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Vattenfall AB Nordic Generation´s Certified Environmental Product Declaration EPD of Electricity from Vattenfall´s Nordic Hydropower

VATTENFALL

CONTENT

1 INTRODUCTION

1.1 The Product

This document constitutes the Certified Environmental Product Declaration for the electricity generated at Vattenfall AB Nordic Generation's (below called Vattenfall) hydropower plants in the Nordic countries.

The declared product is 1 kWh of electricity (the funtional unit) generated and thereafter distributed to the customer during the reference year 2003.

Some of the power stations 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 relatively evenly distributed throughout the year, requiring no other forms of electricity generation.

1.2 The Declaration and the System

Certified Environmental Product Declarations, EPD®, are based on Life Cycle Inventories, LCI, supported by the characterization of a number of given environmental impact categories. EPD® has been established as a prime vehicle for industry in the communication of environmental impact to professional procurers.

This is an EPD® in accordance with the system administered by the Swedish Environmental Management Council (http://www.environdec.com). EPD® is the Swedish application of ISO 14025, Type III environmental declarations. The system and its application are described in MSR 1999:2.

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

- Product category rules, PSR 2004:2, ver.1.0, Product-Specific Requierments (PSR) for preparing an environmental product declaration (EPD®) for Electricity and District Heat Generation
- Requirements for Certified Environmental Product Declarations, MSR 1999:2
- ISO DIS 14025 on Type III environmental declarations
- ISO 14040-14043 on Life Cycle Assessments (LCA)

This EPD® contains certifiable sections in accordance with rules and regulations. In addition, a partly qualitative, partly quantitative, and verifiable description of environmental impact is presented. Assessment of impact on biodiversity is specifically included, based on a method called The Biotope Method© (Blümer and Kyläkorpi, 2001). Vattenfall has developed this method as a tool to quantify environmental impact on biodiversity resulting from land use. The method has been tested on hydropower sites, nuclear power sites, uranium mines, transmission lanes, extraction of forest residues, wind power plants, and on a waste incineration plant. As a complement to LCI, an Environmental Risk Assessment (ERA) has been conducted for the potentially environmentally harmful emissions that may result from abnormal incidents and accidents.

1.3 Vattenfall, LCA, and Environmental Efforts

Vattenfall has employed LCA for several years and accumulated competence and experience as well as an extensive database.

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

- Electricity is used in the manufacturing of virtually every product. Information regarding resource use in electricity 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 addible life cycle data as inputs to their own EPD® and LCA.

- It provides a basis for professional procurement, private as well as public sector, in permitting comparison of different power sources and different producers. This creates an incentive for electricity producers to reduce their use of resources and the impact on the environment caused by their systems.

- It is an effective instrument in the continuing environmental efforts within Vattenfall, the objective being constant improvement.

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.

Questions concerning this EPD® should be directed to Birgit Bodlund, Vattenfall AB Nordic Generation, SE-162 87 Stockholm, telephone +46 8 739 5000 (birgit.bodlund@vattenfall.com).
For additional information about Vattenfall, please visit our web site at http://www.vattenfall.com.

2 MANUFACTURER AND PRODUCT

2.1 Vattenfall AB Vattenkraft

Vattenfall AB Vattenkraft is accountable for Vattenfall AB Nordic Generation's production of hydroelectricity including generating plants annual reservoirs and short-term reservoirs. Vattenfall AB Vattenkraft is part of Vattenfall AB, SE-162 87 Stockholm. The technical and environmental aspects of hydropower are presented in Appendix "Technology and Environment".

Questions regarding Vattenfall AB Vattenkraft should be directed to Sören Ek, Björkvägen 13, SE-960 30 Vuollerim, telephone +46 (0)976 77918 (soren.ek@vattenfall.com) or Hans Lindström, SE-814 26 Älvkarleby, telephone +46 (0)26 837 81 (hans.lindstrom@vattenfall.com).

2.2 Quality, Work Environment, and Environmental Management (KAM)

Vattenfall AB Vattenkraft implements an environmental management system in accordance with ISO 14001 since 1999, and several of the plants have been registered under the Eco Management and Audit Scheme (EMAS). Since 2000, Vattenfall AB Vattenkraft implements a certified quality, work environment and environmental management system designated KAM. This system is based on the standards ISO 9001:2000, AFS 2001:1, and ISO 14001:1996. Questions regarding Vattenfall AB Vattenkraft and KAM should be directed to Sören Ek, Vattenfall AB Vattenkraft, Björkvägen 13, SE-960 30 Vuollerim, telephone +46 (0)976 77918 (soren.ek@vattenfall.com)

2.3 Selected Sites

The selected Nordic sites are majority- (or wholly) owned by Vattenfall AB, and are representative of geographic location, physical geography, type of plant, and size. The large-scale hydroelectric sites are arranged into so called river regions. Small-scale hydropower is assessed separately.

"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. Norrland 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.

River regions in Sweden	SOU 1996:155
Norra Norrland	1, 2
Mellannorrland	3, 4
Södra Norrland	5
Västsverige	8

Vattenfall has no large-scale hydropower in the remaining regions.

It is reasonable to combine 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 because it harbors several northerly and southerly species, and it consists entirely of 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 division between large-scale and small-scale hydropower is organizational and the capacity of the small-scale plants vary between 0.2–5.4 MW. One station is considered.

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 10 Finnish plants vary between 2–84 MW, which means that they are all considered large-scale according to the Finnish definition (small-scale <1 MW).

Vattenfall's hydropower generation from majority- (or wholly) owned plants during an average year is 31.5 TWh. Vattenfall disposes of 30.8 TWh. The selected hydropower stations generate 31 % of this electricity.

A total of 14 power plants in 8 rivers, one of which in Finland, are included in the assessment and presented in the table below. Comprehensive descriptions of the stations are presented in Appendix "Beskrivning av valda anläggningar".

River region	Coverage*	Rivers	Selected stations	Total average annual generation net, TWh	Vattenfall' s share of average annual generation net, TWh
Norra Norrland	29 %	Lule älv	Seitevare Harsprånget Porsi Boden	0.787 2.127 1.146 0.453	0.787 2.127 1.146 0.453
		Skellefte älv			
Mellannorrland	25 %	Ume älv	Juktan Umluspen Stornorrfors	0.088 0.399 2.293	0.088 0.399 1.704
		Ångermanälven	Stalon	0.537	0.537
		Indalsälven	Bergeforsen	0.730	0.338
		Ljungan/Gimån			
Södra Norrland	71 %	Dalälven	Älvkarleby	0.506	0.506
Göta älv	75 %	Göta älv	Olidan Hojum	0.401 0.854	0.401 0.854
Östra Finland	65 %	Vuoksi	Pamilo	0.252	0.252
Small-scale power	4 %	Upperudsälven	Upperud	0.010	0.010
All river regions including small-scale power	31 %			10.582	9.601

** The considered plants' portion of Vattenfall's total generation in the river region.*

Selected power plants.

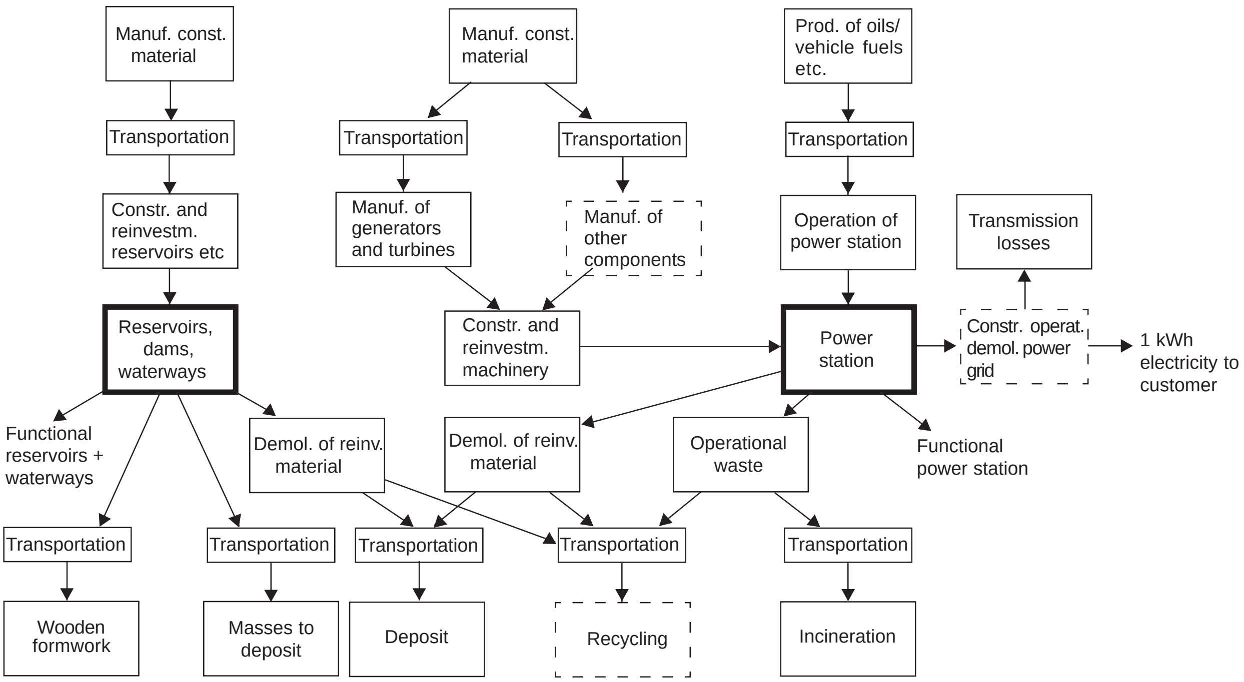
3 ENVIRONMENTAL PERFORMANCE

3.1 Background

This EPD® is based on an LCA for Vattenfall's hydropower generation in the Nordic countries during the reference year 2003. The functional unit is 1 kWh net electricity generated, and thereafter distributed to the customer. Resource use, emissions, and waste in conjunction with the construction, operation, and reinvestment of the power stations are included. Demolition of stations is excluded because of the improbability of that scenario. The reinvestment rate has been set at a level that provides for complete replacement of the power station during its lifetime, i.e. a fully functioning power station will leave the system at the end of the assumed lifetime. This results in greater environmental impact in the LCI than the alternative of including demolition. The level of uncertainty in the description of the impact on biotopes is reduced, because we avoid speculative assessments of how possible/desirable a return to unregulated flows would be, and of the process of re-colonization of affected biotopes from unaffected ones.

3.2 System Boundaries, Allocations, and Data Sources

The figure below is a simplified process tree with system boundaries for Vattenfall's hydropower generation.



