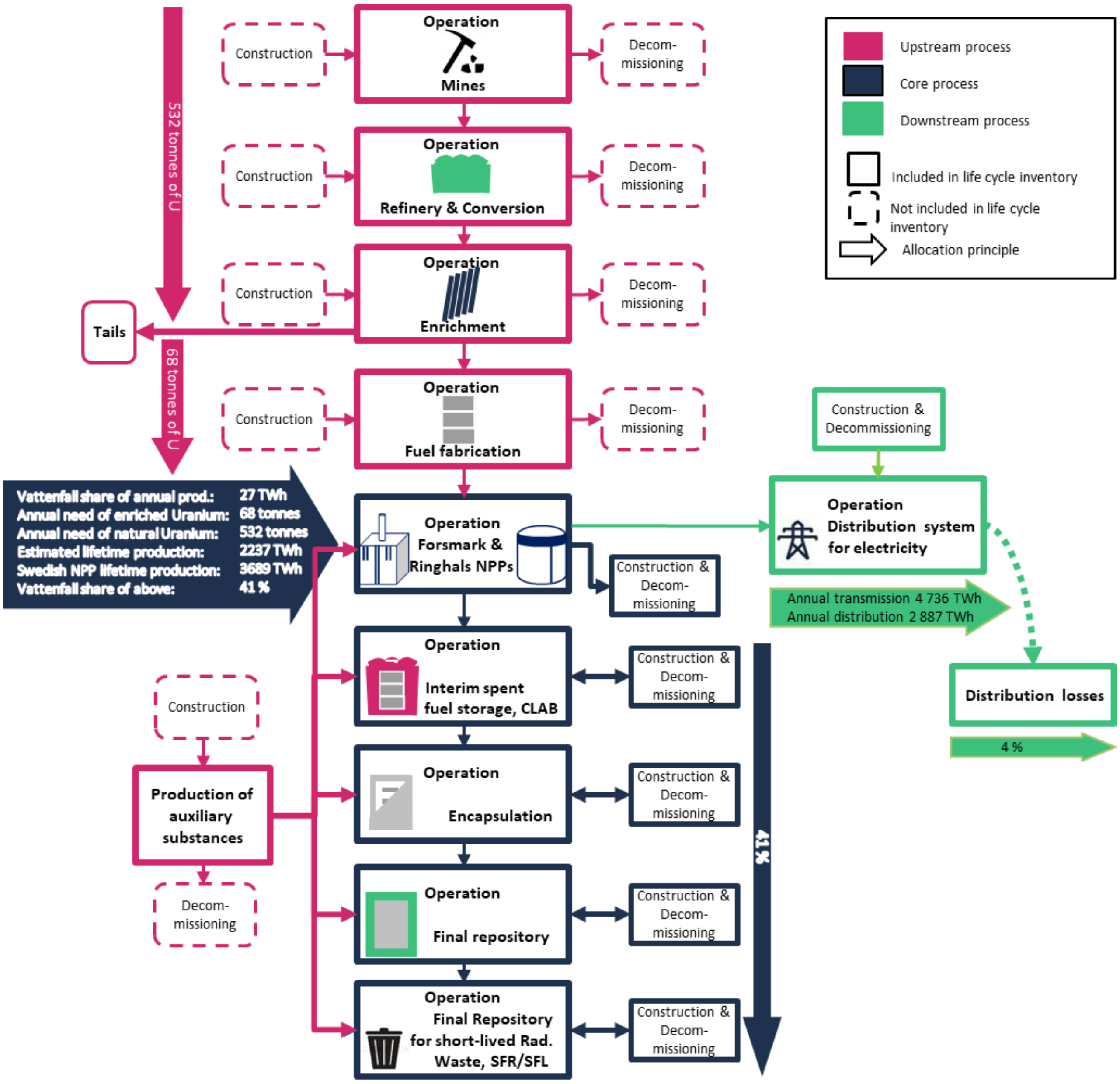


Figure 6 Simplified process tree and boundaries for the LCA in this EPD®. Reference flow in upstream, core and downstream processes are made visible. Conventional waste is handled according to the Polluter Pays Principle within each process step.

Emissions are aggregated in five life cycle stages, as earlier described on page 3. In Table 4 below, the included processes within the life cycle are further described in 13 phases: from mine to final waste deposit and electricity distribution. For the *Upstream* and *Core* modules, the emissions are expressed as per 1 kWh of generated electricity. For the *Downstream* modules, the emissions are expressed as per 1 kWh of electricity delivered to an industrial customer (i.e. including the distribution loss of 4 % of generated electricity).

Table 4 Life cycle divided into 13 phases.

Process module	Process	Included environmental impact
Upstream	Uranium extraction	Includes use of fuels and electricity, raw materials, emissions, production of auxiliary substances and chemicals, transportation of exiting wastes, and all available amounts of wastes.
	Conversion	Includes transport from uranium extraction mines, use of fuels and electricity, raw materials, emissions, production of auxiliary substances and chemicals, transportation of exiting wastes, and all available amounts of wastes.
	Enrichment	Includes transport from conversion plant, use of fuels and electricity, raw materials, emissions, production of auxiliary substances and chemicals, transportation of exiting wastes, and all available amounts of wastes.
	Fuel fabrication	Includes transport from enrichment facility, use of fuels and electricity, raw materials, emissions, production of auxiliary substances and chemicals, transportation of exiting wastes, and all available amounts of wastes.
	Auxiliaries Nuclear power plants	Production of auxiliary substances and chemicals used in nuclear power plants.
	Auxiliaries radioactive waste facilities	Production of auxiliary substances and chemicals used in facilities for management of radioactive waste.
Core	*Operation:* Nuclear power plants	Transport of uranium fuel and auxiliary substances and chemicals to the nuclear power plants, on-site transports, operation of nuclear plants and fossil fuelled reserve power, electricity, raw materials, emissions, transportation of radioactive waste and transportation and treatment of conventional waste.
	Operation: Radioactive waste facilities	Includes use of electricity, raw materials, emissions, all necessary transportation, and transportation and treatment of conventional waste.
	Infrastructure: Construction/ decommissioning of nuclear power plants	Includes manufacturing of inputs (raw materials), groundwork and handling of outputs including all transportation. Emissions form deforestation before the nuclear power plants were constructed are included as well.
	Infrastructure: Construction/ decommissioning of waste facilities	Includes manufacturing of the major construction materials (followed from cradle to grave), necessary blasting and groundwork, and handling of outputs including transportation. Data for not yet existing plants, SFR-expansion and SFL, has been estimated from SFR-existing along with estimations provided by SKB. Data for not yet existing encapsulation and final repository plants has been estimated by SKB. Emissions form deforestation before the waste facilities where constructed are included as well.
Downstream	*Operation:* distribution network	Includes emissions from inspection trips, top-ups in reserve generators, production and emissions of oils and SF6.

	Infrastructure: Construction/ decommissioning distribution network	Includes manufacturing of materials (for lines, cables, pylons, transformers, buildings, and switching stations), groundwork and handling of discharge material including transportation. Emissions form deforestation before the distribution networks where constructed are included as well.
	Distribution losses	Calculated by additional generation in the nuclear power plants to compensate for losses in the electricity distribution system, i.e. 4 % of extra generation of 1 kWh generated electricity.

All necessary transports are included. Assumptions regarding transportation of uranium are based on average uranium fuel volumes and mix of suppliers during the years 2021-2024, including uranium in stock end of 2020. 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.

3.3.2. Allocation Principles

All environmental impact is allocated to the electricity generation.

The uranium quantities from each process from mining to final repository have been calculated according to the proportion of the nuclear power plants' average annual requirement of fuel.

Whereas the nuclear power plant infrastructure is included in relation to Vattenfall's ownership share, a portion of the waste facility infrastructure has been allocated to the lifecycle corresponding to the Forsmark and Ringhals nuclear power plants' life generation in relation to the whole generation of Swedish nuclear power. Total nuclear generation is calculated as the sum of expected life generation for each reactor by adding already produced electricity, plus estimated production until end of the technical service life.

Excluded from the LCA:

- Further processing of scrapped material transported to recycling plant (in accordance with the PCR).
- Impacts due to potential accidents, breakdowns, and leakages (included in Additional Environmental information, section 4.4).
- Impacts due to land use and land use change, apart from emissions from deforestation (included in Additional Environmental Information, see section 4.4).

3.3.3. Specific methodological choices

Environmental impacts have been calculated in accordance with the methodology described in the PCR.

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 nuclear power.

3.3.4. Completeness and the 1 %-rule

The International EPD® System requires that no more 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 the studied core process.

The known exclusions in both the production stage (upstream and core processes) and distribution stage (downstream processes) contribute less than 1 % to reported emission categories respectively. See more details for each life cycle module in the following sections.

Core module and upstream module

All inflows and outflows to the operation of the nuclear power plants, Clab, and SFR-existing are based on what they report either externally or internally. Inputs and outputs from operation of not yet existing plants for handling of radioactive wastes i.e. encapsulation plant, and final repository are based on discussions with experts within SKB. The operation of the final storages for radioactive demolition waste, SFR-expansion and SFL, will be of the same kind and order as the operation of SFR-existing. Input and output data for SFR-expansion and SFL are therefore estimated from SFR-existing. In addition, SKB made estimations originally used for a climate- and energy mapping for current and future facilities in 2020 from which predicted energy use in operation has been applied as operational data.

Major inputs and outputs necessary to construct, maintain and dismantle the infrastructure of nuclear power plants and waste management facilities for radioactive wastes have been included. Production of raw material for buildings, machinery and components is included. The manufacturing process for large machines and components such as generators, transformers and turbines has been included. All known inputs and outputs of the uranium fuel subcontractors' operations have been included. The assumption regarding amounts of material is conservative, especially due to the now closed blocks Ringhals 1 and Ringhals 2 at Ringhals still being included in the model due to that Ringhals previously was modelled as one facility, and Ringhals 1 and Ringhals 2 has hence not been separable from Ringhals 3 and 4.

Infrastructure of the suppliers in the uranium fuel chain is not included. The plants for extraction, conversion and enrichment of uranium as well as production of fuel are used by many users other than Vattenfall. It is difficult to obtain data from the suppliers and the construction and demolition of these plants are assumed to have little impact on the final results regarding the studied environmental impact categories, and are hence not included in this assessment. The infrastructure of other upstream processes is included in most cases since it is included in the LCI data from the used databases (ecoinvent and GaBi Professional).

Since all known inflow and outflows are included in the analysis in the core module, the 1 %-rule is considered to be met. For included processes upstream (excluding gravel, sand, earth, water, and energy resources) all resource flows from nature aggregate to approximately 1.6 g/kWh electricity. The sum of all identified flows not tracked from the cradle is approximately 0.0000042 g/kWh, which is less than 1 % (about 0.0003 %) of aggregated resource flows from nature.

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 ares used to model the construction and dismantling of the national grid. No data gaps have been reported in the documentation of the selected generic data used for construction and dismantling of the networks.

The 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 (2021) and include inspection trips, top-ups in reserve generators, consumption of oil and SF6 including waste management. Operational data for the regional grid are taken from Vattenfall Eldistribution AB (2021) 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.

For included processes (excluding gravel, sand, soil, water, and energy resources) all resource flows from nature aggregate to approximately 1.1 g/kWh electricity. The sum of all identified flows not tracked from the cradle (from compensation of losses) is approximately about 0.01 % of aggregated resource flows from nature. Hence, the risk of an impact contributing more than 1 % to either of the assessed impact categories from excluded flows is deemed to be low.

3.3.5. Data Quality and the 10 %-rule

In the Environmental Impacts, section 3.4, the results are given with three significant figures. It should be noted that the data quality does not always motivate three significant figures. Values smaller than 0.001 are presented with scientific format.

According to the EPD® system's General Programme Instructions, section 1, *specific data* shall always be used if available. If *specific data* are 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 for completeness, precision and representativeness. *Proxy data* are data from commonly available data sources that do not fulfil all of the data quality characteristics of *selected generic data*.

The 10 %-rule is met in all life cycle stages and is hence also met for the entire life cycle. See more details for each life cycle module in the following sections.

Upstream module

Specific data have been retrieved from the suppliers in the uranium fuel chain for operations related to mining, milling, refinery and conversion, enrichment and fuel fabrication. *Selected generic data* have been used for the European suppliers' upstream processes and for production of auxiliary material and chemicals for the nuclear power plants.

Data for upstream processes for non-European suppliers have been applied as "Global" or "Rest-of-the-World" average data, classified as *selected generic data*. In some cases, European average data have been used for non-European suppliers, when other data have not been available. Most of the environmental impact from the upstream processes of non-European suppliers in the uranium fuel chain stems from electricity generation or fuel use, where the country specific data have been applied.

Core

Specific data have been used for the operation of the nuclear power plants and for the operation of the already built waste management plants. Operation of not yet built facilities have been estimated based on already built similar facilities, along with predictions from SKB. Specific data on high, medium and low radioactive waste are applied.

Core – Infrastructure

Specific data have been used with respect to construction material amounts, excavated amounts, etc. Data for production of construction materials, vehicle operation, waste treatment, and generation of electricity supplying the subcontractors are selected generic data. Other generic data have been used for diesel powered machines, and vehicles used for groundwork such as excavating, transports, and handling of masses of stone and soil during construction.

Downstream module

Specific data have been used regarding operation of the networks, network dimensions, electricity transfer and losses. *Selected generic data* have been used for construction and demolition of the national grid, while *specific* and *selected generic data* have been used to model the regional grid.

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* have been used. See Table 5 below for presentation of proxy data in all life cycle stages along with the total share of proxy data for the entire life cycle. As can be seen, no more than 10 % originates in proxy data and the 10 %-rule is therefore met for the entire life cycle for all impact categories.

Table 5 Share of proxy data in all life cycle stages, along with total proxy data share

Impact category[1]	Unit/kWh	Share of proxy				
		Upstream	Core	Core - infr.	Downstream	TOTAL
GWP fossil	g CO_2-eq. (100years)	1.0 %	0.0 %	<10.0 %	0.0 %	**1.7 %**
GWP incl. bio CO_2	g CO_2-eq. (100years)	1.0 %	0.0 %	<10.0 %	0.0 %	**3.7 %**
AP	g SO_2-eq.	0.4 %	0.0 %	<10.0 %	0.0 %	**1.3 %**
EP	g PO_4^{3-}-eq.	0.3 %	0.0 %	<10.0 %	0.0 %	**0.5 %**
POFP	g NMVOC-eq.	0.1 %	0.0 %	<10.0 %	0.0 %	**1.1 %**
PM	g PM 2.5-eq.	0.3 %	0.0 %	<10.0 %	0.0 %	**0.9 %**
ADP Elements	g Sb-eq.	0.3 %	0.0 %	<10.0 %	0.0 %	**1.4 %**
ADP Fossil	MJ. net cal. value	0.9 %	0.0 %	<10.0 %	0.0 %	**1.3 %**
AWARE	m^3 H_20-eq.	0.0 %	0.0 %	<10.0 %	0.0 %	**5.5 %**

[1] GWP = Global Warming Potential, AP = Acidification potential, EP = Eutrophication Potential, POFP = Photochemical Oxidant Formation Potential, PM = Particulate Matter, ADP Elements = Abiotic Depletion of elements, ADP Fossil = Abiotic Depletion of fossil fuels, AWARE = Water scarcity footprint

3.3.6. Characterisation

Characterisation factors have been applied when the impact of various emissions and resource use to the environmental impact indicators was calculated. Calculations and characterisations are in accordance with the General Programme Instructions and the version 1.0 recommendations on www.environdec.com.

