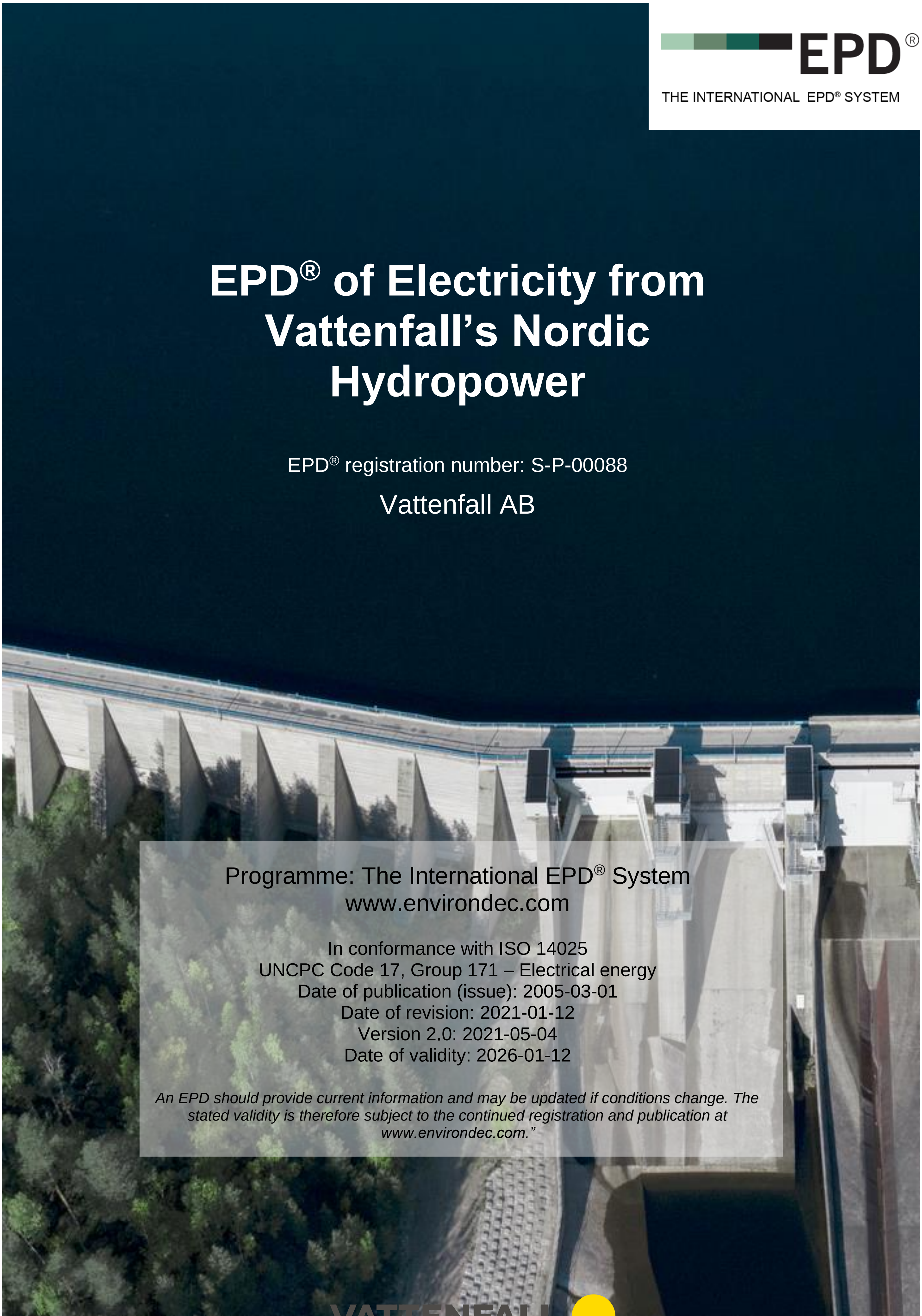

EPD® THE INTERNATIONAL EPD® SYSTEM

EPD® of Electricity from Vattenfall's Nordic Hydropower

EPD® registration number: S-P-00088

Vattenfall AB

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

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

VATTENFALL

Contents

Cover page: Vattenfall Tuggen power station (cropped image, photo: Jennie Pettersson)

Preface

PRODUCER, Vattenfall Business Unit Hydro Nordic is responsible for Vattenfall AB's hydropower generation in the Nordic countries. BU Hydro Nordic is part of Vattenfall AB, SE-169 92 Stockholm, Sweden. Phone: +46 8 739 50 00; www.vattenfall.se and www.vattenfall.com. BU Hydro Nordic implements a certified work environment and environmental management system. This system is based on the standards ISO 14001:2015 and OHSAS 18001:2007 as well as the provision AFS 2001:1.

PRODUCT AND DECLARED UNIT, Electricity belongs to the product category UNCPC Code 17, Group 171 – Electrical energy. The declared unit is 1 kWh electricity net generated and thereafter distributed to a customer connected to the Swedish regional grid (70/130 kV) and represents an average for hydro power Vattenfall. Vattenfall AB owns or has majority share in 56 large-scale hydropower plants in the Nordic countries and 32 small-scale stations. The hydropower generation that BU Hydro Nordic disposes from majority owned plants during an average year is 31 TWh which corresponds to about half of the total hydro power production in Sweden. Several reservoirs enable the generation to follow the load curve, and electricity can be delivered without backup sources.

THE INTERNATIONAL EPD® SYSTEM, managed by EPD International AB as a subsidiary to IVL Swedish Environmental Research Institute, is based on ISO 14025, Type III Environmental Declarations. The relevant governing documents in hierarchical order are: PCR-CPC171, version 4.11; General Programme Instructions for an environmental product declaration, EPD® version 3.01; ISO 14025; ISO 14040, and ISO 14044.

ENVIRONMENTAL PERFORMANCE, based on LCA, see section 3.
System Boundaries, The EPD® describes the core process, i.e. the generation of electricity in Vattenfall's Nordic hydropower plants, upstream process comprising production of auxiliary supplies, and downstream process including distribution of electricity. The core - infrastructure comprising construction of power plants, dams and waterways is also included. Decommissioning has not been included but the technical lifetime has been set at a level that provides for complete replacement of the power plant through reinvestments. Technical lifetime for machinery in power plants has been set to 60 years and for buildings, dams and waterways 100 years. Construction and decommissioning of infrastructure in downstream process have been included. The use of electricity at the consumer has been excluded. Nordic hydropower plants, majority and wholly owned by Vattenfall AB, have been selected for the study to be representative regarding location, physical geography regions, and type and size of station. The stations are located in different river regions. The selected stations have a third of Vattenfall's installed capacity and generate a third of Vattenfall's hydropower. For more information about the selection of hydropower plants, see appendix *Beskrivning av valda anläggningar* (in Swedish).

This certified declaration also contains descriptions of environmental risks and impacts on biodiversity in accordance with the EPD® system instructions.

Table 1 Operations in the different phases of the life cycle

Upstream	Production of oils, chemicals and fuels for operation of the plant and for vehicles and reserve power.
Core	Operation of power plant, i.e. emissions from inspection trips, emissions of oil to water and ground, incineration or deposit of operational waste.
Core – infrastructure	Construction and reinvestments in machinery, dams and waterways. Emissions from land inundated by reservoirs.
Downstream	Operation of electricity networks, i.e. emissions from inspection trips, production and emissions of oils. Additional generation in Vattenfall's hydropower plants to compensate for losses in the networks.
Downstream – infrastructure	Construction and decommissioning of the transmission grid and distribution networks.

Environmental Information

A short summary of compiled data is presented below per generated and distributed kWh of electricity. Distribution of electricity implies losses, which is compensated for by increased generation. The loss to an average large industrial customer connected to the regional distribution network (70/130 kV) amounts to 4% (included in the downstream column below). The losses are different for different types of customers and often higher in the countryside. The average loss to a household customer is around 8%.

Table 2 Environmental impacts

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. (100yrs)	$7,45*10^{-3}$	$3,83*10^{-2}$	1,36	**1,40**	$1,40*10^{-1}$	1,44	**2,99**
	Biogenic	g CO_2-eq. (100yrs)	$4,04*10^{-5}$	$1,91*10^{-3}$	$2,34*10^{-2}$	**$2,54*10^{-2}$**	$1,02*10^{-3}$	0,00	**$2,64*10^{-2}$**
	Luluc[2] (inundation)	g CO_2-eq. (100yrs)	0,00	0,00	$7,98$^10^{-1}	**$7,98$^10^{-1}**	$3,19*10^{-2}$	0,00	**$8,30$^10^{-1}**
	Luluc (deforestation)	g CO_2-eq. (100yrs)	0,00	0,00	2,11	**2,11**	$8,42*10^{-2}$	1,22	**3,41**
	Total	g CO_2-eq. (100yrs)	$6,78*10^{-3}$	$4,02*10^{-2}$	4,29	**4,33**	$2,57*10^{-1}$	2,68	**7,26**
Acidification potential (AP)		g SO_2-eq.	$6,59*10^{-5}$	$5,42*10^{-5}$	$5,15*10^{-3}$	**$5,27*10^{-3}$**	$3,74\times10^{-4}$	$7,84*10^{-3}$	**$1,35*10^{-2}$**
Eutrophication potential (EP)[3]		g PO_4^{3-}-eq.	$1,83*10^{-5}$	$1,59*10^{-5}$	$1,50*10^{-2}$	**$1,50*10^{-2}$**	$6,41*10^{-4}$	$3,51*10^{-3}$	**$1,92*10^{-2}$**
Photochemical oxidant formation potential (POFP)		g NMVOC-eq.	$4,82*10^{-5}$	$1,23\times10^{-4}$	$4,52*10^{-3}$	**$4,69*10^{-3}$**	$6,66\times10^{-4}$	$6,90*10^{-3}$	**$1,23*10^{-2}$**
Particulate matter		g PM2.5-eq.	$1,80*10^{-5}$	$1,94*10^{-5}$	$1,91*10^{-3}$	**$1,94*10^{-3}$**	$1,35*10^{-4}$	$3,12*10^{-3}$	**$5,20*10^{-3}$**
Abiotic depletion potential - Elements		g Sb-eq.	$4,98*10^{-8}$	$3,20*10^{-9}$	$1,09*10^{-5}$	**$1,09*10^{-5}$**	$4,62*10^{-7}$	$2,38*10^{-5}$	**$3,51*10^{-5}$**
Abiotic depletion potential - Fossil fuels		MJ, net cal. Value	$5,89\times10^{-4}$	$5,65*10^{-6}$	$1,43*10^{-2}$	**$1,49*10^{-2}$**	$1,23*10^{-3}$	$1,85*10^{-2}$	**$3,46*10^{-2}$**
Water scarcity footprint		m^3 H_2O-eq.	$3,17*10^{-7}$	$1,76*10^{-7}$	$5,48*10^{-4}$	**$5,48*10^{-4}$**	$2,28*10^{-5}$	$3,12*10^{-4}$	**$8,83*10^{-4}$**

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 Over 69% emanates from COD and inundation of land; this is calculated in accordance with the methodology described in the PCR

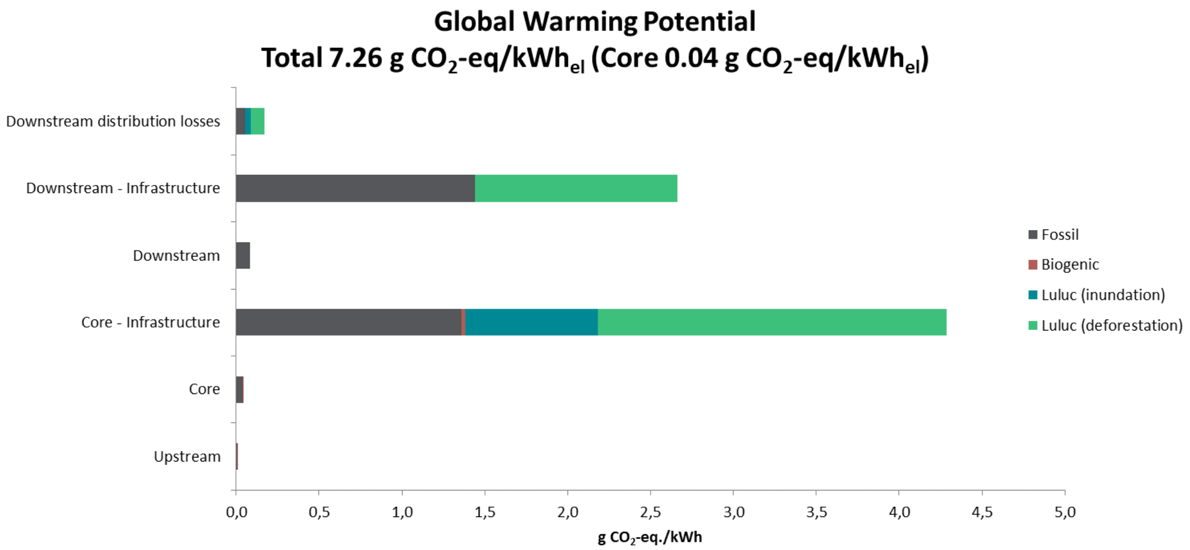

Figure 1 Potential emissions of greenhouse gases

The main contributions to the emission categories in the table above occur in the construction phase of the hydropower plants (core-infrastructure) as well as power networks (downstream-infrastructure), and mainly relate to the use of material for construction and reinvestment. Operation contributes less than 1% in the majority of the assessed impact categories.

With regards to the impact categories Eutrophication Potential and Global Warming Potential, the emissions in core-infrastructure are dominated by activities related to land use change, where inundation in reservoirs is a significant contributor to emissions of eutrophying substances and greenhouse gases. Deforestation, as a result of the construction of water reservoirs (dams) and power network infrastructure, is the single most significant contributor to the emissions of greenhouse gases in both core- and downstream-infrastructure.

If the facilities were to be used beyond the assumed 100 years, the emission per generated kWh would decrease since there would be the same amount of carbon released due to land use change, but a larger amount of kWh generated.

ADDITIONAL ENVIRONMENTAL INFORMATION

Land use and Impact on Biodiversity

Vattenfall´s Biotope Method is used to quantify impacts on biodiversity as a direct consequence of the utilisation of land and water for economic activities. Affected areas are categorised into Critical biotope, Rare biotope, General biotope and Technotope. The 14 selected hydropower stations occupy an area of in total about 74 000 hectares, predominantly river-, lake, and annual reservoirs. This reservoir area constitutes 40% of Vattenfall's total reservoir area and the 14 stations generate 31% of Vattenfall's hydropower.
The table below shows the aggregated change of biotope categories caused by the construction of the 14 stations. The specific values in the table give a rough approximation of the direct biotope changes caused by Vattenfall's Nordic hydropower. Data should be interpreted based on the whole chapter on land use and biodiversity – see chapter 4.1.

Out of the allocated area about 56% is assessed at the highest methodological level (A) and 44% at the next highest level (B). This gives the study an overall quality level of B and therefore the results are given with a two-digit accuracy.

Table 3 Biotope change

Category	Biotope change (ha)	Biotope change per kWh (m^2/kWh)
Critical biotope	-34 000	$-3,1*10^{-4}$
Rare biotope	-15 000	$-1,4*10^{-4}$
General biotope	30 000	$2,8*10^{-4}$
Technotope	18 000	$1,7*10^{-4}$

Environmental Risk Assessment

The risk assessment shows that, allocated over a long period of time, emissions of carbon dioxide, dust and carbon monoxide related to accidents and breakdowns are smaller than emissions occurring under normal conditions. The difference between the environmental risk assessment and the LCI for oil/diesel/petrol is not significant. Emissions of gasified copper and SF_6 are on the same order of magnitude in both assessments. However, the absolute volumes are small for these parameters. See chapter 4.3 for more information on risks.

Noise

The most notable noise outdoors is the sound from water running through above-ground power plants. The noise levels are however lower than before the construction of the hydro power plants.

1. Introduction

1.1. Functional Unit

This document constitutes the certified Environmental Product Declaration EPD® of electricity generated in Vattenfall AB's hydropower plants in the Nordic countries. Electricity belongs to the product category UNCPC Code 17, Group 171 – Electrical energy.

The functional unit is 1 kWh net of electricity generated and thereafter distributed to a customer connected to 70/130 kV

Some of the power plants are constructed for the provision of capacity as well as electricity enabling concurrence with the fluctuations in electricity consumption. Due to annual reservoirs, the delivery of electricity is more or less evenly distributed throughout the year, requiring no other forms of electricity generation.

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. EPD® is an international application of ISO 14025, Type III environmental declarations.

This Environmental Product Declaration is compliant with the International EPD® System, administered by EPD International AB (www.environdec.com): Box 210 60, SE-100 31 Stockholm, Sweden, e-mail: info@environdec.com.

Environmental Product Declarations within the same product category but from different programmes may not be comparable.

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

- Product Category Rules, CPC 171 Electrical Energy, version 4.11.
- General Programme Instructions (GPI) for an environmental product declaration, EPD®, version 3.01.
- ISO 14025 on Type III environmental declarations.
- ISO 14040 and ISO 14044 on Life Cycle Assessments (LCA).

This EPD® contains an environmental performance declaration based on a life cycle assessment (cradle-to-grave, in line with the PCR).

. Additional environmental information is presented in accordance with the PCR:

- Information on land use:
  - an assessment of impact on biodiversity based on The Biotope Method, (Kyläkorpi et al., 2005 and Grusell E., 2015),
  - a categorisation of land use according to Corine Land Cover Classes, land occupation time, periods and exploitative activities,
  - a description of visual impacts,
  - a qualitative description of potential impacts on indigenous people and their traditional activities.
- 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.

For information about verification, see chapter 6.

1.3. Vattenfall, LCA and EPD®

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

There are multiple reasons to declare the environmental performance of electricity, most significantly:

- Electricity is used in the manufacturing of virtually every product. Information regarding resource use in electricity production is central to relevant LCA for other products. This has generated an increased interest in the market for this type of information primarily because users need certified and modular life cycle data that are possible to sum up as inputs to their own EPD® and LCA.
- EPD® provides a basis for professional procurement, private as well as public sector, in permitting comparison of different power sources, heat production technologies, and different producers. This creates an incentive for producers to reduce their use of resources and the impact on the environment caused by their systems.
- EPD® is an effective instrument in the continuing environmental efforts within Vattenfall, the objective being continuous improvement.
- EU's electricity market directive requires member states to provide customers with information regarding the origin of the electricity and, at a minimum, figures on CO_2 and radioactive waste. The information given in an EPD® is of a high quality and exceeds the requirements in the Directive.
- The demand for Climate Declarations. The International EPD® system has issued climate declarations as the first example of single-issue EPD®s. It describes the emissions of greenhouse gases, expressed as CO2-equivalents for a product's life cycle, based on verified results from LCA in accordance with ISO 14067 and ISO 14025.