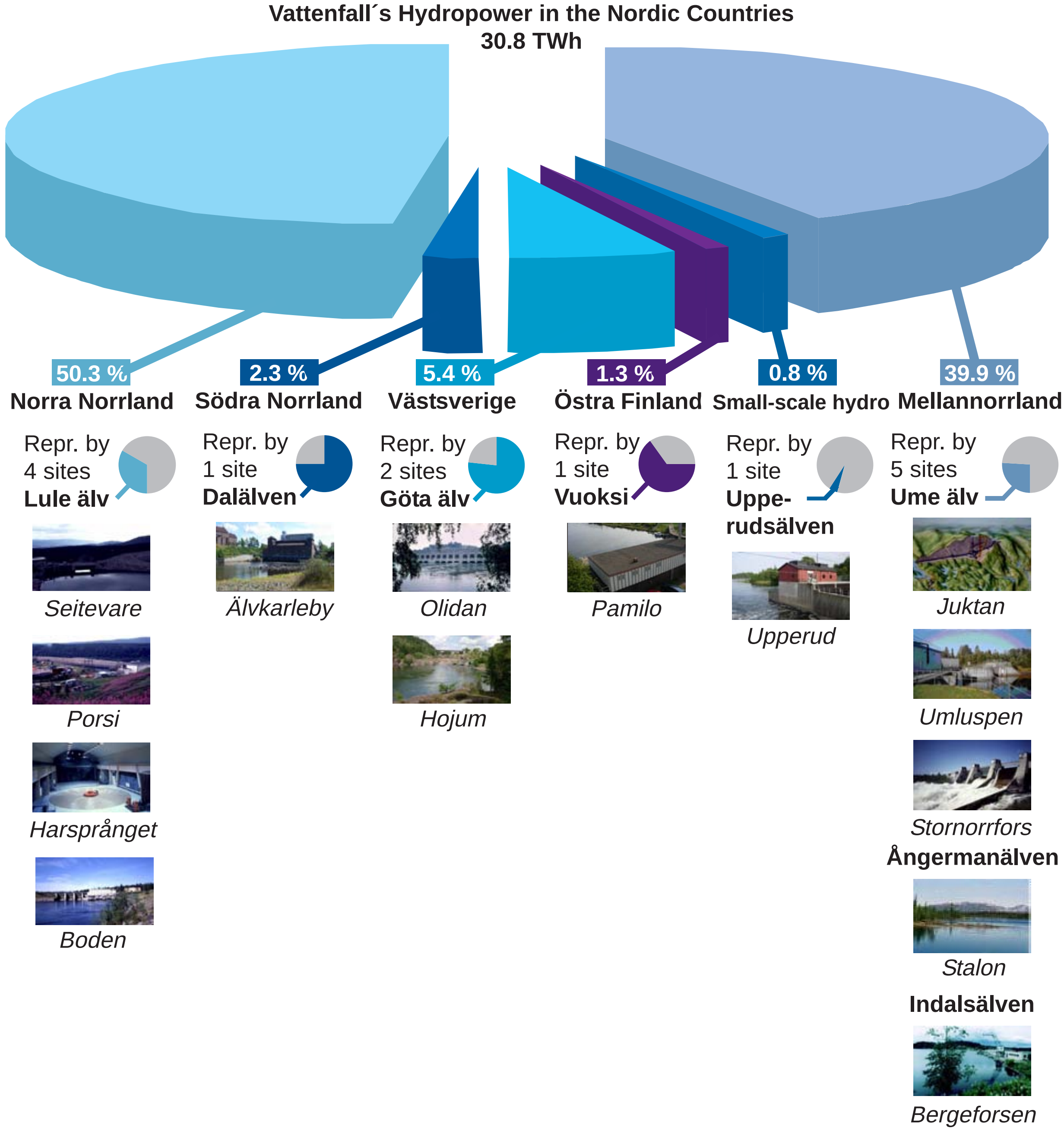
Overview process tree with system boundaries for LCI of Vattenfall´s hydropower. Dotted lines indicate exclusions.

The main function of the selected hydropower units is 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.

Selected stations have been individually assessed regarding construction and operation. Lifetimes are experience based and estimated to 60 years for machinery, and 100 years for dams, buildings, and waterways.

The Ecoprofile for Vattenfall’s hydropower in the Nordic countries is based on the following criteria:

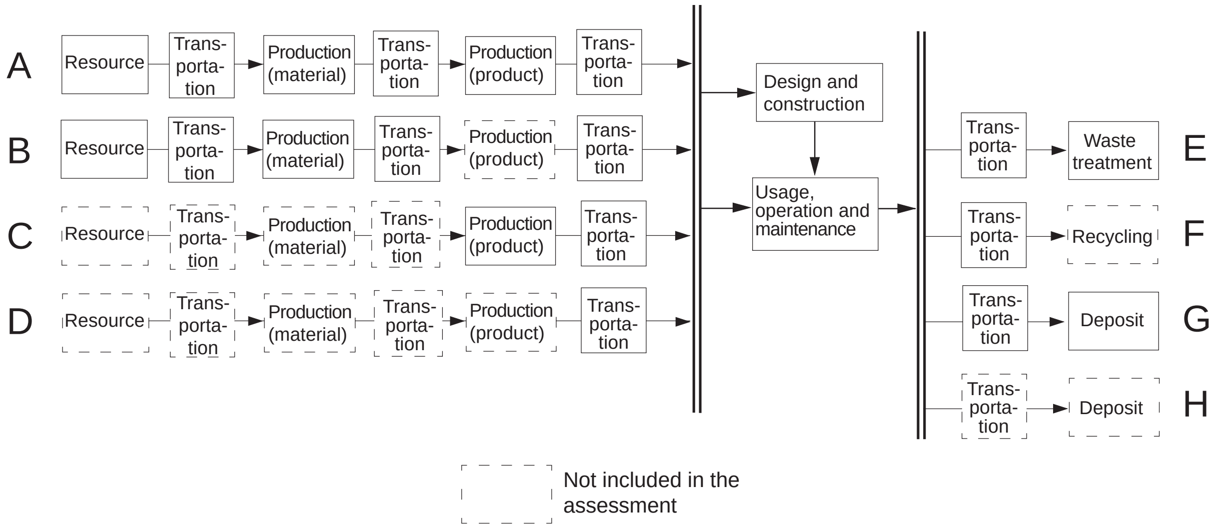
- Environmental impact is calculated for each individual station, and divided by its total production.
- Environmental impact from individual stations is weighted according to Vattenfall’s share of electricity generated in the river.
- Environmental impacts from rivers are aggregated into river regions, and weighted according to electricity generated.
- River regions and small-scale power are aggregated and weighted according to electricity generated.



The diagram shows the method of weighting environmental impact from selected sites to one Ecoprofile for electricity from Vattenfall’s hydropower in the Nordic countries (also table in section 2.3).

A general assumption is that building materials are produced and transported with modern methods.

Flows of consumables and waste in the various stages of the lifecycle are followed “from cradle to grave”, albeit with different scope. The figure below provides a rough picture of the various flows. The solid and dotted lines indicate inclusions and exclusions respectively.



Examples of materials from each branch:

Inflows:
- A Concrete, fuels, metals, most chemicals
- B Metals
- C Some gases
- D Some chemicals used in manufacturing processes of material

Outflows:
- E Combustible waste
- F Metals
- G Inert waste, stone, and rock
- H Subcontractor’s waste

Excluded from the lifecycle:

- Accidents and breakdowns (included in ERA, see section 5)
- Further treatment of scrapped material transported to recycling plant
- Consequences of land-use apart from emissions due to inundation (see section 4)
- Transportation and management of subcontractors’ waste

3.3 Production Phase

The outcome of the LCI calculations is presented in the Ecoprofile below and commented in sections 3.3.1–3.3.5. Numbers are expressed per 1 kWh generated electricity. Transmission losses depend on line voltage and are commented in section 3.3.10.

Ecoprofile		**Electricity Generation**	
Category	**Unit/kWh**	**Input**	**Output**
Resource use			
Non-renewable material resources:			
Aluminum in ore	g	$1.44 \cdot 10^{-4}$	
Bentonite	g	$1.80 \cdot 10^{-4}$	
Caliche	g	$3.92 \cdot 10^{-5}$	
Chromium in ore	g	$2.46 \cdot 10^{-4}$	
Coal**	g	$1.24 \cdot 10^{-2}$	
Copper in ore	g	$5.84 \cdot 10^{-3}$	
Crude oil**	g	$2.94 \cdot 10^{-3}$	
Dolomite	g	$6.77 \cdot 10^{-3}$	
Feldspar	g	$3.42 \cdot 10^{-8}$	
Flourite	g	$5.28 \cdot 10^{-6}$	
Gravel and sand	g	9.48	
Gypsym	g	$1.22 \cdot 10^{-2}$	
Iron in ore	g	0.383	
Lead in ore	g	$7.27 \cdot 10^{-4}$	
Limestone	g	0.372	
Magnesium in ore*	g	$1.06 \cdot 10^{-7}$	
Manganese in ore	g	$1.90 \cdot 10^{-4}$	
Natural gas**	g	$4.42 \cdot 10^{-3}$	
Nickel in ore	g	$1.56 \cdot 10^{-4}$	
Olivine	g	$1.07 \cdot 10^{-3}$	
Qartzite	g	$1.23 \cdot 10^{-2}$	
Rock	g	35.5	
Salt	g	$8.87 \cdot 10^{-3}$	
Soil and moraine	g	19.6	
Sulphur	g	$2.35 \cdot 10^{-4}$	
Volcanic rock	g	$1.42 \cdot 10^{-6}$	
Renewable material resources			
Wood (wet)	g	0.166	
Non-renewable energy resources			
Coal	g	0.197	
Crude oil	g	$9.57 \cdot 10^{-2}$	
Lignite	g DS	$9.45 \cdot 10^{-3}$	
Natural gas	g	$1.15 \cdot 10^{-2}$	
Uranium in ore	g	$3.15 \cdot 10^{-6}$	
Renewable energy resources			
Potential energy of water through the turbines	kWh	1.14	
Wood, dry substance	g DS	$1.96 \cdot 10^{-2}$	
Use of recycled material			
Aluminum scrap	g	$1.48 \cdot 10^{-5}$	
Copper scrap	g	$4.87 \cdot 10^{-3}$	
Lead scrap	g	$4.09 \cdot 10^{-5}$	
Steel scrap	g	$2.89 \cdot 10^{-2}$	

** Not tracked from the cradle   ** Material resource, i.e. not energy resource*

Pollutant emissions	Unit/kWh	Input	Output
Greenhouse gases	g CO_2-equiv. (100 years)		4.22
Ozone-depleting gases	g CFC-11 equiv. (20 years)		$3.82 \cdot 10^{-8}$
Acidifying substances	Mol H^+		$3.06 \cdot 10^{-4}$
Gases contributing to the formation of ground level ozone	g ethene-equiv.		$2.18 \cdot 10^{-4}$
Eutrophicating substances	g O_2		2.14
Emissions contributing to given emission categories:			
Carbon dioxide	g		4.19
COD, chemical oxygen demand to water	g		2.32
Halon-1301	g		$2.74 \cdot 10^{-9}$
Hydrocarbons, unspecified	g		$6.00 \cdot 10^{-4}$
Methane	g		$4.09 \cdot 10^{-4}$
Nitrogene oxides	g		$4.03 \cdot 10^{-3}$
Sulphur dioxide	g		$6.90 \cdot 10^{-3}$
Tetra chloromethane	g		$7.22 \cdot 10^{-9}$
Emissions of toxic and other substances to air, water and ground			
Arsenic	g		$8.51 \cdot 10^{-7}$
Coal-14 to air	kBq		$9.32 \cdot 10^{-7}$
Dioxine to air	g		$6.72 \cdot 10^{-12}$
Krypton-85 to air	kBq		$5.71 \cdot 10^{-2}$
Lead	g		$1.69 \cdot 10^{-5}$
Oil to ground	g		$2.94 \cdot 10^{-5}$
Oil to water	g		$5.02 \cdot 10^{-5}$
Particles to air	g		$9.95 \cdot 10^{-4}$
Polyaromatic hydrocarbons	g		$1.22 \cdot 10^{-8}$
Deposition of phosphor in river sediment	g		$1.47 \cdot 10^{-3}$
Other information			
Hazardous waste, fuel-related:			
High level radioactive waste	g		$9.11 \cdot 10^{-7}$
Intermediate level radioactive waste	g		$1.33 \cdot 10^{-5}$
Low level radioactive waste	g		$7.27 \cdot 10^{-6}$
Ash***	g		$1.90 \cdot 10^{-4}$
*Hazardous waste, non fuel-related****	g		$3.83 \cdot 10^{-3}$
*Other waste, non fuel related****			
Solid waste	g		1.89
Material to recycling:			
Aluminum	g		$3.20 \cdot 10^{-5}$
Copper	g		$4.85 \cdot 10^{-3}$
Concrete	g		0.867
Lead	g		$1.41 \cdot 10^{-3}$
Steel	g		0.100
Land Use:			
Area	m^2	$2.41 \cdot 10^{-2}$	
of which inundated	m^2	$1.99 \cdot 10^{-4}$	
Water use:			
Water****	g	5.98	
Input of material from the technosphere (agglomeration of about 50 substances)*****	g	$5.53 \cdot 10^{-3}$	

**** Not followed to the grave   **** Excludes water through turbines*

****** Agglomerate of inputs not tracked from the cradle*

MSR 1999:2 system requirements impose restriction on selection of data. Ecoprofile must not be distorted by more than 1 % in any specified emission category. The assessment is that the requirement is met.