The characterisation 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 characterisation factors except for AP, which is non-baseline. It should be noted that for the water scarcity indicator, AWARE, the regional characterisation 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. The GWP impact indicators are used to calculate biogenic GWP results, by subtracting the exclusively fossil indicator result from the combined equivalent. An additional GWP indicator is included as well - greenhouse gas emissions as a result of deforestation (GWP Luluc), which are calculated manually with full details made available for the reviewer.

3.4. Environmental Impacts

The assessment results are summarized in Table 6 below and commented in sections 0-0.

Quantities are expressed per declared unit, in line with the PCR:

- 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 connected to the 70/130 kV distribution network. Distribution losses are set to 4 % of generated electricity and are included in *Downstream*.

More information on distribution and distribution losses is presented in section 0 on Distribution of Electricity. More comprehensive inventory data have been made available to the third-party reviewer.

Table 6 Environmental impacts per 1 kWh of electricity generated for Upstream, Core and Core – infrastructure modules, and per 1 kWh distributed for Downstream and Downstream – infrastructure modules

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)	1.60	0.214	0.433	**2.25**	0.168	1.62	**4.04**
	Biogenic	g CO_2-eq. (100years)	0.0442	0.0811	0.0940	**0.219**	0.0094	0.0188	**0.248**
	Luluc[2] (deforestation)	g CO_2-eq. (100years)	0	0	0.00821	**0.00821**	3.28E-04	1.41	**1.42**
	Total	g CO_2-eq. (100years)	1.65	0.296	0.535	**2.48**	0.177	3.05	**5.71**
Acidification potential (AP)		g SO_2-eq.	0.00511	0.00137	0.00242	**0.00890**	4.46E-04	0.0104	**0.0198**
Eutrophication potential (EP)		g PO_4^{3-}-eq.	0.00327	7.11E-04	4.30E-04	**0.00441**	1.94E-04	0.00533	**0.00993**
Photochemical oxidant formation potential (POFP)		g NMVOC-eq.	0.00731	0.00184	0.00197	**0.0111**	7.59E-04	0.00741	**0.0193**
Particulate matter		g PM2.5-eq.	0.00320	3.58E-04	6.43E-04	**0.00420**	1.86E-04	0.00414	**0.00853**
Abiotic depletion potential - Elements		g Sb-eq.	2.81E-05	5.28E-08	7.24E-06	**3.54E-05**	1.42E-06	2.28E-05	**5.97E-05**
Abiotic depletion potential - Fossil fuels		MJ, net cal. value	0.0267	6.73E-04	0.00408	**0.0314**	0.00190	0.0197	**0.0530**
Water scarcity footprint		m^3 H_2O-eq.	0.0685	0.00562	0.328	**0.402**	0.0161	0.199	**0.618**

[1] Distribution losses of 4 % 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.

3.4.1. Global Warming Potential (GWP)

Emissions of greenhouse gases emanate mainly from use of fossil fuels in electricity generating processes, energy use in construction of transmission networks and in other industry processes such as uranium fuel production. The contribution from the different life cycle stages, visualized in Figure 7 below, are further described below.

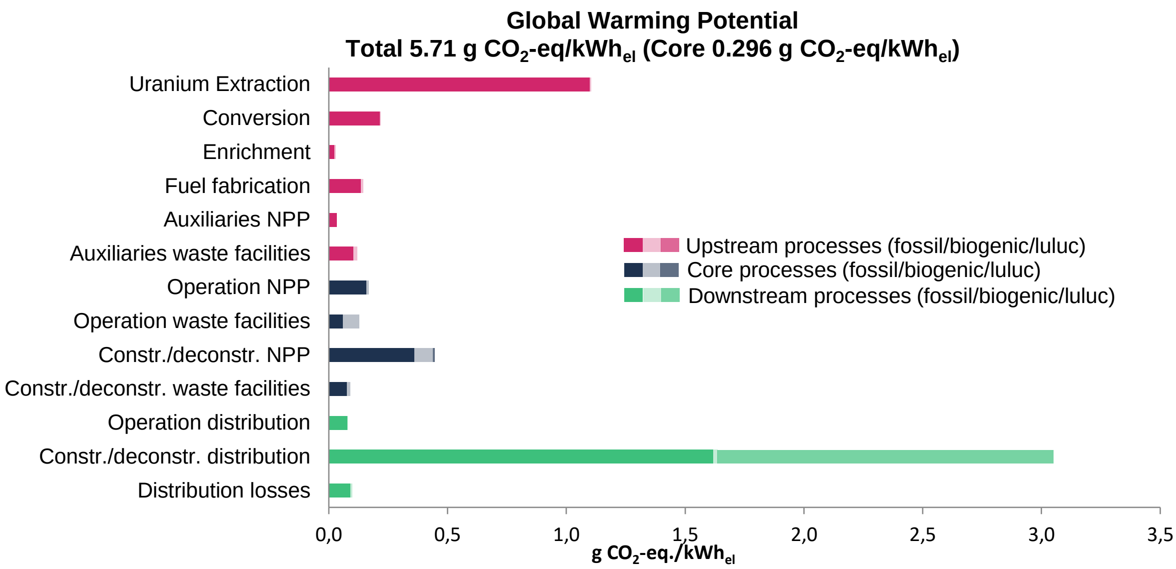


Figure 7 Potential emissions of greenhouse gases. NPP = Nuclear Power Plants, Waste facilities = all SKB's nuclear waste facilities, Constr./Decom. = the construction and decommissioning of the different facilities, Distribution = the assessed transmission and regional distribution network.

- **Upstream process** contributes with about 29 %, which emanates mainly from energy use in the uranium fuel supply chain, where uranium extraction is the largest contributing activity.
- **Core process** (operation of nuclear power plants and waste facilities) contributes by about 5 % of the total emissions, emanating mainly from operational waste treatment and fossil fuel use in the power plants.
- **Core – infrastructure** (construction/demolition of nuclear power plants and waste facilities) contributes with approximately 10 % of total greenhouse gas emissions. The main contribution is driven by production of materials going into the power plants, as well as emissions associated with its demolition. Deforestation is an insignificant contributor to emissions from Core – infrastructure. Its 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** (operation of distribution grid) contributes around 1 %, caused mainly by inspection trips and SF_6 leakages.
- **Downstream – infrastructure** (construction/demolition of distribution grid) contributes with approximately 54 % of total greenhouse gas emissions. The main contribution is driven by production of materials going into the infrastructure along with the deforestation. The emissions from deforestation contribute 46 % 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 about 2 %.

Transports account for about 2 % of total 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 89 % of total. Contributions from other greenhouse gases than CO_2 are mainly from methane (about 5 %), sulphur hexafluoride (about 1 %) and nitrous oxide (about 1 %). The emissions of methane and sulphur hexafluoride occurs mainly in the downstream distribution of electricity, although large shares of methane as well derives from the electricity generation upstream, while nitrous oxide derives mainly from the uranium extraction phase (explosives) and the conversion phase (use of nitric acid).

3.4.2. Acidification Potential (AP)

Figure 8 below presents the distribution contribution of emissions contributing to Acidification Potential from different stages in the life cycle. The dominant contributions are due to emissions of sulphur dioxide and nitrogen oxides, contributing with 53 % and 38 % respectively of total emissions. Remaining 8 % emanates mainly from ammonia which contributes with a total of 5 %. Most of the sulphur dioxide and nitrogen oxides emissions are related to construction of transmission grid, production and transportation of sulphuric acid used in the uranium extraction process, combustion of fossil fuels for electricity generation and diesel combustion at power plants.

Transports account for about 8 % of total emissions in this category. The main contributing emissions are NO_X and SO_2.

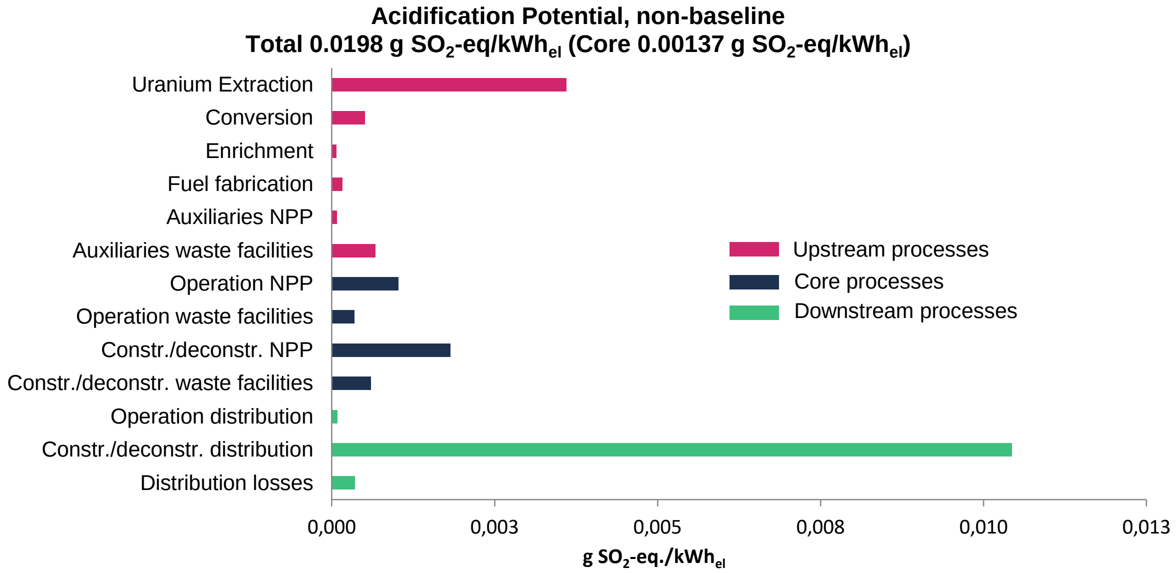


Figure 8 Potential emissions of acidifying substances. NPP = Nuclear Power Plants, Waste facilities = all SKB's nuclear waste facilities, Constr./Decom. = the construction and decommissioning of the different facilities, Distribution = the assessed transmission and regional distribution network.

3.4.3. Eutrophication Potential (EP)

Oxygen consuming substances like organic matter and nutrients like nitrogen and phosphorous compounds cause eutrophication. In Figure 9 below, the distribution contribution of emissions contributing to Eutrophication Potential from different stages in the life cycle is presented. The dominant substances are phosphate (accounts for about 70 %), and nitrogen oxides (about 14 %). Thereafter, ammonia and nitrogen account for about 2 % each, while chemically oxygen demanding substances (COD) and nitrous oxide (laughing gas) contribute with additionally about 1 % each.

The largest contribution comes from construction and decommissioning of the transmission and distribution network. One large part of the emissions in this category comes from the uranium extraction, where production of sulphuric acid together with electricity generation is large contributing factors. Transports account for about 2 % of total emissions in this category.

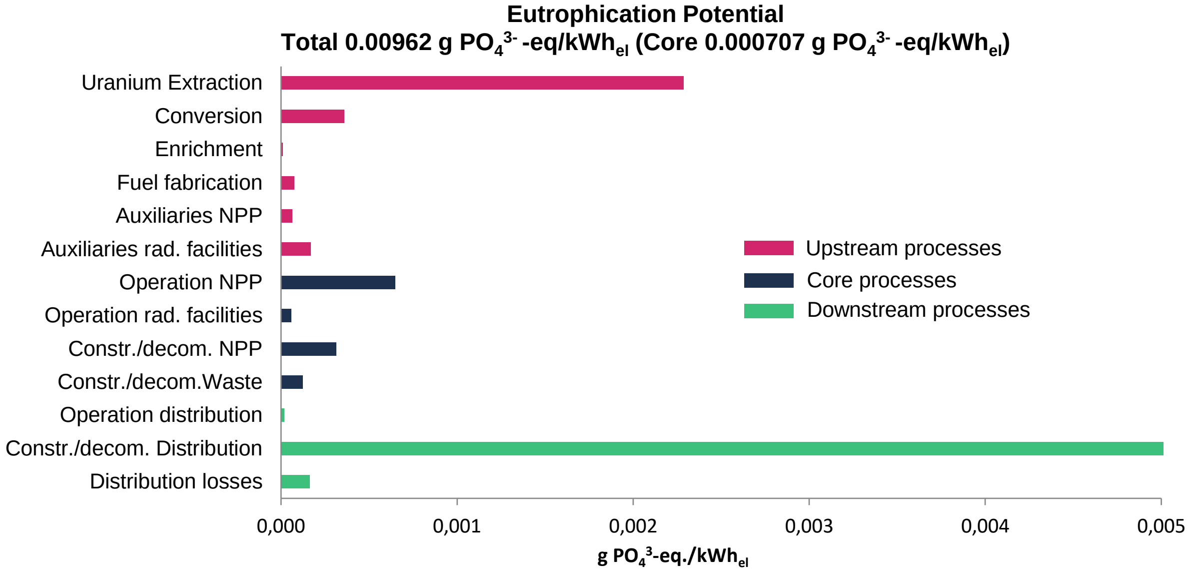


Figure 9 Potential emissions of eutrophying substances. NPP = Nuclear Power Plants, Waste facilities = all SKB's nuclear waste facilities, Constr./Decom. = the construction and decommissioning of the different facilities, Distribution = the assessed transmission and regional distribution network.

3.4.4. 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. Hydrocarbon emissions result from vaporization of oil products and organic solvents and from incomplete combustion of fuels. In Figure 10 below, the distribution contribution of emissions contributing to Photochemical Oxidant Formation Potential from different stages in the life cycle is presented.

In this category the major contributors are nitrogen oxides (about 69 %), unspecified non methane volatile organic compounds (NMVOC, about 17 %), carbon monoxide (about 7 %) and sulphur dioxide (about 7 %). Another substance contributing to this category is methane with about 1 % of total. Most of the emissions in this category derive from the downstream processes, from the construction of the electricity transmissions networks. Other contributing life cycle stages are the uranium extraction (mainly due to transport, electricity generation and diesel combustion) along with the construction of the nuclear power plants (mainly due to steel). Transports account for about 10 % of total emissions in this category.

