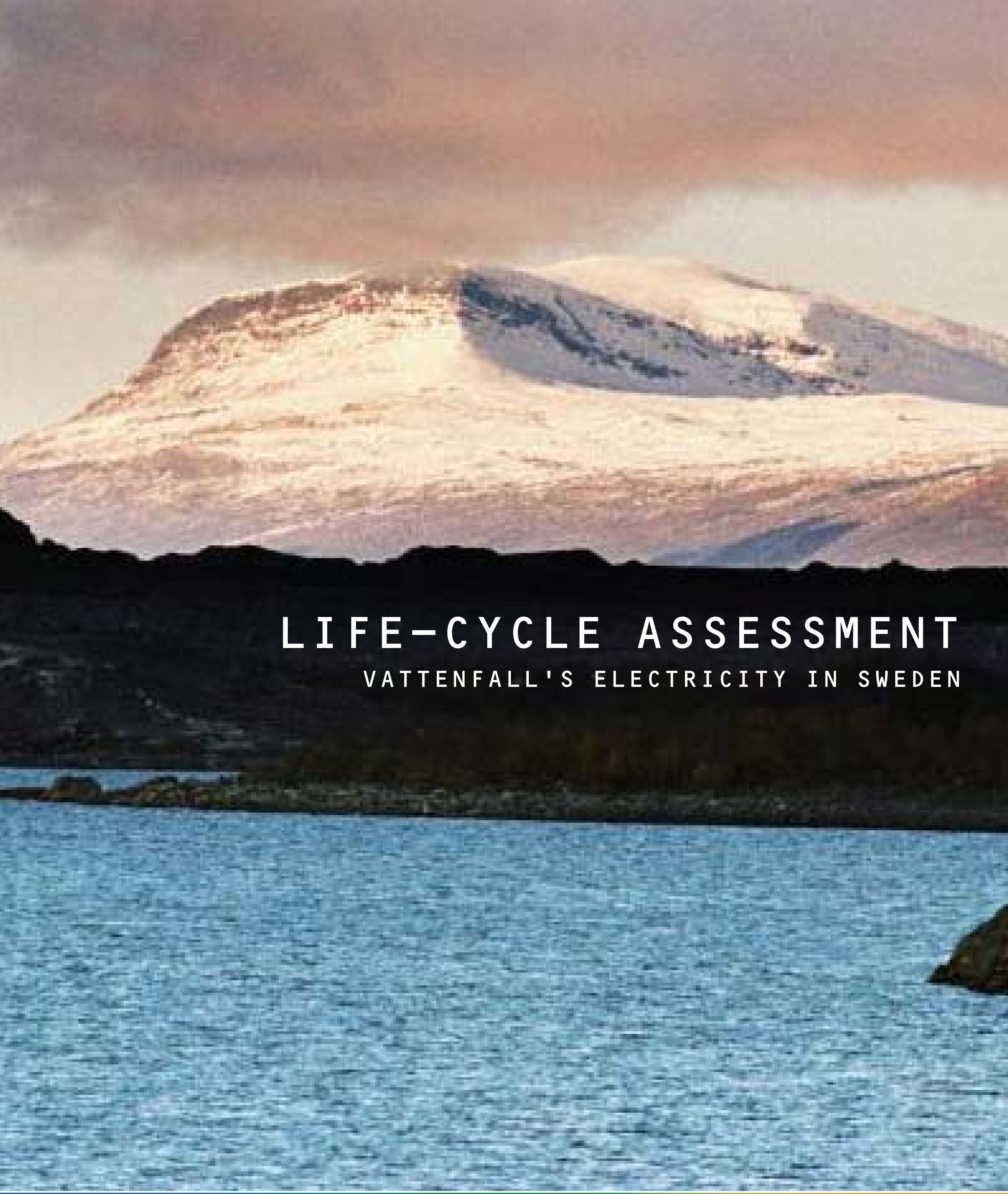

LIFE-CYCLE ASSESSMENT

VATTENFALL'S ELECTRICITY IN SWEDEN

VATTENFALL

TABLE OF CONTENTS

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Our modern society is dependent upon electricity. In a self-evident yet anonymous way, electricity is always available.

Vattenfall wants to have an open dialogue regarding the environmental characteristics of its electricity, as well as the environmental management of the corporation. Therefore, we have assessed the generation and transmission/distribution of electricity from a life-cycle perspective. With our life-cycle assessments, we are able to support our clients and other interested parties with transparent and correct information about the environmental performance of our electricity.

Life-cycle assessments (LCA) have been performed on all of the electricity-generating technologies presently used by Vattenfall Generation Nordic Countries, and also on the transfer of the electricity to the user. We have also studied systems which we do not own ourselves, but which generate electricity that we buy and resell. The assessments also include technologies which may be of interest in the future. We have made a thorough assessment of the Swedish business, using, as far as possible, the actual plants as a base. We have also assessed the potential environmental impacts associated with possible accidents and with operational problems and breakdowns.

The LCAs give detailed information on resource use, emissions and waste generation representative of the various technologies used for generating electricity. This makes it possible to compare the environmental performances of different technologies. Vattenfall does not make value statements on what is positive or negative for our customers. The customers, based on our life-cycle assessments, perform their own valuation of the product.

The work that has gone into these life-cycle assessments results in improved information to our customers. The work has also been useful in our own environmental management. The LCAs clarify where improvements make the biggest difference in our production process.

The life-cycle assessments have been the basis for the environmental product declarations (EPD) which Vattenfall have developed for electricity generated in our hydro, nuclear and wind power plants. The EPD is a certified declaration which has been reviewed by a third party in accordance with regulations determined by the Swedish Environmental Management Council. It lists, among other things, emissions to air, soil and water.

We are happy that we at Vattenfall have been able to contribute to the development and improvement of environmental information on electricity, and hope that this will be useful to our customers.

January 1, 2005

Hans von Uthmann

Alf Lindfors

Göran Lundgren

Electricity-generation systems

The installations which generate the electricity have different characteristics and affect the environment in different ways. The electricity has to be generated at the same time it is being used, since it cannot be stored. For this reason, generation units always have to be on line, which puts certain demands on the generation system.

The preconditions for electricity generation differ from country to country, and the generation systems have to be adapted to local conditions.

Delivery capacity

Since the demand for electricity varies between summer and winter, and also between different times of the day and night, there is a need for generation with different characteristics. There is a need for plants delivering base power at all times, and other plants whose generation can be adjusted to respond to changes in demand, so called regulation or peak power. Apart from these, there is also a need for peak-power plants which can be utilised during extreme demand situations such as cold winter days, or if a disturbance occurs in distribution or generation installations. The system can be complemented with temporary power plants which can only generate during special conditions, e.g. wind power.

Different characteristics

All generation of fuel-based electricity can, in some ways, be controlled. A boiler can be fired by bio-fuel or fossil fuels, yielding steam for the steam turbine. One can also light a gas burner for the gas turbine or start nuclear fission which heats water for steam for the steam turbine. But, there are differences here too. The nuclear reactor starts and changes slowly, which is why nuclear power is best suited as base power. It runs at an even level most of the time. Bio-fuels are often used in combined heat and power plants (CHP), where heat and electricity are generated at the same time. CHP plants are planned such that one only generates electricity when there is a need for heat. District heating is delivered to residences and other buildings, primarily during the colder part of the year, while hot water and steam are needed all year in some industries.

Gas turbines, which are cheap to build, are used as back-up power for when the demand is at its highest, or whenever a base-power plant has a sudden stoppage. They can be started and stopped quickly, but can be expensive to run, since gas and oil are comparatively expensive fuels.

Hydropower can serve as both base and peak power, provided there are storage reservoirs in the river catchment. One advantage with hydropower is that its generation is instantly adjustable. A drawback is that the difference in water availability can be considerable from year to year.

There are also generation technologies dependent on constantly changing natural conditions. The energy of the wind and from the sun can be converted to electricity at suitable wind speeds and solar irradiation. Both of these technologies work well if they are part of a system with fast regulation capacity, e.g. hydropower.

Emissions to air and water

Emissions of various substances to air and water occur during construction, operation and decommissioning of the plants, and also during production of fuels. Emissions commonly discussed in conjunction with electricity generation are nitrogen, sulphur and carbon oxides. Nitrogen and sulphur oxides can normally be kept at low levels through the use of clean fuels or cleaning technologies. This does not, however, take care of all emissions. To separate and deal with carbon dioxide is still not commercially viable, but research is on-going. Emissions to water can consist of e.g. oils or acidifying substances. The emissions can be removed, but traces will always remain.

Waste products

Combustion generates waste products, ashes, which need to be dealt with in various ways. Ash from bio-fuel can be returned to nature and be useful in forestry operations. Some ash from coal, and gypsum from the cleaning of flue gases can be used in the construction of roads and buildings. Some fractions have to be deposited in a safe manner.

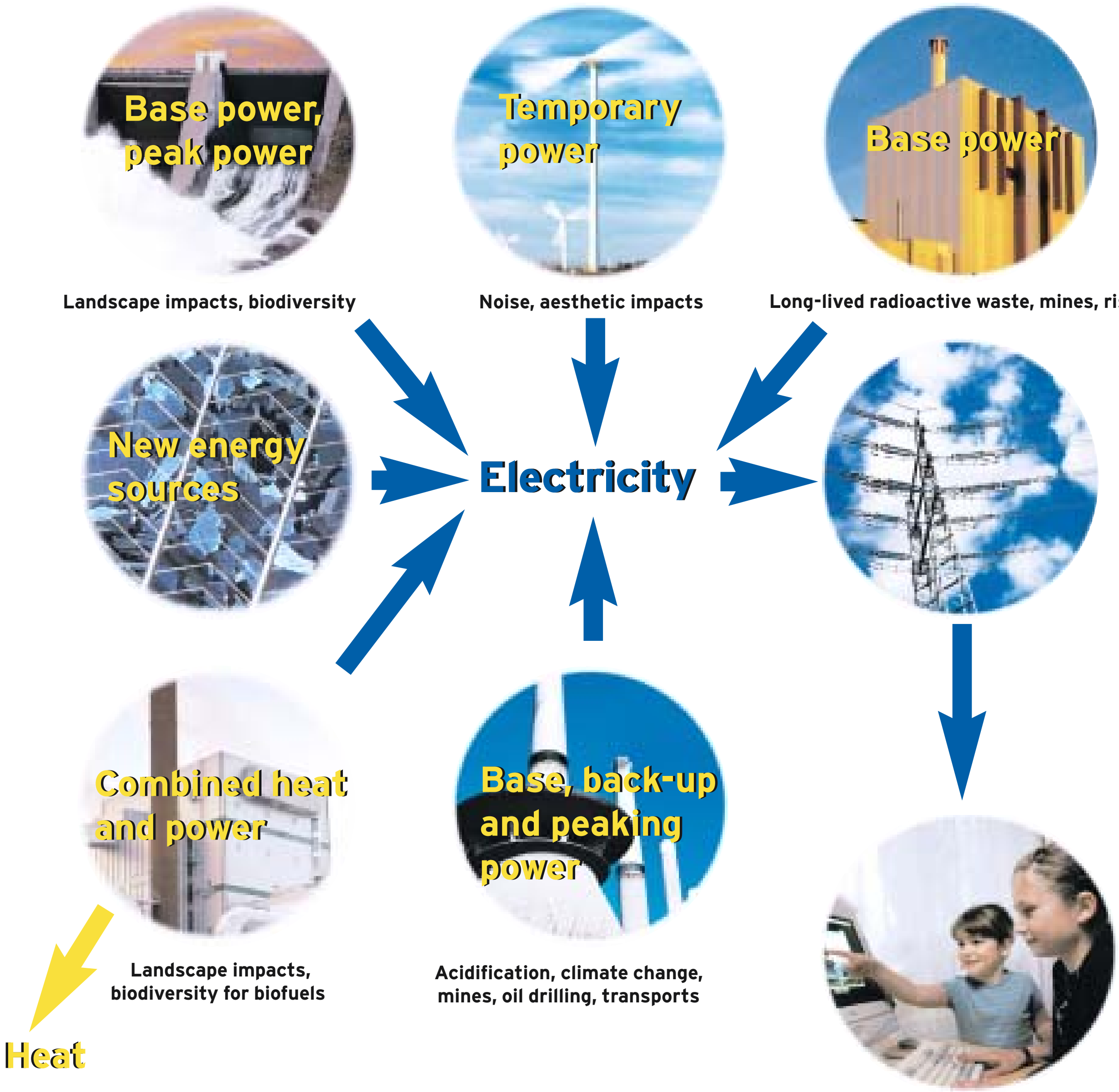
Radio-active waste is dealt with in different ways, depending on the degree of radioactivity. The long-term storage of high-active waste requires the highest levels of security. Such waste will be stored deep down in the rock, and the layers are sealed in such a way that it is extremely difficult to get to it.

Resource use

Drilling for oil or extracting ore are both associated with environmental impacts. Availability and demand vary between substances. This poses limitations on some energy-conversion technologies, such as solar cells. On the other hand, some substances can be recycled, and much of the gold and copper that has been extracted is still available in the technosphere. Recycling is, thus, of importance for the ecoprofile.