The assessment contains data gaps because some substances are not tracked from the cradle. This is not a conscious choice, but rather a consequence of lacking data. The majority of substances not tracked from the cradle are chemicals, alloy metals or minerals used in subcontractors' processes. Regarding greenhouse effect and eutrophication, the dominant factor is emission from inundated land in reservoirs. Excluded manufacturing processes would probably contribute less than 1 %. Contribution to ground level ozone and acidification emanate mainly from production and transportation of predominant building materials concrete and steel, but also from transportation of blasted rock and fill material. Emissions from production of chemicals and minerals are included, but 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. All resource flows from nature in included processes (excluding gravel, sand, earth, water, and energy resources) aggregate to ca. 1 g material per kWh. The sum of all flows not tracked from the cradle is ca. 0.006 g/kWh. The substances not tracked from the cradle are mainly additives in oils, and iron sulfate used for cement production.

Production of raw material for machinery and components is included. Regarding manufacturing of turbines and generators, the production of raw material ending up as metal chips and cuttings is included. Manufacturing processes for other components such as steel gates, beams, girders, and transformers are excluded because of nonexistent data, but material waste in these processes is small compared to that from turbines and generators. Electricity and chemicals are used in the manufacturing of components, but the environmental impact from production of this electricity and these chemicals is small compared to the impact from all process stages in the production of raw materials such as steel and copper.

Inundation is the predominant cause of greenhouse gases and nutrifying substances. Exclusion of the contribution from manufacturing of components results in a minor underestimation of less than 1 % in these emission categories.

The major contribution to emission of acidifying substances and substances contributing to ground level ozone comes from transportation and production of materials. Exclusion of emission from manufacturing of components for construction & reinvestment results in an underestimation of 2 %. Emissions of ozone-depleting substances emanate mainly from incineration of operational waste and electricity generation – these data are collected from the specified database ETH 1996. Exclusion of some component manufacturing results in an underestimation of less than 1 % of ozone-depletion. Ozone-depleting substances are continually being phased out of use and because the applied generic data for incineration and electricity generation date from the mid-1990'ies the contributions are probably overestimated.

According to system requirements in MSR 1999:2: "… generic data can be used when specific data is lacking, and as a general rule, the sum of the contribution from processes described by generic data instead of specific data must not exceed 10 % of the contribution to the separate impact categories". If input data on material quantities is specific, and data from specified generic sources is used, then the LCI-result is considered specific according to PSR 2004:2. Specific data for the selected hydropower stations is applied regarding use of material, groundwork, and operation. Data for production of metals, sea and land transportation of raw material and components, as well as generation of electricity used by subcontractors emanate from specified sources in PSR 2004:2. Some data for materials and chemicals production, and operating data for working machines, dumpers, and cars are not specified, consequently data is collected from other sources. The sum of contributions from generic data exceeds 10 % in several emission categories.

The results for the phases manufacturing & reinvestment in machinery and the phase inundation are 90 %–100 % specific. PSR 2004:2 does not specify data sources regarding production of cement and groundwork, which are the predominant processes in construction & reinvestment in dams, and consequently 85 % of the contributions to the result are considered generic. The operation phase is dominated by inspection trips, i.e. staff transportation in small vehicles, for which data sources are not listed in PSR 2004:2, and consequently their contribution to the result is considered generic. Emissions of ozone-depleting substances emanates exclusively from processes included in specified databases (waste incineration and electricity generation). Emissions due to inundation are based on computations on inundated area and reservoir latitude, and are considered specific.
In summary:

Portion of the Ecoprofile result emanating from specific input data

Greenhouse effect	85 %
Ozone-depletion	100 %
Acidification	50 %
Ground level ozone	25 %
Eutrophication	99 %

3.3.1 Resource use

Real volumes of material resources have been applied in the calculation of environmental impact from production of raw materials for components and dams. This is also the case regarding reinvestments in machinery as well as concrete in dams. A basic assumption is that the power station will be completely renewed during its lifetime. The amounts of recycled material used in construction and reinvestments are reported separately, and quantities are based on industry standard rates of scrap used in the production of the respective metal.

Resource use in operation is derived from the environmental management system KAM and amended with experience-based data for a 60 years operation perspective, based on the technical standard of the power stations in the reference year 2003.

Electricity consumption is converted to renewable and non renewable energy resources as are fuels used in other processes. Hydropower is reported as used potential energy.

3.3.2 Emissions

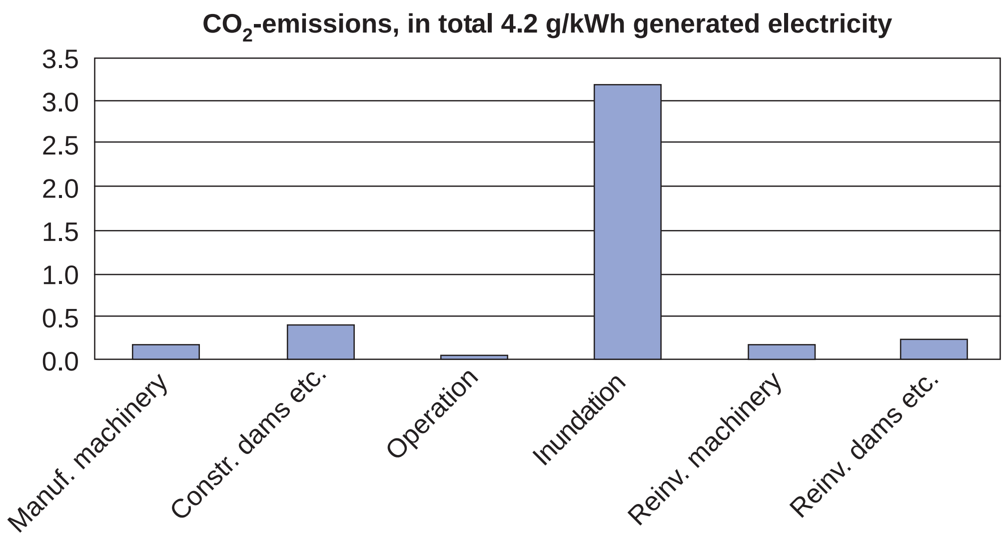
3.3.2.1 General

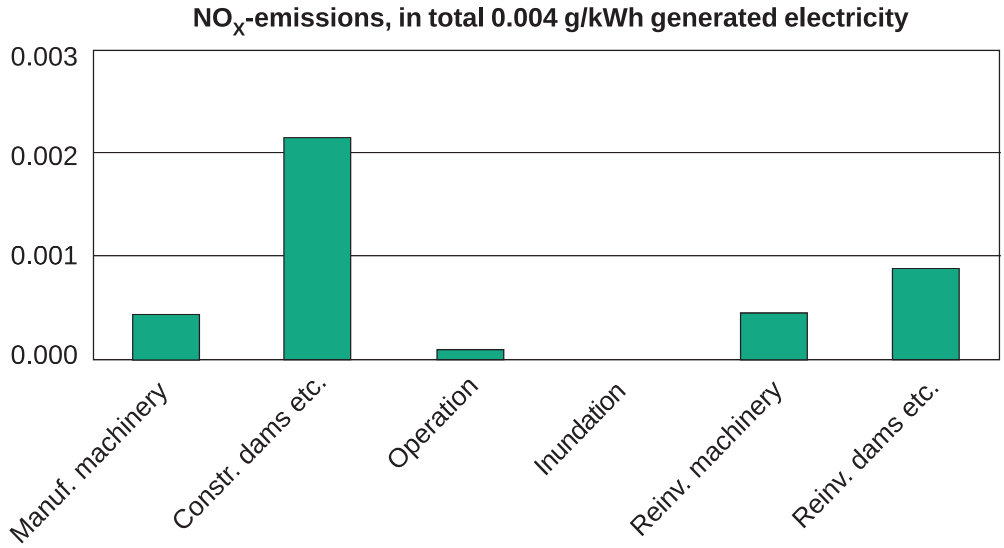
Weighting factors have been applied when contributions to impacts on greenhouse effect, ozone-depletion, acidification, ground level ozone, and eutrophication are added. Calculations and characterizations are in accordance with requirements in MSR 1999:2. Comparisons of CO_2-, SO_2- and NO_X-emissions are common in descriptions of environmental impact from different methods of electricity generation, and are reported below.

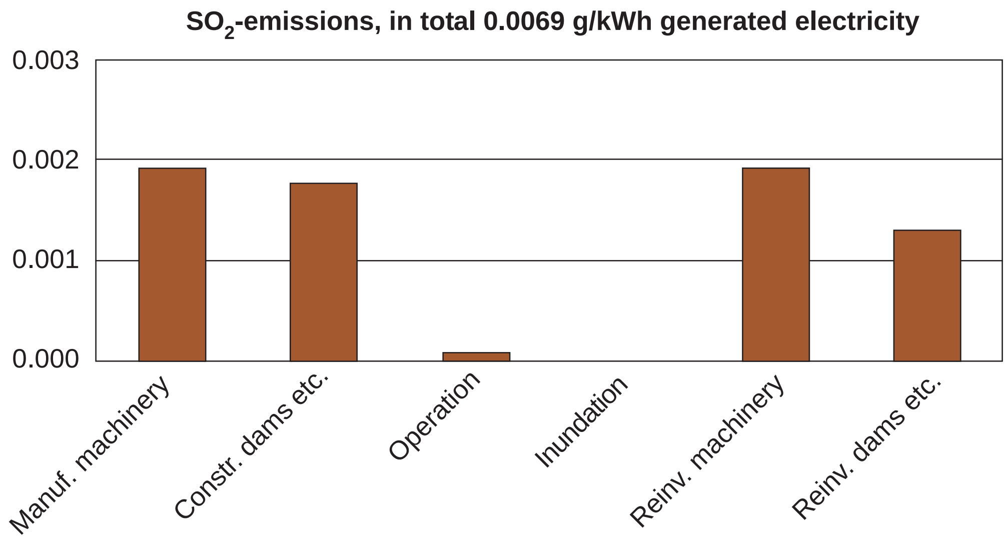
Emissions are aggregated in six lifecycle phases as shown in the diagrams:

Manufacturing machinery	Production of steel, copper, synthetics, oil, etc for turbines, generators, cables and electrical equipment etc.
Construction dams etc.	Blasting, handling of rock, stone and gravel, concrete reinforcements, steel constructions in waterways, buildings, incineration of wooden formwork etc.
Operation	Inspection trips, oil, incineration of oil waste etc.
Inundation	Emissions from inundated land for reservoirs.
Reinvestments machinery	As "Manufacturing machinery" above plus renewal of accumulators every 10 years, and transportation of scrapped material for recycling.
Reinvestments dams, etc.	25 % reinvestment in dams plus 100 % reinvestment of concrete (not buildings), 100 % of steel constructions in waterways.

Table of selected lifecycle phases.



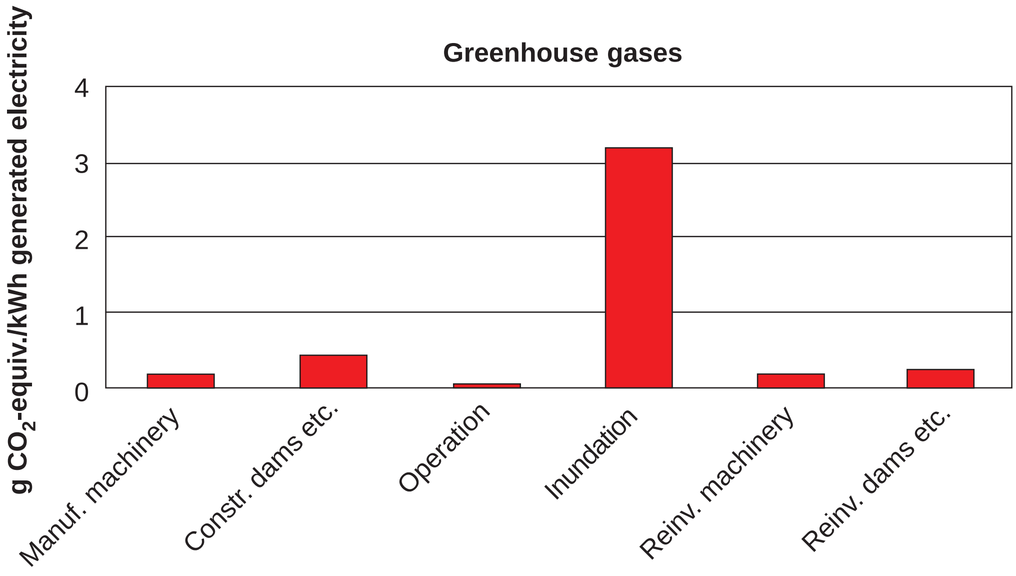




3.3.2.2 *Emissions of greenhouse gases*

Emissions of CO_2 dominate the contribution to greenhouse effect, and 75 % emanate from inundated land for reservoirs. Groundworks and construction of dams, waterways, and buildings contribute 15 % and manufacturing of machinery roughly 8 %, while the rest comes from inspection trips during operation.