The environmental impact of hydropower differs considerably from that of other forms of electricity generation, as it often is direct and tangible. As an economic activity, hydropower generation can be described as a land use based activity, similar to agriculture or forestry. This differs considerably from e.g. generation using fossil fuels, where environmental impact is diffuse and thus more difficult to grasp.
For questions concerning this EPD®, please send an e-mail to epd@vattenfall.com. For additional information about Vattenfall, please visit our website at www.vattenfall.com.

2. Producer and product

2.1. Producer

2.1.1. BU Hydro Nordic
Business Unit (BU) Hydro Nordic is accountable for Vattenfall AB's Nordic generation of hydropower including generating plants, annual reservoirs, and short-term reservoirs. BU Hydro Nordic is part of Vattenfall AB, SE-162 87 Stockholm, Sweden. The technical and environmental aspects of hydropower are presented in appendix *Technology and Environment*.

2.1.2. Vattenfall AB, and Subsidiaries
Vattenfall AB is one of Europe's major retailers of electricity and heat and one of the largest producers of electricity and heat. Group sales amounted in 2019 to 166,4 billion SEK (approximately 16,0 billion EUR). Vattenfall's main markets are Denmark, Finland, Germany, the Netherlands, the UK and Sweden. The Parent Company, Vattenfall AB, is 100% owned by the Swedish state, and its headquarters are located in Solna, Sweden.

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

Vattenfall's ambition is to enable fossil free living within one generation and an important activity on this journey is to reduce environmental impacts throughout the entire value chain. Life cycle assessments and environmental product declarations are important tools in this work. The goal for the Vattenfall Group is to be climate-neutral by 2050, with a 40 % reduction of greenhouse gas emissions by 2030. The 2030 emission reduction targets were approved by the Science Based Targets initiative, SBTi, providing external validation that these are in line with climate science and the Paris agreement.

Vattenfall has five strategic focus areas.

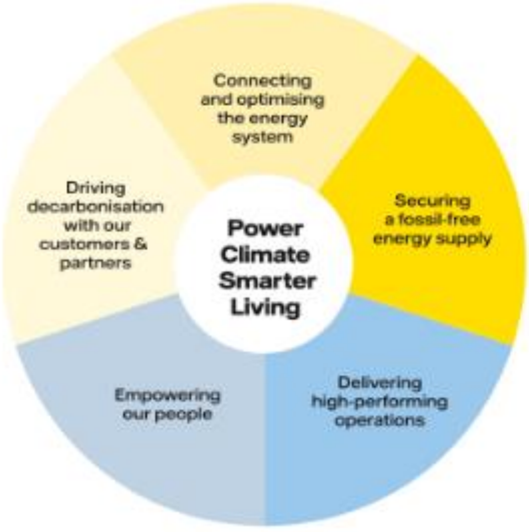

Figure 1 Vattenfall´s five strategic focus areas (source: Annual and Sustainability Report 2019).

Driving decarbonisation with our customers & partners with focus on increasing customer centricity and promoting electrification and climate smart energy solutions in areas where we have a competitive advantage. (Formerly: Leading towards sustainable consumption)
Connecting and optimising the energy system with focus on maximising the value of flexibility and promoting stable and cost-efficient grid infrastructure. (New)
Securing a fossil-free energy supply with focus on growing in renewables, maximising the value of our existing fossil-free assets, and implementing our CO_2 roadmap. (Formerly: Leading towards sustainable production)
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. (Formerly: High-performing operations)
Empowering our people with focus on securing necessary competence while improving the employee journey and providing a safe working environment. (Formerly: Empowered and engaged people)

In 2019 Vattenfall generated 129,3 TWh of electricity of which 30,2 TWh was fossil power, 53,4 TWh nuclear power, 35,8 TWh hydropower, 9,5 TWh wind power and 0,4 TWh biomass and waste. Furthermore, Vattenfall produced 15,5 TWh of heat and sold 59,2 TWh gas during 2019.

2.1.3. Environmental Management System

BU Hydro Nordic implements a certified environmental and occupational health and safety management system. This system is based on the standards ISO 14001:2015 and OHSAS 18001:2007 as well as the provision AFS 2001:1.

2.2. Product System Description

Vattenfall BU Hydro Nordic operates, develops and are responsible for 88 whole- or part owned hydro power plants. Most of them in Sweden but nine in Finland. The hydropower generation that BU Hydro Nordic disposes from wholly (or majority) owned plants during an average year is 31 TWh. Electricity belongs to the product category UNCPC Code 17, Group 171 – Electrical energy. The declared unit is 1 kWh electricity net generated and thereafter distributed to a customer connected to the Swedish regional grid (70/130 kV). No life-cycle stages have been omitted and the EPD is cradle-to-grave. For more information about Vattenfall, see www.vattenfall.com.

For this EPD 14 power plants have been selected to represent Vattenfall hydro power portfolio and the average environmental impact has been calculated by using production shares. See 2.2.1 and Table 5 below. Comprehensive descriptions of the stations are presented in appendix *Beskrivning av valda anläggningar* (only in Swedish).
The power plants are located in 8 rivers, one of which in Finland, and generate 31% of Vattenfall's total hydro electricity.

In 2000, the EU Water Framework Directive was adopted, aiming to create good water quality and access to water on a European basis. The Water Framework Directive is implemented in Swedish legislation through adjustments in the Environmental Code and, based on that, a National Plan for modern environmental conditions for hydro power. According to the plan, all Swedish hydro power stations and the watercourses they operate in will have their environmental conditions and permits tested systematically in the Land and Environment Courts. This is done to ensure that environmental improvements are made in those places where they are most cost efficient and best balanced in relation to maintaining the energy production. The first two of Vattenfall's smaller hydro power stations have already started on the reassessment process now.

2.2.1. Selected Power Plants

Sites selected for this EPD® are wholly (or majority) owned by Vattenfall AB and are representative of Vattenfall's Nordic hydropower plants with respect to geographic setting, physical geography, type of station, and size. The large-scale hydroelectric sites are arranged into river regions. Small-scale hydropower is assessed separately.
The governmental report "Vattendragsutredningen 1996 (SOU 1996:155)" divided Sweden into 13 so-called hydro geographical regions, five of which are in Northern Sweden and eight in Southern Sweden (south of river Dalälven). Region definitions are based on physical geography, climate, geology, topography, flora and fauna. Northern Sweden exhibits a rather homogenous north to south gradient making logical subdivision difficult. SOU 1996:155 attempted to arrive at subdivisions of equal size. This has been adhered to, but for practical reasons some subdivisions are combined, resulting in fewer regions, but nevertheless similar in size.

Table 4 River Regions

River regions in Sweden	Regions according to SOU 1996:155
Northern Norrland	1, 2
Middle Norrland	3, 4
Southern Norrland	5
Western Sweden	8

Vattenfall has no large-scale hydropower in the remaining regions described in SOU 1996:155.
It is reasonable to aggregate regions 1 and 2 because of considerable similarity of geology and topography. The flora also exhibits similarities, and both regions have several northerly species that are absent further south.
Regions 3 and 4 exhibit corresponding similarities. Region 5 must be treated separately because it constitutes the so-called "limes norrlandicus". This region is unique thanks to harbouring several northerly and southerly species, and it consists entirely of the river Dalälven.

Small-scale hydropower in Sweden represents less than 1% of Vattenfall's hydropower and is located in several watercourses, mainly south of river Dalälven. The capacity of the small-scale plants varies between 0,1-5,4 MW. One station is considered in this selection.
Vattenfall's hydropower in Finland is located in the Finnish Lake District in the central and eastern part of the country. Most of the electricity is generated in the eastern part. The capacity of the Finnish plants varies between 2-89 MW, and they are all considered large-scale according to the Finnish definition (small-scale <1 MW)[1].

Table 5 Selected Power plants

[1] According the Swedish definition (small-scale < 5 MW), 8 are small-scale and only one (Pamilo) is considered large-scale.

River region	Coverage[1]	Rivers	Selected power plants	Total average annual net generation, GWh	Vattenfall's share of average annual net generation, GWh
Northern Norrland	29%	Lule älv	Seitevare	787	787
			Harsprånget	2142	2142
			Porsi	1152	1152
			Boden	455	455
Middle Norrland	25%	Ume älv	Juktan	90	90
			Umluspen	430	430
			Stornorrfors	2354	1745
		Ångermanälven	Stalon	560	560
		Indalsälven	Bergeforsen	746	319
Southern Norrland	69%	Dalälven	Älvkarleby	510	490
Western Sweden	77%	Göta älv	Olidan	407	407
			Hojum	864	864
Eastern Finland	69%	Vuoksi	Pamilo	265	265
Small-scale hydropower	5%	Upperudsälven	Upperud	10	10
All river regions including small-scale power	**31%**			**10 772**	**9717**

1 The considered stations' share of Vattenfall's total generation in the river region.

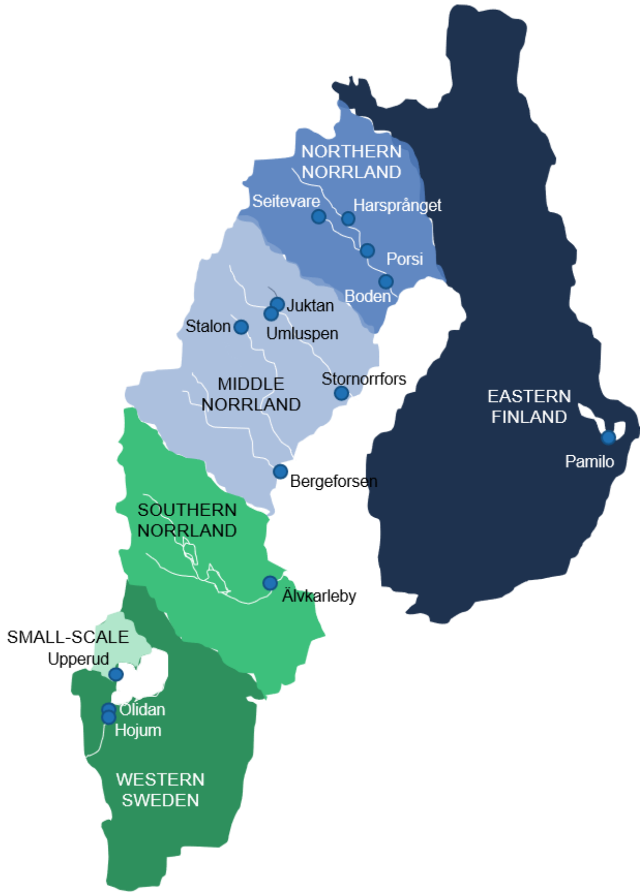

Figure 2 Selected hydropower plants in Sweden and Finland.

2.2.2. Inventory data

Numbers for average generation are based on historical values describing normal year annual average calculated from a 50-year period[2]. This EPD is hence representative for an average kWh generated from the construction of the power stations and 100 years forward. Operational data are based on averages for the years 2017-2019.

Main database for generic data is ecoinvent (ver 3.3 for infrastructure and ver 3.6 for operation). For product system description, see 3.2.1. Values for land use change stem from Swedish National Forest Inventory (SLU).

Sara Nilsson (Ramboll Sweden AB) has been in charge of the data inventory.

2.3. 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 majority, around 99%, of Vattenfall's hydro power production is situated in Sweden and therefore only the Swedish distribution system is considered in the EPD®.

The national grid voltage (220-400 kV) is stepped down to lower voltages (regional network 20-130 kV) for distribution over distribution networks (10-130 kV) and low voltage local networks (0,4-20 kV) to consumers. Large customers, e.g. certain industries, are frequently connected to the high or medium voltage distribution network (10-130 kV), while small users such as single households are connected at 0,4 kV 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 is, the lower are the losses. The diagram below shows the average distribution losses. To an industrial customer connected to the regional network the average distribution loss is 4% whereas the loss to a household customer in the countryside is about 8%.
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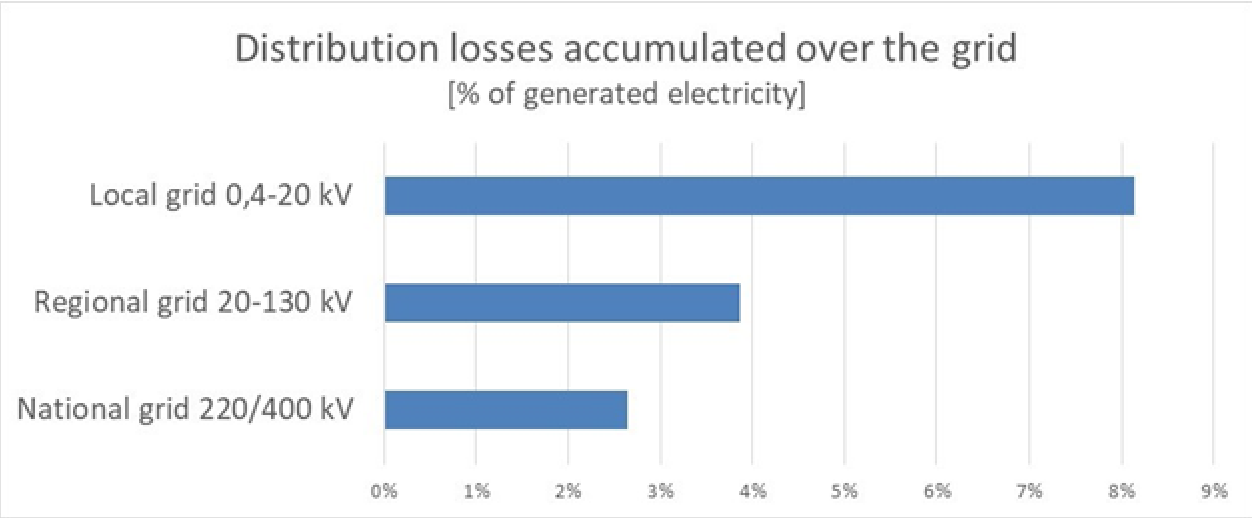


Figure 3 Distribution losses to customers at various voltage levels accumulated from the grid - percent of electricity generated. Source: Vattenfall; Svenska Kraftnät (2019)

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. This means that the impacts of losses arise in an electricity generation plant and in this study the losses are supposed to be compensated for

[2] Using historical values for energy production is considered to be conservative as increased precipitation is expected to lead to larger volumes of water in the future.

through additional generation in the hydropower plants. In chapter 3 the result for delivery to a customer is reported average distribution loss of 4% of generated electricity.

Figure 4 Distribution lines at Porjus power plant, Sweden (photo: Jennie Pettersson)

2.3.1. Environmental Impact in Conjunction with Electricity Distribution

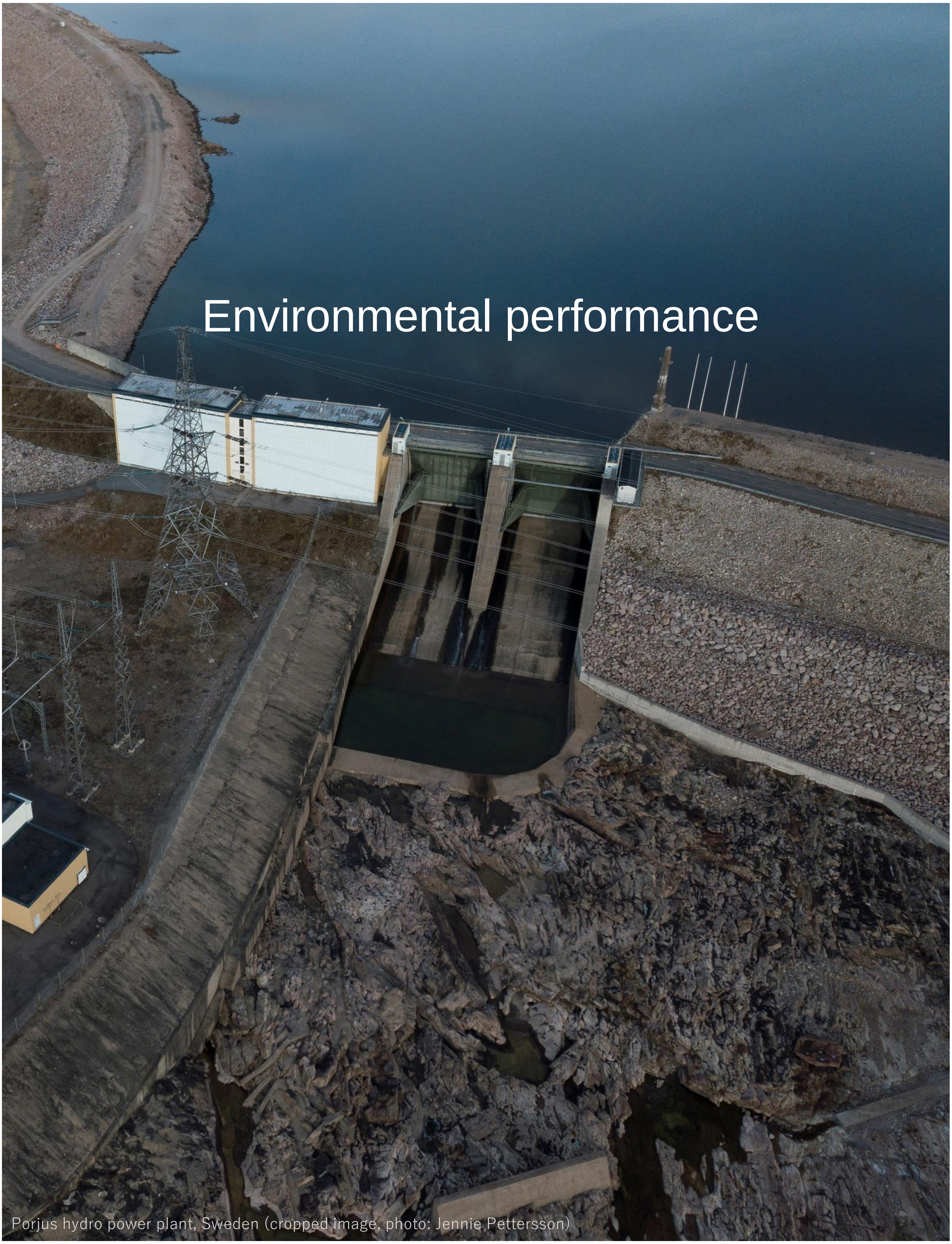
Construction, operation and dismantling of power lines have environmental impact, predominantly in the construction stage. Production of metals, concrete, and insulation material generate emissions for example via the consumption of electricity and fuel.
Additional environmental impact stems from salt impregnated- and creosote impregnated power poles as well as cables that can cause small emissions of heavy metals. As an example, salt impregnated poles can emit arsenic, and galvanized steel emits zinc and cadmium. However, no new creosote impregnated poles are set up today. Older cables can emit some lead. The mentioned emissions are, however, quite local.