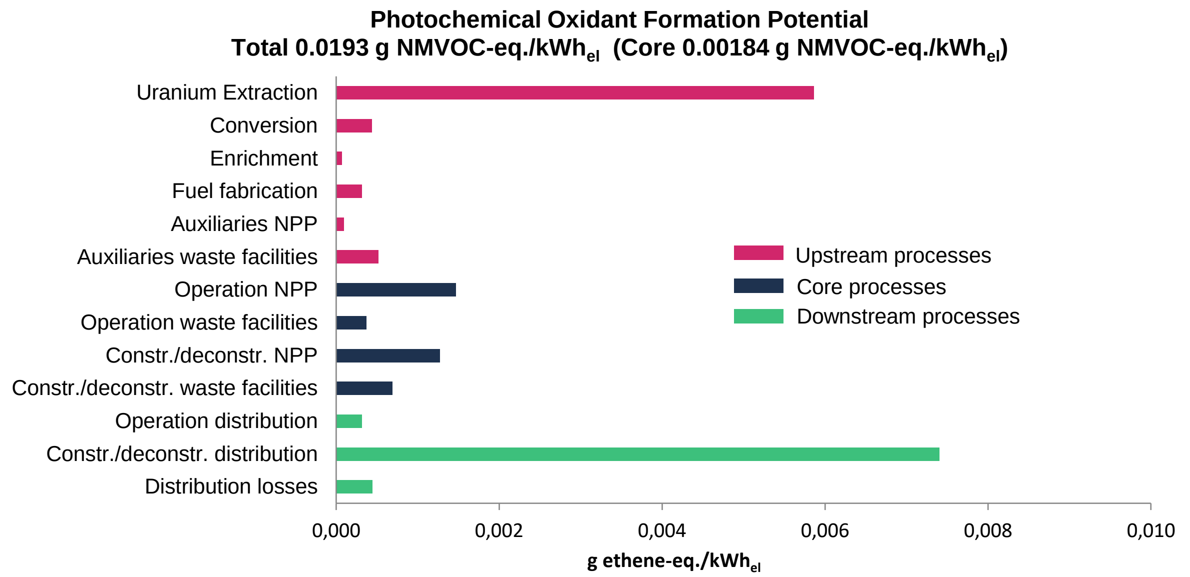


Figure 10 Potential emissions of substances contributing to ground-level ozone. NPP = Nuclear Power Plants, Waste facilities = all SKB's nuclear waste facilities, Constr./Decom. = the construction and decommissioning of the different facilities, Distribution = the assessed transmission and regional distribution network.

3.4.5. Formation of fine particular matter

Emissions of particulate matter to air, presented in Figure 11 below, originate mainly from fossil electricity generation and uranium extraction (mining and milling) and during construction of distribution systems, but also from combustion of fuels. Of all particular matter, the fine particulate fractions (≤2.5 micrometres), are most harmful to human health.

Emission of particles to air during construction and demolition of the nuclear power plant and facilities for handling of radioactive wastes and during uranium extraction have not been considered.

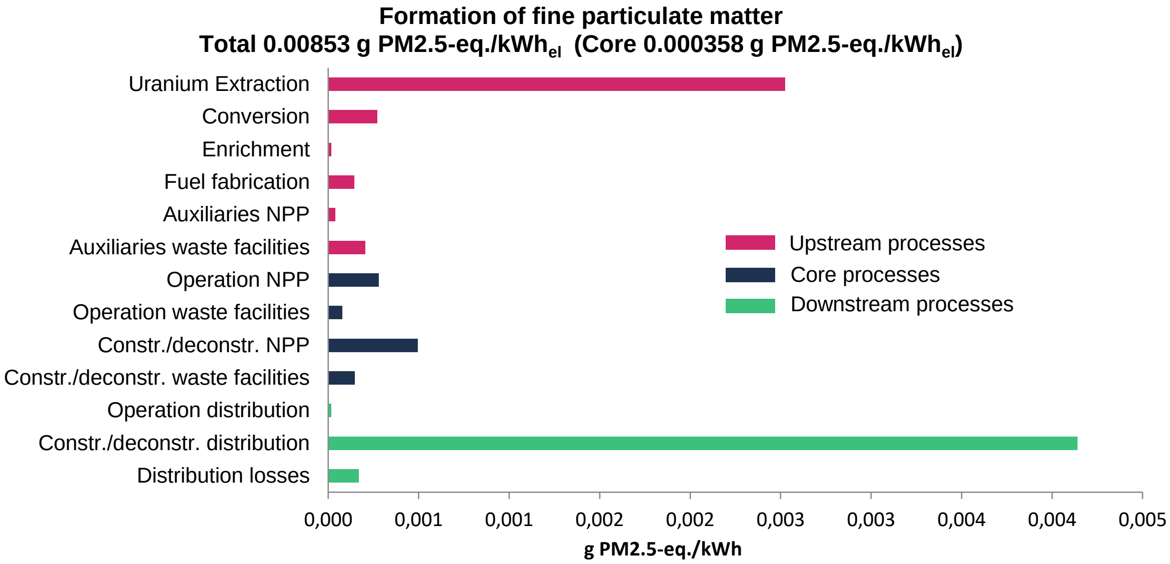


Figure 11 Potential emissions of particulate matter. NPP = Nuclear Power Plants, Waste facilities = all SKB's nuclear waste facilities, Constr./Decom. = the construction and decommissioning of the different facilities, Distribution = the assessed transmission and regional distribution network.

3.4.6. Abiotic Depletion Potential (ADP) – elements and fossil fuels

Abiotic depletion refers to the depletion of non-living (abiotic) natural resources (including energy resources). The two variants assessed herein are described shortly below:

- 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 upstream, approximately 47 % for elements and 50 % for fossil fuels, as well as downstream infrastructure where the corresponding contributions are 38 % and 37 % for elements and fossil fuels respectively, as shown in Figure 12 and Figure 13 below.

For elements, the upstream contribution is driven by the high use of metals when disposing of waste, such as the copper in the canisters used for the final repository of spent nuclear fuel. For downstream infrastructure, the main contributor are the metals used for constructing the transmission and distribution networks, mainly copper.

For the abiotic depletion potential of fossil fuels, the main contribution to upstream impact is driven by fossil fuel use in regional energy production, facility fuel use as well as a minor contribution from transportation (2 %). For downstream infrastructure, the fuel consumption for the construction of the transmission and distribution network is a key contributor.

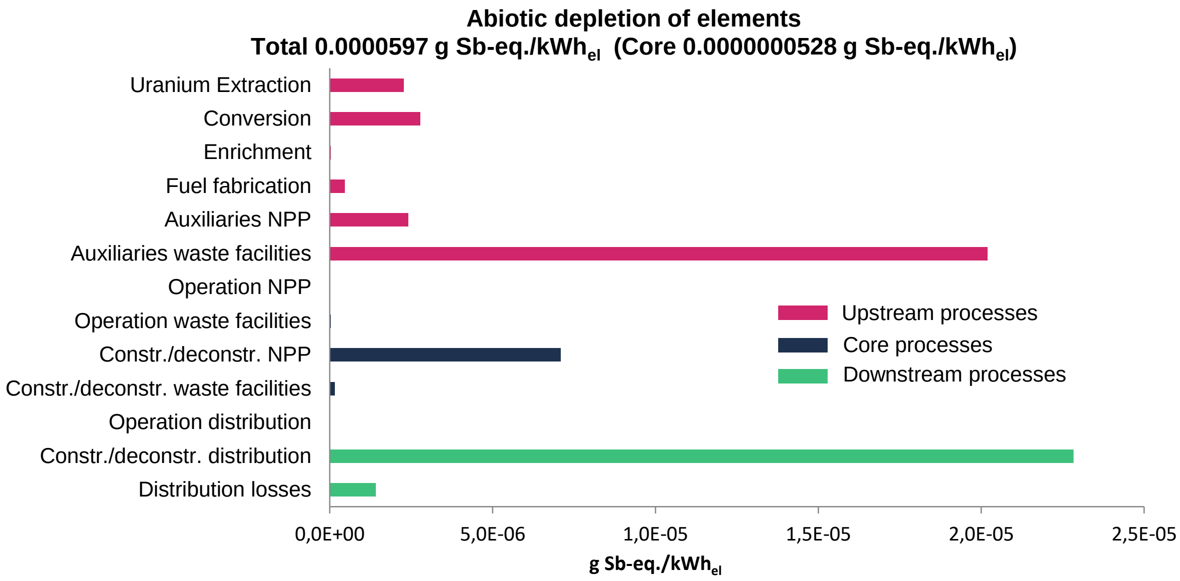


Figure 12 Potential abiotic depletion of elements. NPP = Nuclear Power Plants, Waste facilities = all SKB's nuclear waste facilities, Constr./Decom. = the construction and decommissioning of the different facilities, Distribution = the assessed transmission and regional distribution network.

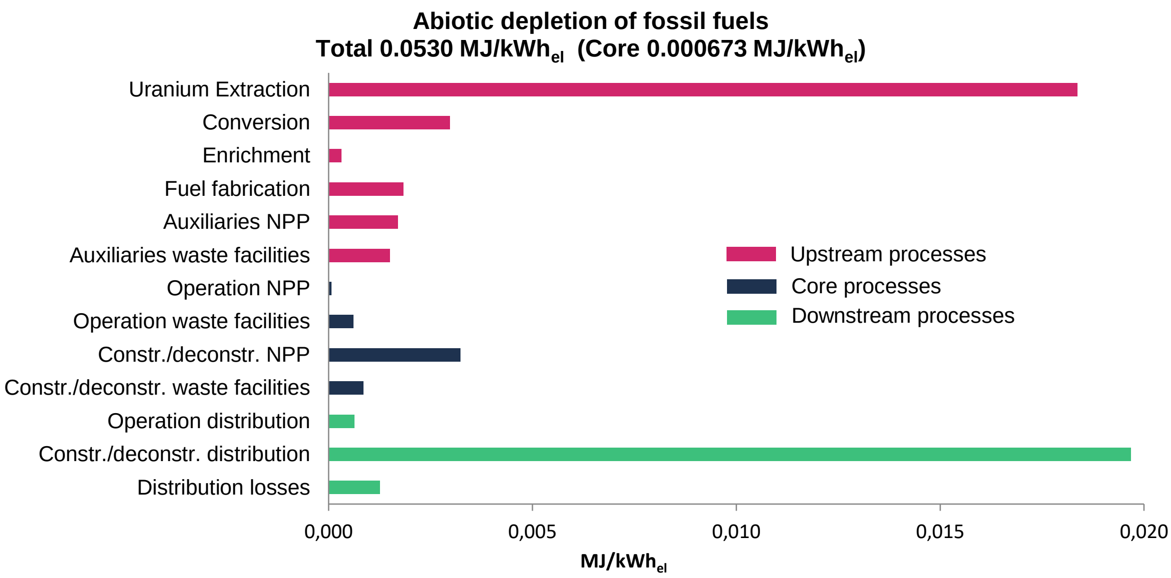


Figure 13 Potential abiotic depletion of fossil fuels. NPP = Nuclear Power Plants, Waste facilities = all SKB's nuclear waste facilities, Constr./Decom. = the construction and decommissioning of the different facilities, Distribution = the assessed transmission and regional distribution network.

3.4.7. 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 takes into account the water scarcity in the region where the water is consumed, so that water which is consumed in a scarce region is weighted higher. Core infrastructure (53 %) and downstream infrastructure (32 %) activities are the main drivers for water scarcity impact, see Figure 14 below.

The significant contribution to water scarcity related to the core infrastructure and downstream infrastructure modules comes from construction and demolition activities, from consumption during construction as well as production of operating materials.

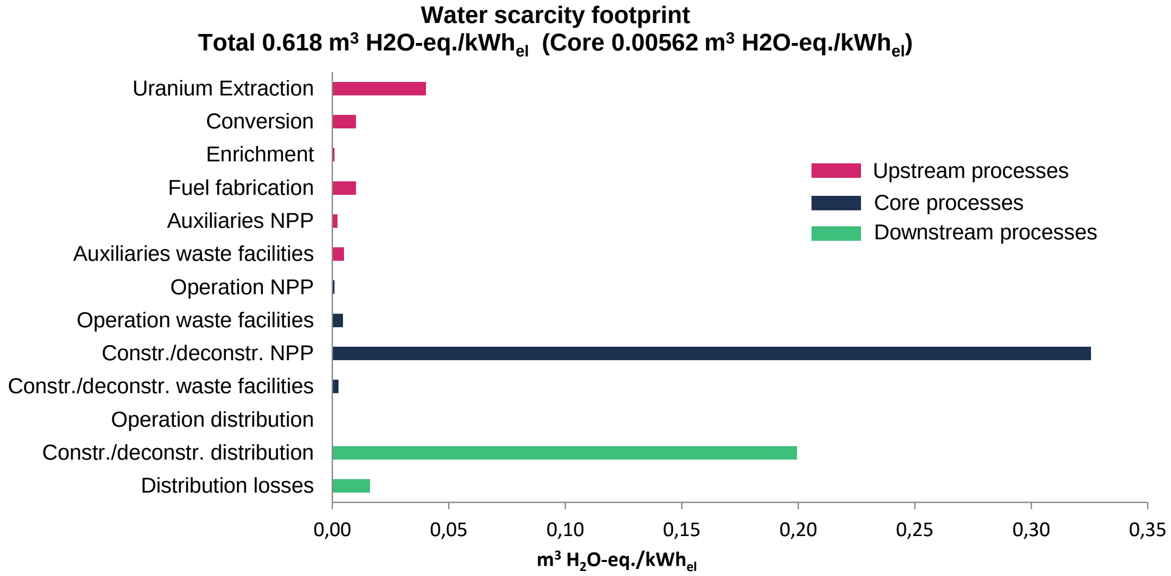


Figure 14 Water scarcity footprint. NPP = Nuclear Power Plants, Waste facilities = all SKB's nuclear waste facilities, Constr./Decom. = the construction and decommissioning of the different facilities, Distribution = the assessed transmission and regional distribution network.

3.4.8. Dominance analysis and Conclusions

Contributions to the studied environmental impact categories distributed between the life cycle stages are presented in Table 7 below. As is made clear in the table, upstream along with the construction and demolition of distribution networks contribute most significantly to all assessed impact categories. Within upstream, it is mainly the uranium extraction phase that accounts for the contribution.

Table 7 Dominance analysis

>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) - total	g CO_2-eq. (100years)	28.9 %	5.2 %	9.4 %	1.4 %	53.5 %	1.7 %	100 %
Acidification potential (AP)	g SO_2-eq.	25.8 %	6.9 %	12.2 %	0.5 %	52.7 %	1.8 %	100 %
Eutrophication potential (EP)	g PO_4^{3-}-eq.	32.9 %	7.2 %	4.3 %	0.2 %	53.6 %	1.8 %	100 %
Photochemical oxidant formation potential (POFP)	g NMVOC-eq.	37.9 %	9.5 %	10.2 %	1.6 %	38.4 %	2.3 %	100 %
Particulate matter	g PM2.5-eq.	37.5 %	4.2 %	7.5 %	0.2 %	48.6 %	2.0 %	100 %
Abiotic depletion potential - Elements	g Sb-eq.	47.1 %	0.1 %	12.1 %	0.0 %	38.2 %	2.4 %	100 %
Abiotic depletion potential - Fossil fuels	MJ, net cal. Value	50.3 %	1.3 %	7.7 %	1.2 %	37.1 %	2.4 %	100 %
Water scarcity footprint	m^3 H_2O-eq.	11.1 %	0.9 %	53.1 %	0.0 %	32.3 %	2.6 %	100 %

Electricity consumption and fuel use in the uranium extraction, conversion and fuel fabrication of uranium, as well as resource use in waste management facilities, dominate the emission categories in the upstream processes. The biggest contribution to emissions in the uranium extraction and milling phase comes from the uranium extraction activity and energy consumption, while it in the enrichment phase derives from the electricity generation. Amongst the radioactive waste facilities, it is the encapsulation plant that accounts for the largest share, this mainly due to the use of copper and steel in the canisters. All in all, upstream processes contribute with about 11-50 % depending on impact category.