Damming causes inundated land to release organic matter, which 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 new biomass generated in the water consumes CO_2. The net effect is calculated and reported for the lifetime of 100 years (for reservoirs), and distributed over electricity generation in the same amount of time.



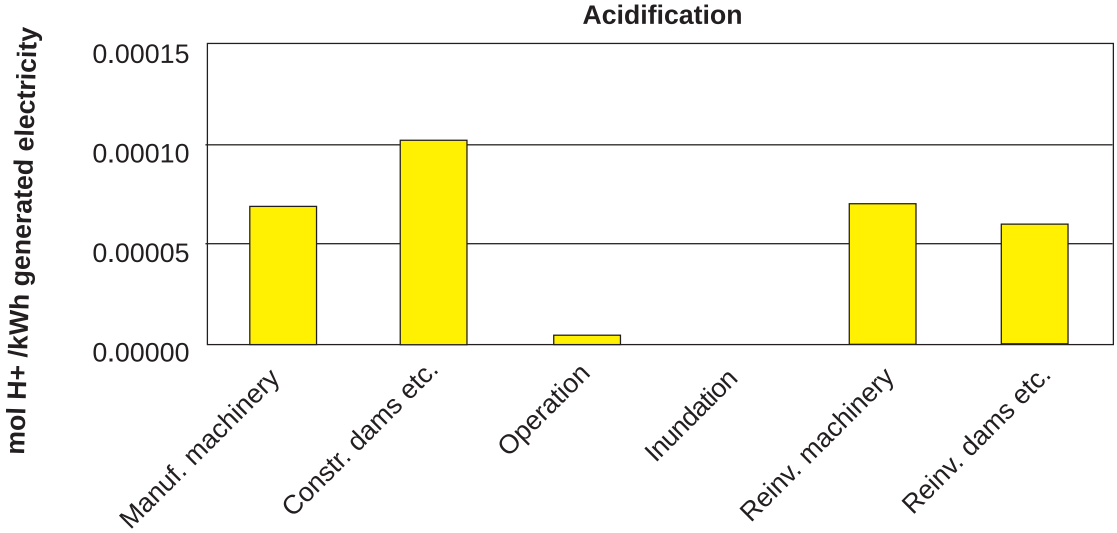
3.3.2.3 *Emissions of ozone-depleting gases*

Substances contributing to ozone-depletion are used in four of Vattenfall's hydropower plants but no emissions were recorded during the reference year 2003. The emissions that have been included during the life cycle stem from incineration of wooden formwork and waste oil, and from the generation of electricity used to manufacture materials etc. These emissions are probably overestimated, because the data applied is from the mid-1990s, and ozone-depleting substances have been and are being phased out throughout the western world.

3.3.2.4 *Emissions of acidifying substances*

Emissions of NO_X and SO_2 are the main contributors to acidification, accounting for ca. 29 % and 70 %, respectively. The emissions emanate mainly from lifecycle phases construction and reinvestments in machinery and dams. Production of copper contributes roughly one third, and incineration of wooden formwork roughly 25 %.

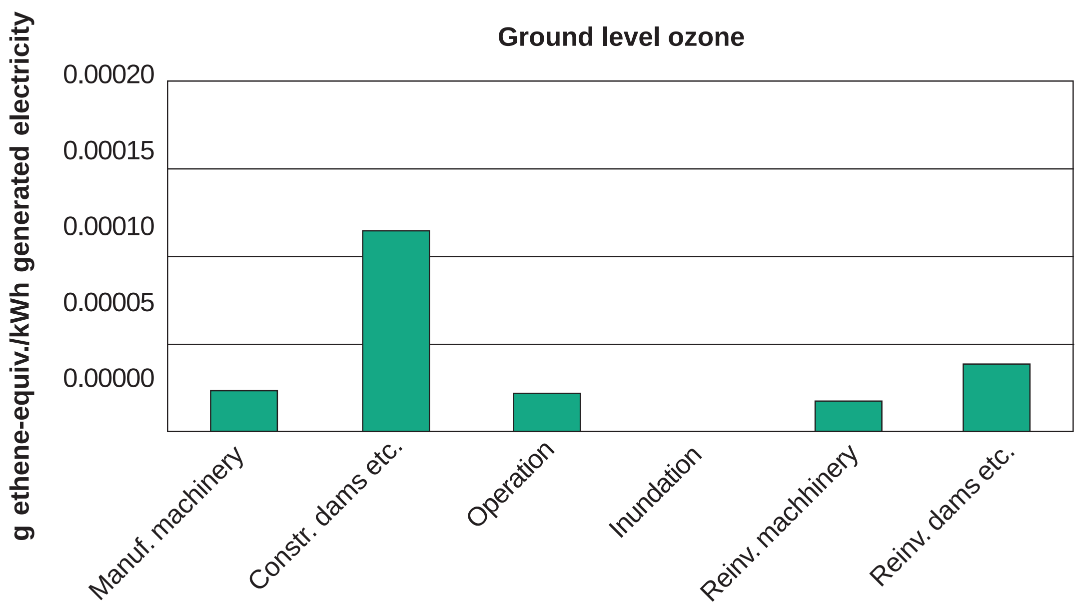
	Manufacturing & reinvestments, machinery	**Construction & reinvestments, dams**	**Operation**
Copper production	37 %		
Steel production	6 %		
Transportation	2 %		
Concrete production		6 %	
Production of material for reinforcements and intake gates etc.		3 %	
Groundwork		17 %	
Incineration of wooden formwork		27 %	
Inspection trips, and incineration of waste oils			2 %
Total	**45 %**	**53 %**	**2 %**



3.3.2.5 Emissions of gases potentially contributing to ground level ozone

In the presence of nitrogen oxides and sunlight various types of hydrocarbons in the air may give rise to photochemical oxidants, primarily ozone. Extensive groundwork etc. during construction and reinvestments of dams and waterways contribute 25 % of hydrocarbon emission, incineration of formwork 20 %, and aggregate from concrete and explosives another 20 %. Production of copper, steel and oil contribute 20 % during the construction & reinvestment phase. Contributions during the operation phase are dominated by incineration of waste oil, followed by inspection trips and production of various oils.

	Manufacturing & reinvestments, machinery	Construction & reinvestments, dams	Operation
Copper production	9 %		
Steel production	3 %		
Production of lubricating, insulating, and hydraulic oils	3 %		
Production of synthetic insulation	2 %		
Transportation	2 %		
Groundwork		26 %	
Incineration of wooden formwork		20 %	
Concrete production		13 %	
Production of explosives		7 %	
Production of material for reinforcements and intake gates etc.		4 %	
Incineration of waste oils, production of oils, and inspection trips			10%
Total	**19 %**	**71 %**	**10 %**

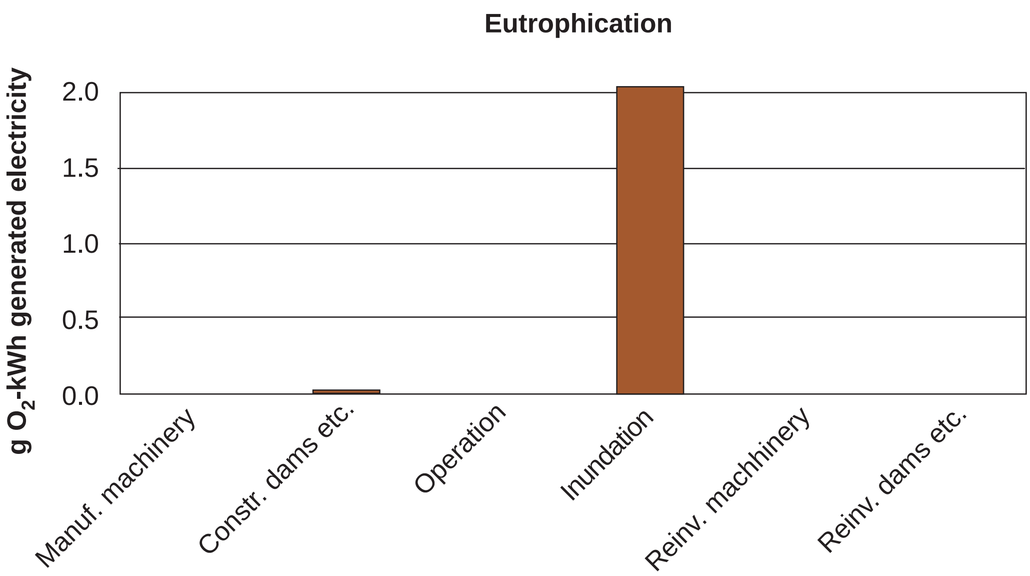


3.3.2.6 Emissions of substances potentially contributing to eutrophication

Oxygen consuming and nutrifying substances (cause of eutrophication) are primarily formed in conjunction with inundation, as carbon released from the inundated soils reacts with oxygen in the water. Inundation also leads to the release of nutrients. Phosphor is one of the two nutrients (the other is nitrogen) that influence the production of plant life both on land and in water. In freshwater, phosphor is the substance that limits production, while nitrogen is the limiting substance in the sea. Regulation causes an increase in the sedimentation of phosphor, thus making it inaccessible to the flora and fauna. Retention exceeds release, i.e. regulated rivers contain less phosphor than natural rivers, and this negative emission of phosphor has been included in the calculations.

Other contributions come from NO_X-emissions related to manufacturing of materials and to transportation.

COD (organic matter from inundated land)	108 %
Phosphor emissions minus phosphor retention	-10 %
NO_X-emissions	1 %



3.3.2.7 Emissions contributing to given emission categories (see also sections 3.3.2.2–3.3.2.6)

The eight parameters given under this heading in the Ecoprofile constitute 98–100 % of the contributions to the reported emission categories: greenhouse gases, ozone-depleting substances, acidifying substances, gases contributing to the formation of ground level ozone, and eutrophying substances.

3.3.2.8 Emissions to air, ground, and water of toxic and other substances

Arsenic, lead, dioxins, polyaromatic hydrocarbons, and oil to water and ground are toxic substances that are reported as inventory data in the Ecoprofile, as are emissions of particulate matter and radioactive isotopes required by PSR 2004:2. These emissions are, relatively speaking, limited and occur above all in conjunction with mining and processing of metals, production of cement, incineration, and electricity generation. Less than 85 % of the emissions of oil to water emanate from the hydropower stations, the remainder mainly in conjunction with oil extraction. The hydropower stations cause 99 % of oil spills to ground.

Minor, long-term leakages of oil from turbines are difficult to detect. These emissions are very small in relation to the amount of electricity generated, at most 0.1 µl/kWh. Seitevare has one of the lowest discharges (58 m^3/s) of the selected stations and an assumed oil seepage of 100 litres during a month results in a mean amount of oil in the water of 0.00000007 %. The emissions applied in the calculations are estimates by the operating staff based on experiences of machinery/equipment in 2003.

3.3.2.9 Retention of phosphor in river sediments

The retention of phosphor described in section 3.3.2.6 results in an accumulation of phosphor in river sediments.

3.3.3 Other information – Waste and recycling

3.3.3.1 Hazardous waste

Hazardous waste is accounted for in the categories fuel-related and non fuel-related. Fuel-related hazardous waste consists of radioactive waste from nuclear power operations and ash from biofuel and fossil fuel power generation – these are followed to the grave.

Non fuel-related hazardous waste consists mainly of filter dust and chemicals from various subcontractors. Oil residues from power stations are not included under this heading because they are incinerated and thus converted to emission to air.

3.3.3.2 Other waste

Other waste is mainly mining waste. Environmental impact from depositing of excavated and blasted materials from construction of dams and waterways has been included in the calculations and thus the amounts are not reported as waste.