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

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-Ionizing Radiation Protection (ICNIRP), an independent body consisting of international experts has however published recommendations[3] regarding acute health problems. The recommendations are based on knowledge about acute health problems due to changing magnetic fields and propose a limit of 1 000 µT for working environment and for the general public a limit of 200 µT at 50 Hz. The EU Council of Ministers recommends a restriction of exposure to electromagnetic fields in accordance with the ICNIRP's recommendations.

According to ICNIRP available research results on lesions due to long-range exposure, for example raised risk of cancer, do not suffice to establish limits. Vattenfall follows ICNIRP's, WHO's and OECD's work and recommendations in the area. The principle at Vattenfall is to follow the precautionary principle, which implies reducing fields that deviate considerably from normality in each specific case.
Power lines above 70 kV can generate corona noise levels of 45 dB(A) at 25 meters, however abating as distance increases.

3 ICNIRP 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.



Porjus hydro power plant, Sweden (cropped image, photo: Jennie Pettersson)

3. Environmental Performance Based on LCA

3.1. Life Cycle Assessment Method

This EPD® for electricity from Vattenfall's hydropower plants is based on a comprehensive LCA. The declared unit is 1 kWh net of electricity generated and thereafter distributed to an industrial customer connected to the regional network (20/130 kV).
The used net electricity generation is calculated as the net annual average electricity generation. The assessment comprises operation of all facilities in the life cycle as well as construction of the hydropower plants. The distribution of electricity has been included in terms of distribution losses as well as construction, operation phase and dismantling.

3.2. System Boundaries, Allocation and Data Sources

3.2.1. System Boundaries

The figure below is a simplified process tree with system boundaries for the LCA for electricity generated in Vattenfall's Nordic hydropower plants and distributed to the consumer.

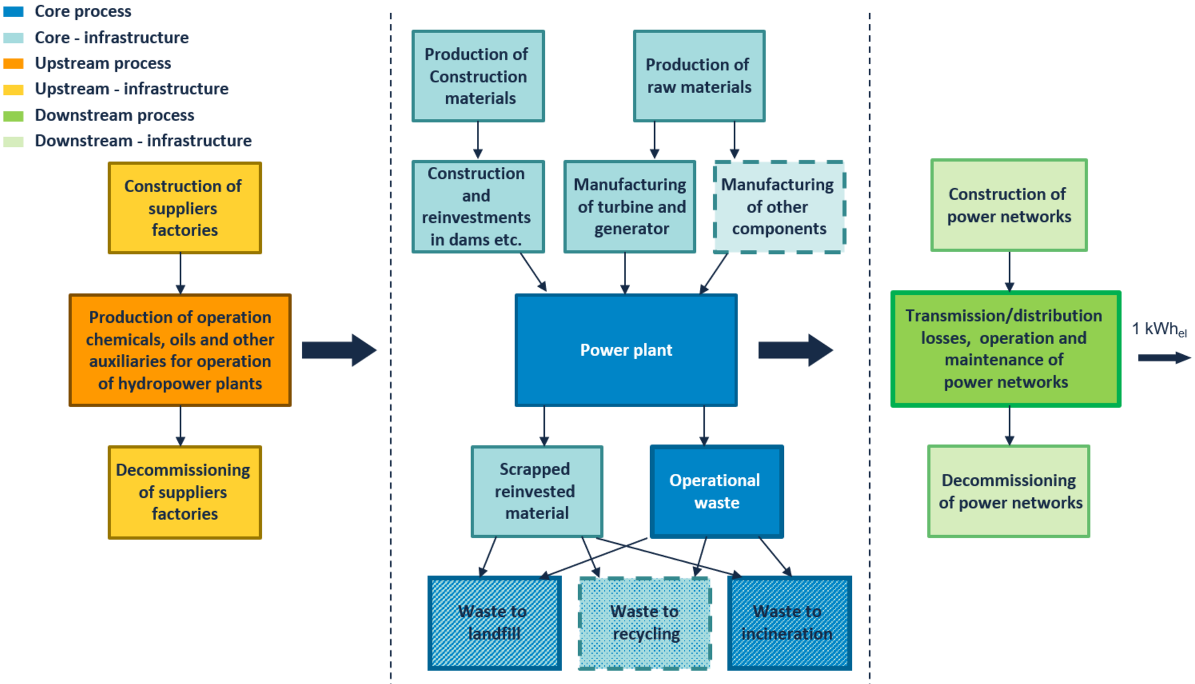


Figure 5 Simplified process tree with system boundaries for life cycle inventory of Vattenfall's hydropower. Boxes with dotted lines are not included. Thick black arrows indicate the lifecycle main flow. Necessary transports are included. Conventional waste is handled according to the Polluter-Pays principle within each process step.

Emissions are aggregated in five life cycle stages, described below.

Table 6 Life cycle stages and processes included

Upstream	Core	Core - infrastructure	Downstream	Downstream - Infrastructure
Production and transport of oils, chemicals and fuels for operation of the hydropower plants, vehicles and reserve	Emissions from inspection trips and reserve power, emissions of oils to water and ground, incineration and	Construction and reinvestments in machinery: Production of steel, copper, plastics, oil etc for turbines, generators, cables, electronic equipment etc, processes for manufacturing of advanced components such as generators and turbines. Specific reinvestment rates are defined for turbines,	Operation of electricity networks, i.e. emissions from inspection trips, production and emissions of oils.	Construction and decommiss-ioning of the transmission grid and regional network,

power, including construction of suppliers' factories.	deposition of operational wastes.	generators, transformers and electrical equipment. Batteries are exchanged every 15 years. Construction and reinvestments in power houses, dams, and waterways: Blasting, handling of masses, production of concrete and reinforcement, incineration of used mould wood etc. 20% of the material in the original dams is added during the lifetime and 50% of concrete and steel in dams and waterways is exchanged. Emissions from inundated land in water reservoirs and deforestation before the land was flooded.	Generation in Vattenfall's Nordic hydropower plants to compensate for losses in the electricity distribution system, 4% of generated electricity	manufacturing of materials, ground work and handling of waste material incl. transportation.

- For the columns *upstream*, *core*, *core– infrastructure*, and *total generated* the numbers are expressed per 1 kWh generated electricity.
- For the columns *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 loss: 4% of generated electricity).

More comprehensive inventory results have been available to the Certifier. Distribution losses for customers connected to more local distribution networks are presented in section 2.3.

3.2.2. Technical service life time and reference flow

The technical service life of the hydropower plants influences the environmental impacts from infrastructure (construction and dismantling). Based on the assumption that power stations and dams are replaced once during their lifetime the following technical lifetime has been used: 60 years for machinery and 100 years for dams, power houses and waterways.

Table 7 Technical service life time and reference flow (Technical service life for hydropower plants is given both for dam / machinery)

Process module	Plant/Facility	Technical service life time (years)	Reference flow, TWh		
			Operation (1 year)	Dam etc (100 years)	Machinery (60 years
Core module	Seitevare	100 / 60	0,787	78,7	47,2
	Harsprånget	100 / 60	2,142	214,2	128,5
	Porsi	100 / 60	1,152	115,2	69,1
	Boden	100 / 60	0,455	45,5	27,3
	Juktan	100 / 60	0,09	9,0	5,4
	Umluspen	100 / 60	0,43	43,0	25,8
	Stornorrfors	100 / 60	2,354	235,4	141,2
	Stalon	100 / 60	0,56	56,0	33,6
	Bergeforsen	100 / 60	0,746	74,6	44,8
	Älvkarleby	100 / 60	0,51	51,0	30,6
	Olidan	100 / 60	0,407	40,7	24,4
	Hojum	100 / 60	0,864	86,4	51,8
	Pamilo	100 / 60	0,265	26,5	15,9
	Upperud	100 / 60	0,0103	1,0	0,6
Downstream module	Grid	Technical service life time (years)	Operation (1 year)	Infrastructure (40/50 years)	
	National grid (transmission)	40	118,5	4 740	
	Regional grid (distribution)	50	73	3 650	

In addition to the technical service lifetime, the specific reinvestment rates of the various materials and components are included in the assessment. The addition of these reinvestment rates is to secure that a functional plant is the output of the life cycle after 100 years of use. This is a deviation from the PCR where it is stated that the estimated technical service life is the time after which 100% of upgrading and reinvestments has taken place to ensure that a functional plant is the output of the life cycle if dismantling is not probable. To avoid the complexity related to that different components have different technical service lifetimes the approach of including reinvestment rates was chosen to obtain the same objective to have a functional plant as the output of the life cycle.

3.2.3. Allocation Principles

The main function of studied systems is the generation of electricity, but they also serve as components in the control of the Swedish generation system. In addition, water levels are controlled e.g. in order to prevent floods. The river systems are also used for fishing and recreational purposes. Despite the additional uses all environmental impact is allocated to electricity generation.
The results for generation (upstream module, core module) of Vattenfall's electricity from Nordic hydropower have been compiled as follows:

- Environmental impact is calculated for each selected individual station, and divided by its total generation
- Environmental impact from selected individual stations is weighted according to Vattenfall's share of electricity generated in the river.
- Environmental impacts from rivers (emissions related to inundated land and deforestation[4] in flooded area) are aggregated into river regions and weighted according to electricity generated.
- River regions and small-scale power are aggregated and weighted according to electricity generated.

The results for distribution (downstream module) of generated electricity have been compiled as follows:

- Environmental impact from operation of electricity networks has been inventoried and divided by the total amount of electricity distributed in that specific network.
- The length (km) of different distribution networks has been inventoried and multiplied by the environmental impact for construction per km (incl. impact from deforestation[4]) and divided by the total amount of electricity distributed in the specific network.
- Environmental impact from distribution losses of 4% has been calculated through multiplication of total environmental impact of generation with 0,04.

Excluded from the life cycle:

- Impacts due to potential accidents, breakdowns, and leakages (included in Additional Environmental Information, chapter 4.3 Environmental Risk Assessment).
- Further treatment of scrapped material that has been transported to recycling plant (according to PCR 171 ver 4.11).
- Impacts of land use and land use change apart from emissions from inundated land and deforestation (included in Additional Environmental Information, chapter 4.2 Land and Water Use).

[4] A share of the impacts from deforestation are allocated to long-lived wood products. See section 3.2.4.

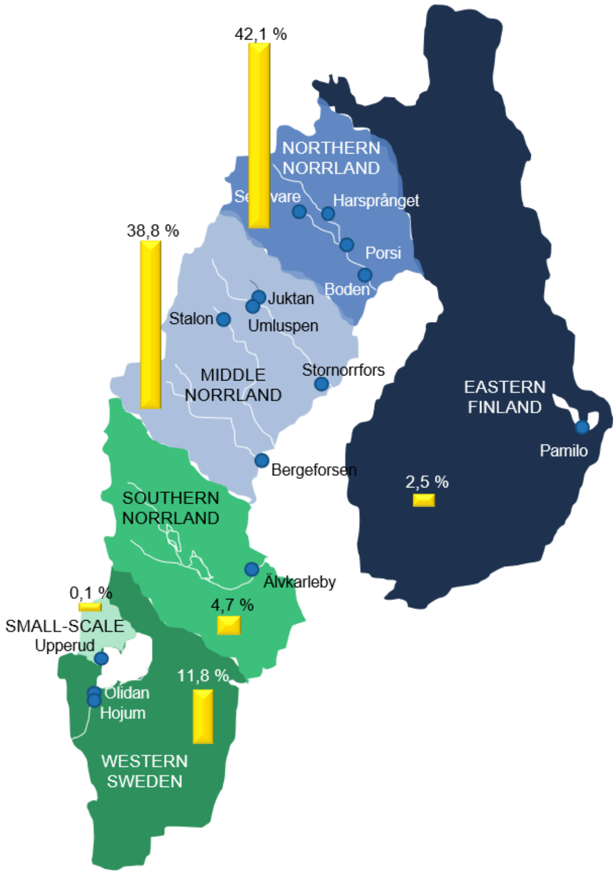


Figure 6 The contribution of the selected sites to the Ecoprofile (see also table in chapter 2.2).

3.2.4. Specific methodological choices

Environmental impacts have been calculated in accordance with the methodology described in the PCR for electricity (ver 4.11).

For emissions from inundation of land, the PCR provides two optional methodological approaches; here alternative 2 (simplified method using carbon content values) has been used, together with default values for methane emissions and carbon degradation but with specific data for carbon content in soil.

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.

Not all emissions related to the clearance of the forest is allocated to the hydropower. Since parts of the harvested trees were used as material for long-lived products, a share (13%) of the impacts of deforestation is allocated to other product systems. Historical data from the Swedish Forest Agency (Skogsstyrelsen) for end use of harvested biomass has been used to determine the allocation to long-lived wood products.

3.2.5. Completeness and the 1% Rule

Core and upstream module

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

The assessment contains data gaps because some substances are not tracked from the cradle. The majority of substances not tracked from the cradle are chemicals, alloy metals or minerals used in subcontractors' processes. Emissions from production of chemicals and minerals that are included have lesser impact per weight unit than emissions from production of concrete and steel. Consequently, the excluded production processes would not significantly influence the outcome if included. All resource flows from nature in included processes (excluding gravel, sand, soil, water, and energy resources) aggregate to approximately 0,9 g material per kWh. The sum of all flows not tracked from the cradle is <0,01 g (~0, 0000005 g) per kWh, which is <1% of the resources used from nature.

Production of raw material and manufacturing of machinery components are included. For turbines and generators, the production of raw material ending up as metal chips and cuttings is included as well as the resource use and the emissions from the different working processes.
In wintertime, closed dam gates must be sealed or heated in order to prevent icing. Bark mixed with various types of silt and soil, sometimes with the addition of rags or strips of plastic are used as sealant. The sealant is not included due to the small volumes involved (approximately one cubic meter per turbine per year).
All known waste flows that have not been followed to the grave, are reported in section 3.5. The environmental burden related to waste incineration with energy recovery have been allocated between the waste generator and the user of the energy, which is in line with the GPI. 50% of the impacts of the waste incineration is attributed to waste treatment and 50% to the energy recovery; no crediting has been performed.
The conclusion is that the known exclusions in the production stage (upstream and core processes) contribute less than 1% to reported emission categories.

Downstream module
In the distribution stage (downstream processes) construction, operation and dismantling of the power network is included as well as the distribution losses in terms of the extra generation necessary as compensation. Selected generic data is used to model the construction and dismantling of the national grid. 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.
Operational data for the national grid are taken from Svenska Kraftnät (2019) and include inspection trips, consumption of oil and SF_6, including waste management. Operational data for the regional grid are taken from Vattenfall Eldistribution (2019) and includes fuels and emission from machines used in maintenance and operation, including clearing of power lanes, from transportation during maintenance and inspections, as well as consumption of oils including waste management.
For included processes (excluding gravel, sand, soil, water, and energy resources) all resource flows from nature aggregate to approximately 1,2 g/kWh electricity. The sum of all identified flows not tracked from the cradle (from compensation of losses) is approximately 0,0003 g/kWh, which is less than 1% of aggregated resource flows from nature.
The conclusion is that the known exclusions in the distribution stage (downstream processes) contribute less than 1% to reported emission categories.

3.2.6. Data Quality and the 10% Rule
In the Ecoprofile the result is given with three value digits. It should be noted that data quality does not always motivate three significant digits.

According to the EPD® system General Programme Instructions (ver 3.01) specific data shall always be used if available. If specific data is lacking generic data may be used. There are two types of generic data, selected generic data and proxy data. Selected generic data are data from commonly available data sources that fulfil prescribed data quality characteristics of selected generic data. Proxy data are data from commonly available data sources that do not fulfil all of the data quality characteristics of selected generic data.
The 10%-rule is met in all life cycle stages and is hence also met for the entire life cycle.

Upstream module
The impact from upstream process has been calculated based on selected generic data for production of chemicals, fuels and transports.
Core module
Data for core processes are specific as specified in the PCR. *Specific data* has been used with respect to construction material amounts, excavated amounts etc. Data for production of construction materials, machine operation, waste treatment, and generation of the electricity supplying the subcontractors are *selected generic data*.
Downstream module

Specific data has been used regarding operation of the network, electricity transfer and regarding losses. *Selected generic data* has been used for construction and demolition of the national grid, while *specific* and s*elected generic data* has been used to model the regional grid. Occurrence of *proxy data* in the regional grid infrastructure is assessed to fall well below the 10% rule.

3.2.7. Characterization

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

- CML2001 - Jan. 2016, Acidification Potential (AP)
- 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 Midpoint (H) - Photochemical oxidant formation
- ReCiPe 2016 v1.1 Midpoint (H) - Fine Particulate Matter Formation
- AWARE, 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 characterization method (OECD+BRIC) for unspecified water was selected based on the geographical scope of the study. Furthermore, the selected indicator considers the same water flows and is consistent with the methodology of the other water use indicator, use of net fresh water, which is a reported resource use indicator.