Land Use

Different energy systems affect the local environment in different ways. Hydropower causes minor emissions



to air and has a fantastic ability to deliver power through its instantaneous capacity regulation, but its reservoirs inundate vast areas. The power plants hinder up-stream fish migration in the rivers. Stretches of river dry up when the water is channelled through tunnels to the turbines. The construction of a wind power plant means that no houses can be built within a certain distance, while the land can still be used for e.g. grazing and crop husbandry.

Biofuels may consist of branches and tree tops made into chips, which are gathered in connection with the cutting of timber and pulp wood. The forested areas are affected since the nutrients in these branches and tree tops are lost which, in the long run, negatively affects the flora. If biofuels are grown for their own sake, land use is changed from agriculture to energy forest. Mines for the extraction of uranium, coal and metals also cause damage to the land.

Risks

Apart from creating long-lived radioactive waste, nuclear power is also associated with risks, defined as the product of the probability and consequences of an accident. Even if the probability is very small, many people find it difficult to accept the consequences that might result. Other energy conversion chains also have risks, e.g. tanker accidents with damaged coasts, chip fires with emissions to air from incomplete combustion, and dam brakes which cause flooding.

Life-cycle assessment

Because of the complexity of electricity generation, and the differences between the various technologies, it is impossible to give an unambiguous answer to the question of which source of power is best from an environmental point of view. All technologies affect the environment in one way or another. We humans, as individuals, have different opinions on what is good and bad in this case.

The main environmental impact does not always occur during operation of the power plant. For certain technologies, the construction phase is decisive, while, for others, fuel production is the dominant source of impact. Because of this, we have chosen to describe the environmental impacts of our generation technologies from a life-cycle perspective, including construction and decommissioning, fuel production, operation and waste management. The ambition is to give correct information in accordance with generally accepted methods.

The life-cycle assessment work yields clear transparent information to customers and other interested parties. However, the work is also useful to us in our environmental management work. The life-cycle assessments show where, in the generation process, improvements have the greatest potential.

What is a life-cycle assessment?

A life-cycle assessment yields extensive information on resource use and environmental impacts. They are gaining in importance for decisions regarding our environment. A life-cycle assessment should include all activities from manufacturing to scrapping. But, it cannot, and does not, have to describe all environmental impacts in detail. It does not consider economic or social aspects, nor does it contain risk assessments for environmental accidents or an assessment of biodiversity impacts. A life-cycle assessment only presents potential environmental impacts, and makes no difference regarding where in the world an emission occurs.

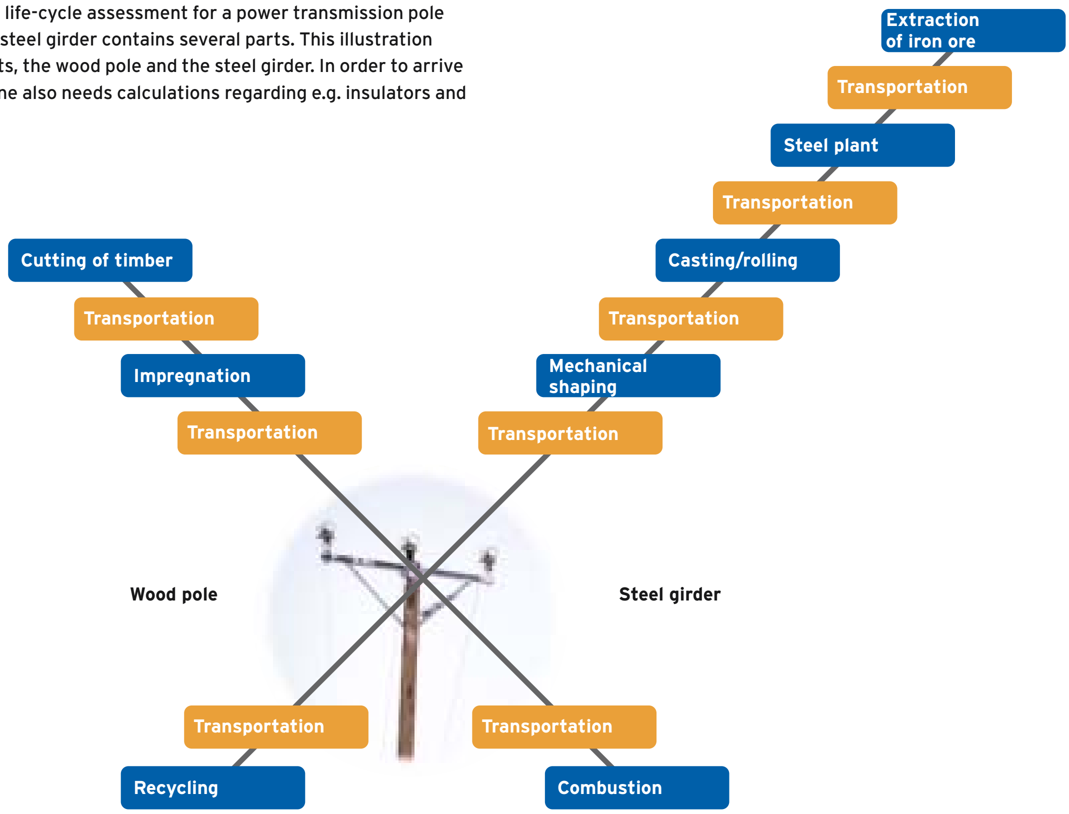
In conclusion, a life-cycle assessments studies a clearly defined system of resource use and emissions from the cradle to the grave.

The system is defined in accordance with the goals and purpose of the study. The international standards ISO 14040-42 give guidelines for life-cycle assessment work.

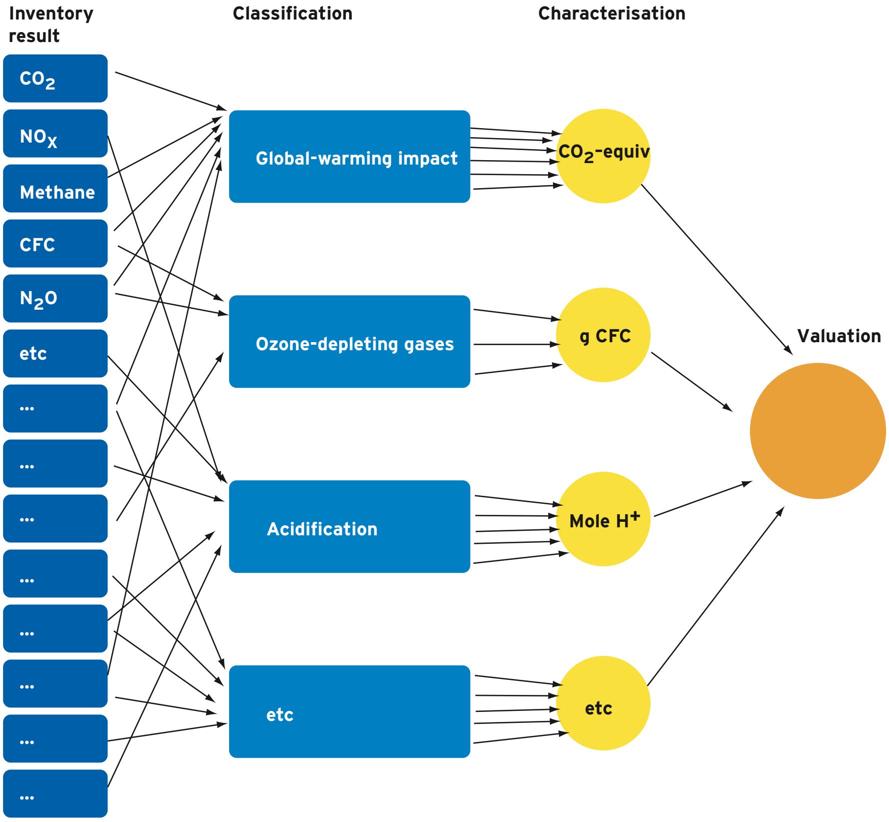
Inventory

The picture gives a schematic illustration of two flows in the life cycle of a transmission pole, a wood pole with a steel girder. In order to get a complete life-cycle assessment, one also needs

Example: A complete life-cycle assessment for a power transmission pole made of wood with a steel girder contains several parts. This illustration shows two of the parts, the wood pole and the steel girder. In order to arrive at a complete LCA, one also needs calculations regarding e.g. insulators and earth works.



How environmental impact is assessed



Some emissions are included in several classifications since they affect the environment in several ways.

calculations regarding e.g. insulators, earth works and so on. At every step, resources consisting of e.g. electricity, fuels and chemicals are spent, and different types of emissions occur. In the inventory stage of the life-cycle assessment, all relevant flows are identified, along with their respective resource use and emissions. All these factors are summed up, and one ends up with the total emissions, of e.g. carbon dioxide, for a transmission pole during its entire life cycle.

Emissions

Different emissions affect the environment in a variety of ways. Carbon dioxide and methane contribute in different ways to the green-house effect, while nitrous oxides contribute to both eutrophication and acidification. In order to identify the total contribution to a certain environmental impact, the various emissions are added together with the aid of generally accepted weighting factors. Some emissions contribute to several environmental impacts, and are then counted in all of these.

The last step of the life-cycle assessment is the valuation, where the various environmental impacts are weighted together into one value. There are several methods, all of which are based on valuations of the relative contribution of the different environmental impacts.

In this report, we have chosen to present the results from the inventory step only. Hence, the results are not weighted, nor valuated.

Certified environmental product declaration

Life-cycle assessments are the bases of the environmental product declarations (EPD) that Vattenfall have developed for electricity generated in the Lule and Ume rivers, the Forsmark and Ringhals nuclear power plants and all of our Swedish wind power. We have also produced an environmental product declaration for heat generation from the waste incineration plant in Uppsala, block 5.

Apart from a life-cycle assessment, an environmental product declaration for electricity and heat generation also requires a description of risks, impacts on biodiversity and information on radiology. It is developed in accordance with product-specific requirements for electricity and heat, and established in a collaborative effort among interested parties at the European level.

In Sweden, the system for certified environmental product declarations is administered by the Swedish Environmental Management Council, owned jointly by the state and industry. It is an international system for the handling of information on the environmental performance of products and services. The aim is for the information to be quality assured, addable and comparable. The information is reviewed by an accredited independent party before certification.

EPDs follow the principles for so called Type III declarations, and are an application of the international standard ISO 14025.

The information should be useable when e.g. purchasing raw materials, or by private consumers when buying e.g. durables.

Certified environmental product declarations are published on the Internet, which makes it possible to spread the information around the world. As the system has developed, it has generated more and more interest among industry and organisations, and is now applied internationally.

An EPD does not contain any environmental requirements, and there are no criteria to fulfil. But, an ecoprofile should be presented, including information on e.g. resource use, emissions and waste generation.

Vattenfalls LCA-work

In 1993, Vattenfall Nordic Countries decided to carry out life-cycle assessments of its electricity generation. The aim was to improve the understanding of the environmental impact of its business. Since then, Vattenfall has worked continuously with life-cycle assessments, partly as bases for certified environmental product declarations, and partly in order to improve our own knowledge and understanding, i.e. as a reference for internal decision-making. The comprehensive and diverse competence available within Vattenfall has contributed to the success, as have contacts with universities, colleges and institutes, both in Sweden and elsewhere.

Purpose

The purpose of this report is to give an idea of what a life-cycle assessment of electricity generation entails, and also to describe how the electricity-generation system is built up The aim is to do this in a transparent manner and with a wide perspective.

Data sources

The data presented in this report comes both from specific information generated in the life-cycle assessment work within Vattenfall Nordic Countries, as well as from public data bases.

- The data for hydropower, nuclear power and wind power has been taken from the on-going assessments carried out as bases for Vattenfall's EPDs.
- The data for natural gas and combined heat and power is based on Vattenfall's assessment from the mid-90's, complemented with new inventories of fuel production and operation. These are updated so that they conform to the new rules for the allocation (distribution) of environmental impacts between heat and power.
- Data for back-up power, such as oil condensers and gas turbines, has been taken from Vattenfall's life-cycle assessment from 1996. However, information on operation, fuel production, material production and transports has been updated. The input data is specific for each installation, and the installations are selected to be representative of Vattenfall's operations in the Nordic region.
- Data for coal power is based on a life-cycle assessment conducted in 1998 by Vattenfall for modern Danish coal power, modified with more recent data from the Swiss data base ecoinvent.
- Data for other sources of power, which Vattenfall Nordic Countries does not have, like fuel cells and solar photo-voltaic cells, has been sourced from the EU project ECLIPSE's data base. The data has been modified somewhat in order to fit Nordic conditions. Vattenfall was an active partner in the ECLIPSE project.
- Data for electricity transmission and distribution is based on a joint project with the National Swedish Power Grid and Göteborg Energy.

Approaches

The results are given for the generation and delivery of 1 kWh of electricity.

Most studies are conducted in accordance with the guidelines for environmental product declarations in which the data bases to be used for the production of metals, chemicals etc., are detailed.

The assessments include construction, decommissioning, fuel production, operations (including normal disruptions), maintenance, reinvestments, and the handling of fuel waste. Resource use, emissions and waste in the different phases have been inventoried, and the environmental impact assessed for a number of environmental effects. A selection of parameters is presented in this compilation. The selection is motivated by the electricity directive of the EU, and common practice in the industry.