Overall, the core processes (Operation nuclear power plant and Operation radioactive waste facilities), including handling of the different waste streams, contribute between 0.1-10 % depending on impact category. The operation of the nuclear power plants generally contributes more than the operation of radioactive waste facilities, accounting for about 0.2-8 % of the total emissions in each impact category. Construction, reinvestments and decommissioning of nuclear power plants and facilities for handling of radioactive wastes (Core - infrastructure) contribute by about 4-53 % depending on impact category, with the construction of the nuclear power plants accounting for the largest shares.

Construction of transmission and distribution networks is dominating in the downstream processes. The environmental impact contribution due to distribution losses in Table 7 above is caused by the extra generation which is necessary to compensate for losses in the distribution network. All in all, the downstream processes contribute with about 35-57 % depending on impact category.

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

3.4.9. Resources

The LCA results regarding use of resources are summarized in Table 8 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 in the power stations and grid infrastructure. Secondary materials are found in metal (aluminum, steel and copper) parts, which contain shares of recycled scrap.

Real volumes of material resources have been applied in the calculation of environmental impact from production of raw materials for components and from plant operation. The amounts of recycled material used in construction and reinvestments are reported separately, and quantities are based on industry data on standard rates of scrap used in the production of the respective metal.

Table 8 Resource use per 1 kWh of electricity generated for Upstream, Core and Core – infrastructure modules, and per 1 kWh distributed for Downstream and Downstream – infrastructure modules

Resources		Unit/kWh	Upstream	Core	Core - infra.	Total - generated	Down-stream[1]	Downstream - infra.	Total - distributed
Primary energy resources - Renewable	Used as energy carrier	MJ, net cal. value	0.00351	0.00181	0.00278	**0.00811**	3.62E-04	0.00113	**0.0096**
	Used as raw material	MJ, net cal. value	1.45E-07	2.85E-09	2.23E-06	**2.38E-06**	9.52E-08	5.28E-07	**3.00E-06**
	Total	MJ, net cal. value	0.00351	0.00181	0.00279	**0.00811**	3.62E-04	0.00113	**0.00960**
Primary energy resources - Non-renewable	Used as energy carrier	MJ, net cal. value	0.0345	0.00517	0.00761	**0.0473**	0.00253	0.0202	**0.0701**
	Used as raw material	MJ, net cal. value	3.02E-08	0	0	**3.02E-08**	1.21E-09	0	**3.14E-08**
	Total	MJ, net cal. value	0.0345	0.00517	0.00761	**0.0473**	0.00253	0.0202	**0.0701**
Secondary material		g	0.00160	0	0.0484	**0.0500**	0.00200	0	**0.0520**
Renewable secondary fuels		MJ, net cal. value	0	0	0	**0**	0	0	**0**
Non-renewable secondary fuels		MJ, net cal. value	0	0	0	**0**	0	0	**0**
Net use of fresh water		m³	0.00276	0.00106	0.00978	**0.0136**	5.47E-04	0.00581	**0.0200**

[1] Distribution losses of 4 % of generated electricity are included in the downstream column.

3.4.10. Waste and output flows

Only waste amounts and output flows that are not treated within the system boundaries are reported in Table 9 - Table 10 below, in accordance with the PCR. The tables present the waste fractions in relation to the production of 1 kWh electricity. For some of the suppliers in the uranium fuel chain and for some other upstream processes, no information on how conventional waste is treated has been available. In those cases, the waste is assumed to be deposited.

See Table 9 Waste production for core processes per 1 kWh of electricity generated for Core and Core – infrastructure modules, and per 1 kWh distributed for total below for waste fractions produced in the core process. Waste and residues from operation of nuclear power plants and facilities for handling of radioactive wastes are reported under Core. Wastes to be landfilled, deposited or incinerated have been followed to the grave and residues to be recycled have been followed to a collection site. Spent fuel with uranium content is reported followed by radioactive wastes to be deposited.

Waste and residues from construction, reinvestments and decommissioning of nuclear power plants and facilities for handling of radioactive wastes is reported under Core - infrastructure. In the process of manufacturing of steel, plastic and copper the waste is not followed to the grave. Wastes to be landfilled, deposited or incinerated have been followed to the grave and residues to be recycled have been followed to a collection site.

Table 9 Waste production for core processes per 1 kWh of electricity generated for Core and Core – infrastructure modules, and per 1 kWh distributed for total

Waste	Unit/kWh	Core	Core - infra.	Total - distributed
Hazardous waste disposed	g	0.00572	9.20E-04	**0.0184**
Depleted uranium (UF6)	g	0.00251	2.32E-04	**0.00789**
Non-Hazardous waste disposed	g	0.0867	2.37	**24.3**
Radioactive waste disposed	g	0.00374	0.0227	**0.0335**
High-level radioactive waste	g	4.62E-06	2.65E-07	**7.50E-06**
Low and medium-level radioactive waste	g	7.34E-05	9.19E-06	**1.68E-04**

See Table 10 below for waste fractions produced in the upstream and downstream processes. Most waste flows in the upstream processes have been followed to the grave. Reported amounts are mainly generated at the supplier in the uranium fuel chain. For some of the suppliers, no information on how conventional waste is treated has been available, in those cases the waste is assumed to be deposited.

All depleted uranium (tails) is reported as hazardous waste - non radioactive, despite the fact that a considerable part is warehoused awaiting higher uranium prices, in which case it could be considered as “by-product”. Concentrations of less than 0.1 % U_{235} precludes economically viable enrichment of tails, which consequently must be classified as hazardous waste.

Table 10 Waste production for upstream and downstream process per 1 kWh of electricity generated for the Upstream module, and per 1 kWh distributed for Downstream and Downstream – infrastructure modules

Waste	Unit/kWh	Upstream	Down-stream[1]	Downstream - infra.	Total - distributed
Hazardous waste disposed	g	0.0110	7.07E-04	0	**0.0184**
Depleted uranium (UF6)	g	0.00484	3.03E-04	0	**0.00789**
Non-Hazardous waste disposed	g	20.9	0.933	0	**24.3**
Ash	g	0	0	0	**0**
Inert (rock, sand etc.)	g	10.1	0.431	0	**11.2**
Radioactive waste disposed	g	0.00579	0.00129	0	**0.0335**
Volume of final repository necessary to deposit radioactive waste emanating from nuclear electricity used in up-and downstream processes	m^3	3.19E-11	1.93E-08	0	**0.0199**
Low-level, no treatment (such as mining/milling wastes)	g	0.0198	7.95E-04	0	**0.0207**

[1] Distribution losses of 4 % of generated electricity are included in the downstream column.

Table 11 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**	0.0139	0.442	0.0771	**0.534**	0.0213	0	**0.555**
Materials for energy recovery	**g**	0	0	0	**0**	0	0	**0**

[1] Distribution losses of 4 % of generated electricity are included in the downstream column

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

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 described for the core processes and mining according to the minimum requirements in the PCR.

Since last update of this EPD, 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 have been received from Corine Land Cover (CLC) data from before the onset of the facility, 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 have 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.

Table 12 Summarized results for all sites concerning land use change according to Corine Land Cover Classes level 1.

	Land cover	Before (m^2)	After (m^2)	Land use change (m^2)
		Mining		
Cameco Cigar Lake (Canada)	1. Artificial Surfaces	0	2 040 000	2 040 000
	3. Forest and seminatural areas	9 900 000	8 400 000	-1 520 000
	4. Wetlands	521 000	0	-521 000
Orano McClean Lake (Canada)	1. Artificial Surfaces	1 650 000	6 350 000	4 700 000
	3. Forest and seminatural areas	20 100 000	20 600 000	573 000
	4. Wetlands	9 140 000	4 050 000	-5 090 000
	5. Water bodies	5 930 000	5 740 000	-192 000
CNUC/Rössing (Namibia)	1. Artificial Surfaces	0	24 600 000	24 600 000
	3. Forest and seminatural areas	20 000 000	0	-20 000 000
	5. Water bodies	4 570 000	0	-4 570 000
BHP/Olympic Dam (Australia)	1. Artificial Surfaces	0	57 800 000	57 800 000

	3. Forest and seminatural areas	54 300 000	0	-54 300 000
	4. Wetlands	544 000	0	-544 000
Nuclear power plant operations				
RAB/Ringhals (Sweden)	1. Artificial Surfaces	64 400	1 090 000	1 026 000
	2. Agricultural areas	513 000	0	-513 000
	3. Forest and seminatural areas	672 000	405 000	-268 000
	4. Wetlands	16 300	0	-16 300
	5. Water bodies	15 030 000	14 800 000	-229 000
FKA/Forsmark (Sweden)	1. Artificial Surfaces	14 300	1 360 000	1 350 000
	3. Forest and seminatural areas	1 570 000	639 000	-934 000
	4. Wetlands	13 500	0	-13 500
	5. Water bodies	10 400 000	10 010 000	-40 200
Waste				
SKB/CLAB (Sweden)	1. Artificial Surfaces	0	51 200	51 200
	3. Forest and seminatural areas	69 700	18 500	-51 200
SKB/ Encapsulation plant (Sweden)	1. Artificial Surfaces	2 700	20 200	17 500
	3. Forest and seminatural areas	17 400	0	-17 400
SKB/SFR (Sweden)	1. Artificial Surfaces	0	179 000	179 000
	3. Forest and seminatural areas	29 000	13 300	-15 700
	5. Water bodies	163 000	0	-163 000

Table 13 Summary of the land-use change of all sites together according to Corine Land Cover classes at level one.

Land cover	**Before (m²)**	**After (m²)**	**Land use change (m²)**
1. Artificial Surfaces	1 730 000	90 500 000	88 700 000
2. Agricultural areas	513 000	0	-513 000
3. Forest and seminatural areas	107 000 000	30 100 000	-76 500 000
4. Wetlands	10 200 000	4 050 000	-6 180 000

5. Water bodies	36 100 000	30 600 000	-5 560 000

Table 14Total area occupied per year of operation by each facility. The figures are based on the increase of artificial surfaces in the After state compared to Before.

Site	Area occupied (ha)	Estimated years of operation	Area occupied / year of operation (m^2)
Cameco/Cigar Lake (Canada)	1 040	8	1 300 000
Orano/McClean Lake (Canada)	3 680	27	1 360 000
CNUC/Rössing (Namibia)	2 460	34	722 000
BHP/Olympic Dam (Australia)	5 780	46	1 260 000
RAB/Ringhals (Sweden)	1 630	60	272 000
FKA/Forsmark (Sweden)	1 200	60	200 300
SKB/Clab (Sweden)	6.97	84	829
SKB/Encapsulation plant (Sweden)	2.02	33	612
SKB/SFR (Sweden)	19.2	81	2 370

4.1.3. Description of impact on biodiversity

Nuclear power's biggest environmental impact is radiation risks and environmental effects when uranium is extracted from the ground and when spent nuclear fuel and other nuclear waste must be stored in the bedrock.

In terms of biodiversity, the biggest impact factors are habitat losses and barrier effects. Habitat losses can mean both the loss of habitats because of natural areas being built up, but also those natural areas change and thus the conditions to be used as a habitat.

The power grid also has an impact on biodiversity, but no quantitative results from changed land use and biodiversity impacts are included in this study from the distribution stage, and no classification of occupied areas according to the EU land cover categorisation system Corine has been made. Power line corridors are regularly cleared creating a possible habitat for species that normally inhabit meadows and pastures. In addition, those corridors constitute ecotones, where two biomes meet and integrate. These are generally considered more biodiverse than homogenous areas. Wider corridors can constitute barriers that may cause fragmentation for some woodland species. In a cultivated landscape the corridors do not have any particular impact on biodiversity, positive or negative.

In some cases, the impact takes place in the form of a change in a biotope. This applies, for example, to cooling water environments. Here Biotestsjön is an interesting example. In general, it can be said that the species that thrive in warm water, for example perch *(Perca fluviatilis)*, increase in size and number. Species that prefer colder water retreat. Seabirds and sea eagles find good resting and wintering conditions, and this has contributed to better nesting results far outside the Forsmark area.

4.1.4. Impact on biodiversity

4.1.4.1. Upstream, Mining

To produce electricity at Forsmark and Ringhals, uranium has been extracted from the following mines: Cigar Lake, McClean Lake, Rössing, and Olympic Dam. A description of the mining areas follows below.

Cigar Lake

Cigar Lake is a uranium mine in northern Saskatchewan, Canada, at the southern end of Waterbury Lake, about 660 km north of Saskatoon. The property is accessible by an all-weather road and by air. Site activities occur year-round, including supply deliveries.

The topography and the environment are typical of the taiga forested lands common to the Athabasca Basin area of northern Saskatchewan. According to GIS data showing land cover for the location, the area outside is now dominated by coniferous forest with minor elements of wetlands and scrubland.

There are not provincially designated endangered or threatened species at risk in the vicinity of Cameco's operations in northern Saskatchewan. There are several species that may exist in the area that are considered endangered or threatened at a federal level.

Woodland caribou *(Rangifer tarandus)* has been identified as the only species potentially present in the general area that has special status (threatened). Northern leopard frog *(Lithobates pipiens)*, and rusty blackbird *(Euphagus carolinus)*, are both potentially present in the operation area and are listed as of special concern. The activity may have had a negative impact on these species.

McClean Lake

The McClean Lake mine is a uranium mine and milling operation located west of Wollaston Lake, about 700 km north of Saskatoon, in the Athabasca Basin region of Saskatchewan, Canada.

A variety of forest associations characterize the region, but upland jack pine *(Pinus banksiana)* and black spruce *(Picea mariana)* stands, and lowland bogs dominate the area. On the organic lowland terrains, black spruce (Picea mariana) or tamarack *(Larix laricina)* exist in pure or mixed stands forming the primary overstory of the treed bogs while open peatlands are often dominated by bog/scrub birch *(Betula glandulosa/pumila)*, bog willows *(Salix pedicellaris)*, and sedges *(Carex sp.)*. Coniferous overstories of the upland sites are a mixture of jack pine and black spruce with some hardwood components, particularly Alaska white birch *(Betula papyrifera var neoalaskana)* on more productive lands; the nature of these sites is largely dependent upon underlying soils and drainage. Riparian areas within the study block were limited, restricted to shorelines and creeks.

The wildlife of major concern which may potentially use habitats in the vicinity of the proposed mine development include ungulates, raptors, and aquatic furbearers. Moose *(Alces alces)* are the principal ungulates in the region although barren-ground caribou *(Rangifer tarandus groenlandicus)* may be expected to infrequently winter here; each possess explicit habitat requirements resulting in a clear differentiation of ranges. Moose preference for early successional forest stands, and shrub rich sites contrasts with caribou's preference for mature and overmature coniferous stand associations which support understory lichens.

Potential impacts on the natural environment arise directly from the development of the project site itself, which has only minor impacts on the local vegetation communities. Project impacts on wildlife and wildlife habitat are also inconsequential, as impacts are very local, and the affected species are broadly distributed in both a local and regional perspective.

Although the terrestrial habitats within the local assessment boundary have the potential to support rare and endangered species filed investigations did not identify any species requiring special management considerations. One species of special concern was identified, the rusty blackbird *(Turdus merula)*. Known threats to this species occur primarily in its winter range habitat in the United States. It does not have status under the Species at Risk Act. The footprint of the Caribou Project, including buffer zones, represents 0.13 % of all caribou habitat within the local assessment boundary for the project. No active raptor nest sites are located within a 500 m buffer zone assessed around the project area. On completion of mining the Caribou site would be levelled or re-contoured and reclaimed with the objective of providing a naturally vegetated area suitable for local species.