3.3. Environmental impacts

Table 8 Environmental impacts

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)	7,45*10^{-3}	3,83*10^{-2}	1,36	**1,40**	1,40*10^{-1}	1,44	**2,99**
	Biogenic	g CO_2-eq. (100years)	4,04*10^{-5}	1,91*10^{-3}	2,34*10^{-2}	**2,54*10^{-2}**	1,02*10^{-3}	0,00	**2,64*10^{-2}**
	Luluc (inundation)	g CO_2-eq. (100years)	0,00	0,00	7,98*10^{-1}	**7,98*10^{-1}**	3,19*10^{-2}	0,00	**8,30*10^{-1}**
	Luluc (deforestation)	g CO_2-eq. (100years)	0,00	0,00	2,11	**2,11**	8,42*10^{-2}	1,22	**3,41**
	Total	g CO_2-eq. (100years)	7,49*10^{-3}	4,02*10^{-2}	4,29	**4,33**	2,57*10^{-1}	2,66	**7,26**
Acidification potential (AP)		g SO_2-eq.	6,59*10^{-5}	5,42*10^{-5}	5,15*10^{-3}	**5,27*10^{-3}**	3,74*10^{-4}	7,84*10^{-3}	**1,35*10^{-2}**
Eutrophication potential (EP)[2]		g PO_4^{3-}-eq.	1,83*10^{-5}	1,59*10^{-5}	1,50*10^{-2}	**1,50*10^{-2}**	6,41*10^{-4}	3,51*10^{-3}	**1,92*10^{-2}**
Photochemical oxidant formation potential (POFP)		g NMVOC-eq.	4,82*10^{-5}	1,23*10^{-4}	4,52*10^{-3}	**4,69*10^{-3}**	6,66*10^{-4}	6,90*10^{-3}	**1,23*10^{-2}**
Particulate matter		g PM2.5-eq.	1,80*10^{-5}	1,94*10^{-5}	1,91*10^{-3}	**1,94*10^{-3}**	1,35*10^{-4}	3,12*10^{-3}	**5,20*10^{-3}**
Abiotic depletion potential - Elements		g Sb-eq.	4,98*10^{-8}	3,20*10^{-9}	1,09*10^{-5}	**1,09*10^{-5}**	4,61*10^{-7}	2,38*10^{-5}	**3,51*10^{-5}**
Abiotic depletion potential - Fossil fuels		MJ, net cal. Value	5,89*10^{-4}	5,65*10^{-6}	1,43*10^{-2}	**1,49*10^{-2}**	1,23*10^{-3}	1,85*10^{-2}	**3,46*10^{-2}**

Water scarcity footprint	**m^3 H_2O-eq.**	$3{,}17*10^{-7}$	$1{,}76*10^{-7}$	$5{,}48*10^{-4}$	**$5{,}48*10^{-4}$**	$2{,}28*10^{-5}$	$3{,}12*10^{-4}$	**$8{,}83*10^{-4}$**

1 Distribution losses of 4% of generated electricity are included in the downstream column. Losses are calculated by multiplying the value in the Total generated column by 0,04. To obtain results without losses, simply multiply the value in Total generated column with 0,04 and subtract the resulting value from the downstream column.
2 Over 69% emanates from COD and inundation of land; this is calculated in accordance with the methodology described in the PCR

3.3.1. Global Warming Potential (GWP)

Carbon dioxide from land use and land use change (luluc) is dominating the contribution to GWP, contributing 58% (47% from to deforestation and 11% from to inundation) to the total GWP of hydropower. The contributions from the life cycle modules, visualised in Figure 7 below, are further described in the following section.

Core process: About 0,6% of the total emissions, emanating mainly from incineration of operational waste and combustion of fossil fuels in service vehicles.

Core – infrastructure contributes approximately 59% of total greenhouse gas emissions. Deforestation is the main contributor to emissions from *core – infrastructure*, contributing 49%. Inundated land is also a significant contributor at 19%. The remaining 32% is driven by production and waste treatment of materials going into the infrastructure.
GWP from inundation is a result of damming, which causes inundated land to release organic matter that is decomposed to CO_2 when subjected to oxygen in the water. Because the reservoirs are deep and the climate cool, no methane is formed. The net effect, i.e. emissions due to decomposing of organic matter is calculated and reported for the lifetime of 100 years (for reservoirs) and distributed over electricity generation in the same amount of time.
GWP from deforestation is a result of removal of the forest before the damming, i.e. land transformation from high carbon stock land (forest) to lower carbon stock land. These are calculated and reported for the lifetime of 100 years (for reservoirs) and distributed over electricity generation in the same amount of time.

Downstream process contributes around 1,2%, caused mainly by inspection trips.

Downstream – infrastructure contribute approximately 37% of total greenhouse gas emissions. The emissions from land use change contribute 46% to emissions from *downstream – infrastructure*, corresponding to 17% to the total GWP of hydropower. 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. This is calculated and reported for the lifetime of 100 years and distributed over electricity distribution in the same amount of time.

Downstream distribution losses contribute 2,4%.

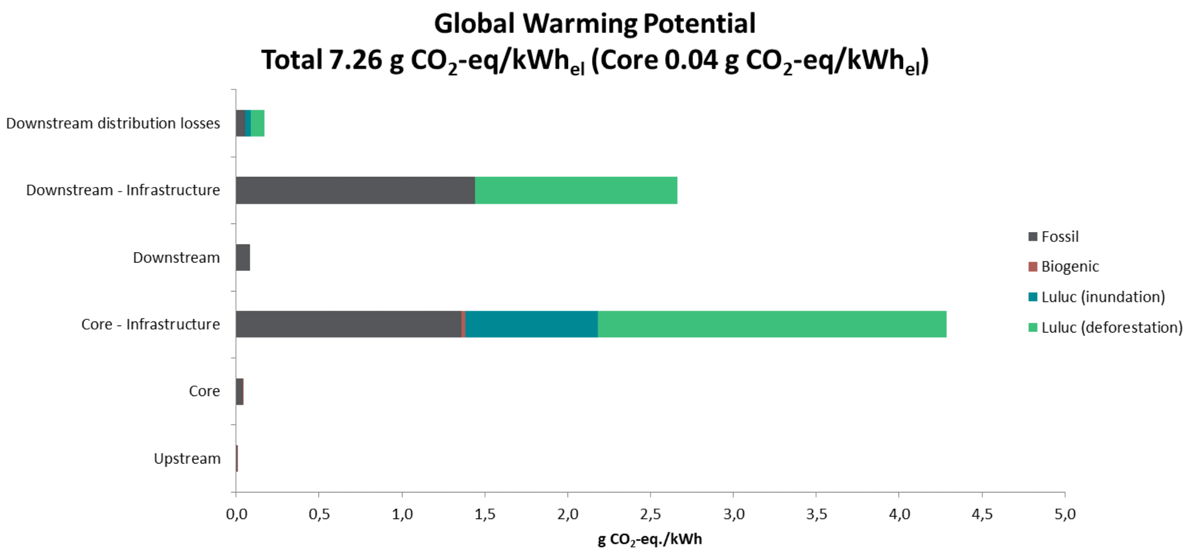


Figure 7 Potential emissions of greenhouse gases

3.3.2. Acidification Potential (AP)

Emissions of NO_X and SO_2 are the main contributors to acidification. Emissions occur mainly from downstream and core infrastructure, during construction of power stations, dams, distribution networks and reinvestment of machinery, as shown in Figure 8.

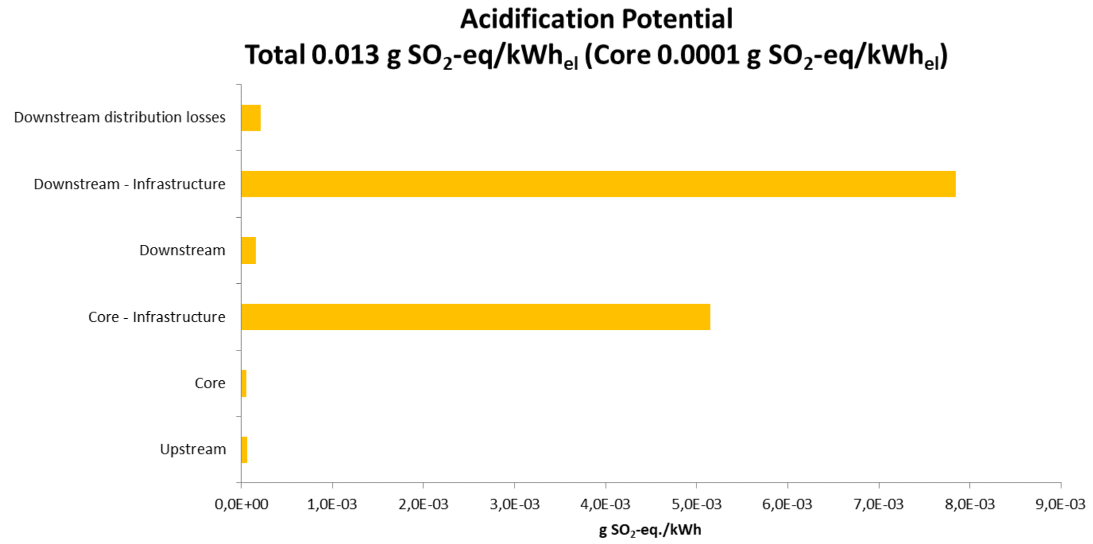


Figure 8 Potential emissions of acidifying substances

3.3.3. Eutrophication Potential (EP)

Oxygen consuming and nutrifying substances (cause of eutrophication) are primarily formed in conjunction with inundation, as the carbon released from the inundated soils react with the oxygen in the water. Inundation also leads to the release of nutrients. Phosphorous and nitrogen are nutrients that influence the production of plant life both on land and in water. In freshwater, phosphorous is the substance that limits production, while nitrogen is the limiting substance in the sea. Regulation causes an increase in the sedimentation of phosphorous, thus making it inaccessible to the flora and fauna. Retention exceeds release, i.e. regulated rivers contain less phosphorous than natural rivers, and this negative emission of phosphorous has been included in the calculations.
The main contribution of the COD is coming from the inundated land (69% of total), as shown in Figure 9. Other contributions come from NO_X emissions related to manufacturing of materials and to transportation.

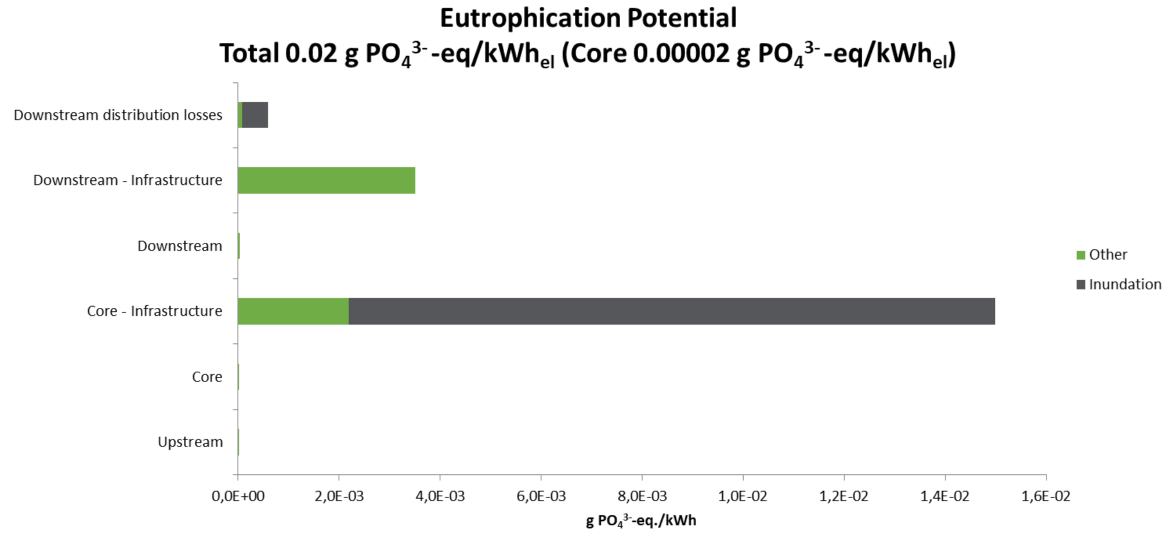


Figure 9 Potential emissions of substances contributing to eutrophication. The grey portion of the core - infrastructure illustrates the emissions due to inundation of land.

3.3.4. Photochemical Oxidant Formation Potential (POFP)

In the presence of nitrogen oxides and sunlight various types of hydrocarbons in the air may give rise to photochemical oxidants, primarily ozone. The main contribution is related to the construction of power networks, approximately 56%, as shown in Figure 10. Other large contributions are related to the core - infrastructure, approximately 37%, where the production of steel dominates.

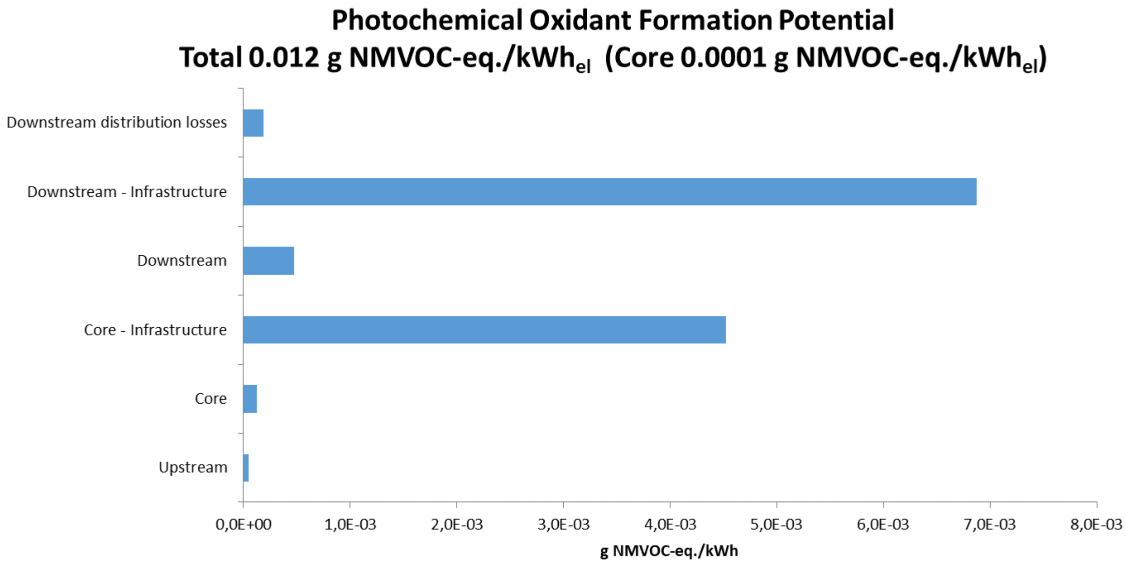


Figure 10 Potential emissions of substances contributing to ground-level ozone

3.3.5. Formation of fine particulate matter

Fine particulate matter can be harmful to human health. Emissions of particulate matter emanate mainly from production of metals (mining) and digging (as during construction of distribution systems) but also from combustion of fuels. Emissions occur mainly from downstream and core infrastructure, as shown in Figure 11.
Dust emissions whirling around in the air during construction of hydropower facilities, waterways, and dams have not been considered.

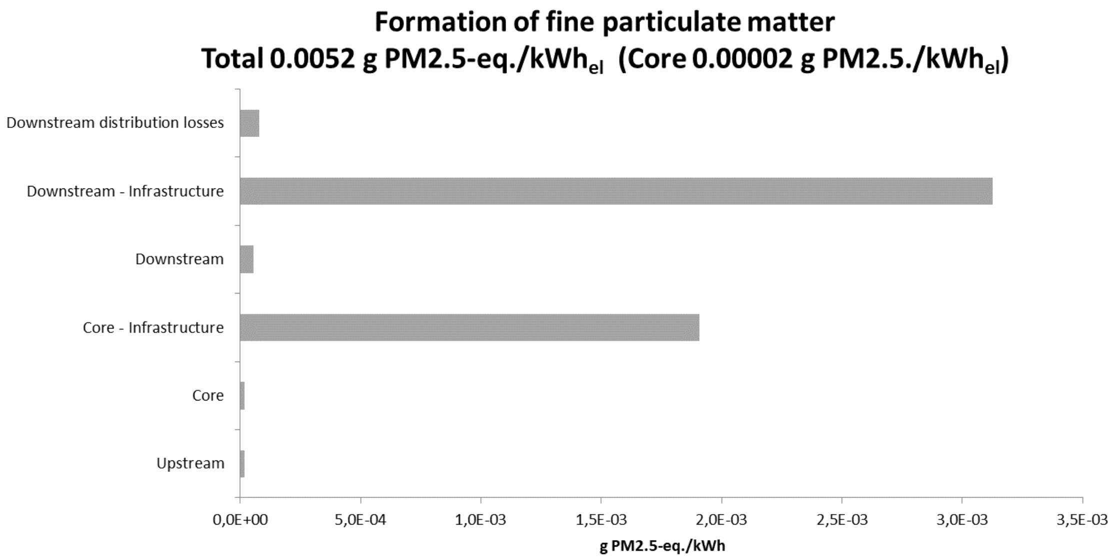


Figure 11 Potential formation of fine particulate matter

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

Abiotic depletion refers to the depletion of non-living (abiotic) natural resources (including energy resources).

Abiotic depletion potential (elements) is a measurement of the non-renewable abiotic depletion of elements, as metals, minerals etc. The impact category takes into account 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. The impact category takes into account the size of the reserves and rate of extraction, so a fossil fuel that is rare is rated higher.

The main contribution to both these indicators is related to the construction of power networks, approximately 68% (elements) and 53% (fossil fuels), as shown in Figure 12 and Figure 13. Other large contributions are related to the core - infrastructure, approximately 31% (elements) and 41% (fossil fuels), where the production of steel dominates.