Our data sources

ECPLISE, Data base with LCI data for new and future decentralised electricity generation systems.

ecoinvent v1.1, Swiss national data base for LCA

EPD for electricity from the Lule River, 2002

EPD for electricity from the UmeRiver, 2002

EPD for electricity from Vattenfall's wind power plants, 2003

EPD for electricity from Forsmark Kraftgrupp, 2004

EPD for electricity from Ringhals AB, 2004

Background data for Vattenfall's CSR report for 2003

Life-cycle assessment for electricity distribution, Vattenfall internal report, 1997

Life-cycle assessment for coal, Vattenfall internal report, 1998

Life-cycle assessment for Vattenfall's electricity generation, 1996

Environmental report, Uppsala 2003, Vattenfall Heat Uppsala

Monitoring of Vattenfall's back pressure plant in Munksund, 2003

Many different competencies, from e.g. companies and universities, are needed for the preparation of a life-cycle assessment.

It is important for Vattenfall to, as far as possible, consult people who are affected by our operations.

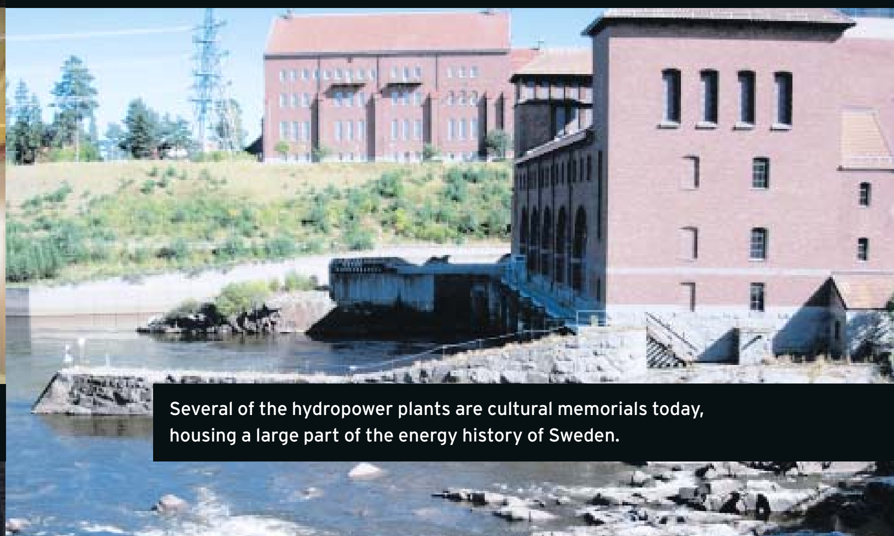
We naturally find out what happens in the mines where uranium is mined. The picture was taken during an environmental review in Namibia.

The biodiversity is affected when dams are built, drying up sections of rivers. Today we run many projects safeguarding the flora and fauna in sensitive areas.

The reindeer husbandry has been affected by the development of hydropower.

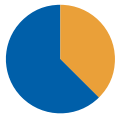
The development affects the natural fish stocks. Vattenfall breeds fish as a compensation measure.

Maintenance is important in order to both secure the delivery of electricity and to minimise the environmental impact.



Several of the hydropower plants are cultural memorials today, housing a large part of the energy history of Sweden.

Hydropower



Hydropower: 37.5 % of Vattenfall Nordic's electricity generation

Hydropower has been harnessed for over 100 years in Sweden, and is still the most important renewable source of electricity.

The availability of water varies during the year, and does not coincide with the need for electricity. Because of this, huge amounts of water are stored in reservoirs, making us able to use the hydropower plants for base and peak-power generation. The reservoirs are very large, and the regulation can mean changes in water levels of up to 30 metres during the year.

The life cycle

The assessments include resource use and emissions from construction, reinvestments and operations. Decommissioning of dams and power plants are not included since the chosen reinvestment model creates an outflow of installations, functionally equal to newly constructed ones, at the end of the chosen life span; 60 years for machinery and 100 years for concrete constructions and dams. This results in a higher environmental impact for emissions and resource use than if the decommissioning had been included, but is a more plausible assumption. It also contributes to the elimination of a number of insecurities which would lead to speculative judgements, among others whether it would be possible to return to an unregulated river flow.

Development affects the landscape

The construction of reservoirs, dams and power plants interferes greatly in the landscape, even if excavated material and blasted rock can be adapted to the natural topography. The water to and from the power plant is often led through long tunnels, reducing or completely removing the flow from a part of the river.

The water level on the river banks varies, and the area between highest and lowest water level loses most of its biodiversity. This in turn affects fish which primarily live in the main water body, but use the near-shore areas during some phases of their lives for e.g. searching for food. Different fish species are affected to various extents. Trout is normally reduced in number, while char and whitefish fare better.

Even if the regulation affects fishing negatively, the reservoirs still provide a large and well-used source for sport and subsistence fishing.

Below the reservoirs and power plants, the reduced river flow affects flora and fauna in such a way that species dependent on fast-flowing water are reduced in number or disappear completely, while species which prefer smooth or still waters often increase in number. When the spring flood is reduced or disappears, plants and animals in the near-shore areas are affected. Those dependent on annual floods disappear or are strongly reduced, and the area turns into something similar to the surrounding land area.

Dams and power plants often block the natural migration routes for, primarily, salmonid fish species.

Mitigation measures

There are several measures that can be implemented in order to minimise the negative impacts on fauna and flora.

If some water is released via the natural river channel, in combination with the construction of low weirs, some of the natural plant and animal life can be maintained. Fish ways and fish ladders make it simpler for migrating fish to pass the migration obstacle. Artificial spawning areas make it easier for the fish to spawn. Furthermore, Vattenfall is obliged to breed fish in order to compensate for the losses.

The hydropower development also affects the reindeer husbandry, agriculture and forestry. The most obvious impact is loss of land through inundation. On the other hand, the regulation causes a more even discharge in the river, reducing the risk of flooding.

The impact of hydropower on landscape, fauna and flora is difficult to compile in a life-cycle assessment. Vattenfall has developed the Biotope Method, which yields a partial quantitative assessment of biodiversity impacts. For the remainder, a qualitative description will have to suffice.

The results

Resource use is largest during construction and reinvestment, primarily through the production of concrete and steel. This causes, among other things, emissions of carbon dioxide, sulphur- and nitrous oxides. During the moving of earth and rock materials, the machinery causes emissions.

The emissions which contribute most to the green-house effect and eutrophication mainly originate from land which has been inundated by the reservoirs. The soil contains organic carbon compounds and nutrients which are continuously decomposed and unbound. These oxygen-consuming substances are decomposed to carbon dioxide with the oxygen in the water. Small amounts of oil leak out into the water ways and, in the case of break downs, larger amounts can enter the water. The environment is also affected in conjunction with inspections and oil changes.

Studied installations

The installations chosen for these studies are typical for Vattenfall.

- 4 power plants on the Lule River
- 3 power plants on the Ume River

Both rivers have multi-year reservoirs. The Lule River is also developed to yield high capacities during short time spans, which can lead to very high plant discharges. The LCAs act as bases for Vattenfall's environmental product declarations.

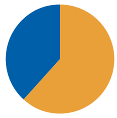
Maintenance is important in order to be able to run plants with high safety standards.

The fuel rods in the reactor are exchanged during the summer.

Emissions to air and water are carefully controlled.

The custom-built ship Sigyn transports spent fuel and other radioactive waste to medium and long-term depositories.

Nuclear power



Nuclear power: 61.7 % of Vattenfall Nordic's electricity generation

Sweden's twelve nuclear reactors were built between 1965 and 1984, responding to the country's increasing need for power. They were placed in four different locations; Ringhals and Barsebäck on the west coast, and Oskarshamn and Forsmark on the east coast. Vattenfall has a majority share in the plants at Ringhals and Forsmark. Nuclear power constitutes base power. The generation can only be increased or decreased to a minor degree in response to short-term fluctuations in demand.

The life cycle

The assessments include resource use and emissions from mining to deep-level depositories, including the construction, operation and decommissioning of power plants, and the installations dealing with radio-active waste. The life span for nuclear technology has been set to 40 years.

The fuel cycle includes the mining of uranium ore, its conversion, enrichment, and fuel production, as well as transports. It takes place in locations spread around the globe. Vattenfall buys fuel from under-ground mines, open-cast mines and in-situ leaching operations. The latter method involves having a liquid circulate through a type of rock that allows the uranium to dissolve into the liquid, which is then pumped up to the surface. In traditional uranium mining, the ore is crushed and the uranium is leached out with the aid of chemicals, yielding a uranium oxide, "yellow cake". This activity results in some radio-active waste products, primarily in the form of sand and waste water. The latter is cleaned while the solids are stored in such a manner as to keep radiation at natural levels.

The uranium oxide is transported to an installation where it is converted to uranium hexafluoride, which then is transported to an enrichment facility where the fraction of fissile isotope, U-235, is increased from around 0.7% to 3–4%. The process yields two fractions; one with the desired enrichment rate, and one so called tail, depleted uranium, with a lower uranium content than the natural one. There are two enrichment methods – gas diffusion, which requires large amounts of electricity; and gas centrifuge, which requires considerably less electricity. Most of Vattenfall's fuel is produced by the latter method. Vattenfall also buys some fuel which has been enriched from tail. Fuel producers manufacture uranium oxide from the uranium hexafluoride, which is pressed into small cylindrical pellets that constitute the actual fuel for the nuclear power plants.

The power plants are shut down every summer for audit, and a fifth of the fuel is replaced with fresh.

The depleted fuel goes to an intermediate storage facility for around 40 years. This facility, known as CLAB, is located adjacent to Oskarshamn's nuclear power plant. In the future, the waste will be placed in a deep-level depository somewhere in Sweden (possibly adjacent to either Forsmark's or Oskarshamn's nuclear power plants). The plan is to encapsulate the depleted fuel in copper and steel, and store these forever in bentonite clay, deep in the very old granitic basement rocks. Other radio-active waste has its final depository, SFR, in rock caverns close to Forsmark.

Environmental impacts

The majority of the environmental impacts of nuclear power are caused by the fuel production. The use of electricity and fuels in the different steps of the process is decisive, and the mix of suppliers has a great impact on the overall result. The generation mix for the electricity used by the suppliers is important; an increased use of fossil-based electricity yields higher environmental impacts through emissions to the air. The mining of uranium is the dominant process step. Just like in all mining activities, there are also local landscape impacts.

During construction of the power plants, the largest use of resources is for steel production, concrete and other construction materials, while copper use dominates the encapsulation of the depleted fuel.

The emissions from the operational phase are dominated by the production of chemicals and the transportation of radio-active waste. The operational phase also generates large amounts of cooling water which warm the sea close to the plants, thus affecting fauna and flora.

During the waste-handling phase, including the construction and operation of waste management facilities, the dominant sources of emissions are the manufacturing of the copper canisters and the transports.

Radiation from fuel production, operations and waste management is far below the limits set by the authorities.

Extensive risk assessments are undertaken for the nuclear power generation (probabilities and consequences), and these are reported to the inspection authorities and, also briefly, as part of the environmental product declarations.

Studied installations

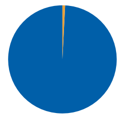
Certified environmental product declarations have been produced for the electricity from the three boiling-water reactors (BWR) in Forsmark, as well as the three compressed-water reactors and one BWR in Ringhals. It is the data generated for these EPDs that is presented in this report.

The combined heat and power plant at Munksund uses bio fuel.

In Uppsala we operate a combined heat and power plant, and installations for heat production from waste incineration.

The wind-power plants in the Kalmar strait have an aesthetic impact on the landscape. The extent to which this is disturbing or not is a matter of debate.

Other power-generation technologies



Other power-generation technologies: 0.8 % of Vattenfall Nordic's electricity generation

Wind power

Vattenfall owns and operates about 40 land-based wind-power plants, located primarily on the Baltic island of Gotland and in the region of Bohuslän (west coast). We have selected 11 of these whose wind exposure, manufacturer and sizes (between 0.2 and 1.5 MW) are representative of our generation.

The primary environmental impacts from wind-power generation come in the construction phase. During the operational phase, the environment is affected by travel, oil consumption and reinvestments. The technical life span is set to 25 years.

The main environmental impact over the life cycle is the aesthetic impacts on the landscape. A certain amount of noise might be created, but is partly blocked out by natural wind noise. There is a small risk of injuries to birds.

The operational time during the year is determined by how much and how often the wind blows, which is of great importance to the environmental impacts from wind power in relation to the number of kWh of electricity which are generated. In order to generate as much electricity as in the natural gas-fuelled combined-cycle power plant described on page 14, it takes approximately 4 000 wind-power plants with a 1 MW capacity each.

Wind-power plants cannot provide the country with electricity by themselves, since they only generate when the wind blows.

Combined heat and power (CHP)

In a combined heat and power plant, both electricity and heat are generated. The electric conversion efficiency is lower than in an installation where the excess heat is cooled off, but instead the heat can be utilised for district or industrial heat.

The fuels used are primarily bio fuels, peat, coal and oil.

The life cycle is primarily based on the CHP plant in Uppsala, which uses several different fuels, and the one in Munksund which primarily uses bio fuel.