Rössing
The Rössing mine is situated in the Namibian desert in southwestern Africa and exploits a 2454 ha land area with a hot desert climate and meagre precipitation. The prevailing conditions are extreme as with monthly average temperatures of +23,8°C (May) and 15,4°C (October) and with monthly maximum temperatures between +31,8°C (July) and +39°C (January). Annual precipitation is a scant 30-35 mm, while evaporation amounts to 3150 mm (*Ashton et al 1991*). A decisive factor for flora and fauna is the fog, which regularly rolls in from the Atlantic Ocean some 60 km to the west. The moist air creates condensation on the ground and in the vicinity of the mine this condensation can go up to as much as 180 mm per year, although more modest amounts are normal.

The mining field is at 575 above Mean Sea Level in a peneplain with a slight relief to the west, north, and northeast. To the south and southeast the terrain is more dramatic with several steep canyons. The riverbeds are usually dry and only heavy rains inland generate short periods of water flow toward the ocean. The vegetation is typical for desert areas; only a limited number of mainly low growing plants sustain the extreme conditions. Various succulents and lichens clearly dominate the barren environment of mountainous hills and plains. The situation in the river valleys is different; water accumulated in the sediment during periods of water flow is exploited by several perennials, among them several species of Acacia, that are important for the fauna. Land use is dictated to available natural resources, mainly mining and extensive animal grazing.

Olympic Dam
Olympic Dam is situated in the inland of South Australia and is principally a copper mine. The exploited land area is 5480 ha. The climate is of a desert like inland type with summer temperatures reaching +35°C. Precipitation is irregular and sparse, approximately 160 mm annually. The area has been used for grazing grounds for animals since the middle of the 19th century. The settlers influenced flora and fauna by introducing grazing animals and rabbits. The regional flora is characterized by sparse and arid-zone vegetation. Some areas, particularly dune fields, are host to Acacias and tall shrubs, and other areas to white cypress pines.

Large quantities of water are used in the mine and in the living areas. Supply is limited and consists mainly of fossil ground water from the Great Artesian Basin. Water is pumped to the surface from several wells and fed to the mine and living quarters through pipelines. There is proof of diminished or ceased natural water flow at two wells. These wells were however already damaged by farmers and did not harbour any of the endemic species as found in some of the other wells. Ground water from the Great Artesian Basin has been used in the area for a long time, particularly for farming purposes. The use of ground water for the mine, including the city of Roxby Downs, constitutes less than 2 % of the total ground water use in the area. The problem of diminishing water flow is recognized, and old farming wells are being sealed whilst efforts are made to increase flow from some wells. Various joint programmes, some in collaboration with authorities, are aimed at a reduction of daily water usage by 37 million litres. This would more than compensate for the daily 32 million litres consumed by BHP/Roxby Downs.

4.1.4.2. Core, Nuclear Power Plants & Waste Management Plants
Forsmark Nuclear Power Plant
Forsmark nuclear power plant is a nuclear power plant outside the Forsmark plant in Östhammar municipality, Uppsala County, Uppland.

From a natural value point of view, Forsmark is a very valuable area, except for the area within the system boundary. South of Forsmark is the Kalllriga nature reserve and north of the facility the Skaten-Rången nature reserve, both areas are also Natura 2000 areas. The high natural values are due to the coastal location, flat topography, rapid shoreline displacement and small but significant height variations (Ekologigruppen, 2010). Other factors are the limestone-rich soil, the location in a border zone between northern and southern nature types and a relatively undisturbed location, except for the nuclear power plant and associated operations.

The entire Forsmark facility is surrounded by a national interest in nature conservation. The national interest is described as an area with botanical and ornithological values, coastal water environments, rich marshes and gullies, as well as natural forests and a farm archipelago with pastures. The area of Forsmark is listed by the county board as an ecologically sensitive area according to chapter 3 § 3 of the Environmental Code. An ecologically sensitive area that is particularly sensitive from an ecological point of view and must be protected as far as possible against measures that could damage the natural environment. During a natural value inventory (Ekologigruppen 2010) south of the facility where the new final repository is planned, finds were found, among other things, of the red-listed (VU) pool frog *(Pelophylax lessonae)*.

The following two maps show the Forsmark area before and after exploitation.

Figure 15 Forsmark area before exploitation.

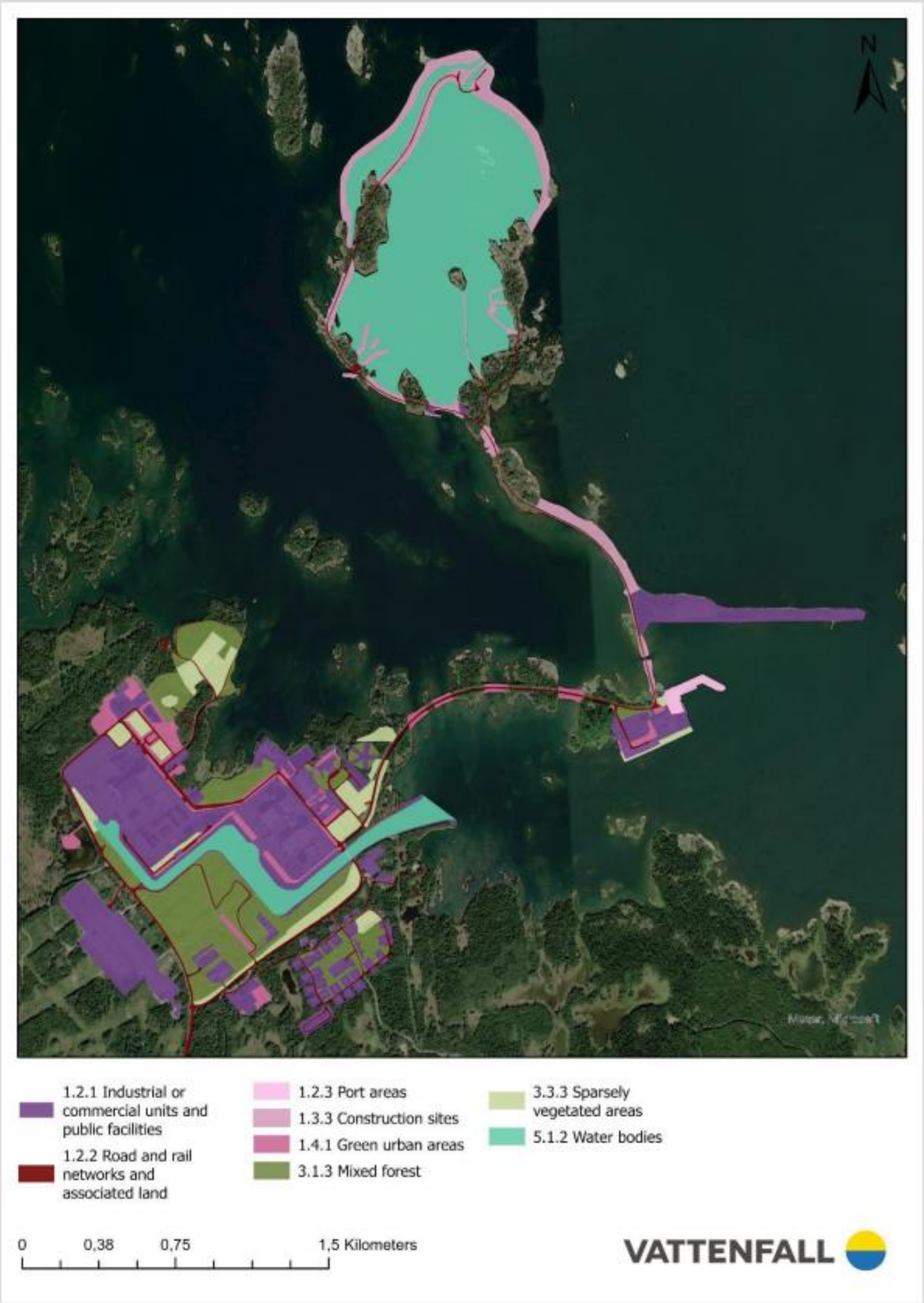


Figure 16 Forsmark area after exploitation

Ringhals Nuclear Power Plant
Ringhals is located in the municipality of Varberg, south of Gothenburg. The power plant has two reactors in operation and two reactors under decommissioning.

The impact on biological diversity has been noticeable within the 1624.5 ha of land that has been claimed by Ringhals. The valuable biotopes that existed before are completely claimed by Ringhals. They consisted of a beach meadow which was a well-known bird locality with high natural values. In addition, there were also two pastures with high natural values. Among other things, pasque flower *(Pulsatilla vulgaris)* and marsh gentian *(Gentiana pneumonanthe)* grew there.

The beach meadow at Båtafjorden is designated as a Natura 2000 area according to the Birds Directive with the presence of many red-listed bird species. Båtafjorden was Before as well as After one of the county's richest birding areas.

Several biotope-improving measures for birds have been taken by Ringhals. This applies, among other things, to the construction of arable islets and the deployment of seashells on "grass with beach meadow species" between the two cooling water intakes.

The extent of the cooling water plume has been estimated based on SMHI's oceanographic surveys outside the Ringhals power plant (SMHI 1988). In SMHI's report from Ringhals, only the area that has ever been affected by at least 1 ºC overtemperature one meter below sea level is reported. When applying the biotope method at Forsmark, the mean value was used when reporting the distribution of the cooling water plume. To be able to compare the biotope loss between Forsmark and Ringhals, an average value has been calculated for the distribution of the cooling water plume outside Ringhals. The calculation is based on a percentage equal ratio between average value and maximum value for both Forsmark and Ringhals. Using one degree of excess temperature as the basis for the delimitation can be considered very conservative, as this change is unlikely to have any impact. However, the available data, especially regarding the spread of the plume, have not allowed for a more detailed and correct assessment, which is why we have chosen this conservative approach.

There are indications that some unusual fish species are attracted to the warm water discharge, such as mullet *(Liza saliens)* and sea bass.

The following two maps show the Ringhals area before and after exploitation.

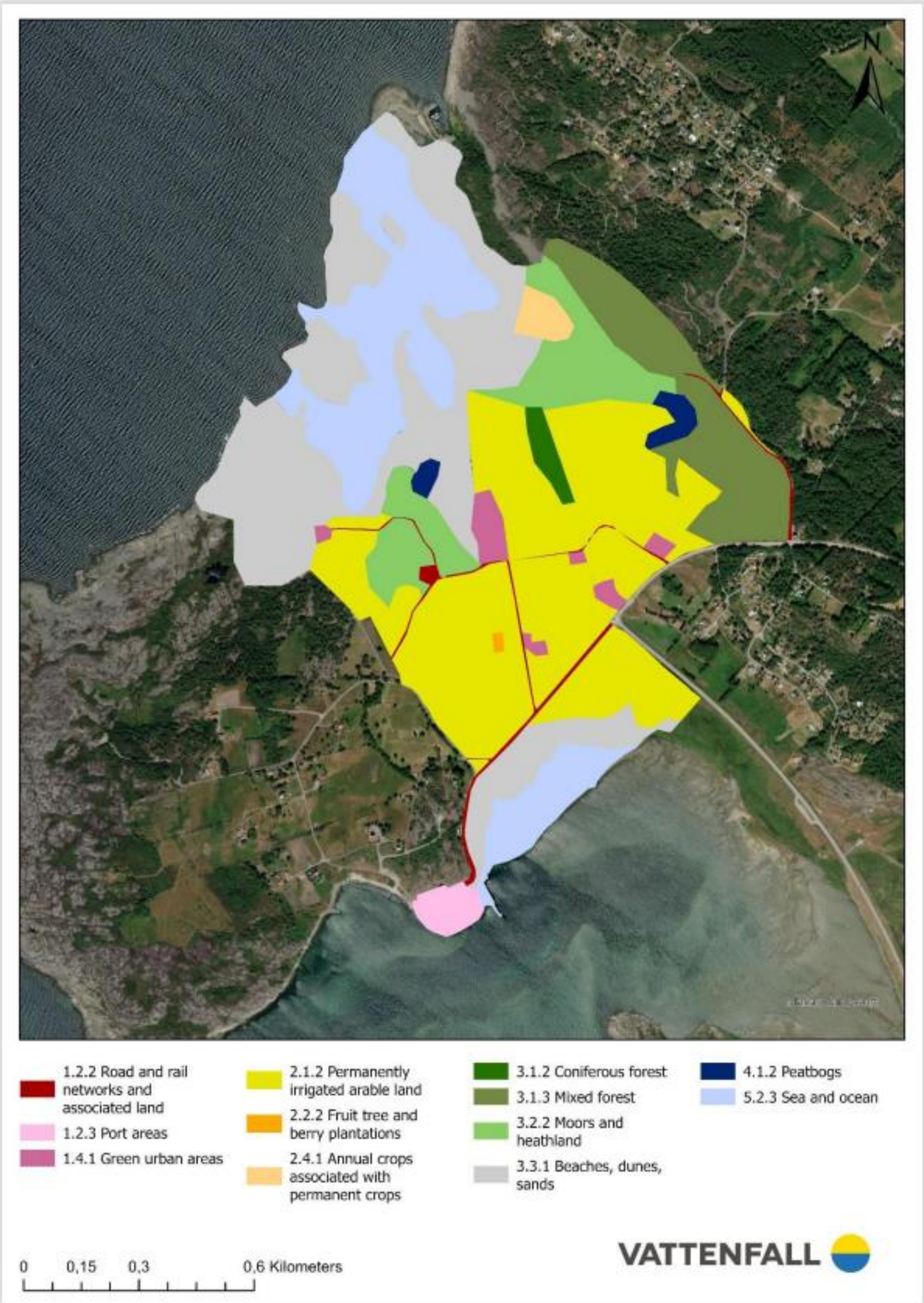


Figure 17 Ringhals area before exploitation.