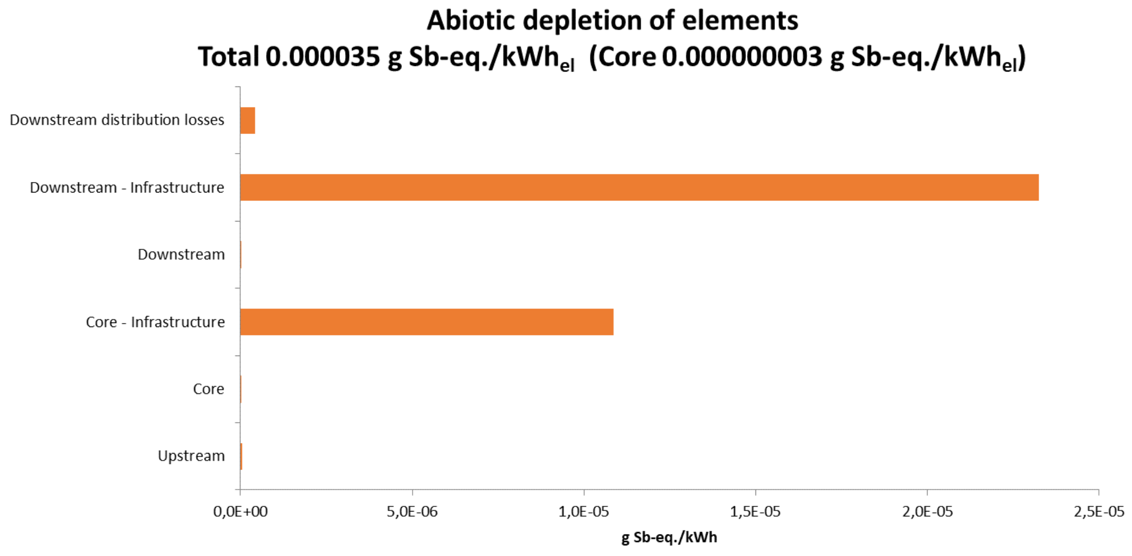


Figure 12 Potential abiotic depletion of elements

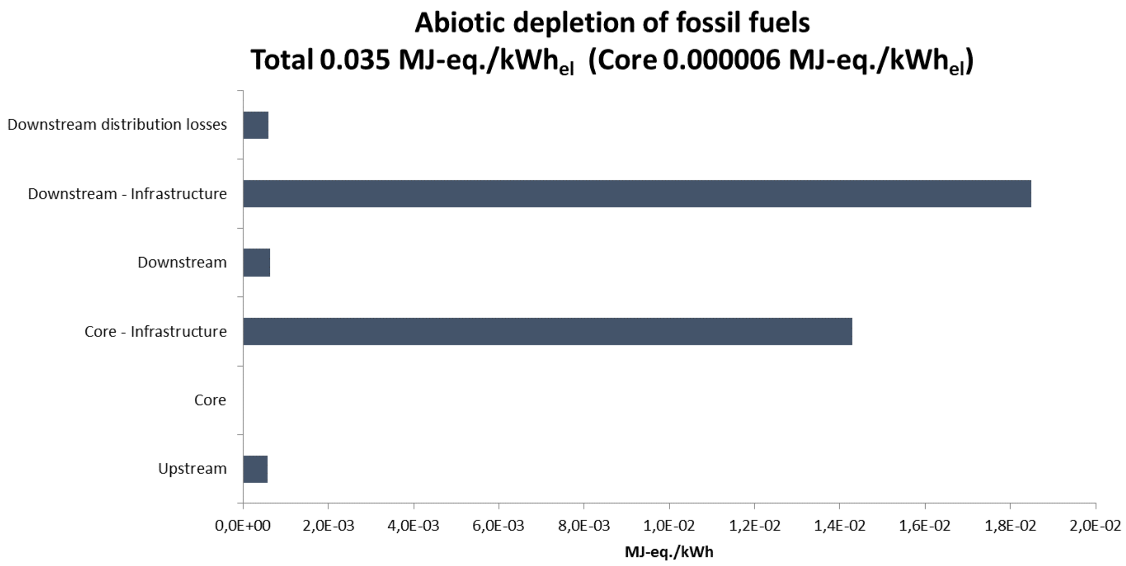


Figure 13 Potential abiotic depletion of fossil fuels

3.3.7. Water scarcity footprint

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.

The main contribution to water scarcity is related to the construction of power stations (core - infrastructure), approximately 62%, as shown in Figure 14. Other large contributions are related to the construction of power grids (downstream – infrastructure), approximately 35%. Water is mainly used in supplier's processes. The impact is mainly driven by unspecified water flows in the production of gravel, concrete and steel.

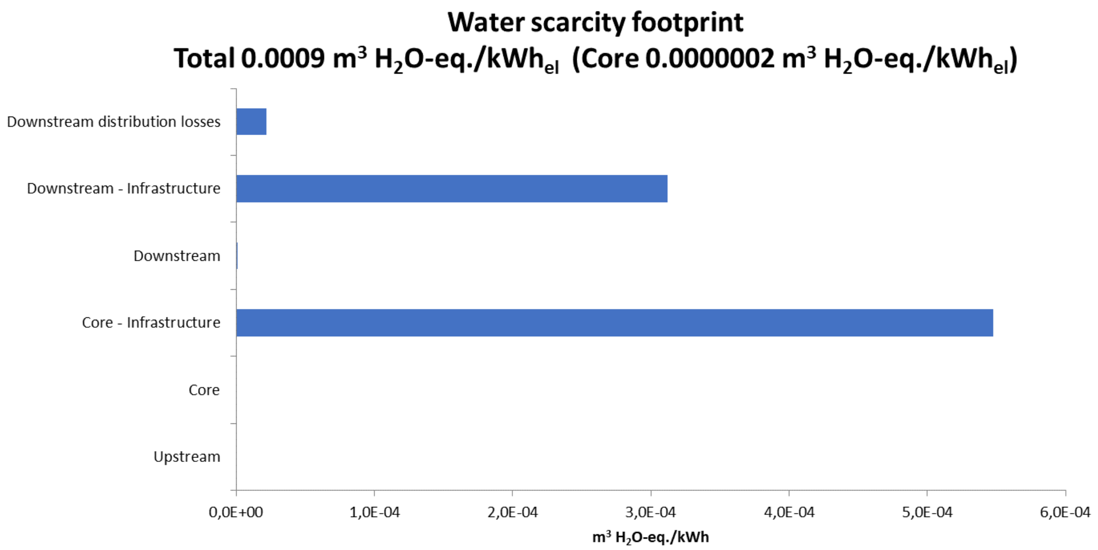


Figure 14 Potential water scarcity footprint

3.3.8. Dominance Analysis and Conclusions

Contributions to the studied emission categories distribute between the life cycle stages as follows.

Table 9 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)	Fossil	g CO_2-eq. (100years)	0,2%	1,3%	45,5%	2,8%	48,3%	1,9%	**100%**
	Biogenic	g CO_2-eq. (100years)	0,2%	7,2%	88,8%	0,0%	0,0%	3,8%	**100%**
	Luluc (inundation)	g CO_2-eq. (100years)	0,0%	0,0%	96,2%	0,0%	0,0%	3,8%	**100%**
	Luluc (deforestation)	g CO_2-eq. (100years)	0,0%	0,0%	61,7%	0,0%	35,8%	2,5%	**100%**
	Total	g CO_2-eq. (100years)	0,1%	0,6%	59,1%[1]	1,2%	36,7%[2]	2,4%	**100%**
Acidification potential (AP)		g SO_2-eq.	0,5%	0,4%	38,2%	1,2%	58,2%	1,6%	**100%**
Eutrophication potential (EP)		g PO_4^{3-}-eq.	0,1%	0,1%	78,2%[3]	0,2%	18,3%	3,1%	**100%**
Photochemical oxidant formation potential (POFP)		g NMVOC-eq.	0,4%	1,0%	36,9%	3,9%	56,3%	1,5%	**100%**
Particulate matter		g PM2.5-eq.	0,3%	0,4%	36,7%	1,1%	60,0%	1,5%	**100%**
Abiotic depletion potential - Elements		g Sb-eq.	0,1%	0,0%	30,9%	0,1%	67,6%	1,2%	**100%**
Abiotic depletion potential - Fossil fuels		MJ, net cal. Value	1,7%	0,0%	41,3%	1,8%	53,4%	1,7%	**100%**
Water scarcity footprint		m^3 H_2O-eq.	0,0%	0,0%	62,1%	0,1%	35,3%	2,5%	**100%**

1 58% of these emissions emanate from inundation and deforestation
2 46% of these emissions emanate from deforestation
3 >85% of these emissions emanate from inundation

Deforestation, as a result of the construction of water reservoirs (dams) and/or power distribution network infrastructure, is a key contributor to the emissions of greenhouse gases. Inundation in reservoirs is also a significant contributor to greenhouse gas emissions and a dominant driver with regards to emissions of eutrophying substances. If the facilities were to be used beyond the assumed 100 years, the emission per generated kWh would decrease since there would be the same amount of carbon in inundated land but a larger amount of kWh generated.

Small-scale hydropower plants are generally so-called run-of-river stations, i.e. they have no reservoir. Small-scale hydropower is mainly located south of the river Dalälven in watercourses that have streaming water all year round, i.e. a reservoir is not required to maintain relatively constant generation. One of the selected power plants, Upperud, is a small-scale power plant. The absence of reservoirs means that no emissions from inundated land nor deforestation occur. The net effect is considerably lower emissions of greenhouse gases and eutrophying substances than for a station with a reservoir. Environmental impact per kWh due to construction, reinvestment, and operation is consistently higher from the selected small-scale hydropower plant than from average large-scale hydropower plants. Investment cost per MW and environmental impact from construction and operation go hand-in-hand.

3.4. Resource Use

The LCA results regarding use of resources are summarized in the Table 10. Resources are divided in renewable and non-renewable primary energy resources, use of secondary materials, fuels along with net use of freshwater.
Primary energy resources classified as raw material are wood, plastics, lubricating oil and paper in components the power station and grid infrastructure.
Secondary materials are found in metal (aluminium, steel and copper) parts, which contain shares of recycled scrap.

Table 10 Resource use

Resources		Unit/kWh	Upstream	Core	Core - infra.	Total - generated	Down-stream[1]	Downstream - infra.	Total - distributed
Primary energy resources - Renewable	Use as energy carrier	MJ, net cal. value	1,68*10^{-6}	4,10	2,33*10^{-3}	**4,11**	1,17*10^{-4}	1,34*10^{-3}	**4,11**
	Use as raw material	MJ, net cal. value	0,00	0,00	4,17*10^{-3}	**4,17*10^{-3}**	1,67*10^{-4}	0,00	**4,33*10^{-3}**
	Total	MJ, net cal. value	1,68*10^{-6}	4,10	6,50*10^{-3}	**4,11**	2,83*10^{-4}	1,34*10^{-3}	**4,11**
Primary energy resources - Non-renewable	Use as energy carrier	MJ, net cal. value	5,92*10^{-4}	5,90*10^{-6}	1,51*10^{-2}	**1,57*10^{-2}**	1,27*10^{-3}	1,91*10-2	**3,61*10^{-2}**
	Use as raw material	MJ, net cal. value	0,00	0,00	2,44*10^{-4}	**2,44*10^{-4}**	9,76*10^{-6}	0,00	**2,54*10^{-4}**
	Total	MJ, net cal. value	5,92*10^{-4}	5,90*10^{-6}	1,54*10^{-2}	**1,60*10^{-2}**	1,28*10^{-3}	1,91*10^{-2}	**3,63*10^{-2}**
Secondary material		g	0,00	0,00	6,16*10^{-2}	**6,16*10^{-2}**	2,46*10^{-3}	1,88*10^{-2}	**8,28*10^{-2}**
Renewable secondary fuels		MJ, net cal. value	0,00	0,00	0,00	**0,00**	0,00	1,78*10^{-8}	**1,78*10^{-8}**
Non-renewable secondary fuels		MJ, net cal. value	0,00	0,00	0,00	**0,00**	0,00	1,94*10^{-8}	**1,94*10^{-8}**
Net use of fresh water		m^3	9,25*10^{-9}	5,25*10^{-9}	1,60*10^{-5}	**1,60*10^{-5}**	6,89*10^{-7}	9,39*10^{-6}	**2,61*10^{-5}**

1 Distribution losses of 4% of generated electricity are included in the downstream column.
2 Includes the net primary energy to produce 1 kWh of hydropower – 4,1 MJ (1,14 kWh) per kWh generated.

3.5. Waste and output flows

Only waste amounts and output flows that are not treated within the system boundaries are reported in Table 11, Table 12 and Table 13, in accordance with the PCR. Impacts related to incineration and deposition of waste which is treated within the system boundaries are included in the environmental impact results.

Table 11 Waste production for core processes

Waste	Unit/kWh	Core	Core - infra.	Total
Hazardous waste disposed	g	1,95*10^{-12}	3,29*10^{-3}	**3,29*10^{-3}**
Non-Hazardous waste disposed	g	7,17*10^{-4}	35,3	**35,3**
Radioactive waste disposed	g	2,56*10^{-8}	3,37*10^{-5}	**3,38*10^{-5}**

Table 12 Waste production for upstream and downstream processes

Waste	Unit/kWh	Upstream	Down-stream[1]	Downstream - infra.	Total - distributed
Hazardous waste disposed	**g**	0,00	$1{,}32 \cdot 10^{-4}$	$2{,}66 \cdot 10^{-6}$	**$1{,}35 \cdot 10^{-4}$**
Non-Hazardous waste disposed	**g**	0,00	1,41	$5{,}28 \cdot 10^{-1}$	**1,94**
Ash	**g**	0,00	0,00	0,00	**0,00**
Inert (rock, sand etc.)	**g**	0,00	1,38	$1{,}73 \cdot 10^{-1}$	**1,56**
Radioactive waste disposed	**g**	0,00	$2{,}16 \cdot 10^{-6}$	$2{,}91 \cdot 10^{-5}$	**$3{,}13 \cdot 10^{-5}$**

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

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

Reported non-hazardous waste emanates from mainly from the disposal of inert waste, e.g. stone and gravel are the deposited excess amounts that could not be used in the construction of power stations, waterways, and dams.

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

Table 13 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**	0,00	0,00	0,00	**0,00**	0,00	0,00	**0,00**
Material for recycling	**g**	0,00	$1{,}15 \cdot 10^{-2}$	$4{,}09 \cdot 10^{-1}$	**$4{,}21 \cdot 10^{-1}$**	$1{,}68 \cdot 10^{-2}$	$2{,}84 \cdot 10^{-2}$	**$4{,}66 \cdot 10^{-1}$**
Materials for energy recovery	**g**	0,00	0,00	$2{,}19 \cdot 10^{-4}$	**$2{,}19 \cdot 10^{-4}$**	$8{,}76 \cdot 10^{-6}$	0,00	**$2{,}28 \cdot 10^{-4}$**

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 generators and turbines and from scrapped components, which are assumed to be stripped down and recycled to 90%. Other waste to recycling consists of batteries, plastic and chemicals.

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

A comparison of the results compared to previous versions of this EPD® can be found in chapter 5.

4. Additional Environmental Information

4.1. Land Use and Impact on Biodiversity

4.1.1. The Biotope Method

The Biotope Method (Biotope Method 2015 - Grusell E., 2014 and Biotope Method 2005 - Kyläkorpi et al., 2005) is a systematic procedure developed by Vattenfall for the quantification of impact on biodiversity following the exploitation of land and water. It is based on comparisons of the extent of various types of biotope before and after project development. According to the Biotope Method before is the situation before the start of the construction work and after is a selected time when the biotope has stabilized in relation to the new conditions. The fundamental assumption is that the changes in biodiversity, which are caused by the utilisation of land and water, are reflected in losses and gains of the various types of biotopes. Affected areas are identified, measured and characterised based on biological value. In this version of the EPD for hydro power the Biotope Method for 2015 is used for the hydro power stations selected to be updated in 2020 and in 2017. The power stations selected 2017 and 2020 are Bergeforsen, Älvkarleby, Stornorrfors, and Umluspen, however, during the update of the Biotope Method in 2014 a draft called Biotope method 2014 was used. This draft was later named the Biotope Method 2015. For the hydro power stations updated before 2014 and described in this EPD, the Biotope Method 2005 is used.

The Biotope Method considers impacts on biodiversity that can be directly related to a specific activity. Indirect or derived impacts, e.g. *fragmentation*[5] and *barrier effects*[6] are outside the scope of the method.

Biotopes are divided in the following categories:

- **Critical Biotope, CB** – A critical biotope is an area that is considered of particular importance for maintaining biodiversity at a global, national and regional level. The area keeps a higher biodiversity compared to its surroundings or other areas of the same biotope in the region or in the country. All Natura 2000 habitats are characterized as critical biotopes. Red listed species occur in the area.
- **Rare Biotope, RB** – A rare biotope is an area that is of particular importance so that the total of such areas is maintained or become larger and their ecological quality in total are maintained or improved. A rare biotope does not need to be particularly important for maintaining biodiversity at a regional, national or global level. The area could eventually or with restoration measures achieve critical biotope. The area keeps a higher biodiversity compared to the everyday landscape and is relevant to the variation in the landscape. Key elements occur and Red listed species occur occasionally.
- **General Biotope, GB** – A general biotope consists of areas known as the everyday landscape. A general biotope includes trivial areas of biological production as e.g. parks and green spaces in urban environments. A few red listed species may occur.
- **Technotope, T** – Areas without preconditions for biological production (e.g. hard-made surfaces and buildings).

The quality of the results depends on the quantity and quality of the underlying data. The method is designed to result in a higher reported impact if input data is of lower quality (no biotope inventory on site, no access to inventory data or interpretable aerial photos + meagre data as for the rest = higher impact). If there is a lack of information, various tools such as aerial photos and assignation keys may be used. The highest quality level according to the Biotope Method is A and the lowest is C. The highest quality level justifies three significant digits whereas the lowest levels should only be reported with one significant digit.

[5] Fragmentation impacts may occur when a large area/biotope is subdivided into smaller units. This may create a situation where certain species have insufficiently large continuous areas, even though the total area remains satisfactory.
[6] Barrier effects may occur when a physical barrier (e.g. a railway, transmission line corridor or road) prohibits contact between sub-populations. This may lead to insufficient genetic exchange between sub-populations.

The figure below represents the changes in categories between the *before* and the *after* situations in principle.

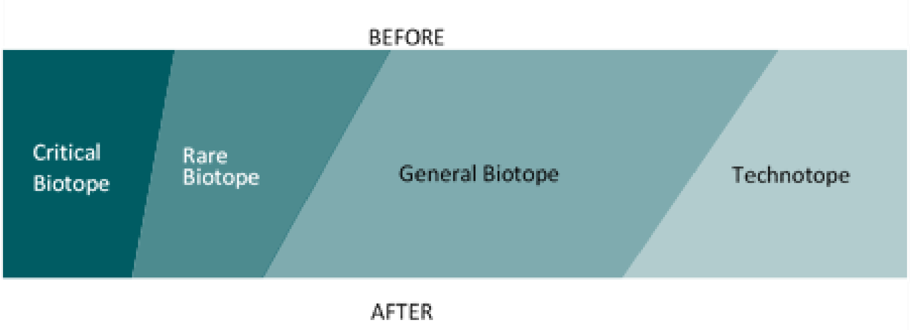


Figure 15 Biotope Method Before – After

As basis for this section there is a separate report in Swedish called *Applikation av Biotopmetoden, El från Vattenfall vattenkraft I Norden* which has been made available to the verifiers.