The life cycle includes fuel production (refining and transport), combustion, and ash disposal as well as construction, reinvestment and decommissioning of the power plants.

Allocation of environmental impacts between the two products, heat and electricity, has been performed in accordance with the rules for environmental product declarations.

Bio fuel The bio fuel used by Vattenfall consists mainly of chipped forestry bi-products, like the tops of trees, branches and bark, as well as waste from saw mills and paper mills in Sweden. In the assessment, we have included gathering, chip production, transport to the plant and a further separation stage. The first phase yields the highest impacts, followed by the transport, which has been estimated at an average of 34 km.

Peat The peat Vattenfall uses primarily comes from bogs in the Swedish region of Härjedalen, and Russia. Diesel-powered machines excavate the wet peat which is then dried in electric dryers. The dried peat is pressed into briquettes and transported by truck, train and sometimes even ship, to the power plant, where the briquettes are ground up. Data for Russian excavation and drying are approximated with Swedish data, but with Russian electricity.

Coal Vattenfall mainly purchases its coal from Russian and Polish mines. The coal is transported by train, ship and truck to the power plant, where it is ground up. The life cycle includes mining in under-ground and open-cast mines with electric and diesel-driven machinery; conversion for the separation of sulphur and some other contaminations; as well as storage and transport. The methane emissions which occur as a part of the mining process have been included. Some of this methane has been used as fuel in mining processes.

Oil The oil fuel consists of a mixture of light and heavy oils, and only constitutes a very small share of all fuel used in Vattenfall's CHP plants.

Oil condensers

In an oil-condensing power plant, only electricity is generated. The heat is cooled off. Today we use the Swedish condensers only during short periods of extremely high power demand.

The basis for the life-cycle assessment is the plant at Stenungsund on the west coast. The fuel is a low-sulphur light oil.

The electric efficiency is 38% and the technical life span is set to 60 years. The rate of reinvestment is low, depending on the low operating time.

The assessed life cycle includes crude oil extraction, refining, transports and combustion in the power plant. European average data has been used for the fuel. Construction and decommissioning of the plant are also included.

The operational phase dominates the environmental impact profile, primarily through emissions to air. The fuel production also causes emissions, while construction contributes only a minor share of the total.

Gas turbine

Gas turbines are used as a back-up source of power which can be started and deliver electricity at short notice. The annual operating time within Vattenfall Nordic Countries is very short.

Data has been taken mainly from the gas-turbine power plant in Slite on the Baltic island of Gotland. The fuel is jet fuel with a low contamination content. The data is a European average for kerosene.

The electric efficiency is 27% and the technical life span is set to 60 years.

The study runs from the extraction of crude oil and includes refining, transportation and combustion in the gas turbines.

The combustion of fuel accounts for the largest emissions to air, followed by the production of the fuel. The construction contributes only a minor share of the total.

Other power-generation technologies, outside of Vattenfall

Natural gas-fuelled combined-cycle power plant

There are no large combined-cycle plants fuelled by natural gas in Vattenfall Nordic Countries at present. The studied plant is a planned 900 MW_{el} natural gas-fuelled combined-cycle plant, in which the excess heat is cooled off. The concept of combined cycle means that electricity is generated from both a gas turbine and a steam turbine. This increases the electricity efficiency considerably, and in our scenario it is assumed that 58% of the input energy is converted to electricity. The technical life span of the installation is set to 40 years.

The life cycle includes the extraction of gas from the North Sea, gas treatment at Kårstö on the Norwegian mainland, transportation in pipelines to Sweden, and combustion in the power plant.

The assessment includes emissions to air and water, resource use and waste products generated during the drilling and extraction of the natural gas, the construction of gas pipelines and gas storage, as well as the construction and decommissioning of the power plant. The largest emissions of carbon oxides and nitrous oxides are caused by the operational phase.

The production, treatment, and transportation of natural gas from gas fields in western Siberia have been tudied. One assumption has been that the current Russian gas transportation system will be modernised and that the gas would be transferred to Sweden via Finland.

The use of Russian, as opposed to Norwegian, gas would increase the emissions of carbon oxides and nitrous oxides by about 10% to 30%, due to efficiency issues in extraction and transportation. At the same time, the sulphur emissions would be reduced, since Russian gas contains less sulphur than does Norwegian gas. In this report, only the case with Norwegian gas is presented.

Coal power

There are no coal-condensing power plants in Vattenfall Nordic Countries at present. The data for construction, decommissioning and operation presented here is based on Vattenfall's 1998 life-cycle assessment of a Danish coal power plant with 385 MW capacity, complemented by coal fuel data from the Swiss data base. The plant is designed to operate both as a condensing plant (high electric efficiency, 47%, the excess heat is cooled off), and as a CHP plant (lower electric efficiency, 30%, but the heat is used for process or district heating). We have assumed 7 000 hours operating time per year, out of which slightly less than the half the year as CHP (average efficiency at 65%). The plant is a conventional type with boiler and steam cycles, has electro-filter for the cleaning of particulate matter, wet sulphur removal with chalk (the waste product is gypsum), and nitrogen reduction with ammonia.

The life cycle includes construction, reinvestments, decommissioning, mining (underground and open-cast); purification and refining of the fuel; fuel transportation and storage; combustion in the plant and treatment of ash including leaching from ash deposits.

The technical life span is set at 40 years.

The environmental impact from coal power primarily comes from the combustion of the fuel, but the production and transportation of the fuel also entail resource use and emissions.

Solar cells

In Sweden, solar cells are presently used in remote locations, far from the existing electricity grid and with a small demand. Light houses, weather stations and isolators in the grid are some examples which are also equipped with back-up batteries. In the case of the isolator, the solar cell serves particularly well since it demands a separate source of electricity. Solar cells are also often used in consumer products such as calculators.

Solar cells convert solar energy directly into electricity. Solar cell systems are modular, and are serially connected to modules, which are in turn connected to solar panels. In order to be able to use the panels, some other equipment, such as tripods, is necessary. etc. Solar cells are made from semiconducting material, and generate direct current at low voltage. There are crystalline silicon cells, but also thin-film cells with varying composition. If connected to the grid, an inverter for conversion to alternating current is needed. The net generation of electricity in a solar-cell system is affected by e.g. efficiency (5–15%), irradiation (1 000–2 000 kWh/m^2/ year in Europe), the angle of the cells to the sun, and losses in the inverters.

The studied system is a grid-connected building-integrated one with commercial silicon technology. The solar panels are assumed to be produced in Europe and mounted on a roof at an optimum angle in relation to irradiation. The calculations have been adjusted for Nordic conditions, 1 150 kWh/m^2. The choice of this type of installation is motivated by the fact that it is commercially available, and that integration with buildings is a growing market, while there is no demand for stand-alone fields of solar panels on the European market at present.

The life cycle includes the manufacturing of the solar-cell modules and accessory equipment, as well as operation and decommissioning/scrapping.

The environmental impacts caused by solar-cell systems primarily come from the manufacturing phase, particularly from the production of silicon, followed by the manufacturing of the accessories.

Fuel cells

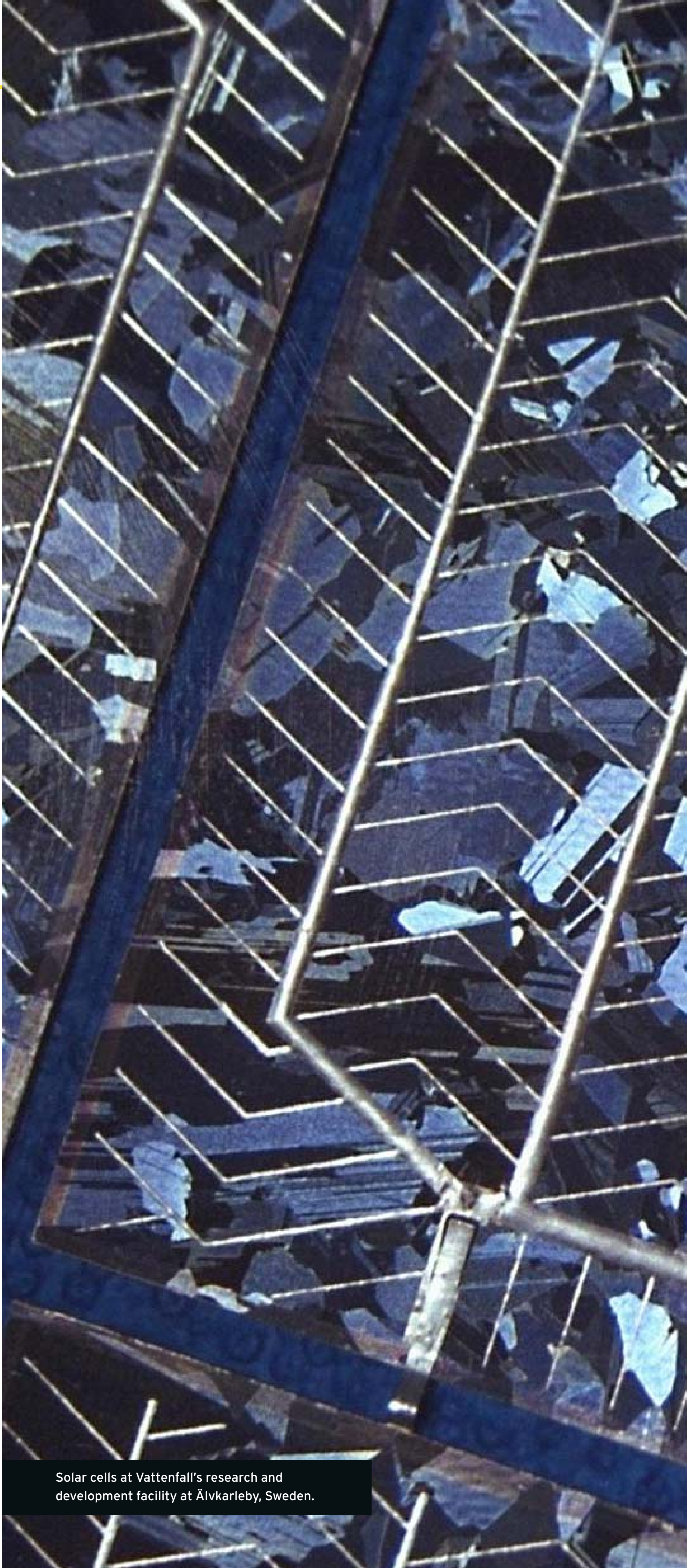
Fuel cells are viewed as an interesting alternative for future generation of electricity, and the technology is developing. A fuel cell is a local source of electricity, and is connected to the low-tension grid. It is the potential for use as a power source for cars that is driving the development, but the fuel cell we present here, SOFC (solid-oxide fuel cell), will likely only be used in stationary applications, given the high operation temperature of over 1 000°C.

Fuel cells are electro-chemical devices which convert chemical energy to electricity at low tension. They generate a direct current through the oxidation of the fuel (e.g. hydrogen) with the aid of oxygen from the air. Several fuel cells are connected to a stack in order to achieve the desired voltage and capacity. A fuel-cell installation consists of four principal components and supporting devices like pumps and control systems. The principal components are a fuel processor which cleans and possibly converts the fuel (e.g. natural gas) to hydrogen, a fuel-cell stack where the electricity is generated, an inverter which converts the direct current to alternating current, and a system for harnessing the excess heat. Emissions to air during operation are low.

The studied installation generates both electricity and heat and has an electrical capacity of 250 kW, an electrical efficiency of 47% (the total efficiency is 80%), and is run on natural gas. The technical life span is set at 100 000 hours of operation, and the life-time generation is 25 GWh of electricity.

The allocation of environmental impacts between the two products, electricity and heat, has been conducted in accordance with the guidelines for environmental product declarations.