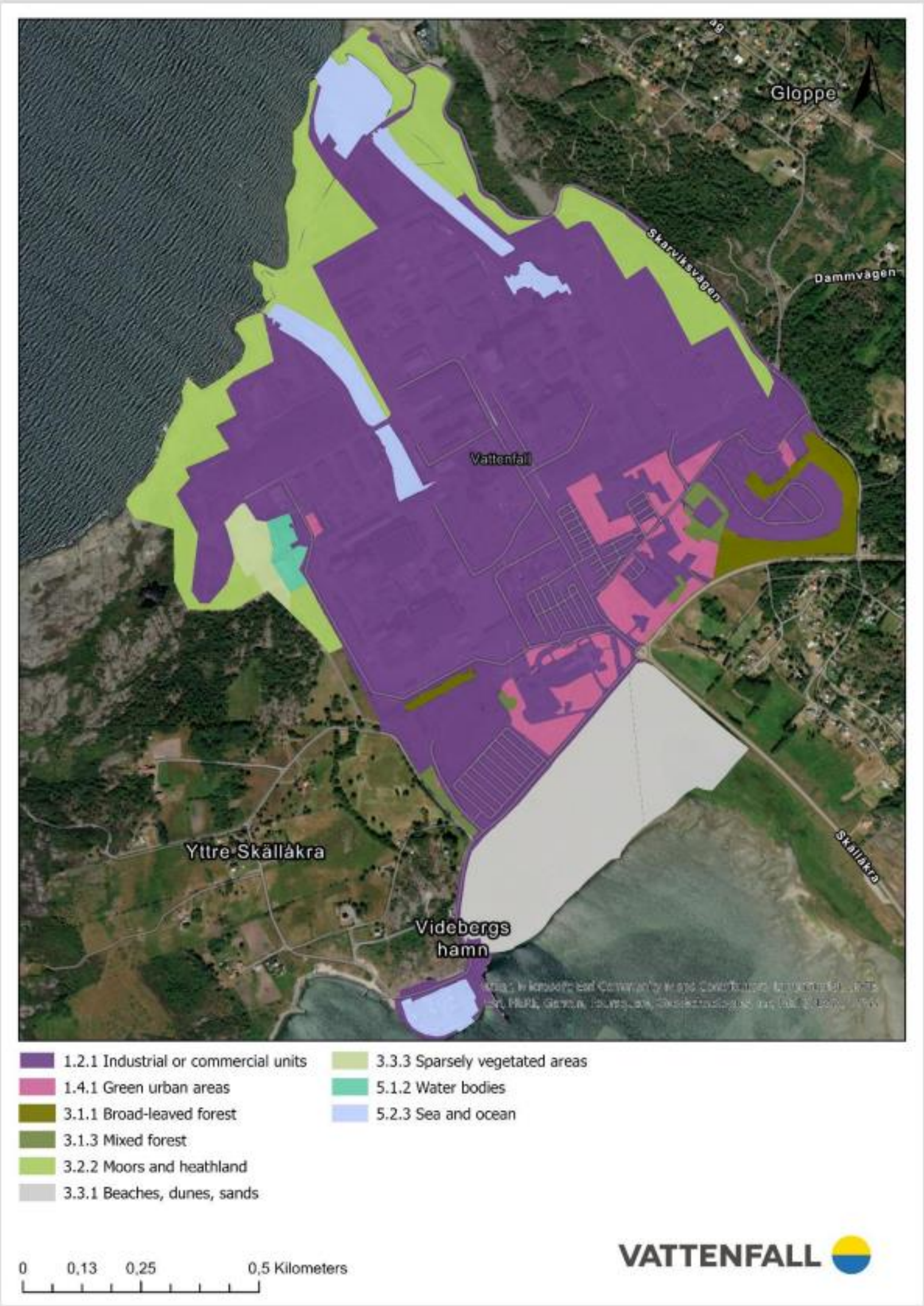


Figure 18 Ringhals area after exploitation

Clab
The Laxemar/Simpevarp area is in a natural geographical region that is characterized by a rift valley landscape with small differences in height, heathland stable forest, broadleaf forest, bare skerries and rocky beaches.

The buildings in the immediate area are sparse. The nearest housing development is in Åkvik, approximately 600 m southwest of Clab. Within the Simpevarp peninsula and in its vicinity, there are several different national interests and along the county road 743 is the Natura 2000 area Figeholm.

The heated water coming from the cooling water channel gives rise to both direct and indirect effects in the environment. It is mainly Hamnefjärden that is affected. In addition to the direct increase in temperature, the discharge leads to changed current conditions in and outside the bay. The flora and fauna of the surroundings are also affected. Environmental control is conducted by Oskarshamn's nuclear power plant and shows that the heated water works well access to oxygen and nutrition and thus increased growth for both flora and fauna, with a changed species composition consequently. However, the effects on the natural environment are generally considered to be positive the development of certain fish species and for the flora and fauna on the seabed. The contribution from Clab is negligible as the volume used at Clab is less than 0.2 % of the total volume heated water.

Within the Simpevarp peninsula and in its vicinity, there are several different national interests and along the county road 743 is the Natura 2000 area Figeholm.

Encapsulation plant
An encapsulation facility will be built next to Clab in Oskarshamn. This facility is a link in the management of the spent nuclear fuel. The fuel must be enclosed in canisters made of copper and cast iron before final storage. Construction of the encapsulation facility, which was supposed to begin in 2012 at the earliest, has been delayed.
The biotopes consist of mowed grassland and coniferous forest. The pine forest that is used by the encapsulation facility and the establishment area during the construction period consists of cultivated forest that today lacks high natural values. A few older pines have a future value, but the nature type is common in the immediate area and region. Some small marshes are at risk of disappearing, but the natural values attached to these are deemed to be limited and they only have a limited water retention function. There are no nesting sites for red-listed birds within the localization area, and the area is also not considered to be an important foraging or resting area.
Claiming the forest area is therefore deemed to entail insignificant consequences for the natural environment.

The encapsulation plant's area of influence partly affects the national interest for the Västervik and Oskarshamn archipelagos. The criteria for national interest include the archipelago's landscape type and rarity nature types in an essentially unaffected natural area with rich flora and fauna. These values are affected not by the encapsulation facility. Other protected nature areas that are within the impact area is also deemed not to be negatively affected by the encapsulation facility.

Operations at the encapsulation facility will cause noise, especially during construction time, in connection with blasting, transport and possible crushing. The listed bird species that are judged to have territories/nests within the impact area and along county road 743 have been the subject of studies in connection with bird inventories carried out between the years 2002 and 2004. The purpose of the study was to study how these species are affected by noise from drilling. The study shows not on any noticeable negative consequences. Apart from nesting osprey *(Pandion haliaetus)*, all known nesting sites are at a great distance from those areas where interference from the encapsulation facility may occur. The facility is also well located margin outside the extended disturbance zone of 500 m which is considered justified for osprey nesting. Overall, noise is judged to give rise to very little or no consequences for all listed bird species within the impact area, as the completed study shows that the majority of species are not sensitive to noise. The consequences of vibrations are judged to be negligible for animal life.

SFR-existing
SFR is located within Forsmark's construction area and low- and medium-level radioactive waste from the Swedish nuclear power plants, industry, healthcare, veterinary care, and research is stored here.

The impact on biological diversity has been small within the 19.2 ha of land that has been claimed by SFR. Before the facility was built, no critical or rare biotopes have been identified. Today, there is 35 % of the area of public biotope that was specified in the Before situation. However, the biotopes have changed. The Baltic Sea area and sand/rock beach that used to be a public biotope has been taken over and today only a little beach remains. Otherwise, the general biotope consists of grassland, mixed forest, and a bush area in the harbour. No known compensatory measures have been implemented to compensate for the claimed area.

Before the construction of the nuclear power plant, a natural value inventory of the area to be used was carried out (Hjelm and Skarpe 1970). The inventory aimed to find objects that have high values for outdoor life and/or that are of cultural and scientific interest. The objects that were found were graded on a three-point scale according to importance for nature conservation. As justification, the natural value(s) that the object exhibits, i.e., geology, vegetation, limnology, bird life or recreational opportunities, were used. The division of the area's biotopes into the Before state has been based on the above study.

The result of the inventory shows that no objects with values high enough to obtain a grading were found within the area that was used for the repository.

4.2. Safety, Barriers and Radiation

To prevent any major impact that the site might have on the environment, safety is always top priority at the nuclear power plants. Production output and economic factors must never compromise the safety of environment, personnel or facilities – this is imprinted in the mind of every employee and subcontractor.

4.2.1. Regulatory Authorities

The nuclear power industry is closely regulated by several laws, which concern environment, water, hazardous materials, nuclear technology, and radiation[3]. In addition, there are regulations from the Swedish Radiation Safety Authority (SSM).

Various decisions and licenses issued by authorities also regulate the industry. These are concerned with reactor safety, radiological environment as well as with the external conventional environment. In addition to these controls, the management of Vattenfall has objectives of its own. To secure uncompromising implementation all routines and procedures are documented in the Management & Quality Manual.

4.2.2. Safety at Three Levels

Design and operation of nuclear power plants must incorporate maximum protection against technical failures as well as external events such as fire, lightning, and sabotage. If something goes wrong the safety systems must prevent radioactive and other harmful substances from reaching the environment.

- **Preventative level**
  Safety is a design criterion for the nuclear power plants. In addition to expert staff the crucial factors in accident prevention are operating routines, maintenance, and safety assessments.

- **Monitoring level**
  The second level of safety is designed to prevent failures that occur, despite preventative measures, from developing into accident scenarios. There are safety and monitoring systems and all the important systems have redundancy. Simultaneous system failures are avoided by diversification of technical solutions, e.g. independent electrical and hydraulic systems. Systems are furthermore located in different areas of the facility, to reduce the risk of fire damage. In the case of a serious failure the reactor(s) are automatically shut down.

[3] Swedish legislation: Miljöbalken, and specific to nuclear activities: Kärntekniklagen and Strålskyddslagen.

- **Consequence-relief level**

The third level is designed to control the radioactive and other harmful substances even if all other systems have failed and the fuel core is melting. The reactor containment is an important barrier made of steel and pre-stressed concrete. In the event of a serious accident the surrounding strong building is automatically sealed to prevent radioactivity from reaching the environment.

4.2.3. Barriers and safety systems

To protect the radioactive substances from reaching the environment there are several independent barriers and safety systems.

The barriers are described below and illustrated in *Figure 19*.

- **The fuel**
  The fuel itself is a barrier. The uranium fuel pellets are sintered to high chemical and mechanical stability, virtually insoluble in water and air with a melting point of 2 800 °C.

- **Fuel rods**
  The fuel pellets are encapsulated in strong tubes of zirconium alloy, which is particularly suited for nuclear applications due to high resistance to corrosion and they are completely gas proof.
- **Reactor vessel**
  The reactor vessel and associated pipe systems are designed for high pressure. The vessel wall surrounding the fuel core is made of 15-20 cm thick steel.

- **Reactor containment**
  The reactor vessel and associated pipe systems are surrounded by the reactor containment which is made of metre-thick pre-stressed concrete reinforced with gastight steel plates.

- **Reactor building**
  The reactor building is made of steel and concrete and is designed to withstand strong forces from both inside and outside. It is also an obstacle to forced entry. For PWR, the reactor containment and the reactor building are one and the same.

There are multiple safety systems for cooling the reactor core and preventing radioactive substances from reaching the environment. To protect radioactivity to reach the environment even in the case of a core meltdown, the reactors are equipped with safety filters. The reactor containment is protected from over-pressure by releasing steam and gas to the filter, which takes care of at least 99,9 % of radioactive substances.

4.2.4. Safety of workers

Uranium and uranium compounds are toxic. Uranium is a heavy metal and has a chemical toxicity equivalent to that of lead. Experimental animal studies have shown that high intakes of uranium can affect kidney function. Strict hygiene conditions apply to workers who handle concentrates of uranium compounds. In practice, this means the use of respiratory protection, control of uranium in the air through measurement and wearing gloves when handling.

Intake of uranium can lead to increased risk for cancer. Studies conducted on the health effects of uranium have not shown any excess risk of uranium-related kidney damage or cancer in uranium workers.

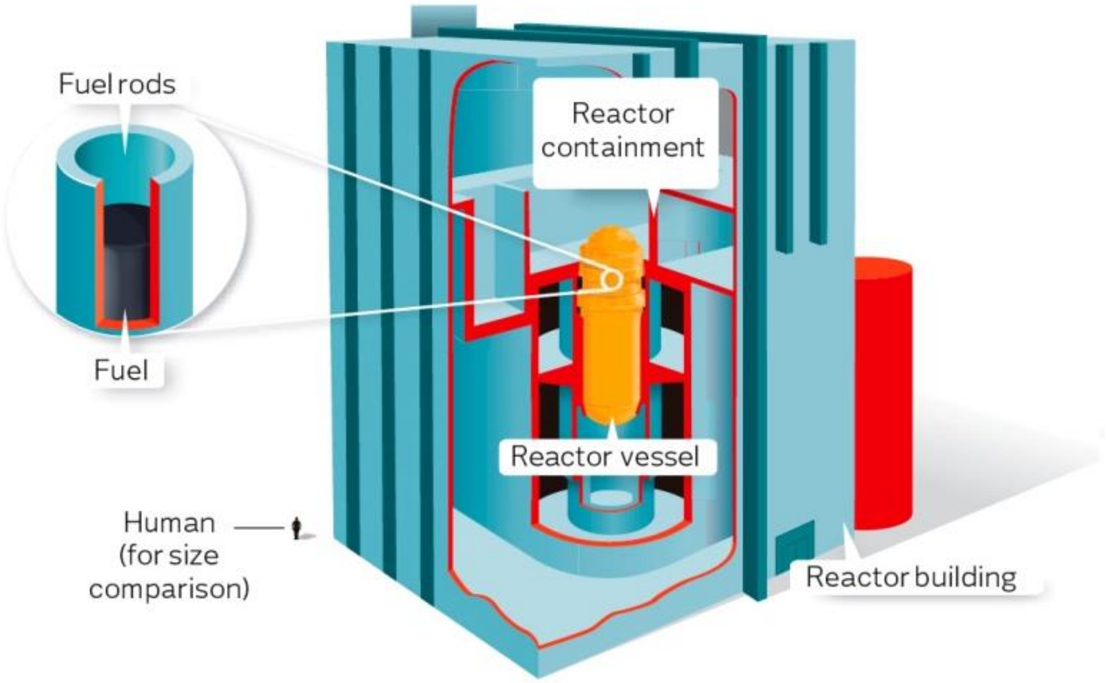


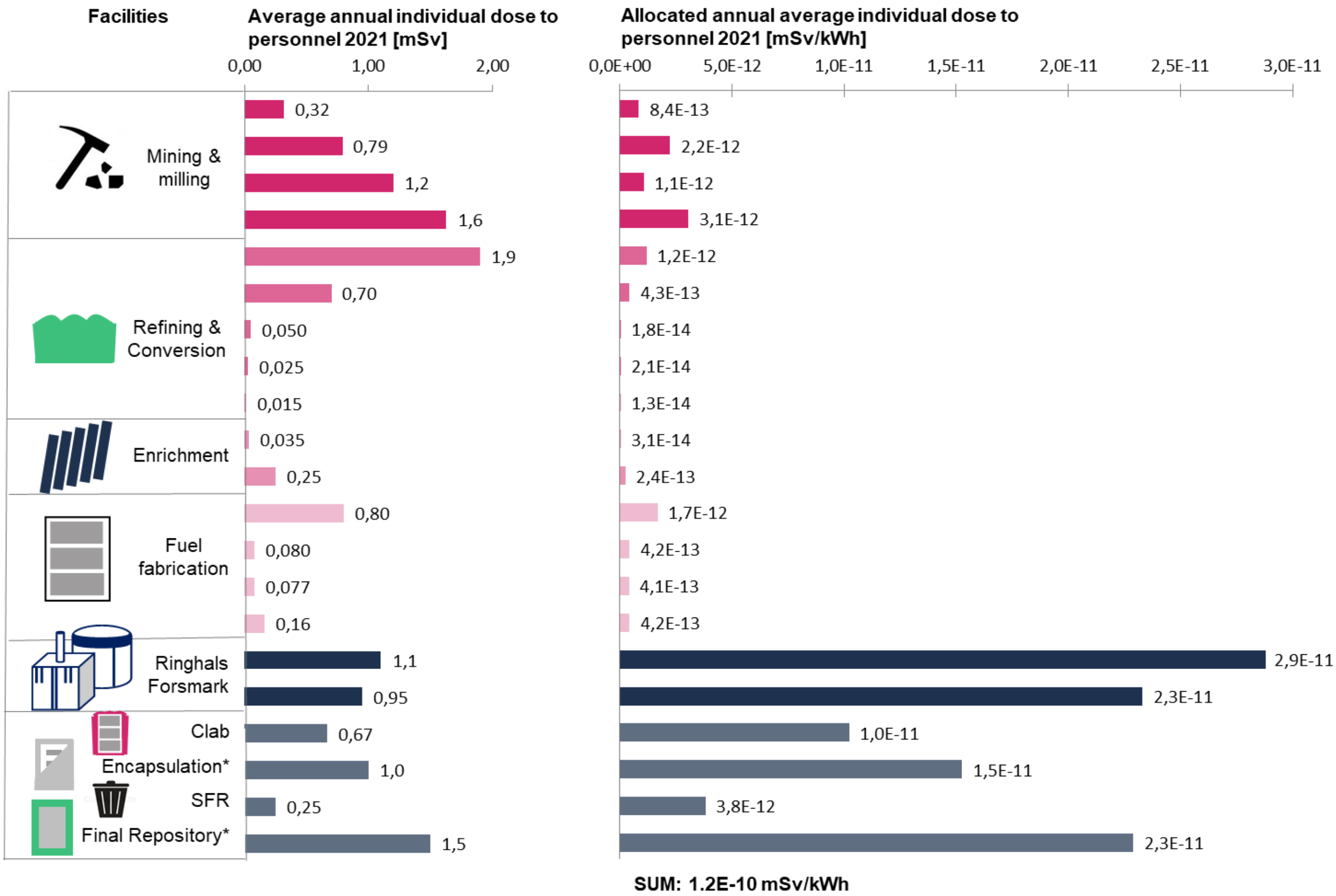
Figure 19 Barriers against radioactive emissions

4.3. Ionizing Radiation

Radioactive substances in various forms are handled during normal operation in facilities within 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). Radiation from normal operation is minor compared to natural background radiation, and results in annual doses of less than 0,001 mSv to persons living in the vicinity of the nuclear power plants (third party).