3.3.3.3 Recycling of material

Manufacturing of generators and turbines result in considerable amounts of scrap metal, which is recycled. Substituted components are assumed sent to dismantling and recycling. Total quantity of materials for recycling is reported in the Ecoprofile.

3.3.4 Other

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 is used as sealant. The sealant is not included, but considering the small volumes involved (ca. 1 cubic meter per turbine per year), insignificant environmental impact is assumed.

3.3.5 Land Use

The Ecoprofile accounts for dry land use as well as inundated land for reservoirs. The impact of land use is presented in chapter 4, LAND USE AND BIODIVERSITY.

3.3.6 Inflows and outflows not tracked from cradle or to grave

3.3.6.1 Inflows not tracked from the cradle

Some minor inflows have not been tracked from the cradle due to lacking data. The effect is an underestimation of environmental impact; see also section 3.3 Production Phase regarding the 1 % requirement.

3.3.6.2 Outflows not followed to the grave

By-products are not followed to the grave, and no environmental impact has been allocated to such by-products. The effect is an overestimation of environmental impact.

3.3.7 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 perceived differently.

The most characteristic outdoor noise from hydropower generation is the sound of streaming water at above ground stations. These sound levels are, however, lower than pre regulation and more often than not considered pleasant.

Noise levels from transformers are generally moderate (45–60 dB), but the frequencies are low (<100 Hz). This means that unfavorable 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 in unfavorable conditions can be disturbing at distances of up to 1 km. At Porjus, levels of 92 dB(A)[1] have been measured at 1 meter, and of 42 dB(A)[1] at 800 meters from the transformer.

Power lines over 70 kV may give rise to noise (corona noise). Sound levels are moderate, 45 dB(A)[1] at 25 meters, decreasing rapidly.

3.3.8 Dominance analysis and conclusions

Contributions to environmental impacts during different lifecycle phases:

	Manufacturing & reinvestments, machinery	Construction & reinvestments, dams	Operation	Inundation
Greenhouse effect	9 %	16 %	1 %	75 %
Ozone-depletion	1 %	98 %	1 %	
Acidification	45 %	53 %	1 %	
Ground level ozone	19 %	71 %	10 %	
Eutrophication	0 %	1 %	0 %	99 %

Inundation in reservoirs dominates impacts on greenhouse effect and eutrophication. If the facilities were to be used beyond the assumed 100 years emission per generated kWh would decrease since there would be same amount of carbon in inundated land but a larger amount of kWh generated.

Emissions of ozone-depleting substances are dominated by incineration of wooden formwork.

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

Acidification is caused by production of materials – copper, steel, and concrete (over 50 %), by incineration of wooden formwork and waste oils (almost 30 %), and by groundwork and transportation (ca. 20 %).

Hydrocarbon emissions emanate from production of materials and oils (ca. 40 %), from groundwork and transportation (ca. 30 %), and from incineration of wooden formwork and waste oils (ca. 30 %).

At the Porsi power station one of the three standard generators was substituted in 2001 by a Powerformer, which generates electricity at a voltage permitting direct feed to the grid. This reduces transformer losses and thus increases average annual production. The unit connected to the Powerformer is a fixed blade propeller turbine requiring a specific flow for optimal generation and therefore runs less than the Kaplan turbines with adjustable blades. The result is that average annual production for the station increased only marginally.

Environmental impact per generated kWh decreases as average annual production increases, but because system boundaries are changed in PSR 2004:2 (see section 3.3.9) no improvement in the Ecoprofile of Porsi is discernible.

One of the selected power stations, Upperud, is a small-scale station. Small-scale stations are generally so called run-of-river plants, i.e. they have no reservoir. Small-scale power stations are mainly located south of the river Dalälven in watercourses that have streaming water all year round, i.e. a reservoir is not required for relatively constant production. The absence of reservoir means no emissions from inundated land. The net effect is considerably lower impact on greenhouse effect and eutrophication than for a station with reservoir.

Environmental impact per kWh in conjunction with construction, reinvestment, and operation is consistently higher from the selected small-scale hydropower station than that from average large-scale hydropower stations. Investment cost per MW and Ecoprofile per kWh are co-variant.

3.3.9 Differences vs. previous EPD® for the rivers Ume älv and Lule älv

There are several differences between this EPD® and previous EPD® for Vattenfall's hydropower from the rivers Ume älv and Lule älv, which were certified in 2002.

This EPD® incorporates power stations in the following rivers: Ume älv, Lule älv, Indalsälven, Ångermanälven, Dalälven, Göta älv, Vuoksi in Finland, and Upperudsälven (small-scale). Inundation is lower in the Swedish rivers other than Ume älv and Lule älv, which leads to less inundation per generated kWh. Inundation in Finland is higher because of low heads. The resulting, weighted environmental impact from inundation in Vattenfall's hydropower generation is somewhat reduced.

This EPD® is based on a later version of PSR with changed requirements, which entails a.o. new data sources for copper, steel, and transportation and addition of processes for waste incineration and deposition. The production of raw material ending up as metal scrap during manufacturing of generators and turbines has been added. The new data for production of metals is based on predominantly fossil fuelled electricity rather than as previously based on the Swedish electricity mix.

The table below compares the outcomes of this EPD® with those of the weighted result from the previous EPD®s for hydropower from the rivers Ume älv and Lule älv:

Emissions	Unit	Vattenfall's Nordic Hydropower 2005	Weighted values Ume älv and Lule älv 2002
Greenhouse gases	g CO_2-equiv. 100 years	4.22	4.89
Ozone-depleting gases	g CFC-11 equiv. 20 years	$3.82 \cdot 10^{-8}$	$9.03 \cdot 10^{-9}$
Acidifying substances	Mol H+	$3.06 \cdot 10^{-4}$	$1.41 \cdot 10^{-4}$
Ground level ozone	g ethene-equiv.	$2.18 \cdot 10^{-4}$	$1.90 \cdot 10^{-4}$
Eutrophication	g O_2	2.14	2.72

Emissions of pollutants in the EPD® for Vattenfall's Nordic Hydropower, reference year 2003 (certification year 2005) compared with the weighted result for EPD®s for the rivers Ume älv and Lule älv, reference year 2000 (certification year 2002).

3.3.10 Distribution of electricity

The description of distribution of electricity is based on Vattenfall's assessment of the transmission system amended with new data on transmission losses at different voltages.

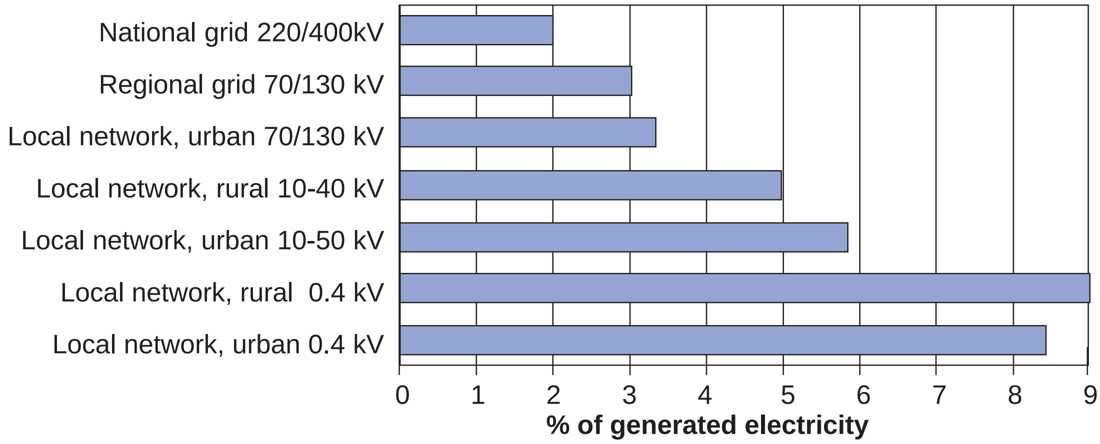
The grid comprises transmission and distribution systems consisting of numerous lines, cables, transformers, and switchyards. The national grid voltage is stepped down to lower voltages for distribution on regional, and finally on local networks to end users. Large customers, e.g. certain industries, are frequently connected directly to regional or distributional grids (6–130 kV), while small users such as single households are connected at 0.4 kV to low voltage local networks.

The functional unit for distribution of electricity is 1 kWh transferred electricity

Transmission losses

Transmission losses depend on several factors, such as distance, load, station feed voltage, and user connection voltage. The diagram shows average transmission losses in various situations. When a hydropower plant feeds at national grid voltage to an industrial customer connected to the regional network the average transmission loss is ca. 3 %.

Average transmission losses at different voltages accumulated from the national grid – percentage of generated electricity.



Environmental impact

Transmission losses lead to reduced delivery of useful kWh, which must be compensated by additional generation of electricity, and consequently resource use and emissions are allocated to a smaller amount of kWh. The table below shows some parameters for an industrial consumer connected at 130 kV.

Emissions	Unit/kWh	Generation	Comp. for losses	Delivered
Greenhouse gases	g CO_2-equiv. (100 years)	4.22	0.127	4.35
Ozone-depleting gases	g CFC-11 equiv. (20 years)	$3.82 \cdot 10^{-8}$	$1.14 \cdot 10^{-9}$	$3.93 \cdot 10^{-8}$
Acidifying substances	Mol H^+	$3.06 \cdot 10^{-4}$	$9.17 \cdot 10^{-6}$	$3.15 \cdot 10^{-4}$
Ground level ozone	g ethene-equiv.	$2.18 \cdot 10^{-4}$	$6.54 \cdot 10^{-6}$	$2.25 \cdot 10^{-4}$
Eutrophying substances	g O_2	2.14	$6.41 \cdot 10^{-2}$	2.20
Emissions contributing to given emission categories				
Carbon dioxide	g	4.19	0.126	4.32
COD, chemically oxygen consuming substances	g	2.32	$6.95 \cdot 10^{-2}$	2.39
Halon-1301	g	$2.74 \cdot 10^{-9}$	$8.22 \cdot 10^{-11}$	$2.82 \cdot 10^{-9}$
Hydrocarbons, unspecified	g	$6.00 \cdot 10^{-4}$	$1.80 \cdot 10^{-5}$	$6.18 \cdot 10^{-4}$
Methane	g	$4.09 \cdot 10^{-4}$	$1.23 \cdot 10^{-5}$	$4.21 \cdot 10^{-4}$
Nitrogen oxides	g	$4.03 \cdot 10^{-3}$	$1.21 \cdot 10^{-4}$	$4.15 \cdot 10^{-3}$
Sulfur dioxide	g	$6.90 \cdot 10^{-3}$	$2.07 \cdot 10^{-4}$	$7.11 \cdot 10^{-3}$
Tetra chloromethane	g	$7.22 \cdot 10^{-9}$	$2.17 \cdot 10^{-10}$	$7.43 \cdot 10^{-9}$

"Building-operating-dismantling" power lines have environmental impact, predominantly in the building phase. Production of metals, concrete, and insulation material generate emissions via the consumption of electricity and fuel.

Additional environmental impact stems from emissions of small amounts of arsenic, zinc, and cadmium from poles and towers, as well as some lead from old cables. Such emissions are, however, quite local, within 0.2 meters of source.

The power grid also has 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 biodiverse than homogenous areas. Wider lanes may constitute barriers that may cause fragmentation for some woodland species.

Electro-magnetic fields (EMF) appear in the vicinity of all electrical equipment and power lines. Research results so far do not warrant exposure limits for low-frequency fields. Vattenfall follows the precautionary principle exemplified in general recommendations from the Swedish Radiation Protection Authority and the Swedish Work Environment Authority. This implies reducing fields that deviate considerably from normality in each specific case.

4 LAND USE AND BIODIVERSITY

This section is based on a separate report in which the application of the method is described in more detail. This report in Swedish can be ordered from Vattenfall.

4.1 Background

The 14 selected power stations use a total of 74 850 hectares, predominantly river-, lake, and annual reservoirs, which amount to 70 320 hectares.