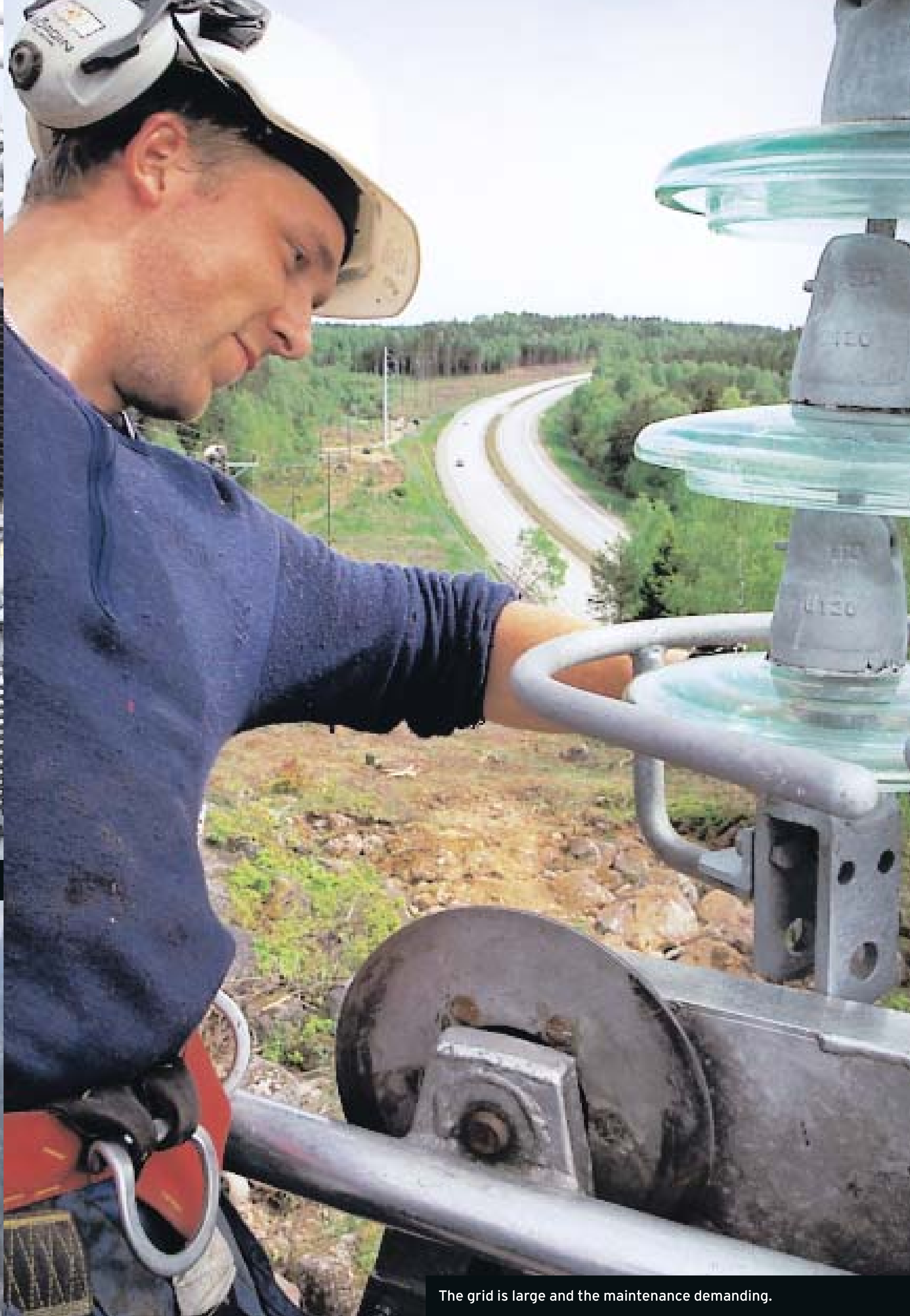
Emissions of CO_2 is dominated by the operational phase, whereas all other impacts are dominated by the fuel production phase. The environmental impacts from the manufacturing of the installation are comparatively low.



Solar cells at Vattenfall's research and development facility at Älvkarleby, Sweden.

A grid consists of many components.

Transmission-line corridor
seen from the air.



The grid is large and the maintenance demanding.

Transmission poles come in various designs.

The electric grid

Power plants and consumers are connected to a nation-wide integrated supply system for electricity. It is made up of transmission and distribution systems and consists, simply put, of a large number of cables, lines, transformers and switch gear.

Electricity is mainly generated in large centralised installations, like nuclear power plants, at voltages of about 6–25 kV. The power is then stepped up to the voltage of the main grid, 220 or 400 kV, for distribution across the country. From the main grid, the power is stepped down to lower voltages when the electricity is transmitted via regional (70/130 kV) and local networks (0.4–70 kV), for distribution to the customers. Medium-sized generation units, like municipal CHP plants, can deliver electricity to regional or high-voltage, local grids. Small-scale generation units like wind-power plants, solar cells and fuel cells deliver to local grids (0.4–130 kV).

Large consumers, e.g. certain industries, are often connected to the regional network or a high-voltage local grid (6–130 kV), while smaller consumers, e.g. households, are connected to the low-voltage local grid (0.4 kV).

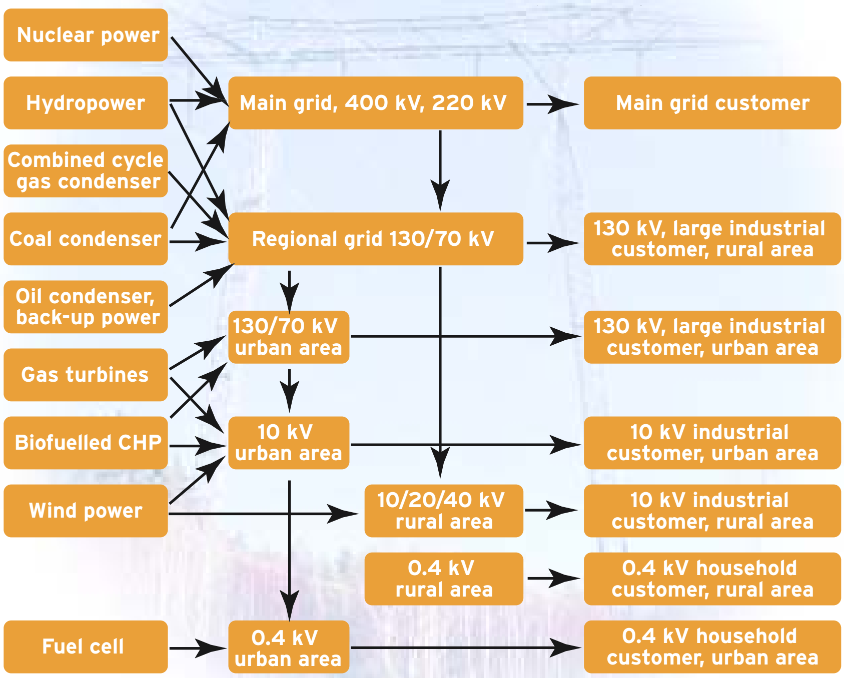
Structure of grid ownership

Svenska Kraftnät (National Swedish Power Grid), owns and operates the high-tension, national grid. Regional networks are owned by different companies, of which Vattenfall is one. The local distribution uses local grids at tensions between 0.4 and 130 kV. There are about 180 companies distributing electricity in Sweden at present, and around 125 traders, selling electricity.

Lines and cables

Transmission and distribution use aerial lines or underground cables. The most common conduction material is aluminium, with copper also being used in some cases. Polyethylene is normally used as insulation.

The electricity's way from plant to customer



The electricity can take many different routes from plant to customer.

The poles for the higher voltage levels are often made of galvanised steel. Impregnated wooden poles are used for lower voltage levels. Wood and concrete are used for foundations and the anchoring of struts. The isolators are made of glass or porcelain.

Substations

The substations contain transformers and switch gear with their respective control gear. The transformers step the power up and down between different voltage levels. Most of the components necessary for operating the transmission system are joined in the switch yards. All connections, current and voltage measurement, and communication with the operation centres are all performed there. The switchyards contain rail systems connecting the transformers with the in- and outgoing lines. Connections are made with circuit breakers or load switches.

Operation, maintenance and dismantling

Transmission and transformer losses occur during the operational phase. Maintenance includes inspections, tests, audits, repairs and the clearing of transmission-line corridors.

The use of vehicles dominates the environmental impact from this phase. A major share of the spent material is recycled in conjunction with the dismantling process.

Environmental impact

The transmission/distribution of electricity affects the environment in direct and indirect ways. Directly, through resource use and emissions in conjunction with the construction, operation and maintenance of the grid; and indirectly, through grid losses since these losses need to be replaced by higher generation in the power plants.

Losses from the grid

The grid losses during the distribution of electricity to the consumer vary considerably. Important factors affecting the real losses are: transmission distance, instantaneous load on the grid, voltage level at which the power plants are connected, and voltage level at which the customer is connected. Average distribution losses can be calculated for different voltage levels or group of voltage levels in the grid.

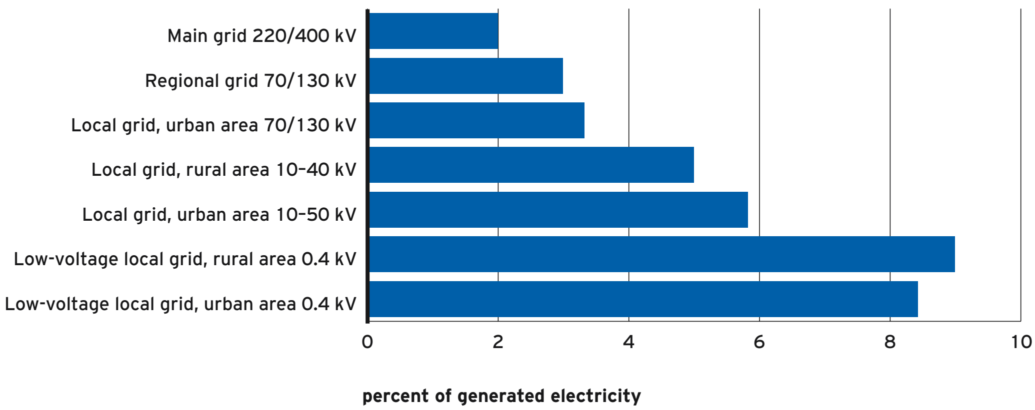
If the power plants are connected to the main grid, the average loss when delivering to a household consumer at 0.4 kV in an urban setting is 8.5%.

In this presentation, we only consider the environmental impacts caused by the extra generation needed to compensate for the grid losses.

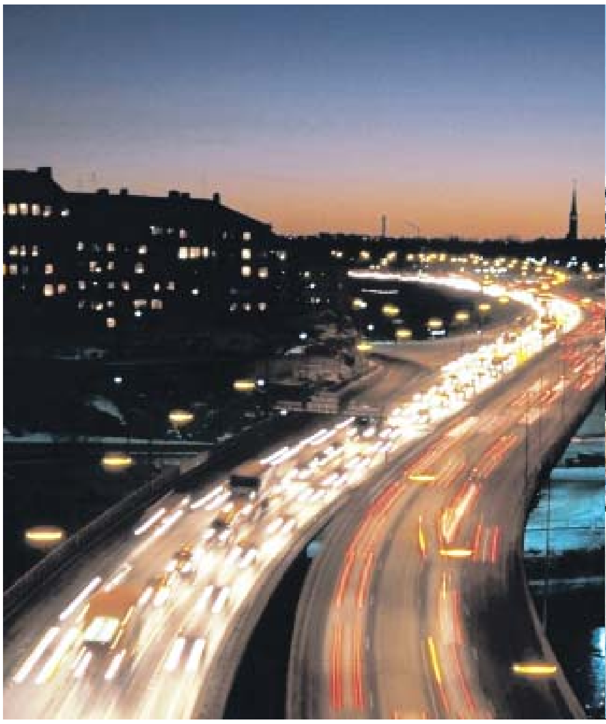
Electric and magnetic fields

Electro-magnetic fields are found around all electrical devices and cables. Vattenfall works in accordance with the precautionary principle. This is clarified in general advisories published by the Swedish Radiation Protection Authority and the Swedish Work Environment Authority. In practice, this means that we strive to avoid fields which deviate strongly from what can be considered normal in the environment in question.

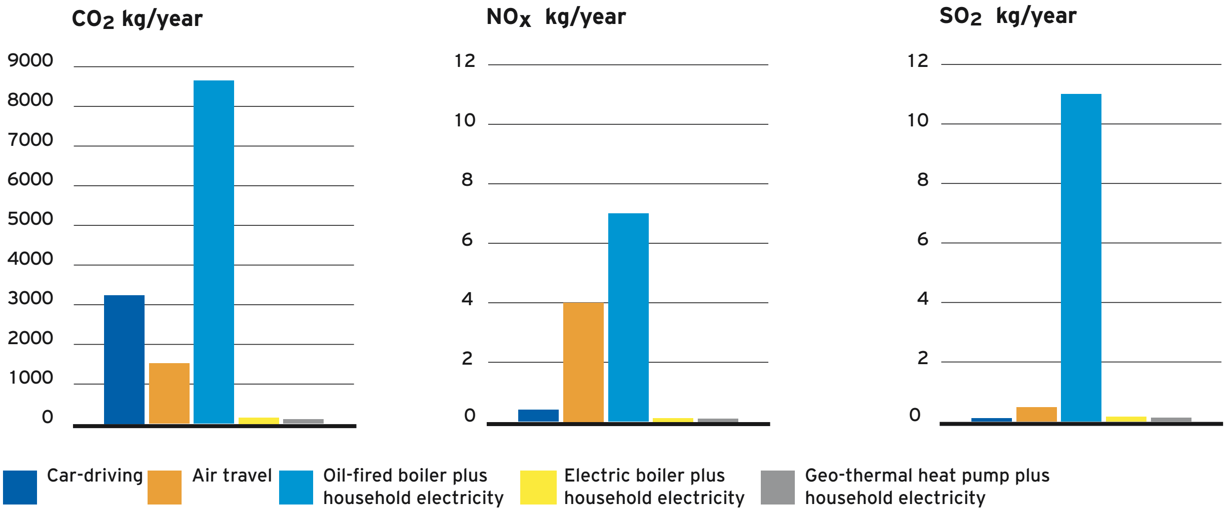
Average transmission losses to customers at different voltages levels, accumulated from the main grid



Our everyday environmental impact



Comparison to other activities



Comparison to other activities
This describes a potential family in central Sweden (the Mälardalen area, near Stockholm) which lives in a townhouse from the early 1980's, has a car and travels on one charter vacation trip every year. (The results are calculated with operational emissions, not the entire life cycle). The figures above show the emissions caused by electricity, residential heating and the family's travel during one year.