The 14 selected hydropower stations occupy an area of in total about 74 000 hectares, predominantly river-, lake, and annual reservoirs. This reservoir area constitutes 40% of Vattenfall's total reservoir area and the 14 stations generate 31% of Vattenfall's hydropower. This means that selected hydropower stations have larger reservoir areas than Vattenfall average.

Table 14 Land use in studied rivers

	Lule älv	Ume älv	Ångermanä lven	Indals-älven	Dalälven	Göta älv	Upperuds-älven	Vuoksi Pamilo	Totalt
Total area (ha)	9400	30 000	6900	2100	190	380	91	25 000	**74 000**
% of total area	13%	40%	9,0%	3,0%	0,3%	0,5%	0,1%	34%	**100%**

It is important to note that studies of individual power stations do not provide a comprehensive picture of ecological effects in a river. It would be misleading to relate biotope changes to the electricity generated at a single power station. This would be to the disadvantage of stations with annual reservoirs, and to the advantage of stations with no or short-term reservoirs. Therefore, ecological effects for entire catchments should be quantified from a representative selection of power stations. Northern Norrland is represented by stations in the river Lule älv. Middle Norrland is represented by stations in the rivers Ume älv, Ångermanälven, and Indalsälven. Southern Norrland and Western Sweden are represented by stations in the rivers Dalälven and Göta älv respectively, Finland is represented by Vuoksi and small-scale river by Upperudsälven.

4.1.2. Result

The land use and quality levels used at the various stations are specified in the table below.

Table 15 Land use and quality levels of the included stations

River region	River	Stations	Quality level (Biotope Method 2015)
Northern Norrland	Lule älv	Seitevare	A
		Harsprånget	A
		Porsi	A
		Boden	A

Central Norrland	Ume älv	Juktan	A
		Umluspen	A
		Stornorrfors	A
	Ångermanälven	Stalon	B2
	Indalsälven	Bergeforsen	A
Southern	Dalälven	Älvkarleby	B2
Western Sweden	Göta älv	Olidan	B2
		Hojum	B2
Small-scale	Upperudsälven	Upperud	A
Eastern Finland	Vuoksi	Pamilo	B2

The approach is to achieve the highest possible quality level with a reasonable effort. Several stations have posed a problem because pre-exploitation data is missing due to lack of aerial photographs and inventories, particularly for stations built in the 1950's and earlier. The large proportion of quality level B2 reflects this. Note that biotope impact is overestimated when characterization keys are applied in quality level C.

Table 16 Studied land use 2020 per quality level using the quality levels according to the Biotope Method 2015.

Quality level (Biotope Method 2015)	% of total area	**Areal (ha)**
A	56%	41 000
B	44%	33 000
C	0%	0
Sum	100%	**74 000**

Table 17 Land use per application (hectare):

	Lule älv	Ume älv	Ångerman älven	Indals-älven	Dalälven	Göta älv	Upperuds-älven[2]	Vuoksi Pamilo	Total (ha)
Dams	25	25	1	8	0,9	0,3	0,2	0,2	**60**
Reservoirs	8900	27 000	6000	1900	150	350	90	25 000	**70 000**
Dry riverbanks	94	480	74		4,0	2,4		99	**760**
Distribution plants	11	5,6	0,5	1,0		0,4		0,4	**19**
Buildings (permanent) incl. roads	12	68	5,5	1,5	4,8	1,2		0,3	**93**
Tailrace	41	39			0,2	6,7	0,1	2,2	**89**
Quarries	60	10						1,0	**71**
Stores	32	150	22		8,1				**210**
Buildings (temporary[1])	0	14							**14**
Other	180	1600	770	240	27	20	0,9[2]	370	**3200**
Total (ha)	**9400**	**30 000**	**6900**	**2100**	**200**	**380**	**91**	**26 000**	**74 000**

1 Temporary now moved or demolished buildings used during the construction phase and where the area still is not recovered.
2 Upperudsälven: Dam area includes buildings.

Table 18 Biotope category areas related to the electricity generation in the respective river region

River region	Category	Area *before* (ha)	Area *after* (ha)	Biotope change (ha)	Change per kWh el. (m^2/kWh)
Northern Norrland	Critical biotope	6200	0	-6200	$-1,4*10^{-4}$
	Rare biotope	2700	52	-2700	$-5,9*10^{-5}$
	General biotope	380	3300	2900	$6,4*10^{-5}$
	Technotope	110	6100	6000	$1,3*10^{-4}$
Middle Norrland	Critical biotope	18 000	580	-17 000	$-5,5*10^{-4}$
	Rare biotope	8100	6000	-2100	$-6,7*10^{-5}$
	General biotope	13 000	20 000	7000	$2,2*10^{-4}$
	Technotope	4,0	12 000	12 000	$3,9*10^{-4}$
Southern Norrland	Critical biotope	78	5,0	-72	$-1,5*10^{-5}$
	Rare biotope	78	0	-78	$-1,6*10^{-5}$
	General biotope	39	180	140	$2,8*10^{-5}$
	Technotope	0	14	14	$2,8*10^{-6}$
Western Sweden	Critical biotope	150	0	-150	$-1,2*10^{-5}$
	Rare biotope	150	0	-150	$-1,2*10^{-5}$
	General biotope	76	370	300	$2,3*10^{-5}$
	Technotope	0	9,0	9,0	$7,5*10^{-7}$
Small-scale	Critical biotope	90	90	0	$-4,9*10^{-7}$
	Rare biotope	0	0	0	0,0
	General biotope	0	1,0	0	$2,1*10^{-6}$
	Technotope	1,0	0	0	$-1,6*10^{-6}$
Eastern Finland	Critical biotope	10 000	200	-10 000	$-3,8*10^{-3}$
	Rare biotope	10 000	0	-10 000	$-3,9*10^{-3}$
	General biotope	5100	25 000	20 000	$7,6*10^{-3}$
	Technotope	0	110	110	$4,3*10^{-5}$

The table above is a condensation of biodiversity impact for the 14 selected power stations related to electricity generation over 100 years.

The Biotope Method requires that the digit accuracy of the results mirror the uncertainty in underlying data. The site with the lowest quality level decides the digit accuracy in the aggregated result. In this case 75% of the sites were studied with quality level A or B. Consequently, the aggregated result can be presented with two value digit accuracy.

The aggregated biotope change at the 14 selected sites is a considerable but necessary simplification. The specific values in the table are nonetheless indicative of ecological effects of Vattenfall's Nordic hydropower. The results should be interpreted based overall of this section.

Table 19 Biotope change

Category	Biotopförändring (ha)	Förändring per kWh el (m2/kWh el)

Critical biotope	-34 000	$-3{,}1*10^{-4}$
Rare biotope	-15 000	$-1{,}4*10^{-4}$
General biotope	30 000	$2{,}8*10^{-4}$
Technotope	18 000	$1{,}7*10^{-4}$

4.2. Land and Water Use

4.2.1. Description of Land Use in the river regions

The following text is a description of land and water exploitation in the different river regions caused by the selected stations.

4.2.1.1. Northern Norrland

In the river region Northern Norrland, four stations have been studied in the river Lule älv. River region Northern Norrland is characterised by vast water reservoirs and a large annual average hydropower generation. The four stations exploit 14% of the total land and water area that is exploited by the 14 selected stations and they contribute approximately 33% to the annual average generation of the stations in the river region.

River Lule älv

Area and biotope data for the stations Seitevare and Porsi has been updated in the EPD® for 2014. Area and biotope data for the stations Boden and Harsprånget has been compiled for and presented in previous EPD®. The average annual generation data has been updated for all the 4 selected power stations in the River Lule älv.

Seitevare, Tjaktjajaure (quality level A)

The Tjaktjajaure annual reservoir at Seitevare represents more than 75% of the area occupied by the four stations. Biotope categorization *before* exploitation is based on aerial photographs and geological data from earth deposit maps. 75% of the area harboured the following critical biotopes: coniferous forest, braided rivers, rivers with flat bottom, actively meandering rivers, rivers with alternating pits and streams. The remaining biotopes constitutes 24% rare biotopes and 1% general biotopes.
After exploitation condition assessment is based on actual biological data collected during the 2014 EPD® field study. The field study shows that 77% of the area constitutes technotopes and that the remainder is general biotope. No critical biotope remains. The reservoir, parts of the five gravel pits, a water-filled quarry dismantled are categorized as general biotopes.

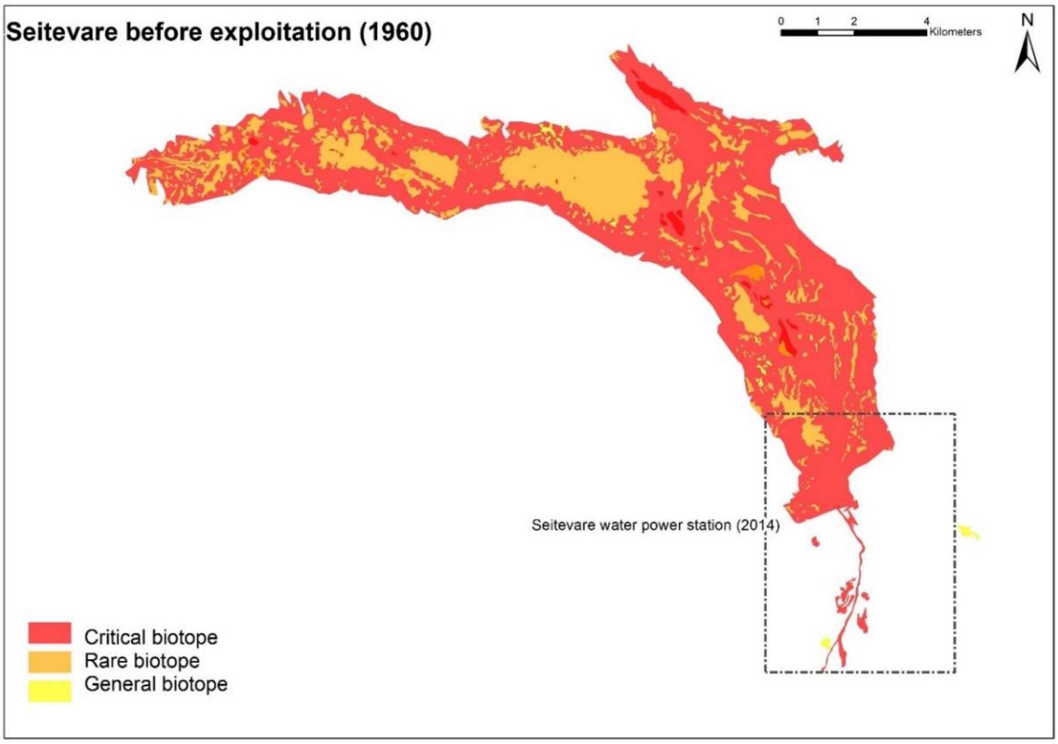


Figure 16. Seitevare with biotope categories before exploitation 1960.

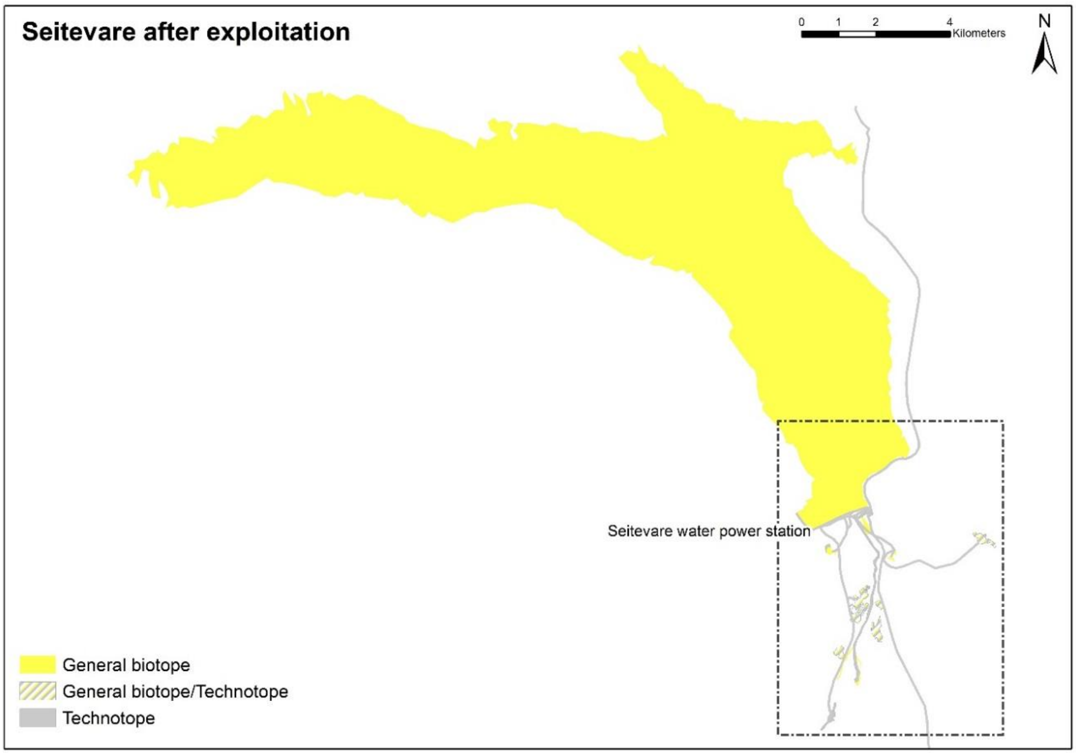


Figure 17. Seitevare with biotope categories after exploitation.

Porsi (quality level A)

Biotope categorization *before* exploitation is based on aerial photographs and geological data studied during the EPD® 2014. 30% of the area harboured following critical biotopes: low meandering rivers, rivers with flat bottom and rivers formed as stairs. The remaining areas constitute 70% rare biotopes.
After exploitation condition assessment is based on data collected at the field study for the 2014 EPD®. As a part of Vattenfall's work with biodiversity protection, Vattenfall has formed two protected areas (VVO-areas) with high nature conservation values in Lule river valley. A smaller part of those areas connected to the Porsi hydro power station are categorized as a critical biotope (see information below), 0,2%. The remaining area constitutes 1,5% rare biotopes (VVO-areas), 83% general biotopes and 15% technotopes.
During 2005 parts of the dam at Porsi hydro power station were reinforced. This leads to a relocation of three red-listed moonwort species, *Botrychium lunaria* (NT), *Botrychium matricariifolum* (EN) and *Botrichyum multifidum* (NT) growing on the slope of the dam. The plants were moved to a new site in Messaure were they are monitored. This new site, due to the presence of these species, was in the EPD® for 2011 categorized as a critical biotope. During field study for the 2014 EPD® the site in Messaure was investigated and *B. lunaria, B. matricariifolum* and *B. mulifidum* where found. At the dam slope at Porsi station, approximately 30 plants of *B. lunaria* were found. This part of the dam slope is in the EPD® for 2014 categorized as a critical biotope.

Harsprånget (quality level A)

During 2011 the station Harsprånget was updated from quality level C1 to A. Characterization of pre-exploitation conditions is based on data from inventories and fieldwork. A remarkable result is the loss of technotopes (-7135 hectares) between the situation before and after. The reason is an existing station in the *before* situation. A major part of the critical biotopes in the before situation has been valued as general biotope in the after situation, due to lack of red-listed species.
Before exploitation data showed the presence of several red-listed species such as the moss *Cinclidotus fontinaloides*, the lichen *Everina divaricata*, and *Calypso bulbosa*. In the *after* situation a few red-listed birds were observed within the area. The evaluation is that those birds cannot be related to the actual biotope in these cases.

Boden (quality level A)

During 2011 Boden was updated from the quality level C5 to the quality level B2. New applications with a field study have been performed 2011 by the utilized land and water areas. Updating also resulted in that the surface of the system boundary decreased in the updated version. This is because some water bodies which were included in the earlier application were assessed to be unaffected in the updated version.
Biotope characterization of the pre-exploitation condition is based on an area-specific standard list. Post-exploitation condition assessment is based on data from inventories and fieldwork. The result shows that 12,5% of the area constitutes technotope and the remainder is general (49,9%) and rare biotope (37,6%).

4.2.1.2. Middle Norrland

In the river region, Middle Norrland four stations have been studied in the rivers Ume älv, Indalsälven, and Ångermanälven. In the river Indalsälven Bergeforsen is updated in the EPD® for 2014 using the draft for the new Biotope Method for 2015 River region Middle Norrland is characterised by vast water reservoirs and a large annual average hydropower generation. The four stations exploit 51% of the total land and water area that is exploited by the 14 selected stations and they contribute approximately 26% to the annual average generation.

Ume River

Area and biotope data have been compiled for and presented in previous EPD®. Input data regarding the dam at Umluspen power station as well as the average annual generation data has however been updated.

Juktan (quality level A)

There is scant historical data from the area around the power station at Juktan, and an area-specific standard list has been applied to *before* exploitation conditions. The inundated area (predominantly coniferous forest on moraine) was characterized by the Swedish Society for Nature Conservation (Naturskyddsföreningen, 1960) as having "meagre vegetation". Apart from agricultural areas, the inundated area was a general biotope.
The streaming water in the river Juktån is characterized as critical biotope both *before* and *after* exploitation. More than 40% of critical biotopes remain *after* exploitation according to a fieldwork during 2000, but rare biotopes are non-

existent. Approximately 4% of both critical and rare biotopes *before* exploitation have become general biotope or technotopes *after* exploitation.
In conjunction with the retrial of the regulation permits in the early 1990's, Vattenfall implemented extensive restoration of biotopes, amounting to 144 ha (55%) of streaming water in Juktån. In addition, 14,6 ha (almost 6%) new biologically important area was created, mainly by opening previously closed off by/side-runs, etc. There are now vital colonies of grayling and trout.

Umluspen (quality level A)

Biotope categorization *before* exploitation is based on aerial photographs and geological data studied during the EPD 2017. Storuman, the reservoir, represents about 70% of the area occupied by the station. 1% of the area harboured critical biotopes, limnic biotopes but also some natural forests. 85% consisted of rare biotopes and 15% consisted of general biotopes. The area was affected by flooding before the expansion of hydroelectric power, which means that there could be some uncertainty about which biotopes are affected by what activity.
After exploitation condition assessment is based on data collected at the field study for the 2017 EPD. The field study shows that the land and water areas *after* exploitation harboured 0% critical biotope, 0% rare biotope, 70% general biotope and 30% technotopes.