	Lule älv	Ume älv	Ånger-manälven	Indals-älven	Dalälven	Göta älv	Vuoksi Finland	Upperuds-älven	Total
Total area (ha)	10 352	29 514	6 874	1 980	189	381	25 470	91	**74 850**
% of total area	13.8	39.4	9.2	2.6	0.3	0.5	34.0	0.1	**100**

Land use in selected rivers.

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 effect for entire catchments should be quantified from a representative selection of power stations. Norra Norrland is represented by stations in the river Lule älv. Mellannorrland is represented by stations in the rivers Ume älv, Ångermanälven, and Indalsälven. Södra Norrland and Västsverige are represented by stations in the rivers Dalälven and Göta älv respectively.

4.2 The Biotope Method©

The Biotope Method© (Blümer and Kyläkorpi, 2001) 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. The fundamental assumption is that the changes in biodiversity, which are caused by the utilization of land and water, are reflected in losses and gains of the various types of biotope. Quantification is carried out by measuring the areas of various types of biotope and then classifying and characterizing them for Nordic conditions, in part on the basis of ArtDatabanken's (at the Swedish University of Agricultural Sciences), red-list of endangered species - www.artdata.slu.se

The Biotope Method© considers impacts on biodiversity which can be directly related to a specific activity. Indirect or derived impacts, e.g. *fragmentation*[1] and *barrier effects*[2] are outside the scope of the method.

[1] 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.

[2] 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.

Biotopes are characterized as follows:

Critical Biotope – Biotope, which harbors, or has the potential to harbor, red-listed species.
Rare Biotope – Biotope, which deviates from surrounding areas by high species diversity, a profusion of regionally rare species or by an abundance of key features.
General Biotope – Remaining biotopes, i.e. those that cannot be put in any of the other categories.
Biotope Loss – Areas lacking the preconditions for biological production (e.g. paved areas and buildings).

The quality of the results depends on the quantity and quality of the underlying data, as well as the time put into the effort. The more and the better data that is available, the higher quality levels are possible to reach. If less effort is put into gathering relevant data, the method is designed to result in a lower quality level and to give a higher impact.

The diagram below presents an outline of how the distribution of different biotope categories may be changed by a project.

The Biotope Method© principle.

4.3 Result

The Biotope Method© comprises different quality levels, where the highest is achieved by performing site inventories both before and after development. At lower levels, various tools such as standard charts and characterization keys may be used. The land use and quality levels used at the various stations are specified in the table below, where A1 is the highest and C2 the lowest level.

River Region	River	Stations	Area, ha	Quality-level
Norra Norrland	Lule älv	Seitevare	8 484	B1
		Harsprånget	258	A2
		Porsi	1 307	C1
		Boden	303	C2
Mellannorrland	Ume älv	Juktan	9 433	B1
		Umluspen	18 774	C2
		Stornorrfors	1 306	C1
	Ångermanälven	Stalon	6 874	C1
	Indalsälven	Bergeforsen	1 980	C1
Södra Norrland	Dalälven	Älvkarleby	189	C1
Västsverige	Göta älv	Olidan	381	C1
		Hojum		C1
Östra Finland	Vuoksi	Pamilo	25 470	C1
Small-scale	Upperudsälven	Upperud	91	A1

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 ies and earlier. The large proportion of quality levels C1 and C2 reflects this. Note that biotope impact is overestimated when characterization keys are applied in quality level C. With available data it is possible to improve quality levels for Harsprånget and Umluspen. The table below shows land use per quality level:

Quality level	**A1**	**A2**	**B1**	**C1**	**C2**	**Total**
Area (ha)	91	258	17 918	37 506	19 077	**74 850**
% of total area	0.10	0.34	23.9	50.1	25.5	**100**

The table below shows land use per application:

	Lule älv	**Ume älv**	**Ånger-manälven**	**Indals-älven**	**Dalälven**	**Göta älv**	**Upperuds-älven**	**Vuoksi Pamilo**	**Total (ha)**
Dam	74	25	0.5	5.3	0.9	0.3	0.2*	0.2	**107**
Reservoir	9 761	27 119	6 000	1 850	150	350	90	25 000	**70 320**
Dry river banks	71	482	74		4.0	2.4		99	**731**
Distribution plant	6.0	5.6	0.5	1.0		0.4		0.4	**14**
Buildings (permanent) including roads	75	68	5.5	4.0	4.8	1.2		0.3	**159**
Tailrace	34	39			0.2	6.7	0.1	2.2	**82**
Quarries	55	10						1.0	**66**
Store	39	149	22		2.1				**212**
Buildings (temporary)	39	14							**53**
Other	198	1 602	772	119	27	20	0.9	370	**3 108**
Total (ha)	**10 352**	**29 514**	**6 874**	**1 980**	**189**	**381**	**91**	**25 470**	**74 850**

*Dam area includes buildings.

The table below is a condensation of biodiversity impact from all phases for the 14 selected power stations related to electricity generation over 100 years.The condensation is a simplification in that different quality levels are intermixed. The results are nonetheless indicative of ecological effects.

Biotope type	**Before**		**After**		**Difference**	
	ha	m^2/kWh	ha	m^2/kWh	ha	m^2/kWh
Biotope Loss	0.6	$6.4 \cdot 10^{-9}$	18 994	$2.0 \cdot 10^{-4}$	18 993	$2.0 \cdot 10^{-4}$
Critical Biotope	28 504	$3.0 \cdot 10^{-4}$	625	$6.5 \cdot 10^{-6}$	-27 879	$-2.9 \cdot 10^{-4}$
Rare Biotope	23 352	$2.4 \cdot 10^{-4}$	5 192	$5.4 \cdot 10^{-5}$	-18 160	$-1.9 \cdot 10^{-4}$
General Biotope	22 993	$2.4 \cdot 10^{-4}$	50 040	$5.2 \cdot 10^{-4}$	27 046	$2.8 \cdot 10^{-4}$

Summary of biotope changes for the 14 selected power stations.

	Norra Norrland		Mellan-norrland		Södra Norrland		Västsverige		Östra Finland		Small-scale hydro	
	ha	m^2/kWh	ha	m^2/kWh	ha	m^2/kWh	ha	m^2/kWh	ha	m^2/kWh	ha	m^2/kWh
Before												
Biotope loss	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	$6.20 \cdot 10^{-6}$
Critical biotope	5 797	$1.28 \cdot 10^{-4}$	12 201	$3.98 \cdot 10^{-4}$	75	$1.49 \cdot 10^{-5}$	153	$1.22 \cdot 10^{-5}$	10 188	$4.04 \cdot 10^{-3}$	90	$9.00 \cdot 10^{-4}$
Rare biotope	983	$2.18 \cdot 10^{-5}$	11 953	$3.90 \cdot 10^{-4}$	75	$1.49 \cdot 10^{-5}$	153	$1.22 \cdot 10^{-5}$	10 188	$4.04 \cdot 10^{-3}$	0.0	0.0
General biotope	3 571	$7.91 \cdot 10^{-5}$	14 214	$4.64 \cdot 10^{-4}$	38	$7.46 \cdot 10^{-6}$	76	$6.08 \cdot 10^{-6}$	5 094	$2.02 \cdot 10^{-3}$	0.4	$4.00 \cdot 10^{-6}$
After												
Biotope loss	6 896	$1.53 \cdot 10^{-4}$	11 962	$3.90 \cdot 10^{-4}$	14	$2.74 \cdot 10^{-6}$	9	$7.55 \cdot 10^{-7}$	113	$4.46 \cdot 10^{-5}$	0.5	$4.56 \cdot 10^{-6}$
Critical biotope	0.9	$1.99 \cdot 10^{-8}$	331	$1.08 \cdot 10^{-5}$	5	$1.07 \cdot 10^{-6}$	0.0	0.0	197	$7.81 \cdot 10^{-5}$	90	$9.00 \cdot 10^{-4}$
Rare biotope	1.6	$3.55 \cdot 10^{-8}$	5 190	$1.69 \cdot 10^{-4}$	0.0	0.0	0.3	$2.63 \cdot 10^{-8}$	0.0	0.0	0.0	0.0
General biotope	3 454	$7.65 \cdot 10^{-5}$	20 884	$6.81 \cdot 10^{-4}$	169	$3.35 \cdot 10^{-5}$	371	$2.96 \cdot 10^{-5}$	25 160	$9.98 \cdot 10^{-3}$	0.6	$6.15 \cdot 10^{-6}$

Land use per biotope type and river region.

4.3.1 Norra Norrland

Four stations in the river Lule älv were selected in the river region Norra Norrland.

The river region Norra Norrland is characterized by vast reservoirs and large average annual production. Lule älv's share of total use of land and water area is 14 %, whereas it contributes ca. 48 % of average annual production.

Lule älv

Area and biotope data has been presented in conjunction with previous certification, however average annual production data is updated.

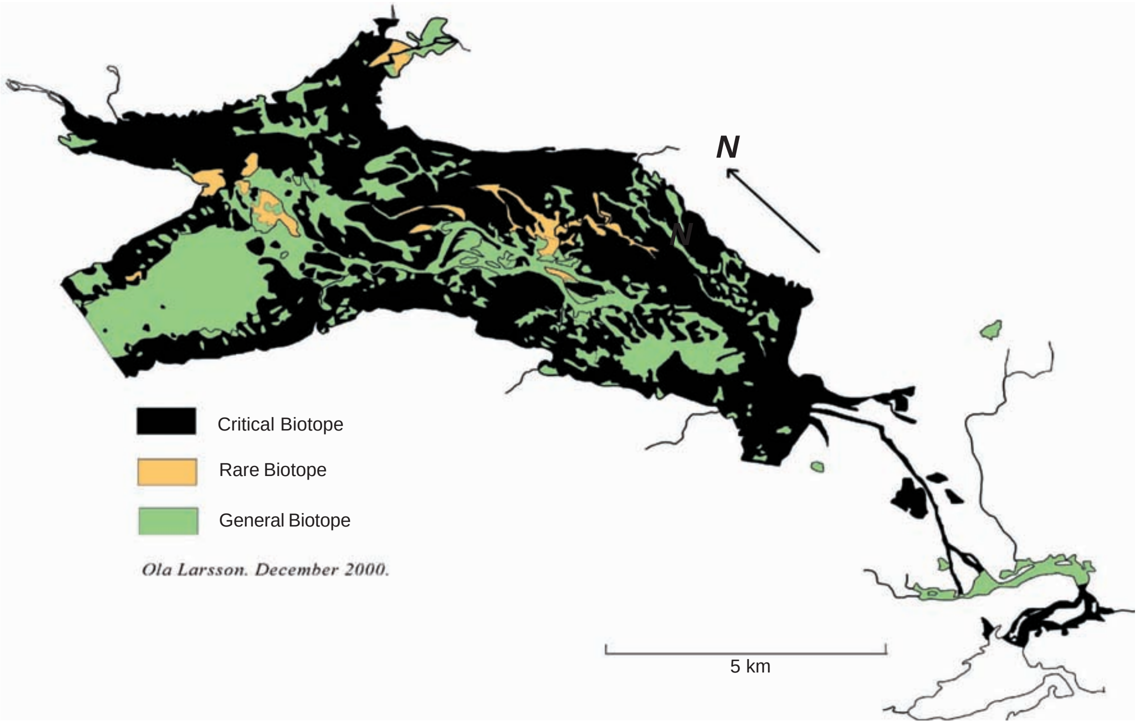
Seitevare, Tjaktjajaure (quality level B1)

The Tjaktjajaure annual reservoir at Seitevare represents more than 75 % of total Lule älv area. Biotope classification pre-exploitation is largely based on aerial photographs. Biotope characterization is based on an area-specific standard list, and 60 % of the area harbored a.o. the following critical biotopes: streaming water, rapids, oxbow lakes, backwaters, and riverine grasslands.