Car-driving *Volvo V70 2.4, 2002 model, 170 hp. Driven 15 000 km/year, city and rural roads. Source: Volvo Car Corporation.*

Air travel *Boeing 737–800 Euro. Mallorca return, 4 950 km, 90% capacity. Source: SAS*

Heat and electricity *Heating consumption: 20 000 kWh/year. Electricity consumption: 5 000 kWh/year. Three heating alternatives: oil-fired boiler with 70% efficiency, electric boiler with 90% efficiency, geo-thermal heat pump with heat factor 2.8.*

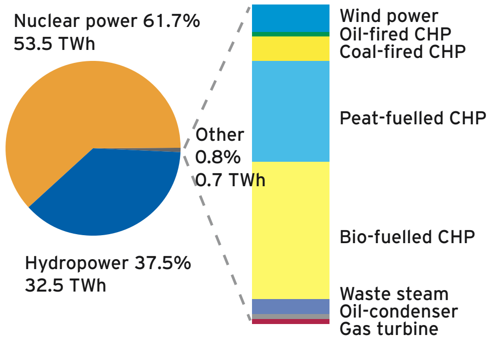
Sources: Heating consumption and combustion data – Swedish Energy Agency, electricity – Vattenfall AB, average generation mix.

Results – Vattenfall's electricity in Sweden

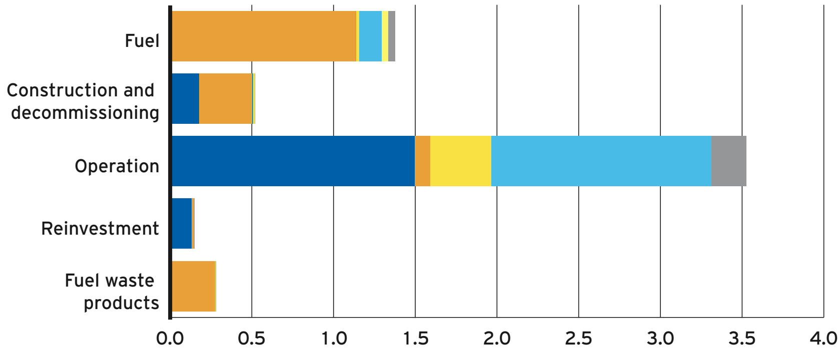
Vattenfall generates approximately 86.7 TWh of electricity per year in Sweden, and the pie chart below shows the average generation mix (forecast 2004–2006) with 61.7% nuclear power, 37.5% hydropower and 0.8% other sources.

- The environmental impact of an average kWh generated by Vattenfall can be calculated provided we know the following:
- The proportion of Vattenfall's generation from each source
- The annual generation in the respective plants/installations
- The environmental impact per generated kWh for each source of power.

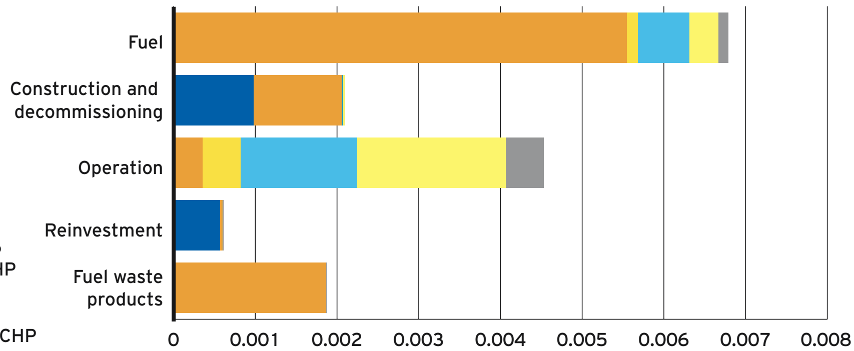
Vattenfall's average generation mix in Sweden



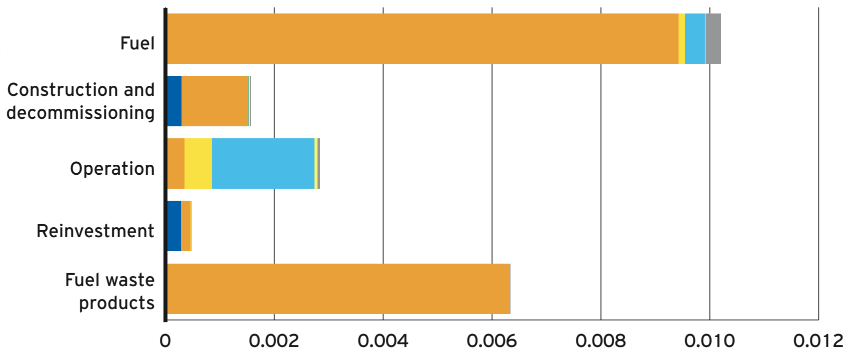
Average emissions of fossil CO_2 (g/kWh) from Vattenfall (total 5.8 g/kWh electricity)



Average emissions of NO_X (g/kWh) from Vattenfall (total 0.016 g/kWh electricity)



Average emissions of SO_2 (g/kWh) from Vattenfall (total 0.021 g/kWh electricity)



Hydropower | Nuclear power | Wind power | Fossil-fuelled CHP | Peat-fuelled CHP | Bio-fuelled CHP | Back-up power

The bar graphs show some of the environmental impact parameters. The results are valid for the whole life cycle. Some parts, such as the construction of the plants and installations, occurred entirely in the past; some occur continuously during operation, and others, such as dismantling and demolition, will occur in the future The emissions not only occur in Vattenfall's installations, but also in the processes of our suppliers who manufacture e.g. building materials, chemicals and fuels.

Nuclear power, or more correctly the electricity and fuel used during the production of uranium fuel, dominates Vattenfall's emissions of NO_X, SO_2 and particulate matter. In the life-cycle phase "management of waste products from the fuel", the copper used for encapsulation of spent nuclear fuel, together with transports of bentonite clay, are of major importance.

The impact of hydropower is mainly seen during the phases of construction and reinvestment. Regarding CO_2, there is also a contribution from the operational phase, emissions from land areas inundated by the reservoirs.

In spite of the small power-generation contribution made by CHP and back-up power, their contributions to emissions are significant in the operational and fuel-production phases.

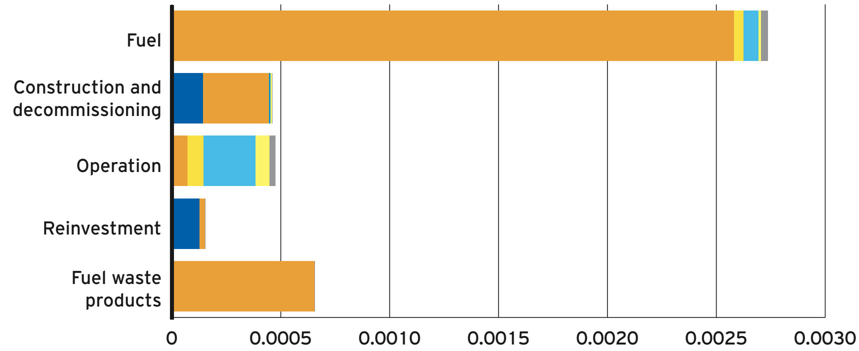
Copper is used in generators, transformers and cables during construction and reinvestment, but primarily used for the encapsulation of spent nuclear fuel for the long-term storage in deep-level rock-chamber depositories.

Highly active radio-active waste is generated both in the operation of the nuclear power plants, and also during the fuel production, since electricity from nuclear power is used by several suppliers in the nuclear fuel chain.

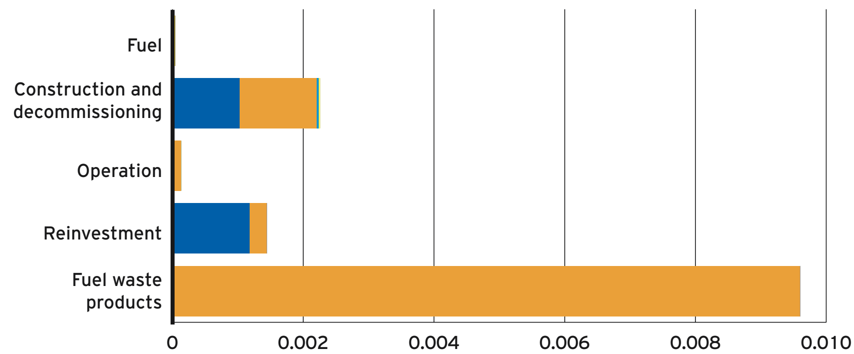
In order to calculate the environmental impact all the way to the customer, one has to add the electricity generation needed to compensate for transmission losses (see pp. 17–18).

Vattenfall can sell about 68 TWh out of the 87 TWh generated in the installations in which it has a majority interest. The rest is sold by the minority owners. Vattenfall's electricity sales to its own electricity customers in Sweden is smaller than the generation.

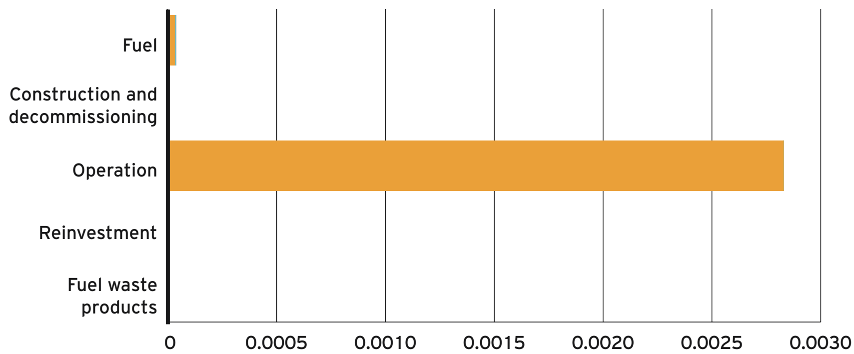
Average emissions of particulate matter (g/kWh) from Vattenfall (total 0.0045 g/kWh electricity)



Average use of copper (g/kWh) from Vattenfall (total 0.013 g/kWh electricity)



Average generation of highly radio-active waste (g/kWh) from Vattenfall (total 0.013 g/kWh electricity)



Hydropower | Nuclear power | Wind power | Fossil-fuelled CHP | Peat-fuelled CHP | Bio-fuelled CHP | Back-up power

Results per distributed kWh for each power source

Note that these results are valid under the assumptions made in this report. They cannot be considered representative for electricity generation in general.

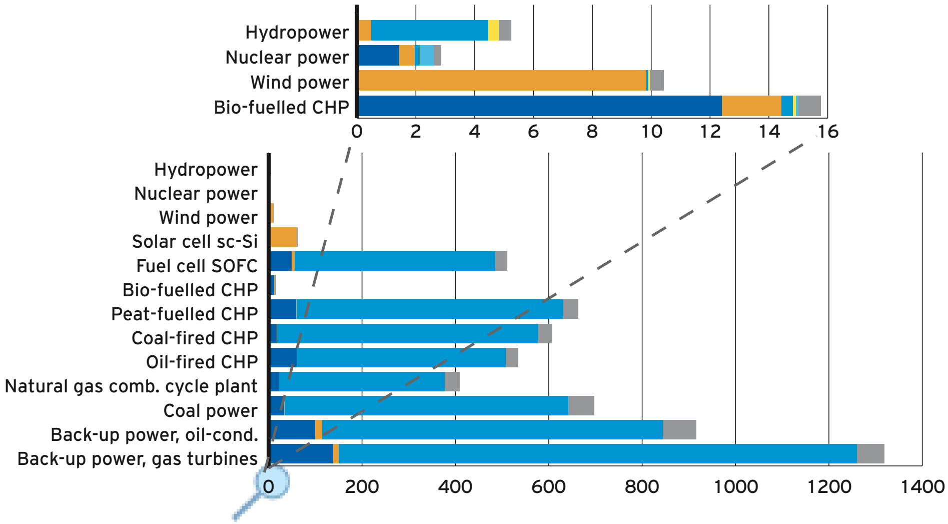
The environmental parameters are expressed in grams per generated and transmitted kWh of electricity to urban household customers (0.4 kV). By presenting the emissions in relation to the delivered service, the different power-generation technologies can be compared irrespective of the amount of electricity generated. It is important to remember that the different technologies cannot completely replace each other, since they serve different functions.