4.3.1. Occupational exposure

This section concerns dose to personnel for all facilities in the nuclear fuel cycle. The table below shows the annual average individual dose at each facility and the respectively share of that dose that can be allocated to generated electricity in terms of an average dose to an individual.



*Encapsulation plant and Final repository are not yet built, doses are conservatively calculated.

Figure 20 Occupational exposure at the facilities in the nuclear fuel cycle, annual doses and allocated per kWh.

4.3.2. Public exposure

Controlled release of radioactive substances to air and to water is normal during operation of facilities in the nuclear fuel cycle. Laws, regulations, and licenses in the respective country dictate permitted emission levels. Swedish nuclear power plants report emissions to the Swedish Radiation Safety Authority (SSM) on a scheduled basis. The emissions will affect people living in the vicinity of the facilities (local effect). Some of the released substances with longer half-lives may affect the global population.

The internal exposure of man by ingestion of water and food goes via dispersion, deposition, transportation, and receptor uptake. The deposition on water in a normal situation is of marginal importance compared to land. The path from release to dose (to third party) goes via dispersion, deposition and uptake. Man takes up radioactive substances from water and food. Conclusively, man is externally and internally exposed to low amounts of radioactive substances released from nuclear facilities during normal operations.

Dose to third party is assessed as:

- dose to a representative individual
- collective dose

Dose to representative individual is an assessed 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 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 2021 from Forsmark and Ringhals was 0,00012 and 0,00079 mSv respectively. 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 annual dose to people in Sweden varies, but the average is about 4 mSv including for instance medical radiation and radon in homes.

Collective dose (manSv) is the product of average effective dose and the number of exposed individuals in a specific area. The dose is calculated either from measured data (occupational exposures) or from estimated doses (public exposures) with mathematical modelling.

4.4. Environmental Risk Assessment

4.4.1. 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 the environmental risk inventory 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 operations of a power plant, which also includes accidents with a probability of occurrence more often than every third year, the aim of the environmental risk inventory is to describe unexpected and rare mishaps that occur or have occurred during operations less frequent than every third year, also referred to as "abnormal operation". Both conventional and radiological environmental risks are considered.

In relation to the Land use and Biodiversity section of the EPD, the Environmental risk inventory covers abnormal events and includes risks with consequences relating to mainly 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 impact on the marine environment from cooling water let out in the sea.

In the inventory, accidents and incidents in the core and core-infrastructure processes, according to Figure *21* Core process facilities location, have been taken into consideration, meaning:

- Operation of nuclear power plants, maintenance included
- Radioactive waste management
- Transportation of fuel and waste

The following aspects are beyond the scope of the inventory:

- Accidents and incidents due to sabotage, acts of war, or terror
- Risks related to manufacturing of raw materials and chemicals are not included
- Manufacturing of spare parts or re-investments machinery
- Regional risks connected to impact on biodiversity
- An abnormal discharge or an accident might lead to production of more material in order to replace parts, which may lead to additional impact on the environment.

Potential undesired events with high or very high impact but low or minute probability, for nuclear meaning reactor meltdown, is described qualitatively in 4.4.3.1. below.

4.4.2. 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.

Information was mainly retrieved by communication with and reports developed by the power plant owners and the waste treatment facility owners.

Data obtained have been assessed quantitively by using a risk matrix. The risk scenario of the identified mishaps/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 highest score in the risk matrix is presented by the red colour. Yellow represent moderate risk, and green small risk, see Table 15.

Table 15 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 3-9 years
4 Every 10-99 years
3 Every 100-999 years
2 Every 1000-9 999 years
1 Less than every 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.

4.4.3. Risk Assessment and the Nuclear Sector

Before the nuclear power plants were built, risk analysis were carried out in order to prove the plant design safe and has the ability to handle major incidents, such as large pipe-breaks or loss of external power.

For conventional risks, with non-radiological consequences, the nuclear power plants use environmental risk assessments where probabilities and consequences of potential environmental accidents are inventoried. Those assessments are carried out regularly and based on results from the risk assessments, mitigation activities are carried out within areas where risks with unacceptable consequences are identified.

For the operating plants, Probabilistic Safety Assessments (PSA) have been applied both in the nuclear power as well as in other industries. It is a systematic approach to calculate the ability for a facility to withstand incidents and breakdowns, and answers the following questions:

- What incidents may occur, and how frequently?
- What barriers are required to contain the incident, and what is the probability of barrier malfunction?

Forsmark and Ringhals have plant specific PSA models for all reactors.

In response to the Fukushima nuclear accident all operators of nuclear power plants in the EU had to review the response of their nuclear plants to extreme situations, especially loss of safety functions such as loss of ultimate heat sink. As a consequence all reactors in Forsmark and Ringhals were equipped with independent core cooling.

The paragraphs below summarize the conventional environmental risk and the radiological risks for different parts of the core module.

4.4.3.1. Operation of the nuclear power plants
Risk assessments regarding emissions of radioactive substances to the environment were made prior to the actual construction of the nuclear power plant. The results have influenced the construction of the facilities, which are built to contain a core melt with only minor radioactive emissions. Conventional risks have also been studied, and the major environmental aspects have been identified. Risk assessments have been performed whenever justified and they are continuously updated.

Conventional environmental risks
Conventional environmental risks are assessed partly using a risk matrix, partly using a scenario analysis method. The scenario analysis describes all the risks in financial terms, while the matrix-based method focusses on the environmental impact. The basic description of the risks is however useful for gaining an understanding of the risk.

Many different chemical substances are used at a nuclear power plant. Substances listed below have been selected for a risk assessment, since they a) occur in large quantities and b) may have negative effect on the environment (as well as on humans):

Oil/diesel Many scenarios can be found, e.g. minor oil-spills, leakage from oil tanks, oil leakage from spare transformer.

Firefighting water In the case of a fire, firefighting water may reach the environment. Depending on the burning object and depending on the method for fighting the fire, the amount and the substances present in the water may vary.

Ethanol In Forsmark there are fuel tanks for petrol, diesel and ethanol. The largest risks associated with them are related to filling of the ethanol tank.

Sodium hypochlorite Used for chlorination of auxiliary cooling water in Ringhals. The substance is stored in three tanks.

Hydrazine This is used to reduce oxygen in water and thereby reducing corrosion. Ringhals 3-4 each have a storage tank close to the turbine hall.

The most significant conventional environmental risks identified at Forsmark and Ringhals using the risk matrix are:
- Release of and contamination by process chemicals.
- Emissions from sanitary sewage treatment plant: The sewage treatment plant entails emissions of mainly organic and oxygen-consuming substances.
- Fires, e.g. fire in transformer, turbine hall, electronic components and flammable chemicals.
- Fuel truck accident.

Ringhals is classified according to Seveso's higher level mainly based on the storage of hydrazine, which requires additional reporting on the use of Seveso chemicals. Risk scenarios according to Seveso include storage and transfer of hydrazine, transport and storage of diesel oil, and fire/explosion caused by hydrogen gas accidents.

Radiological environmental risks
An integrated review of the plant design and operational safety for a nuclear power plant is performed through the use of Probabilistic Safety Assessment (PSA). PSA is a quantitative method that is used to evaluate and rank all possible initiating events and sequencies that can result in core damage and releases of radioactivity to the environment. Forsmark and Ringhals have plant specific models for all reactors in operation.

To be able to use PSA to evaluate the overall plant safety Forsmark and Ringhals have defined safety goals for the frequency of core damage and for the frequency of unacceptable cesium releases. The safety goals are based on international practices. Although assumptions and uncertainties are inevitable in a PSA the current models are judged to give a good enough picture of the plants to show that the results are in line with the safety goals. This implies that the total core damage frequency, for all events and operating modes, is around or below one incident per 100,000 years for each unit and that there are good margins to avoid unacceptable releases.

The incident with the largest effects in a nuclear power plant is a reactor meltdown, which would cause radioactive emissions. What has been seen so far in the nuclear history, those emissions will not cause acute danger to most people but can affect the environment around the nuclear power plant causing indirect negative effects on those living in the area. For this reason, PSA is used to predict events that can result in core damage (which can potentially cause a reactor meltdown) and release of radioactivity to the environment.

4.4.3.2. Waste Management

Land Repository

Both Forsmark and Ringhals have implemented an on-site repository for low level radioactive waste, which is used periodically. Conventional environmental risks connected to the land repositories include water penetration through the waterproofing, impaired function in infiltration bed, fire and flooding.

Regarding radiological risks, a number of extreme scenarios have been designed in order to calculate the maximum doses of exposure. Examples of analysed scenarios are intrusion into landfill, extreme fire, and construction of well in the repository. For all identified extreme scenarios, the resulting doses to the public will be low, at the most 10 µSv/year, even when making very conservative assumptions about the impact on waste and repository. Thanks to several barriers along with different safety arrangements, such as regularly environmental monitoring, none of these risks are expected to be realised. If they do happen, the consequences are considered small.

SFR (Final Repository for Radioactive Operational Waste)

Operational waste (Low and Intermediate Level Waste) from Swedish nuclear power plants and similar waste from industry, health services, and research facilities is deposited at SFR, located in the Forsmark area. The facility is located in bedrock some 60 meters below the sea floor and the water depth is five meters. The location was selected after geological examination. Seismic activities as well as the probability of tremor-related displacements are very low.

The most serious incident identified during operation would be if a waste container dropped from a lifting device. Clean-up personnel could then be subjected to irradiation if the container is damaged. The calculated sum of doses to all personnel is 15 mmanSv (no dose to the public).

Chemical risks are considered negligible since only minor quantities of chemicals are involved.

The risk of future generations being exposed to radioactive substances have been analysed for extreme scenarios:

- Radioactive particulates and contamination from waste can only propagate via the ground water, which attaches major importance to its flow in the bedrock. One thousand years after sealing off the facility, the calculated flow of ground water will be 5 litres/m^2 annually. As the land-elevation continues, the flow will reach 15 litres/m^2 annually, approximately 2,500 years after sealing. Chemical examinations of the ground water show that present water flow through the rock is very limited, 0.2 litres/m^2 annually.
- The repository will remain covered by saltwater for the first 1,000 post-sealing years. A fresh-water ecology implying downstream wells may have evolved after 2,500 post-sealing years. The first 1,000 years are called the saltwater period, during which the direct migration path for radioactive substances to humans via drinking water can be excluded.
- In a realistic scenario, where the barriers are intact, the maximum dose to an individual occurs approximately 100 years post sealing and is calculated to be 0.0001 mSv/year. This can be compared to the natural background radiation of 0.5-1 mSv/year.

Clab (Central Interim Storage Facility for Spent Nuclear Fuel)

Spent fuel will be stored at Clab in cooled water pools for several years. The water in the pools acts as radiation shielding as well as a coolant for the hot fuel. The quantity of water is large enough and evaporation gradual enough for a temporary disruption of the cooling to not pose any danger. It will take a full month before enough water has evaporated to uncover the top of the fuel assemblies. A fundamental design principle is the duplication of essential safety arrangements, e.g. power supplied by independent sources.

The bedrock site provides ample protection against intrusion, theft, sabotage, and other acts of violence as well as protection against acts of war. The storage area and cooling systems are designed to withstand the effects of anticipated Swedish seismic activity without damage to the spent fuel.

The dose outside the facility has been estimated based on conservative assumptions regarding release of radioactive substances. Most of the radioactivity inside the fuel has subsided while resident in the on-site storage pool at the nuclear power plant before transportation to Clab. Activity and temperature are still high, requiring shielding as well as cooling.

Doses to the environment are based on emissions from 20 meters height and lasting one hour. Examples of analysed events are fire, loss of cooling or electricity supply and mishaps/failure of components in the management of fuel. All identified events are considered acceptable. Either the probability of occurrence is extremely low, or the consequences can be mitigated and are below the set criteria. The maximum effective dose at a 200 meters distance was calculated to be 0.013 mSv. This can be compared to the natural background radiation of 0.5-1 mSv annually.

The assessed incidents are related to emissions of radioactivity. Chemical risks have not been analysed, as there are only minor amounts of hazardous chemicals at Clab.

Encapsulation Plant
An encapsulation plant will be built that is integrated with Clab. Here the spent fuel, after interim storage at Clab, will be encapsulated before final disposal. Clab and the encapsulation plant will then be operated together as one unit called Clink.

A risk assessment, similar to that of Clab, has been made for the future encapsulation facility. The assessment considers possible incidents during the operating lifetime of the facility regardless of the expected frequencies and consequences. Various incidents are considered, such as fire, handling mishaps regarding fuel elevator cage, fuel assembly, receiving dock, insert, and transport cask and external incidents. None of these incidents are estimated to result in serious consequences for the surroundings. The residual heat (in the spent fuel) is considerably lower in this facility than in Clab, which results in slower processes in case of incidents. Consequently, available time for corrections increases proportionately.

The conclusion is that the more probable incidents neither cause damage to the fuel within the facility, nor lead to consequences for the environment. Critical functionality affected by incidents can either be handled by other systems or temporarily suspended.

Spent nuclear fuel repository
SKB has concluded that a suitable site for the final repository for spent nuclear fuel is available adjacent to Forsmark. Applications for necessary permits to build and operate this repository have been approved in early 2022 by the Swedish government, The Land and Environment Court, and The Radiation Safety Authority (SSM).