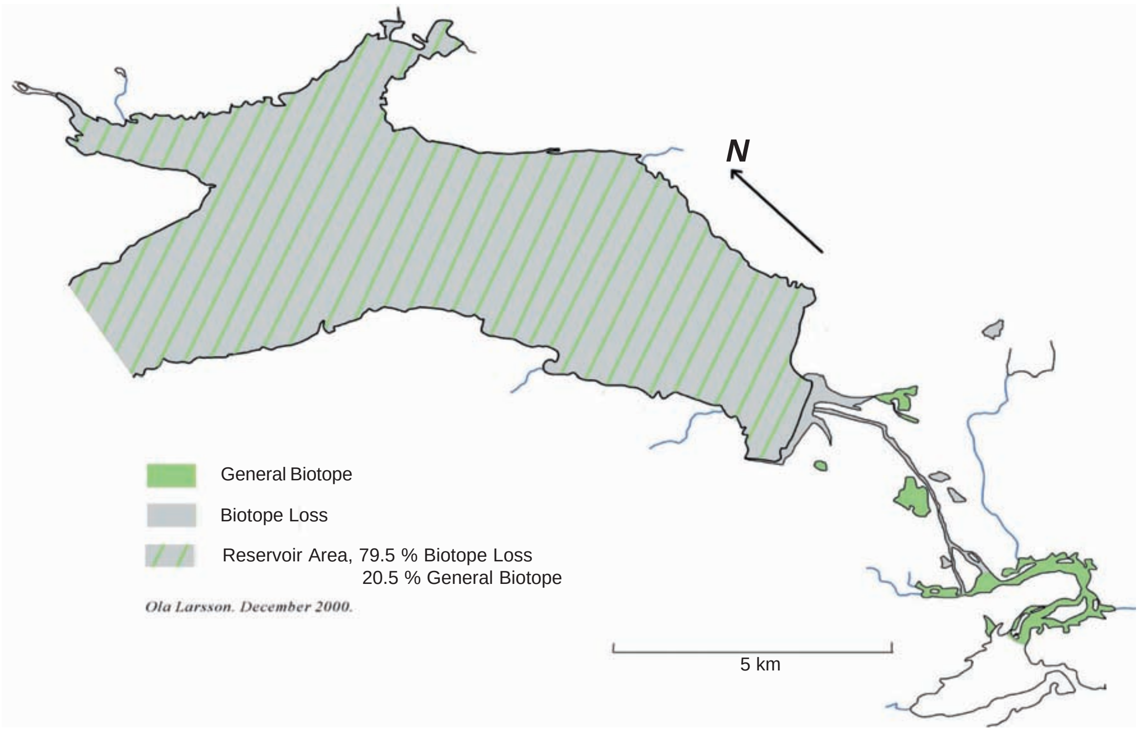
Post-exploitation condition assessment is based on actual biological data, and shows that 78 % of the area constitutes biotope loss and that the remainder is general biotope. No critical biotope remains. The reservoir, one of five gravel pits, a water-filled quarry, and an area where buildings have been demolished are characterized as general biotope.

The maps below show biotope categories before and after exploitation for Seitevare power station and the eastern part of Tjaktjajaure annual reservoir.

Seitevare HPP – Categories Before



Seitevare HPP – Categories After



Harsprånget (quality level A2)
Biotope classification and characterization pre-exploitation are based on aerial photographs, data inventories, descriptions in Vattenfall's archives, and on documentation brought before the Vattendomstolen (Water Court). Critical biotope (streaming water and rapids) constituted 25 % of used area, whereas the remainder was general biotope. Post-exploitation conditions have not been inventoried, and a characterization key has been applied.

Pre-exploitation data showed the presence of a number of red-listed species such as the moss *Cinclidotus fontinaloides*, the lichen *Everina divaricata*, and *Calypso bulbosa*. The existence of these species post-exploitation is unknown and consequently a characterization key was applied. General biotope is assigned to areas where no biotope loss is registered.

Porsi (quality level C1)
Pre-exploitation data from the area around Porsi power station is nonexistent, and a characterization key has been applied.

Assessment of post-exploitation conditions is based on inventoried biological data and show that ca. 82 % of the area constitutes general biotope, while the slope of the dam (0.2 % of the area) harbors rare as well as critical biotopes. Red-listed moonwort species like *Botrychium matricariifolum* and *Botrychium multifidum* have been registered on the downstream dam slopes. The remaining area constitutes biotope loss, particularly in the reservoir drawdown zone, but also on dumps and built-up areas.

Boden (quality level C2)
Characterization keys have been applied to pre- and post-exploitation conditions at the Boden power station. The reservoir, built-up areas and spillways without vegetation are characterized as biotope loss, but constitute merely 1 % of the area. Virtually all the area related to Boden power station post-exploitation is general biotope.

4.3.2 Mellannorrland

Five stations in the rivers Ume älv, Indalsälven, and Ångermanälven were selected in river region Mellannorrland.

The river region Mellannorrland is characterized by vast reservoirs and large average annual production. The region's share of total use of land and water area is 51 %, whereas the three rivers contribute ca. 32 % of average annual production.

Ume älv
Area and biotope data has been presented in conjunction with previous certification, however data regarding the dam at Umluspen power station, and average annual production data is updated.

Juktan (quality level B1)
There is scant historical data from the area around the power station at Juktan, and an area-specific standard list has been applied to pre-exploitation conditions. The inundated area (predominantly coniferous forest on moraine) was characterized by Svenska Naturskyddsföreningen (1960) as having "meager vegetation". With the exception of agricultural areas, the inundated area constituted general biotopes.

The streaming water in the river Juktån is characterized as critical biotope both before and after exploitation. More than 40 % of critical biotopes remain post-exploitation, but rare biotopes are nonexistent. Approximately 4 % of both critical and rare biotopes pre-exploitation have become respectively general biotope and biotope loss post-exploitation.

During the timber-floating period Juktån underwent substantial river training that resulted in canal like bottom in large parts of the river, which in turn had negative impact on fish and other organisms. In addition, important reproduction areas for fish, e.g. by/side-runs were closed off by levees and similar constructions.

In conjunction with the reappraisal 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.

Based on the above we can conclude as follows:

- Despite reduced average annual discharge, the critical biotope area (i.e. the area covered by water during winter conditions) is only marginally reduced
- As a result of biotope restoration, Juktån now provides improved conditions for biological life compared to during the timber-floating period.
- Reopening of previously closed off waterways has created important reproduction areas for fish.

Umluspen (quality level C2)

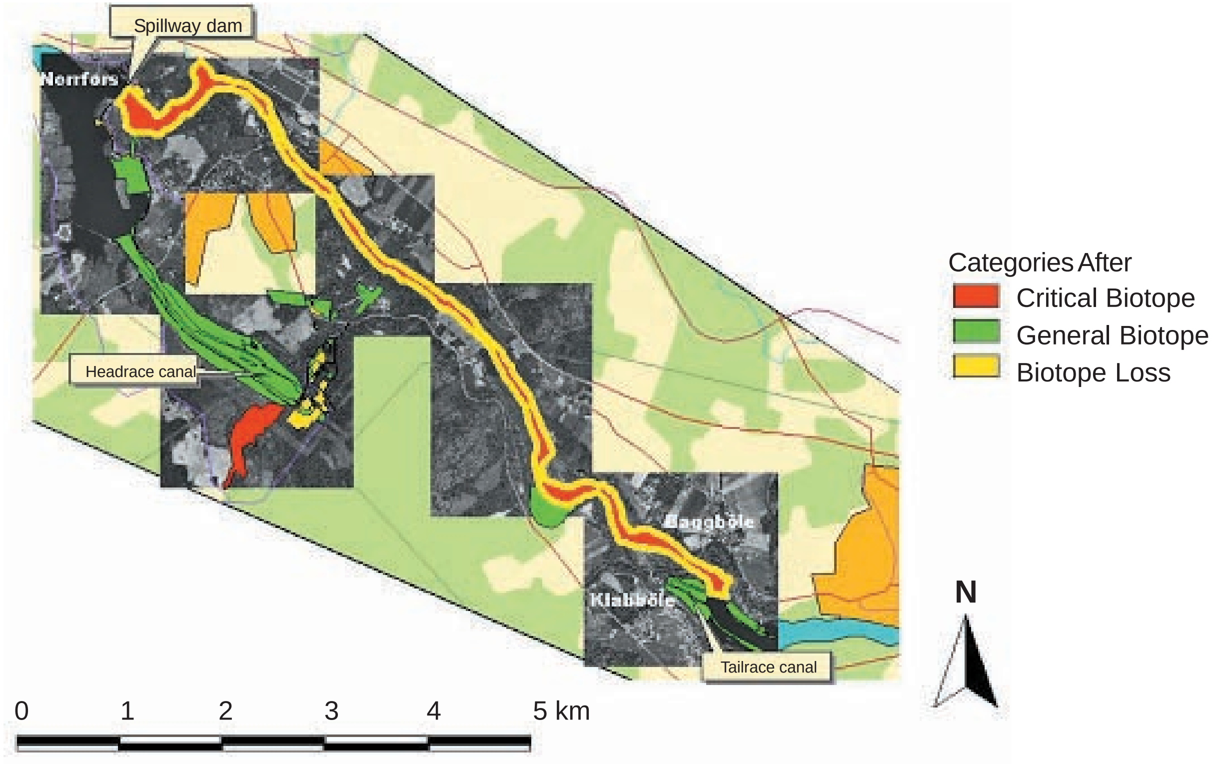
Historical data from the area around the power station at Umluspen is nonexistent, and a characterization key has been applied to pre exploitation conditions. It is assumed that the area constituted 40 % critical biotope, 40 % rare biotope, and 20 % general biotope. A characterization key is applied to the post-exploitation conditions as well. Land and water areas post-exploitation are assessed as 31 % biotope loss and 69 % general biotope.

Stornorrfors (quality level C1)

Historical data from the area around the power station at Stornorrfors is insufficient, and a characterization key has been applied to pre-exploitation conditions. Characterization of post-exploitation conditions is based on biological data from fieldwork and literature.

Biotope loss occurred even before Stornorrfors was constructed because of the pre-existence of three smaller power stations in the same area. The present reservoir inundated the Norrfors reservoir drawdown zones, which are thus converted from biotope loss to general biotope. There was also a spillway within the area, which is now inundated upstream from the present one. Besides the above conditions, the reservoir and biological flow stretch of the river were influenced by timber-floating and fishing operations prior to the construction of Stornorrfors. It has been impossible to quantify these biotope losses due to the lack of detailed information. One part of the streaming water stretch of the river is characterized as critical biotope, and harbors migrating red-listed wild salmon. Vattenfall has implemented activities to facilitate fish migration. There remain 5.4 % critical biotopes and 2 % rare biotopes after the exploitation.

The map below shows biotope categories post-exploitation at Stornorrfors power station.



Stornorrfors, categories after.

Indalsälven: Bergeforsen (quality level C1)

Historical data from the area around the power station at Bergeforsen is insufficient, and a characterization key has been applied to pre-exploitation conditions. Characterization of post-exploitation conditions is based on biological data from fieldwork and literature. Streaming water downstream from the power station is characterized as rare biotope because this stretch harbors rich fish fauna and various key elements such as sand banks. The area is 6 % of the total area. No critical biotope is identified post-exploitation, and biotope loss is ca. 55 %.

Ångermanälven: Stalon (quality level C1)

The power station Stalon is located in the upper section of the river Ångermanälven, more specifically in the branch named Åseleälven. The station is underground and utilizes the height of fall of 199 meters between the lakes Kultsjön and Malgomaj.

Historical data from the area around the power station at Stalon is insufficient, and a characterization key has been applied to pre-exploitation conditions. Characterization of post-exploitation conditions is based on biological data from fieldwork 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 habor fine populations of trout and char. More than 70 % of the area is characterized as rare biotopes and the remainder as biotope loss.

4.3.3 Södra Norrland

Älvkarleby power station in river Dalälven is selected for the river region Södra Norrland. The river region Södra Norrland uses ca. 0.3 % of total land and water use, whereas it contributes ca. 5.3 % of average annual production.

Dalälven: Älvkarleby (quality level C1)

Historical data from the area around the power station at Älvkarleby is insufficient because the station was built in the beginning of the 20th century. Aerial photographs and data inventory from the pre-exploitation period are nonexistent, and a characterization key has been applied to pre-exploitation conditions. Characterization of post-exploitation conditions is based on biological data from fieldwork and literature. Kungsådran represents 3 % of the area and harbors migrating salmon, and is characterized as critical biotope. Vattenfall has implemented extensive activities to improve biotopes for fish. Recreational fishing waters in Älvkarleby are among the best in Sweden for salmon and trout. No critical biotope is identified post-exploitation, and 90 % is registered as general biotope.