It is generally true that:

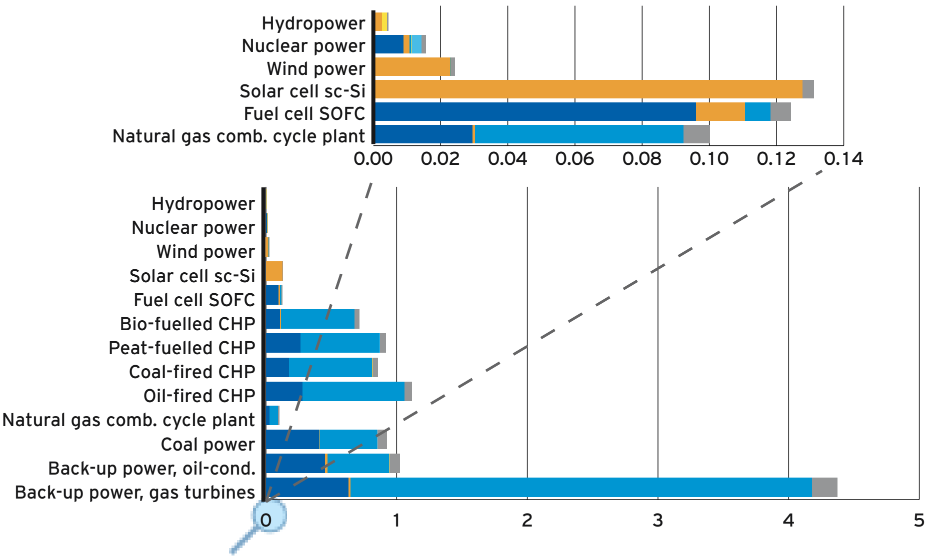
- Construction dominates for the technologies lacking fuel, instead using a flowing source of energy (hydro-, wind- and solar power).
- The operational phase dominates for all fuel-burning power plants, followed by fuel production.
- Electricity from CHP plants often yields lower emissions than does electricity from condensing power plants using the same fuel.
- The demolition/dismantling phase causes a comparatively low impact since e.g. metals and concrete can be recycled.

For generation technologies using flowing energy sources, it is clear that the "amount of material per installed capacity" is an important environmental parameter for the environmental impact profile, as are the materials used. The greater the amount of materials, and the rarer the materials are, the worse the environmental impact profile is. It is also important where the manufacturing of the materials occurs, as well as what source of electricity is used. A great deal of fossil-based electricity yields higher emissions to air. On top of this, the efficiency, i.e. how

Emissions of fossil CO_2, g/kWh electricity delivered to household customer



Emissions of NO_X, g/kWh electricity delivered to household customer



Base power: hydropower, nuclear power, coal power, CHP
Peak power: hydropower, gas turbines
Back-up power: oil-condensing power plants, gas turbines
Temporary power: CHP, solar cells, wind power

Fuel | Construction and decommissioning | Operation | Reinvestment | Fuel waste products | Compensation generation to cover losses effectively the flowing energy source is converted to electricity, and the availability of the flowing energy during the year are important for the environmental impact profile.

The efficiency, i.e. how effectively the energy in the fuel is converted to electricity, is decisive in determining the impacts from the fossil-, peat- and bio-fuelled technologies. The purity of the fuel and the efficiency of the flue-gas cleaning are also important. The results for the natural gas-fired combined-cycle plant and the coal plant shown in the graphs illustrate modern technology with high efficiencies and effective flue-gas cleaning. The data for the oil condenser and gas turbine have been sourced from older installations with relatively low efficiencies and limited or no flue-gas cleaning. Since the back-up power is utilised for very limited periods of time, the authorities allow higher emissions. The CHP results are representative of the technology in place within Vattenfall. The fuel cell is a potential future design.

The production of fossil, peat and bio fuels has greater impacts on the results the lower the efficiency is, since it takes more fuel to generate one kWh at lower efficiencies.

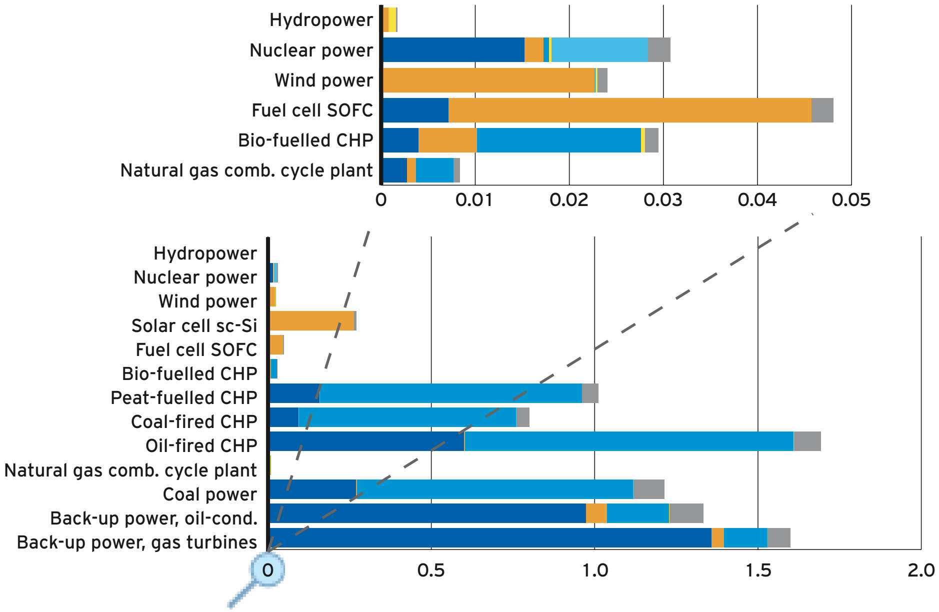
The data for the production of coal for CHP (see the bar for “CHP coal” in the graph) is representative of Vattenfall’s actual purchases, while the coal in the bar “Coal power” represents an average for European use of coal, sourced from all over the world.

The oil fuel for CHP (the CHP oil bar in the graph) consists of half heavy and half light oils, which works well since there is cleaning equipment installed. Cleaner fuel is used in the back-up power plants in order to stay within the emissions limits.

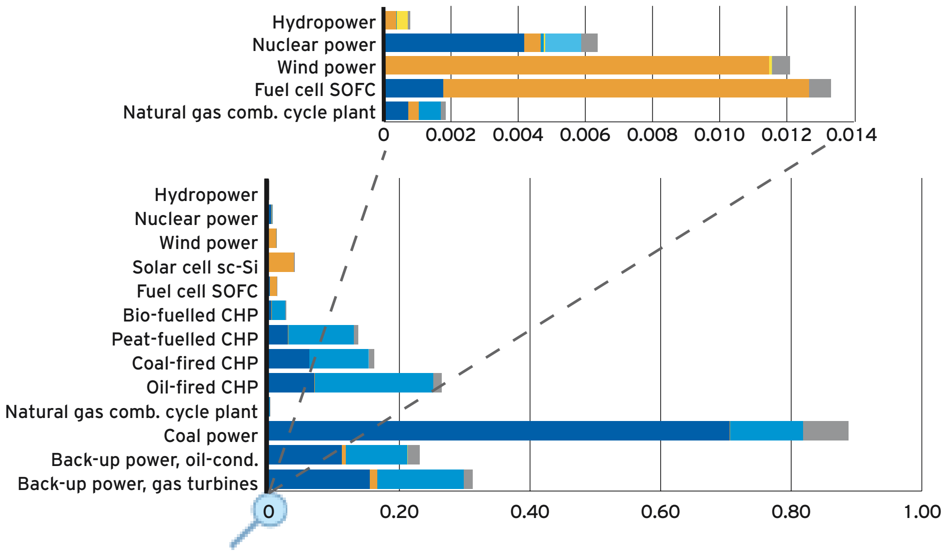
Drying peat requires a considerable amount of electricity. This electricity is responsible for a rather large share of the emissions from the studied peat-fuelled CHP plant (the bar “CHP peat”). This is particularly true for Russian peat, since a large share of the Russian electricity generation, over 65%, is fossil-based. The long transportation distances from Russia also affect the environmental impact profile.

The fuel production is responsible for more than half of the emissions to air from the nuclear-fuel life cycle. The choice of suppliers in the fuel chain is of great importance, particularly in the case of mines and enrichment facilities. The concentration of uranium in the ore has an impact, as does the choice of enrichment method. The use of electricity can differ by a factor 10 between different uranium-enrichment methods. The amount of fossil-based electricity used by suppliers in the fuel chain is also important. The presented results are representative of Vattenfall’s nuclear power.

Emissions of SO_2, g/kWh electricity delivered to household customer



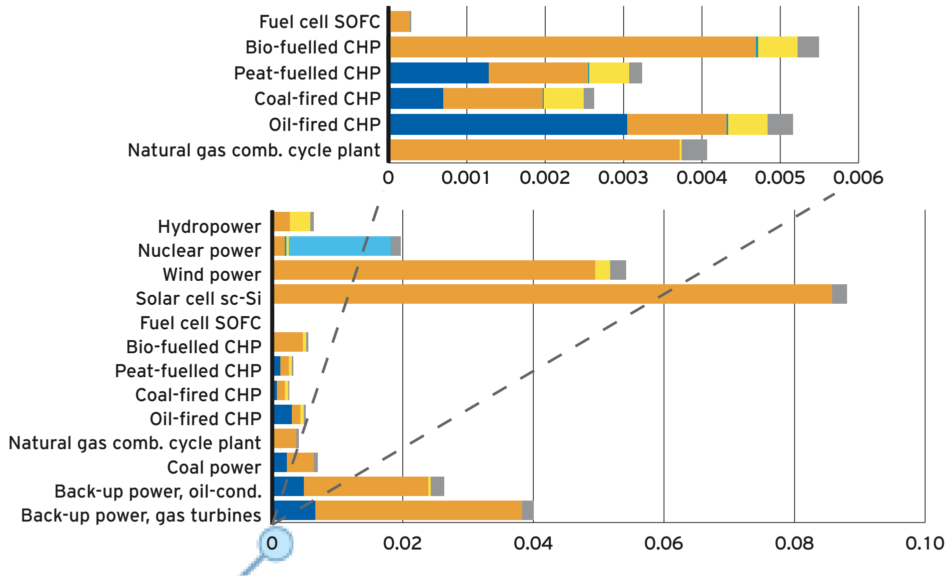
Emissions of particulate matter, g/kWh electricity delivered to household customer



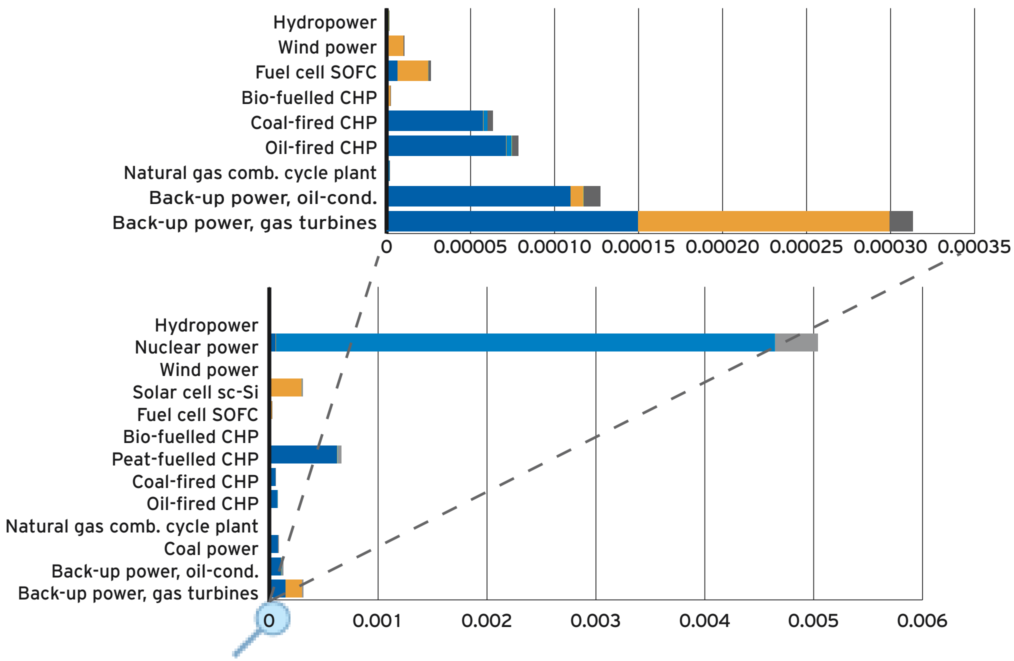
Copper is a resource in high demand, particularly in the nuclear industry which needs it for the encapsulation of the spent nuclear fuel in preparation for placing it in the deep-level depositories. It is not possible to recycle this copper, at least not in the foreseeable future, since the fuel needs to be stored for 100 000 years. Other power technologies utilise copper primarily in the construction phase, and this can be recycled to a large extent. Copper is an integral part of many components such as generators, transformers, cables etc. Of the presented power technologies, solar cells use the highest amount of copper, followed by wind power. The back-up power scores rather high per generated kWh since the generation is very limited.

All power technologies indirectly cause the generation of high-active radio-active waste, since nuclear electricity is used in the manufacturing of fuels, materials and chemicals.

Use of copper from mine, g/kWh electricity delivered to household customer



High-active radio-active waste, g/kWh electricity delivered to household customer



Fuel
Construction and decommissioning
Operation
Reinvestment
Fuel waste products
Compensation generation to cover losses

Electricity generation compensating for losses

We have assumed that the different power sources connect to the grid in accordance with the table below. The losses en route to a household customer then vary between the different technologies. In the bar charts, we generally assume that the losses are compensated by the same power technology.