Stornorrfors (quality level A)

Biotope categorization *before* exploitation is based on aerial photographs and geological data studied during the EPD 2017. 88% of the area harboured critical biotopes, mainly limnic biotopes but also meadows. The remaining areas constitute 4% rare biotopes, 8% general biotopes and 0,2% technotopes. Technotope existed even before Stornorrfors was constructed because of three older smaller power stations in the same area.
After exploitation condition assessment is based on data collected at the field study for the 2017 EPD. The field study shows that the land and water areas after exploitation harboured 24% critical biotope, 62% rare biotope, 7% general biotope and 7% technotopes.
A new fish ladder and a new small turbine were commissioned during 2010. These new installations have not affected the already used land surfaces.
The present reservoir inundated the older Norrfors reservoir drawdown zones, which were thus converted from technotopes to general biotope. There was also a spillway within the area, which is now inundated upstream the present one.
The reservoir and biological flow stretch of the river were influenced by timber-floating and fishing operations prior to the construction of Stornorrfors. One part of the streaming water stretch of the river is characterized as rare biotope today, and harbours migrating red-listed wild salmon. Vattenfall has implemented activities to facilitate fish migration.

River Indalsälven: *Bergeforsen (quality level A)*

The station was updated to quality level A in 2020. Biotope categorization before the exploitation is based on aerial photos. In the state after exploitation 5,6% of the biotopes are categorized as rare biotopes. This due to the high biodiversity in fish fauna and various key elements such as sand banks. No critical biotope is identified after exploitation, and technotopes is approximately 58%.

River Ångermanälven: *Stalon (quality level B2)*

The power station Stalon is located in the upper section of the river Ångermanälven, more specifically in the branch named Åseleälven.
Historical data from the area around the power station at Stalon is insufficient, and a characterization key has been applied to *before* exploitation conditions. Characterization of *after* exploitation conditions is based on data from fieldwork during 2004 and literature. Streaming water is characterized as rare biotope because of high quality trout population. Selen, the lakes along river Kultsjöån, and the reservoir Kultsjön harbour fine populations of trout and char. More than 70% of the exploited area is characterized as rare biotopes and the remainder as technotopes.

4.2.1.3. Southern Norrland

Area and biotope data have been compiled for and presented in previous EPD. The average annual generation data has however been updated. Älvkarleby power station in river Dalälven has been selected in the river region Södra Norrland and it occupies approximately 0,3% of the total land and water area that is exploited by the 14 selected stations, whereas it contributes approximately 5,3% to average annual generation.

River Dalälven

Älvkarleby (quality level B2)

A field visit at the site was made at 2020. Historical data from the area around the power station at Älvkarleby is insufficient. It was built in the beginning of the 20th century. Aerial photographs and biotope inventories from the *before* exploitation period are non-existent, and a characterization key has been applied. Characterization of *after* exploitation conditions is based on biological data from fieldwork during 2004 and literature. Kungsådran represents 3% of the area and harbours migrating salmon and is characterized as critical biotope. Vattenfall has implemented extensive activities to improve conditions for fish. Recreational fishing waters in Älvkarleby are among the best in Sweden for salmon and trout. No critical biotope is identified *after* exploitation, and 90% is registered as general biotope.

4.2.1.4. Western Sweden

Area and biotope data have been compiled for and presented in previous EPD. The average annual generation data has however been updated. In the river region Western Sweden, the stations Olidan/Hojum in the river Göta älv have been studied. The two stations exploit 0,5% of the total land and water area that is exploited by the 14 selected stations and they contribute approximately 13% to the annual average generation.

Göta älv

Olidan/Hojum (quality level B2)

Historical data from the area around the power stations at Olidan/Hojum is insufficient. The first station was built in the beginning of the 20th century. Maps show that the area was home to industrial operations, which caused extensive technotopes in the before exploitation period. Aerial photographs and inventories from the before exploitation period are non-existent, and a characterization key has been applied to before exploitation conditions. Characterization of after exploitation conditions is based on data from fieldwork and literature. No critical biotopes and/or red-listed species exist within system boundaries. 97,42% of the area is characterized as general biotope and 2,48% as technotopes. The remaining 0,087% is rare biotopes.

4.2.1.5. Eastern Finland

Pamilo power station in river Vuoksi has been selected for the river region Eastern Finland. The river region Eastern Finland is characterized by vast reservoirs and relatively low average annual generation. The Pamilo station exploit 34% of the total land and water area that is exploited by the 14 selected stations and it contributes approximately 3% to the annual average generation.

River Vuoksi

Pamilo (quality level B2)

Pamilo is in the catchment area of river Vuoksi, which runs up northeast of Pamilo in Russia and discharges into Lake Ladoga, also in Russia.

Historical data from the area around the power station at Pamilo is insufficient. Aerial photographs exist, inventoried data is non-existent for the *before* exploitation period, i.e. before 1955, and a characterization key has been applied. Characterization of *after* exploitation conditions is based on data from inventory during 2004 and fieldwork. The river Koitajoki represents 1% of the area and harbours the red-listed (freshwater) Saima-salmon (*Salmo salar saimaensis*) and is characterized as critical biotope. The main part of the area is general biotope.

4.2.1.6. Small-scale Hydropower

River Upperudsälven

Upperud (quality level A)

Upperud power station in river Upperudsälven has been selected as an example of small-scale hydropower stations. Vattenfall acquired the site and constructed the present power station in the 1980'ies. Before that, hydropower had been used in Upperud for at least 300 years. Biotope classification and characterization before construction of the present station are based on aerial photographs and inventories. Characterization of after exploitation conditions is based on data from inventories and fieldwork in 2004. The new station has not caused any major change in biotopes. Almost all biotopes are critical.

The reservoir Upperudshöljen harbours the red-listed species freshwater crayfish (Astacus astacus L.) and the fish species (Cobitis taenia L.). Vattenfall implemented activities to improve biotopes in conjunction with the construction.

4.2.2. Land use and classification according to Corine – core and upstream processes

4.2.2.1. Land use before and after exploitation

A classification according to Corine Land Cover Classes has been made[7]. Occupied areas are expressed in hectares. In the *before* situation it is not possible to classify the occupied areas in artificial areas, agricultural areas, forested areas, wetlands, and water bodies for the power stations Porsi, Umluspen, Stornorrforsen, Stalon, Bergeforsen, Älvkarleby, Olidan, Hojum, and Pamilo due to lack of data. Hence classification is not possible for 75% of the total area occupied by the 14 selected power stations.
In the *after* situation necessary data for Corine classification is available for all the14 selected power stations. For power stations with quality level C2 and C5 according to the Biotope Method 2005, or B2 according to the version 2015, complete data is missing, and the classification according to Corine is unspecified.
The large difference regarding the possibilities to classify the areas according to Corine between the *before* and *after* situation, is caused by the lack of available knowledge regarding the circumstances before the stations were built. For Harsprånget and Boden an assignation key has been used in the *after* situation for the area that is not artificial.

Table 20 Occupied areas (hectare) in the before and after situation in accordance with the Corine Land cover Classes.

Land cover class	Before (m2)	After (m2)
Artificial surfaces (e.g. roads and railroads networks and airports)	5 700 000	10 000 000
Agricultural areas	2 300 000	30 000
Forests and semi natural areas	80 000 000	2 100 000
Wetland	15 000 000	10 000
Water bodies	83 000 000	710 000 000
Unspecified[1]	560 000 000	20 000 000
Total	**740 000 000**	**740 000 000**

1 For power plants with quality level C2 and C5 according to Biotope Method 2005 complete data is missing

4.2.2.2. Time of area occupation

Vattenfall's hydropower reservoirs are assumed to have a technical lifetime of 100 years. Continuous reinvestments ensure further use and no deconstruction is assumed.

4.2.2.3. Description of exploitative activities on occupied area

Table 21 is a compilation of the areas occupied by the 14 studied hydropower stations.

Table 21 Areas occupied by the 14 studied hydropower plants

Type of area	Total (ha)	Percent (%)
Dams	60	0,1
Reservoirs	70 000	95
Dry river banks	76	0,1

[7] http://sia.eionet.europa.eu/CLC2000/classes

Distribution plants	19	0
Buildings (permanent) incl. roads	93	0,1
Tailrace	89	0,1
Quarries	71	0,1
Stores	210	0,3
Buildings (temporary)	14	0
Other	3100	4,3
Total (ha)	**74 000**	**100**

4.2.3. Land use downstream processes – distribution of electricity

The power grid also has an impact on biodiversity, but no quantitative results from application of the Biotope method are included in this study from the distribution stage and no classification of occupied areas according to Corine has been made.

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

4.3. Environmental Risk Assessment

4.3.1. Method

In this EPD®, risks refer to potential risks or hazards to the environment that may cause damage or other negative impact on the environment. Environmental risks can arise when events or incidents beyond the ordinary occur, or during normal activities, e.g. construction or transport. The events are converted to emissions per average year and the amount emitted per kWh of electricity produced.

An environmental risk assessment is carried out in accordance with a set method in order to ensure good quality of the assessment. The following is a description of the procedure after the boundaries have been set and other methodological decisions have been made. Good general knowledge of, in this case, hydropower plants is a prerequisite.

The first step is to acquire background data and material that describe the plant, such as design drawings, pictures, lists of the chemicals present, etc. A preliminary list of conceivable accident scenarios is compiled.

The next step is a visit to the site to verify that reality matches the picture that emerged from background data and material. Operation and maintenance staff are interviewed to check whether further scenarios can be identified and to get an overall, rough assessment of the consequences and probabilities involved.

A more detailed analysis of the consequences is carried out on the basis of the existing material. Historical material is reviewed in order to assess probabilities. If historical events are non-existent, which may be the case regarding infrequent events, other sources are sought.

Once all this has been done and the facts are compiled, the material is referred to and examined by persons with different backgrounds and experience, partly to identify any potential accidents that may have been overlooked, and partly to verify the assessments made.

Probability forecasts are, by nature, always impaired by uncertainties. The degree of uncertainty is greatest for infrequent events, and for events caused by human error. Assessments of potential consequences may also be uncertain, e.g. it is difficult to quantify the content of flue gases in uncontrolled combustion.

The values presented here should therefore be construed only as an indication of the order of magnitude of various emissions.

4.3.2. System boundaries

The environmental risk assessment comprises accidents in conjunction with:

- The construction of dams and power plants
- The manufacturing of large components for power plants
- The transportation of material required for construction and operation
- Operation, including maintenance

Neither demolition of dams or power plants, environmental risks associated with sabotage, nor wars are included.

Exceptional emissions or accident may cause demand for more raw materials to replace what has been lost or to rebuild the plant, which in turn leads to new emissions. This has not been taken into account.

Automobile accidents during travel to and from work have not been included.

Section 4.3.9 below presents quantification of some emissions to air and water caused by accidents during the life cycle, and a comparison is made with emission levels during normal operation. Possible accident scenarios are described in sections 4.3.4-4.3.8.

4.3.3. Summary of Risks

The environmental risk assessment shows the potentially environmentally damaging emissions that may result from undesired events. Emissions in conjunction with accidents and breakdowns are generally small, in terms of total emissions as well as per generated kWh. Allocated over an extended period, only emissions of oil, diesel fuel, gasoline, SF_6 and gasified copper, reach the same levels as emissions during normal operating conditions.

The largest single potential emission is that of oil to the river from a breakdown in the hub of a Kaplan turbine (installed at 50% of selected stations). The reason being that this type of turbine is equipped with hydraulically adjustable blades, which is not the case for Francis or Pelton turbines.

Local environmental impact may result if a car or tractor is involved in an accident and fuel is discharged into a small watercourse. Major dam break has not been assessed in detail. This is a very low probability event, but it would have major consequences in the river valleys and vicinity.

Figure 18 Vattenfall Letsi power plant in Finland (photo: Vattenfall)

4.3.4. Natural Phenomena
The Swedish and Finnish climate and associated natural phenomena are benign by international standards, but events relating to thunder and lightning, icing, and other ice phenomena are included in the statistics used. In the future, climate change related impact on the Swedish and Finnish climate has to be assessed in this aspect.

4.3.5. Transportation, general
Large quantities of material are transported in conjunction with construction of power plants and particularly dams. This includes rock, soil and cement, but also deliveries of turbines, generators, batteries, etc. Transportation is on-road, off-road, and to a certain extent by sea. In the operating phase, inspection trips are made by car, and snow clearing by tractor.

Fuel may leak or ignite because of an accident, in which case lubrication/hydraulic oils, cables or cargo (e.g. lead batteries) may also catch fire. Every power plant/dam probably has a stationary diesel fuel tank, which may spring a leak.

The probability of truck accidents is expressed as accidents per kilometre, while dumper and tractor accidents are expressed per operating hour. The consequences are often personal injuries (including those suffered by a third party), and environmentally damaging emissions. Local environmental impact may result from fuel leaks, e.g., in or near a catchment area or watercourse with sensitive flora and fauna.

4.3.6. Construction of plants and facilities

4.3.6.1. Reservoirs and dams
Accidents related to transportation and blasting (see above) have been identified as the only accidents of significance for the environment during construction of reservoirs and dams. Emissions would primarily consist of the spillage/leakage of oil/diesel fuel.

4.3.6.2. Power plant
The construction of power plants involves large quantities of material and environmental impact may result from spillage of oils, solvents, etc. Handling of solid materials such as concrete, building materials, etc. causes negligible environmental impact. The quantities of solvent releases are small, as is the probability of this occurring, and such emissions are disregarded. Oil spills do occur, but the quantities are small on each occasion.

4.3.6.3. Tunnels
Construction of tunnels and provision of fill for the dam requires blasting. Blasting accidents may occur resulting in slides blocking the tunnel or landing in the wrong place. It is highly improbable that such events cause negative environmental impact.

Tunnel construction involves sealing, normally various types of mortar, but in exceptional cases synthetic compounds (epoxy and polyurethane foam) as well. Water may transport residues from these injection compounds. They would be very dilute and neither acute nor long-term toxic environmental impacts are anticipated. Personal injuries or environmental damage may occur when using these injection compounds, but this is not considered here.

4.3.6.4. Manufacturing of components
One generator manufacturer has provided information about handling of oils and chemicals in conjunction with manufacturing and delivery of generators and transformers. The quantity of chemicals used in the manufacturing and delivery of a generator is reported to be in the range of 100-400 kg. No chemicals have ever leaked out, and there has been no serious fire.

Fires in manufacturing facilities for generators, turbines, transformers, or batteries are excluded, partly because such events have a low probability, and partly because the potential environmental impact is very small.

4.3.7. Operation of Power plants
4.3.7.1. Breakdowns, fires and spillage
The relevant breakdowns in power stations that cause emissions to the surroundings are mainly damaged to control systems, bearings, switches, etc. that result in leakage of oil or to emission of pyrolysis products.

The hub of a Kaplan turbine may break down. This would result in turbine oil leaking into the river because this type of turbine is equipped with hydraulically adjustable blades, which is not the case for Francis or Pelton turbines. In case of a total breakdown, all the oil in the system could leak out. For Porsi, this would mean approximately 21cubic meters of oil, and for Boden approximately 14 cubic meters. The implementation of high-pressure systems will lead to decreased quantities of oil in control systems.

A fire could be initiated by a grounding fault or short-circuit in a generator, local power system, transformer, switchgear, etc., and would lead primarily to emissions of CO_2. Burning insulation, cables, or chemicals would cause more toxic emissions.

Electric arcing causes pyrolysis products from oils as well as from metals (Cu, Al).

4.3.7.2. SF_6

SF_6 is a gas frequently used as electric insulation, for example in switches, and it has a high GWP-factor. There are SF_6-insulated switches in 11 of the selected power plants, and there are SF_6-insulated cable conduits at two power plants. Emission of SF_6 may be caused by breakdowns of switches or in the case of fire.

4.3.8. Large water flows and dam break

The Swedish power industry is carrying out extensive work around dam safety. Dams are continually being improved in order to cope with more extreme water flows, and safety risks are systematically eliminated. Methods for measuring and detecting beginning damage to dams, as well as the causes of such damage, are being developed. According to current estimates by the power industry, the probability of a significant dam break is around 0,00001 per year.

The geological/geographical characteristics of watercourses change continually, and the extent depends on the quantity of water. A dam break would cause very high discharges, and, in narrow parts of a river, the channel could be stripped clean and large blocks of rock might be torn loose. Banks would be eroded, trees undermined and torn loose, and the material carried along by the water could form logjams damming the water. As a result, the river might try to find new paths. In flat areas, a lot of fine material could be deposited in meter thick layers on top of the original ground. Saturated and eroded banks could continue to collapse even after the discharge returned to normal levels.

Once the composition of soils and landforms has been altered, there will be no return to original conditions. The water may be deeper or shallower. New, different varieties of vegetation more suited to the new water and nutrient conditions will establish themselves and re-population will begin immediately.

The effects of a dam break are similar to those of natural extreme floods. Apart from damage to nature, man-made objects such as buildings etc. are also destroyed. People may also be injured or drown. Human activity often takes place closer to developed, regulated rivers than near natural rivers, because the water level varies less. Extreme water flows in natural rivers are normally not sudden, and there is time to get people to safety, and to move hazardous substances that may otherwise be carried away by the water. In the case of a dam failure, however, there is much less time to issue a warning, and the consequences will be greater.

Events in conjunction with a dam break on the river Lule älv could be fierce, especially if it happened in the upper parts of the catchment, as the quantity of water involved would be enormous. A dam break at Tjaktjajaure (upstream from Seitevare) would cause an enormous flood wave to sweep down the length of the river all the way to the coast. Such a flood wave would probably damage other dams in its path. The event would be limited in terms of time and would continue for up to a week.

Variations in water levels resulting from variations in precipitation are not considered as environmental risk in this conjunction because increased precipitation does not constitute “undesired event” as defined in this context. However, climate change related impact causing increased water flows might make it necessary to revaluate this matter in the future.

4.3.9. Results and comparison with emissions under normal conditions

The table below summarizes the potential emissions identified in the environmental risk assessment, and the events that provide the predominant contribution to these emissions. Emissions less than 0,1 kg per year and power plant are not presented. Sulphur dioxide emissions are thus no longer presented. In order to get an idea of whether these emission levels are small or large, a comparison is also made with the emissions that occur under normal operating conditions, see Table 26. In the column Lifecycle emissions under normal conditions the LCA results from generation of electricity is shown, i.e. distribution is not included.