Different kinds of disruptions and mishaps can occur during the time the plant is in operation, i.e. during the time that the deposition is ongoing. After the core components of the decommissioning of the nuclear power plants have been deposited, the plant will be sealed (which means 40 years have passed after the last reactor ceased operations in Sweden).

Conventional environmental risks are described and evaluated for all stages of the facility, i.e. construction, operation, decommissioning and closure. The risks are evaluated in order to see which ones are of a more serious nature. A very large proportion of the risks that occur is emission of oil or gas, primarily on land. In general, the risks are present mainly in connection with the construction phase and then is no different from the risks involved at every major construction project. With a good organisation and a high environmental profile, emissions can be minimised and if necessary, decontaminated. Also, some of the other risks can be reduced significantly through preventive measures.

Risks evaluated to be of high priority (red) are:
- Lack of knowledge of the land (risk of harming valuable environments and species)
- The model of the geohydrological balance is incorrect (greater groundwater immersion and saline penetration)
- Powerful water-carrying crack is missed in front of tunnel operation
- Temporary fuel tanks
- Nitrogen contamination from blasting that remains on rock masses that are deposited
- Sealing work/injection resulting in groundwater immersion
- Emissions from components/vehicle

No event that would damage the canister during operation has been identified. A hypothetical case has been created where it is assumed that the capsule breaks and activity leaks through a crack. One must assume that not only the canister is damaged, but also the equipment inside, as well as damage to the fuel cladding. Only gaseous activity can be released. This hypothetical case gives a dose of 0.04 mSv to a person standing in the same tunnel as the canister for one hour immediately after the capsule break (compare to natural background radiation of 0.5-1 mSv/year).

The principle acceptance criterion, expressed in SSMSF 2008:37, concerns the protection of human health in terms of cancer and heredity effects. The risk limit set corresponds to an effective dose limit of about 0.014 mSv/year. This, in turn, corresponds to around one percent of the effective dose due to natural background radiation in Sweden. Furthermore, the regulation SSMFS 2008:21 requires descriptions of the evolution of the biosphere, geosphere and repository for selected scenarios; and evaluation of the environmental impact of the repository for selected scenarios, including the main scenario, with respect to defects in engineered barriers and other identified uncertainties.

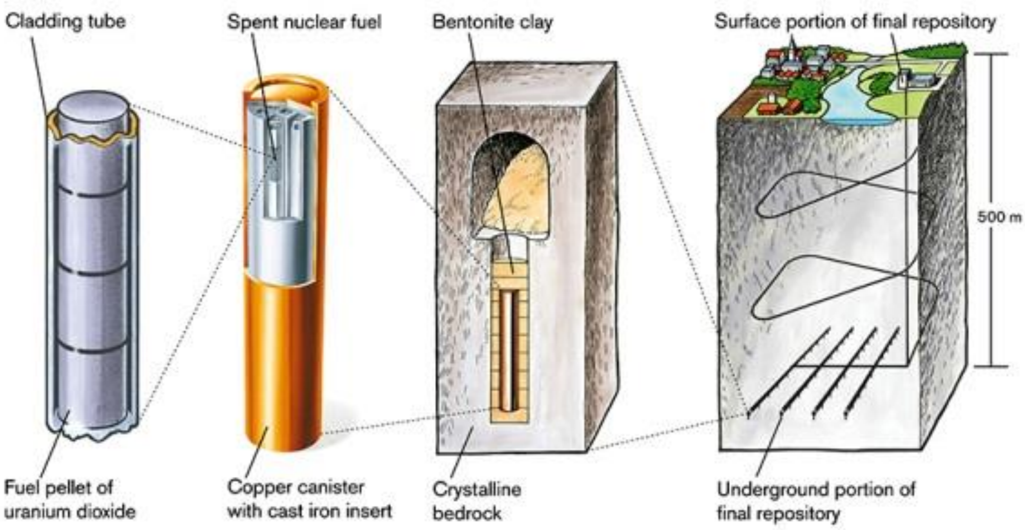


Figure 22. Physical Barriers.

4.4.4. Transportation

Worldwide, goods containing radioactive materials are routinely transported on public roads, railways and ships, and are thus consequently subject to general risks connected to goods transport. However, only about 5 % of these transports are intended for the nuclear power industry.

Uranium is only weakly radioactive before it has been used as fuel, and its chemical toxicity is then more significant than its radioactivity and radiotoxicity. Transports within mining, refining, conversion, enrichment, and fuel fabrication takes place on land and at sea and accidents can occur, but consequences are minor due to built-in safety barriers.

The purpose-built ship Sigrid transports spent fuel enclosed in heavy-duty transport containers to Clab, with Sigrid providing radiation shielding and damage protection. The containers are robust and designed to withstand severe stresses, exceeding IAEA standards.

4.5. Electromagnetic Fields

Electromagnetic fields (EMF) 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-Ionising Radiation Protection (ICNIRP), an independent body consisting of international experts, has however published recommendations[4] 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 people in the working environment, and for the general public they set 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, does 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.

4.6. Noise

Noise has been measured in the surroundings of the nuclear power plants. 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 wind direction and temperature. Maximum noise levels have been measured to be kept within the environmental permits at 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). Power lines over 70 kV may give rise to noise (so called corona noise). Sound levels are moderate: 45 dB(A)[7] at 25 meters, however abating rapidly as distance increases.

4.7. Visual Impacts

Forsmark's and Ringhals' reactor buildings can be viewed from sea, especially Ringhals can be seen from far out to sea. The visual impact from land is however limited, if not close to the power plant. Ringhals is located on a peninsula that is reserved for electricity production but can be seen from Bua society, and Forsmark is located in a forested area. The reactor buildings have a height of about 50-60 meters and are equipped with chimneys with a height of about 60 (pressurized water reactors, PWR) to 100 meters (boiling water reactors, BWR).

Figure 28 Forsmark and Ringhals power plants.

[4] 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.

5. Differences versus previous version of Vattenfall's EPD® for Nuclear Power

5.1. Differences in Life Cycle Assessment

There are some differences in the results between this EPD® and the corresponding EPD® certified in 2019, see Table 16 below and clarifications in the subsequent sections. The requirements of the updated PCR and GPI have resulted in an increased number of reported environmental impact indicators in the EPD®, as can be seen in Table 16, somewhat limiting the comparability with the 2019 EPD®. One aspect affecting a previously assessed impact category as well, is the new inclusion of CO_2 emissions as a result of deforestation (GWP Luluc). To make the GWP comparable towards 2019, Table 16 presents the results with and without the inclusion of GWP Luluc.

Table 16 Differences vs. earlier version. Per 1 kWh of electricity generated and distributed, respectively

Environmental impact categories	Unit/kWh	Vattenfall's EPD® for Electricity from Nuclear power					
		2022		2022 (excl. Luluc)		2019 (excl. Luluc[1])	
		Total - generated	Total - distributed	Total - generated	Total - distributed	Total - generated	Total - distributed
Global warming potential (GWP) - total	g CO_2-eq. (100years)	2.48	5.71	2.47	4.28	2.76	4.44
Acidification potential (AP)	g SO_2-eq.	0.00890	0.0198	0.00890	0.0198	0.00861	0.0185
Eutrophication potential (EP)	g PO_4^{3-}-eq.	0.00441	0.00993	0.00441	0.00993	0.00355	0.00856
Photochemical oxidant formation potential	g NMVOC-eq.	0.0111	0.0193	0.0111	0.0193	NR	NR
Particulate matter	g PM2.5-eq.	0.00420	0.00853	0.00420	0.00853	NR	NR
Abiotic depletion potential - Elements	g Sb-eq.	3.54E-05	5.97E-05	3.54E-05	5.97E-05	NR	NR
Abiotic depletion potential - Fossil fuels	MJ, net cal. value	0.0314	0.0530	0.0314	0.0530	NR	NR
Water scarcity footprint	m^3 H_2O-eq.	0.402	0.618	0.402	0.618	NR	NR

* NR = Not reported

[1] In 2019, Luluc was not part of the calculations

5.1.1. General

The largest difference in impact is related both to an updated supplier mix and the fact that the impact from some of the suppliers has been reduced. Concerning all assessed impact categories, an increase in mining contribution takes place while a reduction takes place in enrichment of uranium, further described below.

- Mining
  - No recycled uranium is used during the period of validity for this EPD®, leading to an increased amount of primary uranium used per kWh. This results in an increase in relative contribution for the mining activity.
  - The increased share of primary uranium overshadows the impact reduction from:
    - A smaller share now originates from open pit mining, which generally is connected to a higher impact.
    - Improved energy efficiency of suppliers.
    - A now higher average price of metals, allocating more emissions to by-products in the BHP Olympic Dam mine.
- Enrichment
  - Recycled uranium is no longer part of the supply chain, removing a large driver for enrichment impacts.

- Urenco Capenhurst plant now uses nuclear energy, with certificate, which impacts emissions associated with electricity consumption for the enrichment activity. They previously used a national electricity mix.

With the exception of several plans in the core infrastructure module, all Ecoinvent data have been updated from Ecoinvent 3.5 to Ecoinvent 3.8, which usually is an important factor in the changes in environmental impact. In addition, the data sets for construction and demolition of deep repository, SFL and SFR-expansion, were updated to more recent GaBi versions, as the facilities are not yet constructed. Additionally has the national residual electricity mix been applied where feasible, where previously the national grid mixes have been used, in accordance with the PCR. Characterisation factors for all impact categories have been updated in accordance with the PCR and the international EPD® System.

The reference flow, electricity generated in the power plants, is for Ringhals now calculated with only Ringhals 3 and Ringhals 4, due to Ringhals 1 and Ringhals 2 being closed down during the previous validity period of the EPD®. That leads to a potential overestimation of results, as the reactors are not modelled separately. Consequently, resource flows connected to Ringhals 1 and Ringhals 2 are included in Ringhals' construction plans although they are not producing energy during the validity period of this EPD®. However, this is not judged to impact the results substantially.

5.1.2. Uranium extraction and Milling

There are no changes in suppliers of uranium extraction since 2019, although the share of primary uranium has increased due to the removal of recycled uranium from the supply mix. Underground mines remain dominating as suppliers over the period 2021-2024 even though purchased uranium from open-pit mining is still warehoused. Hence, the impact contribution from open-pit mining is further reduced compared to 2019, as it constitutes an even smaller share of the uranium supply.

The share from open-pit mines have thus been reduced, which in turn reduces the environmental impact since open-pit mines in general have a higher impact. However, the supply chain is now without recycled uranium, increasing the impacts from the otherwise avoided processes of mining, milling, refining and conversion.

Overall, the impacts from uranium extraction are higher than the earlier version for all assessed impact categories.

5.1.3. Refining and conversion

As mentioned in section 5.1.1. above, one major difference is that recycled uranium is no longer part of the supply chain, hence are the impacts from the processes of refining and conversion of primary uranium increased. A new supplier is included in the modelling but apart from that, no major changes have been made for the refining and conversion supply chain since 2019. Overall, the impact from refining and conversion has reduced since 2019 regarding all comparable impact categories (GWP, AP and EP), due to a relatively lower energy and material use and the introduction of a new supplier into the supplier mix.

5.1.4. Enrichment

As recycled uranium is no longer part of the enrichment supplier mix, the impacts associated with enrichment decreases across all impact categories. In addition to that the energy mix used by suppliers is partly changed to nuclear only.

5.1.5. Fuel Fabrication

There are no changes in suppliers of fuel fabrications since 2019,. Overall, the impact contribution from the fuel fabrication phase is decreased for all impact categories, due to a change in the respective suppliers' contribution to the delivered fuel, along with changes in energy and material consumption for fuel fabrication activities.

5.1.6. Nuclear Power Plant

The nuclear power plants are expected to have a lower electricity generation compared with earlier version, as Ringhals 1 and Ringhals 2 are no longer active. This results in a bit higher share of impact from the core phase as well as the construction and decommissioning of the nuclear power plants.

5.1.7. Waste handling
A change in waste management allocation procedure for Clab was implemented, but with an insignificant impact on results. Updated data delivered by SKB were implemented, updating the core-infrastructure plans for SFR-expansion as well as the final repository for spent nuclear fuel.

5.1.8. Distribution
Distribution losses have been changed from 3 % to 4 % to reflect the average losses during the most recent 5-year period. This change has resulted in increased environmental impact from distribution of electricity.

5.2. Differences in Land Use and Impact on Biodiversity

The method has been updated since EPD® for electricity from the Nordic nuclear power plant, certified in 2019. The scope is limited compared to previous years and does now comprise the mining facilities and the core module, which follows the minimum requirements in the EPD framework. Reasons for changing methods is that emissions from land use changes are included in the LCA calculations meaning that emission parts of land use change effects are handled there, and a bigger emphasis has been put on describing effects and potential effects on biodiversity instead.

5.3. Differences in Ionizing Radiation

In the table below, the difference in annual occupational dose range compared to the former EPD is shown. The changes are within normal variation. Newly built facilities show comparatively lower dose than older ones. The highest dose in the lifecycle of nuclear fuel origins from waste handling and final depository of spent fuel, 1.5 mSv. That value is a conservatively calculated dose and unchanged since last EPD.

Occupational dose	Unit	Upstream facilities	Nuclear power plants - operations	Nuclear waste handling
Average individual dose 2018	**mSv**	0.07 – 1.8	0.96 – 0.98	0.1 – 1.5
Average individual dose 2021	**mSv**	0.02 – 1.9	0.95 – 1.1	0.25 – 1.5

5.4. Differences in Environmental Risk Assessment

The method has been updated since EPD® for electricity from the Nordic nuclear power plant, certified in 2019, and is now more stringent. The scope is limited compared to previous years and does now comprise the core module, which follows the minimum requirements in the EPD framework, and in addition transports of fuel to site are included. The data compilation for nuclear environmental risks has not changed significantly.

There are no changes in the risks inventoried and impact on environment for the included modules since last update.

6. Information from the Certification Body and Mandatory Statements

6.1. Information on the Independent Verification of this EPD®

This EPD® has been verified within Vattenfall's EPD® Management Process. The independent verifiers Caroline Setterwall (Hitachi Energy), Håkan Stripple (IVL), and Lasse Kyläkorpi (Vattenfall), 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 3.01, 2017-12-11, and Product Category Rules (PCR) CPC 171 version 4.0, 2020-03-16). This certification is valid until 2027-12-31.

6.2. Verification of Vattenfall's EPD® Management Process

Vattenfall's EPD® management process is third party verified on annual bases, the last review was made 2022-03-28. 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.

6.3. Mandatory Statements

6.3.1. 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.

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 end consumers. This EPD® is aimed for industrial customers and not meant for private customer communication.

6.3.4. 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 4.2

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: Caroline Setterwall, Hitachi Energy, Håkan Stripple, IVL Swedish Environmental Research Institute, and Lasse Kyläkorpi, Vattenfall AB

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:** 2027-12-31

7. Links and References

Internet sites

www.vattenfall.com

www.environdec.com homepage of EPD International Ltd, where you can download supporting documents for this EPD®.

Databases:

Generic data mainly stem from the database Ecoinvent version 3.8 (2020) and GaBi Professional database 2019 Edition.

Contact information:

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

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

Specific questions regarding Forsmark's environmental topics should be directed to Rebecca Laitinen, e-mail: reb@forsmark.vattenfall.se.

Specific questions regarding Ringhals' environmental topics should be directed to Helene Holgersson e-mail: Helen.Holgersson@vattenfall.com.