4.3.4 Västsverige

Olidan/Hojum power stations in river Göta älv are selected for the river region Västsverige.The river region Västsverige uses ca. 0.5 % of total land and water use, whereas it contributes ca. 13 % of average annual production.

Göta älv: Olidan/Hojum (quality level C1)

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 biotope losses in the pre-exploitation period. Aerial photographs and data inventory from the pre-exploitation period are nonexistent, and a characterization key has been applied to pre-exploitation conditions. Characterization of post-exploitation conditions is based on biological data from fieldwork and literature. No critical biotopes and/or red-listed species exist within system boundaries, merely general biotopes.

4.3.5 Östra Finland

Pamilo power station in river Vuoksi is selected for the river region Östra Finland.

Vuoksi: Pamilo (quality level C1)

The river region Östra Finland is characterized by vast reservoirs and relatively low average annual production. The river region Östra Finland uses ca. 34 % of Vattenfall’s total land and water use, whereas it contributes less than 3 % of average annual production.

Pamilo is located in the catchment area of river Vuoksi, which runs up northeast of Pamilo in Russia and discharges into lake Ladoga, also in Russia. The catchment area comprises 74 890 square kilometers, of which 6 390 upstream and 68 500 downstream.

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

4.3.6 Small-scale hydropower

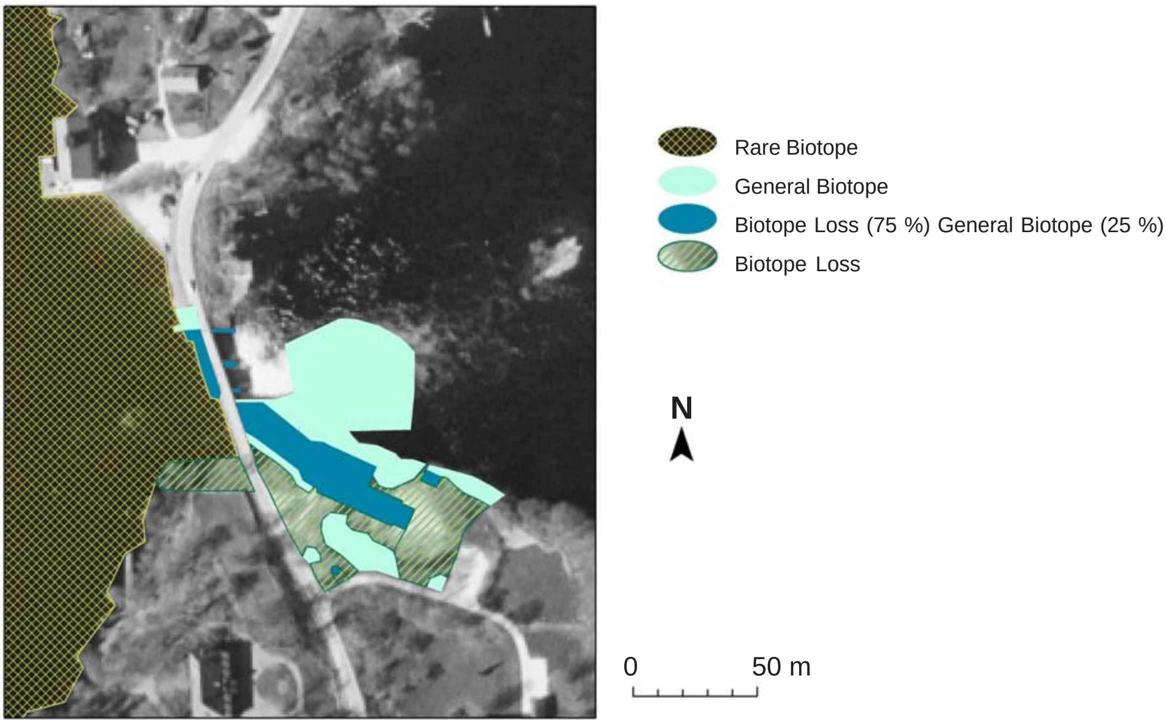
Upperudsälven: Upperud (quality level A1)
Upperud power station in river Upperudsälven is selected as an example of small-scale hydropower stations.

Small-scale hydropower uses ca. 0.1 % of total land and water use, and contributes ca. 0.1 % of average annual production.

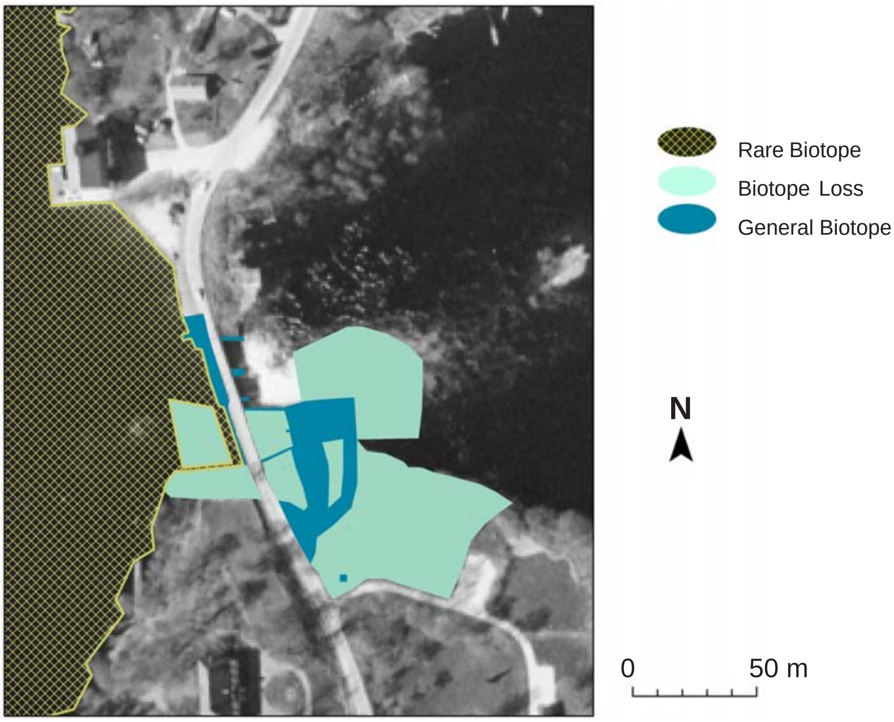
Pre-exploitation biotope classification and characterization are based on aerial photographs and inventories. Vattenfall acquired the site and constructed a new facility in the 1980'ies. Hydro power had been used in Upperud for at least 300 years. Characterization of post exploitation conditions is based on biological data from inventory and fieldwork. The new station has not caused any major change in biotopes. Almost all biotope is critical.

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

The maps below show biotope categories at Upperud power station before and after exploitation.



Upperud, categories before.



Upperud, categories after.

5 ENVIRONMENTAL RISK ASSESSMENT

5.1 What is risk?

In this EPD®, risk is identified as the probability of an unwanted event multiplied by the consequence of the event. We illustrate this with an example regarding everyday use of an automobile:

Assume that the probability of an accident where you receive minor injuries, petrol leaks out and the car needs repair is 0.5 in 10 000 km. This is multiplied by the consequences:

- Euro 200 is lost due to repair costs and an increased insurance premium
- 20 liters of gasoline leak into a ditch
- 10 days of convalescence

The risk is thus quantifiable as Euro 10 *and* 1 liter of spilled gasoline *and* 0.5 days convalescence per 1 000 km of driving. ***The risk over time is constant, which is to say that the risk does not increase after 10 or 100 driven kilometers. Every time you take a drive the risk per kilometer is the same.***

5.2 Procedure

An environmental risk assessment is carried out in accordance with certain routines in order to ensure good quality. 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 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 nonexistent, which may be the case regarding infrequent events, generic sources are sought.

Once all this has been done and 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.

5.3 System Boundaries

The environmental risk assessment comprises accidents in conjunction with:

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

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

Exceptional emission 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 5.10 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 5.4–5.9.

5.4 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 SF_6, oil, diesel fuel, gasoline, and to a certain extent 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 waterway. Major dam failure 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.

5.5 Natural Phenomena

The Swedish climate and associated natural phenomena are benign by international standards, but events relating to thunder and lightning, icing, and other ice phenomena are included.

5.6 Transportation, General

Large quantities of material are transported in conjunction with construction of power stations and particularly dams. This includes rock, earth 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 station/dam probably has a stationary diesel fuel tank, which may spring a leak.

The probability of truck accidents is expressed as accidents per kilometer, 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.

5.7 Construction of Plants and Facilities

5.7.1 Reservoirs and dams

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

5.7.2 Power station

The construction of power stations involves great quantities of material and environmental impact may result from spillage of oils, solvents, etc. Solid materials such as concrete, building materials, etc. cause 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.

5.7.3 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 residue from these injection compounds. They would be very dilute and neither acute nor long term toxic environmental impacts are anticipated.

5.7.4 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 have 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.

5.8 Operation of Power Stations

5.8.1 Breakdowns, fires and spillage

The relevant breakdowns in power stations that cause emissions to the surroundings are mainly damage 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 ca. 50 cubic meters of oil, and for Boden ca. 12 cubic meters. The implementation of high-pressure systems will lead to lesser 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).

5.8.2 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 stations, and there are SF_6-insulated cable conduits at two power stations. Emission of SF_6 may be caused by breakdowns of switches or in the case of fire.

5.9 Large Water Flows and Dam Failures

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 failure is around 0.00001 per year, after implementation of Vattenfall's planned measures to be completed by 2007.

The geological/geographical characteristics of watercourses change continually, and the extent depends on the quantity of water. A dam failure 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 failure 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 river 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 failure 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 huge. A dam failure 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.

5.10 Results and Comparison with Emissions during normal Operation

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 station are not 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.

Dominating events causing emissions of the substance	Substance to air	Substance to ground or water	Emissions caused by accidents and breakdowns (g/kWh)	Emissions in normal operating conditions (g/kWh)
Fire: In turbine, transformer, switch and emission from carbon dioxide extinguishing	Carbon dioxide Carbon monoxide Sulphur dioxide Dust		10^{-5} 10^{-7} 10^{-6} 10^{-7}	4.2 $7.4 \cdot 10^{-3}$ $6.9 \cdot 10^{-3}$ $1.0 \cdot 10^{-3}$
Breakdown of magnetic transformer or switch (arc), cable fire	Gasified copper		10^{-6}	$2.8 \cdot 10^{-6}$
Breakdown of switch, leakage or fire in switch	SF_6		10^{-6}	$5.1 \cdot 10^{-7}$
Turbine breakdown, switch breakdown, control system leakage		Oil, diesel fuel, or gasoline	10^{-4}	$8.0 \cdot 10^{-5}$

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

This comparison shows that, allocated over a long period of time, only emissions of SF_6, oil, diesel fuel, gasoline, and gasified copper reach levels of emissions under normal operating conditions. Another conclusion is that emission levels in conjunction with accidents and breakdowns are generally small in terms of total quantity as well as per kWh.

It should be pointed out 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.

6 INFORMATION FROM THE CERTIFICATION BODY

Vattenfall AB Nordic Generation has completed this EPD® for electricity generated in Vattenfall’s hydropower plants in the Nordic countries. It adheres to system requirements according to MSR 1999:2 and PSR 2004:2, ver. 1.0. Impact on biodiversity and risks related to electricity generation are described. The certifying body has had access to comprehensive underlying material as well as to this report. The totality has been examined by BVQI Sverige AB and found to conform to system requirements. This certification is valid until 2008-03-01 inclusive.

7 LINKS AND REFERENCES

www.vattenfall.com
www.vattenfall.se
www.environdec.com
(The Swedish Environmental Management Council, EPD®s and methodology documents)
http://www.vattenfall.se/om_vattenfall/var_verksamhet/miljo/rapporter/
(Vattenfall AB Vattenkraft Environmental Report 2003, in Swedish only, also downloadable at www.environdec.com)

Following appendices support this EPD® and can be downloaded at www.environdec.com:
The Biotope Method© March 2001
Technology and Environment
Description of selected hydropower plants (in Swedish only)

Contact Vattenfall for the following reports:
Application of the Biotope Method©, on Vattenfall´s Nordic Hydropower (in Swedish only)
Environmental Risk Inventory – description of method

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