Table 26 Emissions to air, ground, and water in conjunction with accidents at selected hydropower plants, compared to normal operation (LCI emissions).

Dominating events causing emissions of respective substance	Substance to air	Substance to ground or water	Potential emissions due to accidents in the core process [g/kWh]	Potential emissions caused by accidents during construction of the core process infrastructure [g/kWh]	Lifecycle emissions under normal conditions (excluding distribution of electricity) [g/kWh]
Fire in turbine, transformer, breaker and emission from carbon dioxide extinguishing	**Carbon dioxide**		10^{-5}	10^{-6}	10^{-1}
	Carbon monoxide		10^{-7}	0	10^{-2}
	Dust[1]		10^{-7}	10^{-7}	10^{-3}
Breakdown of magnetic transformer or breaker (arc), Cable fire	**Gasified copper**		10^{-7}	0	10^{-4}
Breakdown of breaker, leakage or fire in breaker	**SF_6**		10^{-6}	0	10^{-6}
Turbine breakdown **Breaker breakdown** **Control system leakage**		**Oil/diesel /petrol**	10^{-5}	10^{-6}	10^{-3}

[1] The total amount of dust for Hydro. It is difficult to divide between *core* and *core infrastructure* (construction). The total amount still shows that the quantities for ERA are smaller than for LCI.

This comparison shows that, allocated over a long period of time, emissions of carbon dioxide, dust and carbon monoxide related to accidents and breakdowns are smaller than emissions occurring under normal conditions. The difference between the environmental risk assessment and the LCI for oil/diesel/petrol is not significant. Due to uncertainty connected to the LCI data for oil/diesel/petrol, it is difficult to draw conclusions from this result. Emissions of gasified copper and SF_6 are on the same order of magnitude in both assessments. However, the absolute volumes are small for these parameters.

Emission levels in conjunction with accidents and breakdowns are generally small in terms of total quantity as well as per generated kWh.

Emissions might also occur due to accidents or breakdowns in the electricity distribution system. These risks have however not been quantified.

It should be emphasised that there are uncertainties in the assessment of the probability of various breakdown scenarios, but these are not large enough to impair the conclusions above.

4.4. Electromagnetic Fields

EMF (Electromagnetic Fields, or for power frequency, Electric and Magnetic Fields) appear in the vicinity of all electrical equipment and power lines. There are no binding limits regarding exposure to EMF.

The International Commission on Non-Ionizing Radiation Protection (ICNIRP), an independent body consisting of international experts, has however published recommendations[8] regarding acute health problems. The

[8] ICNIRP 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.

recommendations are based on knowledge about acute health problems due to changing magnetic fields and propose a limit of 1000 μT for working environment and for the general public a limit of 200 μT at 50 Hz. The EU Council of Ministers recommends a restriction of exposure to electromagnetic fields in accordance with the ICNIRP´s recommendations.

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

4.5. Noise

Sound propagation depends on several factors such as medium, frequency, amplitude, temperature, humidity, wind, and geography. Consequently, noise levels from one and the same source may vary from day to day. It also means that two identical sources of noise in different locations may give rise to completely different noise levels and propagation patterns and may be experienced differently.

Hydro power is steered through the regulation of water operations (Chapter 11 in the environmental code). Noise may be regulated in the permit *if seen as necessary* but none of the power stations have any noise requirements in the existing permits.

The most distinguishing outdoor noise from hydropower generation is the sound of streaming water at above ground stations. These sound levels are, however, lower than before regulation and can also be considered as pleasant. Noise levels from transformers are generally moderate (45–60 dB), but the frequencies are low (<100 Hz). This means that unfavourable conditions may cause this noise to be disturbing at distances of up to 0,5–1 km. In some cases, there are also loud fan and vibration noises (>80 dB), which under unfavourable conditions can be disturbing at distances of up to 1 km. At Porjus, levels of 92 dB(A) [9] have been measured at 1 meter, and of 38 dB(A) at 800 meters from the transformer.

Power lines above 70 kV can generate corona noise levels of 45 dB(A) at a distance of 25 meters, however abating as distance increases.

4.6. Visual Impacts

The regulation of a watercourse and the construction of dams, reservoirs and power plants affect and change the landscape and the natural environment. Where there used to be rapids, streams and seals, water reservoirs are created that are more similar to lakes in their appearance. Land reclamation destroys or changes forest areas, arable land and natural habitats, which in turn affect land use for forestry, agriculture, reindeer husbandry, fishing and tourism.
The power production uses the water's drop height to utilize the water's kinetic energy and therefore the water is led in many places past the original current or rapids via tunnels. It creates dry furrows with little or no of the original flow. It also means that many of the currents in the unregulated watercourse disappear. Current distances generally belong to the more varied and species-rich environments in running water and many functions such as spawning and rearing areas for salmonids are linked to these stretches.

Values have changed regarding landscape and aesthetics since the establishment of the first impoundments. The development of hydro power plants has caused changes to the landscape of both a permanent and a temporary nature. The area around the seasonal reservoirs is normally severely affected. Variation of the water flow changes the surrounding landscape, causes erosion and leads to impacts for example for angling. For a more in-depth description of landscape effects, see appendix *Technology and Environment*.

[9] dB(A) indicates that a standard method of measurements has been used where the value has been corrected with respect to the sensitivity of the human ear at different frequencies.

Figure 19 Vattenfall Harsprånget hydro power plant, Sweden (photo: Jennie Pettersson)

4.7. Social impacts

In fall 2016, BU Hydro Nordic initiated a pilot study of their systematic sustainability work to find improvement opportunities. The pilot study started with a stakeholder dialogue inviting over 700 stakeholders from different perspectives to identify material issues to work with for BU Hydro Nordic. During 2019 BU Hydro Nordic conducted a thorough materiality assessment as an update of this. The identified stakeholder groups were co-workers, suppliers, municipalities, county governments, associations and local residents.

One of the aspects that received the highest rate within social sustainability was to attract and retain competence. Other co-worker related aspects that have received a high score was to fight discrimination and strive for equality in the workplace and to secure health and safety at the workplace.

To protect indigenous rights and engage in local communities received a high score when identifying important aspects within social sustainability. The indigenous people mainly affected by Vattenfall's hydropower is the Sami. A central part of the Sami culture and tradition is the reindeer herding, which has been facing many consequences due to large-scale hydropower. The main issues are loss of grazing areas, loss of migration routes and impacts on infrastructure. More information about impacts related to hydropower development can be found in the appendix *Technology and Environment*.

Based on the results of the material analysis, BU Hydro Nordic have developed a sustainability strategy including the following prioritized social areas:

- Engagement in local communities, aiming to build good relationships with stakeholders to understand their needs, find sound solutions and reach acceptance
- Attract and retain competence, to secure right competence and enable personal development
- Safe and healthy work places, to create a safe and attractive work environment for the co-workers

5. Differences vs. Earlier Versions of Vattenfall's EPD® for hydropower

This EPD® is an update of a previous version. Vattenfall's EPD® for electricity from Nordic Hydropower was first published in 2005 and this EPD® is the fifth update.

In the table below a comparison is made between the results of this EPD® and the EPD® for Vattenfall's hydropower, certified in 2017. As the same representative selection of plants have been used, and since changes in hydropower station are limited, the changes from different years mainly relate to differences in generic LCA database data and calculation methods. The requirements of the updated PCR and GPI has resulted in an increased number of reported environmental impact indicators in the EPD, as can be seen in Table 22, limiting the comparability with 2017.

Table 22 Differences versus earlier version

Environmental impact categories		Unit/kWh	Vattenfall's EPD® for Electricity from Hydropower			
			2020		2017	
			Excl. Distribution	Incl. Distribution	Excl. Distribution	Incl. Distribution
Global warming potential	Fossil	g CO_2-eq. (100years)	1,40	2,99	1,31	2,78
	Biogenic	g CO_2-eq. (100years)	0,025	0,026	0,54	0,58
	Luluc (inundation)	g CO_2-eq. (100years)	0,798	0,83	7,14	7,35
	Luluc (deforestation)	g CO_2-eq. (100years)	2,11	3,41	NR	NR
Acidification potential		g SO_2-eq.	$5{,}27 \cdot 10^{-3}$	$1{,}35 \cdot 10^{-2}$	$5{,}59 \cdot 10^{-3}$	$1{,}69 \cdot 10^{-2}$
Eutrophication potential		g PO_4^{3-}-eq.	$1{,}50 \cdot 10^{-2}$	$1{,}92 \cdot 10^{-2}$	$1{,}14 \cdot 10^{-1}$	$1{,}23 \cdot 10^{-1}$
Photochemical oxidant formation potential		g NMVOC-eq.	$4{,}69 \cdot 10^{-3}$	$1{,}23 \cdot 10^{-2}$	NR	NR
Particulate matter		g PM2.5-eq.	$1{,}94 \cdot 10^{-3}$	$5{,}20 \cdot 10^{-3}$	NR	NR
Abiotic depletion potential - Elements		g Sb-eq.	$1{,}09 \cdot 10^{-5}$	$3{,}51 \cdot 10^{-5}$	NR	NR
Abiotic depletion potential - Fossil fuels		MJ, net cal. Value	$1{,}49 \cdot 10^{-2}$	$3{,}46 \cdot 10^{-2}$	NR	NR
Water scarcity footprint		m^3 H_2O-eq.	$5{,}48 \cdot 10^{-4}$	$8{,}83 \cdot 10^{-4}$	NR	NR

NR – Not reported

The main contributions to the emission categories in the table above occur in the construction phase of the hydropower plants (core-infrastructure) as well as power networks (downstream-infrastructure), and mainly relate to the use of material for construction of the stations and electricity grids. Operation causes small emissions. For the impact categories Global warming potential and Eutrophication potential, inundation of land and deforestation have a significant influence on the results.

The most significant changes from previous versions are:

- CO_2 emissions related to deforestation is included for the first time. This is particularly relevant for the core- and downstream infrastructure, where the removal of forest before construction of water reservoirs (dams) and power network results in approximately 2 g CO_2-eq/kWh increase compared to 2017 values excluding distribution and 3 g CO_2-eq/kWh including distribution.
- Changes have been made to the underlying values used to calculate emissions from inundation. For this year, specific data from *Skogsdata (2017)*[10] for carbon stock in soil is used. Previously, the default values in the PCR have been used. This change has resulted in an almost tenfold decrease of the CO_2 emissions arising from inundation; from 7,14 to 0,79 g CO_2-eq/kWh excluding distribution. Similarly, this also reduces the Eutrophication potential as the COD emissions arising from inundation have decreased significantly; from 5,2 to 0,58 g COD/kWh excluding distribution (corresponding to 0,114 and 0,0127 g PO_4^{3-}-eq/kWh).

In addition, the following updates and changes have been made since 2017:

- The generic LCA data containing emissions related to production, treatment and transport of auxiliary materials and fuels consumed during the operation of the power plants and power networks has been updated to a more recent version - from ecoinvent 3.3 to ecoinvent 3.6. This update has a negligible influence on the results.
- An error in the calculation of upstream transportation has been amended. This change has resulted in slightly increased environmental impact from the upstream module. However, this has a negligible influence on the total.
- Plant machinery inventories have been updated. This concerns four plants (Bergeforsen, Boden, Porsi and Stornorrfors) that reported changes to their machinery inventory. This update results in slightly higher environmental impact from core infrastructure.
- Downstream processes have been updated based on new data from Svenska Kraftnät and Vattenfall Eldistribution AB such as information about the distribution infrastructure and environmental impact during operation of the grid. This includes:
    - The regional network infrastructure, which was formerly modelled with generic data from ecoinvent, has been updated with specific data from Vattenfall Elistribution AB. Ramboll has conducted an LCA of the regional grid in Sweden owned by Vattenfall Eldistribution AB in 2020, covering the infrastructure, operation and demolition of the grid. This model is used to represent the regional network in Sweden. The new dataset is more comprehensive and contains more information than previous. This update results in slightly lower environmental impact from downstream infrastructure.
    - Distribution losses have been changed from 3% to 4% to reflect the average losses during the period for which operational data is collected (2017-2019). This change has resulted in increased environmental impact from distribution of electricity.
- Phosphorus emissions resulting from a changed balance in regulated waterways are no longer part of the covered environmental impacts (“Balansen av fosfor i reglerade vattendrag; Björn Svensson, SwedPower AB) which is in line with the updated PCR. This exclusion has led to a slightly increased impact of Eutrophication potential, as the changed balance in regulated waterways resulted in negative emission of phosphorous.
- The environmental burden related to waste incineration with energy recovery have been allocated between the waste generator and the user of the energy, which is in line with the GPI. 50% of the impacts of the waste incineration is attributed to waste treatment and 50% to the energy recovery. Hence, Vattenfall’s electricity only carries half of the burden from waste incineration compared to previous versions. This results in lower environmental impacts from incineration of waste in core, core-infra, downstream and downstream-infra modules.

[10] Skogsdata, 2017. Aktuella uppgifter om de svenska skogarna från Riksskogstaxeringen. Inst f. skoglig resurshushållning, Sveriges Lantbruksuniversitet, Umeå.

Changes in the biotope impact assessment are presented below.

Table 23 Differences versus previous version regarding changes in biotope

	2020		2017	
Category	**Biotope change (ha)**	**Change per kWh electricity (m^2/kWh)**	**Biotope change (ha)**	**Biotope change per kWh (m^2/kWh)**
Critical biotope	-34 000	$-3{,}1*10^{-4}$	-21 400	$-2{,}21*10^{-4}$
Rare biotope	-15 000	$-1{,}4*10^{-4}$	-27 000	$-2{,}78*10^{-4}$
General biotope	30 000	$2{,}8*10^{-4}$	30 000	$3{,}09*10^{-4}$
Technotope	18 000	$1{,}7*10^{-4}$	18 400	$1{,}89*10^{-4}$

The Biotope Method requires that the digit accuracy of the results mirror the uncertainty in underlying data. The site with the lowest quality level decides the digit accuracy in the aggregated result. In this case 54,9% of the sites were studied with quality level A. I the revision 2017, 75% of the sites were with quality A. In this study is a lower level achieved compared with the revision 2017. The reason why the figures for quality level A differs is that a mistake was found in the calculation for 2017 that has now been corrected. Another reason for the change in figures seen from the previous update is that Bergeforsen is now updated according to quality level A. This means that the proportion of critical biotope has decreased, and the proportion of rare biotope has increased. During the previous update, Bergeforsen was described according to division keys.

A comparison of the results from the environmental risk assessment to corresponding values from the 2017 Vattenfall EPD for the hydro power are shown in Table 24. The main differences are the decrease of oil and diesel, SO_2 gasified copper and dust. This is mainly due to an update in the number of turbines, generators and transformers.

Table 24. Comparison between values for potential emissions per kWh from ERI 2017 and ERI 2020.

Category	**2020 (g/kWh)**	**2017 (g/kWh)**
Oil/diesel/petrol	10^{-5}	10^{-4}
Carbon dioxide	10^{-5}	10^{-5}
Carbon monoxide	10^{-7}	10^{-7}
Sulphur dioxide	10^{-8}	10^{-8}
Gasified copper	10^{-7}	10^{-6}
SF_6	10^{-6}	10^{-6}
Dust	10^{-7}	10^{-7}

Mandatory statements References

Detail from indside Söderforsen hydro power plant in Sweden, (cropped image, photo: Jennie Pettersson)

6. Information from the Certification Body and Mandatory Statements

6.1. Information from the Certification Body

This EPD® has been verified within Vattenfall's EPD® Management Process. The independent verifiers Caroline Setterwall, Hitachi ABB Power Grids, Martin Erlandsson, IVL and Lasse Kyläkorpi, Vattenfall AB, confirm that the product does not violate 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 2019-09-18, and Product Category Rules (PCR) CPC 171 version 4.11, 2020-03-16). This certification is valid until 2026-01-12.

6.2. Verification of Vattenfall's EPD® Management Process

Vattenfall's EPD® management process is third party verified annually, last review was made 2020-10-19. Bureau Veritas Certification, accredited by SWEDAC, the Swedish Board for Accreditation and Conformity Assessment, hereby confirms that Vattenfall's EPD® Management Process follows the requirements of EPD International AB expressed 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 from different EPD® programmes may not be comparable. When comparisons are made between different products in this product category it should be noted that energy can be supplied through different energy carriers like heat/steam or electricity, but the amount of kWh needed will differ with different energy carriers due to different energy quality and conversion/distribution efficiencies.

6.3.2. Omissions of Life Cycle Stages

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

6.3.3. Means of Obtaining Explanatory Materials

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

6.3.4. Information on Verification

EPD® programme: **The EPD® system managed by EPD International AB as a subsidiary to IVL Swedish Environmental Research Institute, www.environdec.com**	
Product Category Rules: **Electricity, steam and hot water generation and distribution, version 4.11, CPC 171 Electrical Energy**	
PCR review was conducted by: **The Technical Committee of the International EPD® system. Chair: Claudia A. Peña. Contact via info@environdec.com**	
Independent third-party verification of the declaration and data, according to ISO 14025:2006 **X EPD® Process Certification** **has been performed within Vattenfall's certified EPD® Management process.**	
Internal and external verifiers: **Caroline Setterwall, Hitachi ABB Power Grids, Lasse Kyläkorpi, Vattenfall AB and Martin Erlandsson, IVL**	
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: 2026-01-12**
Procedure for follow-up of data during EPD validity involves third-party verifier **X No**	

7. References

Reports

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

- Technology and Environment
- Beskrivning av valda anläggningar (Swedish only)

The following reports and guiding documents can be downloaded at Vattenfall's webpage:

- The Biotope Method (2015) The Biotope Method, (Kyläkorpi et al., 2005 and Grusell E., 2015): https://group.vattenfall.com/uk/siteassets/images/vatt_3238_broschyr_biotopmetoden_eng_h.pdf

Guidelines

- Product Category Rules, CPC 171 Electrical Energy, version 4.11.
- General Programme Instructions (GPI) for an environmental product declaration, EPD®, version 3.01.
- ISO 14025 on Type III environmental declarations.
- ISO 14040 and ISO 14044 on Life Cycle Assessments (LCA).

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

Databases:

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

Contact information:

For more information about Vattenfall: *www.vattenfall.com*

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

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

Specific questions regarding environmental issues in Vattenfall's Hydropower should be directed to Richard Holmgren, Head of Environment BU Hydro, telephone +46-920-77175 or e-mail: Richard.holmgren@vattenfall.com