Power technology	Assumed to connect to this grid for further stepping down to 0.4 kV	Average losses in %
Hydropower	Main grid	8.4
Nuclear power	Main grid	8.4
Wind power	Local grid, rural area 10-40 kV	4.6
Solar cell sc-Si	Low-voltage grid, urban area, 0.4 kV	2.6
Fuel cell SOFC	Local grid, urban area, 10-50 kV	5.1
CHP bio	Local grid, urban area, 10-50 kV	5.1
CHP peat	Local grid, urban area, 10-50 kV	5.1
CHP coal	Local grid, urban area, 10-50 kV	5.1
CHP oil	Local grid, urban area, 10-50 kV	5.1
Natural gas comb. cycle plant	Main grid	8.4
Coal power	Main grid	8.4
Back-up power, oil-cond.	Main grid	8.4
Back-up power, gas turbines	Local grid, rural area, 10-40 kV	4.6

Biodiversity

Land use

The different power technologies have varying demands on land area, both in terms of size and type, making it difficult to compare them.

A hydropower reservoir requires a large area, but can be utilised for e.g. fishing and boating. The gathering of bio fuel in connection with tree harvesting in a wood happens at most every 80 years, and during much of that time the area can be used for e.g. hunting and recreation. Houses cannot be constructed too close to wind-power towers, but the surrounding ereas may be utilised for agriculture. Nuclear power causes the release of cooling water, and the warmed water affects fauna and flora in the sea closest to release point.

Processes such as materials manufacturing, transport etc., also require land. All mining causes major impacts on the environment, something that is also true for infrastructure in the form of roads and railroads, which slice through the landscape making it more difficult for animals and plants to move and reproduce.

The Biotope Method©

The life-cycle assessments do not include impacts on biodiversity. Because of this, Vattenfall has developed the Biotope Method©, with which it is possible to describe such effects in a quantitative manner. The method is used in the environmental product declarations' sections on biodiversity. The approach is to identify, delimit, measure, classify and characterise the land areas affected by the development. This is accomplished with the aid of maps, aerial photographs, literature, data bases and site visits to the affected areas. In order to characterise the areas as biotope losses, as well as general, rare and critical biotopes, we use, among others, the national red lists for species, published by the Swedish species information centre. This is done for two different points in time, called "Before" and "After". "Before" is just before the studied activity started, and "After" is a time when the activity has been going on for some time, and the habitats have recovered from the construction and reached a renewed equilibrium (this is defined on a case-by-case basis). By comparing the difference in coverage of various categories between "Before" and "After", one arrives at a measure of the change caused by the activity under study. The result is always complemented by a qualitative description.

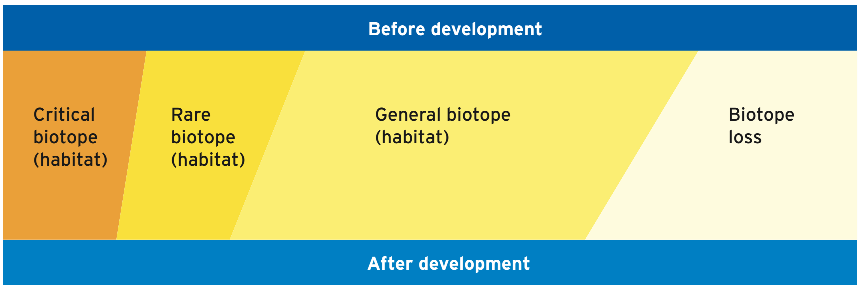
Transmission-line corridors

Vattenfall has carried out inventories indicating that transmission-line corridors can be advantageous to biodiversity. The clearing of the corridors create environments reminiscent of grazed meadows, which are getting rarer and rarer in the Swedish landscape. The corridors become the home of e.g. a number of rare herbs and butterflies. Some corridors have obtained Natura 2000 status.

Sheep grazing below a wind power tower.

Butterflies thrive in transmission-line corridors.

Fairy slipper (Calypso bulbosa) and Sarcosoma globosum from one of Vattenfalls protected areas in northern Sweden.



The illustration is a schematic rendition of how an area might change as a result of an installation.

Environmental risks

The life-cycle assessment only deals with the normal operation of the installations and plants. However, accidents and stoppages can occur. During normal operation, emissions take place continuously and in a controlled manner, while accidents often cause large emissions in a short time. The consequences of an accident are often local, i.e. affect the immediate surroundings. Vattenfall has developed a method for the inventory of environmental risks in a systematic manner. The environmental risk inventories are used in the environmental product declarations.

Risk is defined as the probability that an unwanted incident occurs, multiplied by the consequence of such an incident.

Environmental risk inventories are performed in several steps. After the determination of system boundaries, where it is determined which systems are affected by the activities under study, there is a gathering of information describing the activities; drawings, pictures, lists of chemicals in use, etc. A preliminary list of potential accident scenarios is developed. The next step is a site visit. Operational and maintenance staff is interviewed in order to get a coarse assessment of consequences and probabilities. A further analysis of consequences is made with the aid of archive material, literature and data bases. The results are reviewed by people with a variety of experience and competences, and the judgements adjusted in co-operation with these reviewers.

Forecasts regarding probabilities always suffer from various kinds of uncertainties. The uncertainty is greatest when dealing with extremely rare occurrences or where human error is the main cause. Judgments on consequences can also be uncertain. As an example, it is difficult to quantify the content of smoke from an uncontrolled fire.

In spite of the uncertainties, the results give an idea about the magnitude of emissions caused by stoppages and accidents. These, in turn, work as a good foundation for the determination of what preventive actions yield the biggest environmental benefits.

The environmental risk inventories so far implemented for Vattenfall's power plants (Forsmark, Ringhals, wind power, hydropower in the Ume and Lule rivers and waste incineration in Uppsala) show that, over time, emissions from accidents are small compared to normal operations. However, this does not mean that an accident cannot have major local consequences.

Exempel
The probability of experiencing a car accident with minor personal injury, petrol leakage and car repair is 1 in 20 000 km. This probability is multiplied by the following consequences:

2 000 SEK lost due to repair costs and higher insurance premiums.

20 litres of petrol leaking into a ditch.

10 days of medical recovery.

The risk can be calculated to 100 SEK, 1 litre of spilled petrol and 0.5 days recovery per each 1 000 km driven. Every trip carries the same risk per kilometre.

The risk is constant over time, i.e. it does not increase after 10 or 100 driven km. Every trip carries the same risk per kilometer.

Reinforcement of the dam at Suorva

The control room at Forsmark.

Practical benefits

Life-cycle assessments, environmental risk inventories and biotope/habitat studies are the bases for Vattenfall's environmental product declarations, but also function as tools in the everyday environmental management work. The results are, in conjunction with other information, the basis for decisions regarding environmental aspects, actions and investments.

The tools, including the EPDs, have for instance contributed to the following:

- We found interesting habitats near the Lule River, which have now been protected as "värnområden", a kind of private protected area.
- High water usage was identified at Forsmark. The remedial actions have led to a reduced use of water, chemicals and electricity.
- Vattenfall Bränsle AB (the nuclear-fuel subsidiary of Vattenfall) uses the results from the life-cycle assessments for the identification of the steps in the nuclear fuel chain; mining, conversion, enrichment and fuel production, which have high environmental impacts. The results are used in the dialogue with the suppliers.
- A system for the recycling of materials for transmission grids has been developed in co-operation with a cable manufacturer.
- Vattenfall Eldistribution AB (the transmission subsidiary) has developed a tool based on life-cycle assessments, which can be used when constructing new electricity transmission systems.
- The environmental product declarations are used in permitting processes.
- Work on reducing the risks for oil emissions to soil and water is now on-going.

Generally improved awareness and commitment among the Vattenfall staff have led to an increased use of life-cycle thinking as an integral part in the planning for refurbishments and investments.

One example is the waste incineration plant, block 5 in Uppsala, where the environmental product declaration has been prepared at the same time as the plant has been built.

The analyses are also used for evaluating different technical solutions such as:

- ABB's generator Powerformer.
- Transmission poles made of composite material compared to ones made of wood.
- Mobile switch yards compared to stationary ones.
- Switch yards isolated with SF_6 compared to those using air.
- Different types of drilling techniques for storing the spent nuclear fuel (SKB – Swedish Nuclear Fuel and Waste Management Co).
- Solar cells for the electrification of summer houses in Sweden.
- When purchasing wind power equipment, information is requested from the suppliers in order to facilitate evaluation from a life-cycle assessment point of view.

Small glossary

EPD Environmental Product Declaration, certified in accordance with the EPD system, a system for information on the environmental performance of products and services, based on life-cycle assessment.

LCA Life-Cycle Assessment

LCI Life-Cycle Inventory.

LCIA Life-Cycle Impact Assessment, part of LCA.

CLAB Centralised intermediate storage facility for spent nuclear fuel.

SFR Final depository for low- and medium-active nuclear waste.

Do you want to know more?

The alternative production method
Method for the allocation of environmental impact between electricity and heat for a combined heat and power plant. See PCR Product Category-specific Rules for preparing an Environmental Product Declaration (EPD) for Electricity and District Heat Generation, PSR 2004:2, annex 2. *www.environdec.com*

The Biotope Method© Method for the quantification of biodiversity impact. *www.vattenfall.se*

ECLIPSE Environmental and eCological Life cycle Inventories for present and future Power Systems in Europe, research project in the 5th framework programme of the EU, area "Energy, Environment and Sustainable Development". Data base with LCI data on new and future decentralised electricity-generation systems *www.eclipse-eu.org*

ecoinvent Swiss data base for LCA. *www.ecoinvent.ch*

EU's directive on electricity markets Can be found via EU's main web page: *http://europa.eu.int/index_en.htm*

Forsmarks kraftgrupp At *www.forsmark.com* you can find more information on Vattenfall's nuclear power plant, Forsmark. (In Swedish)

The Swedish Environmental Management Council Manages the EPD system. Has all EPDs and methodological documents available on its web site. *www.environdec.com*

MSR 1999:2 Rules for certified environmental product declarations, EPD, an adaptation of ISO TR 14025 TYPE III ENVIRONMENTAL PRODUCT DECLARATIONS, The Swedish Environmental Management Council, 2000. *www.environdec.com*

PSR 2004:2 PCR Product Category-specific Rules for preparing an Environmental Product Declaration (EPD) for Electricity and District Heat Generation, PSR 2004:2 *www.environdec.com*

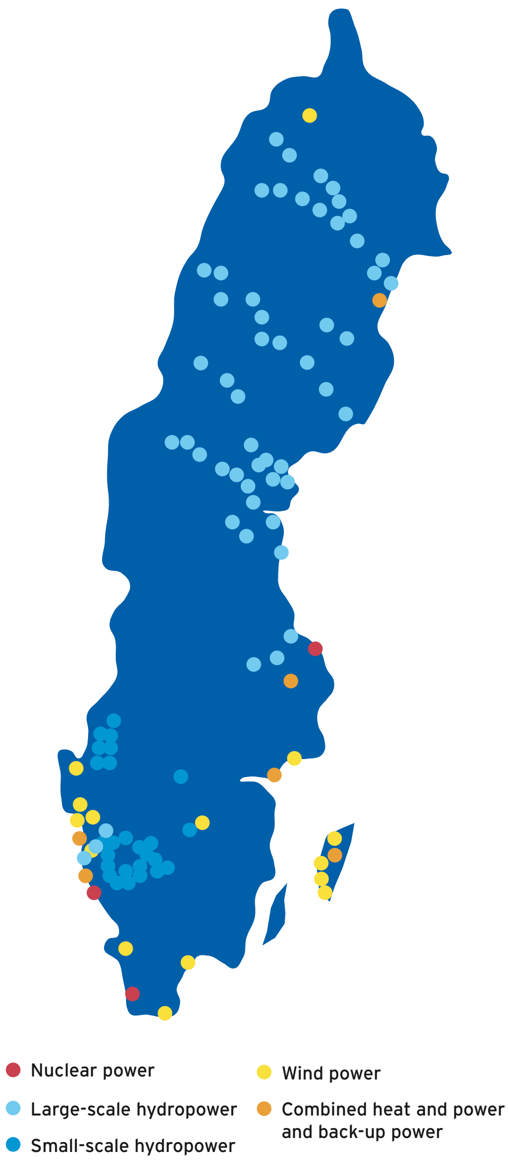
Ringhals AB At *www.ringhals.se* you can find more information in English about Vattenfall's nuclear power plant, Ringhals.

SIS, Swedish Standards Institute Here you can find information and order standards for LCA and EPD, ISO 14040 ff and ISO TR 14025. *www.iso14000.nu*

SKB, Swedish Nucelar Fuel and Waste Management Co Is charged with the management of the radio-active waste generated from Swedish nuclear power plants, but also manages other radio-active waste. *www.skb.se*

Vattenfall AB Here you can find more about Vattenfall's work with environmental management in the Nordic countries. (In Swedish) *www.vattenfall.se*

Vattenfall's Värnområden VVO Areas Vattenfall has undertaken to manage in such a way that biodiversity is conserved. *www.vattenfall.se*



Energy terminology

Capacity units
Capacity is energy per time unit
Capacity is expressed as watt (W)
1 kW (kilowatt) = 1 000 W
1 MW (megawatt) = 1 000 kW
1 GW (gigawatt) = 1 000 000 kW

Energy units
Energy is capacity multiplied by time
1 kWh (kilowatt hour) = 1 kW during one hour
1 MWh (megawatt hour) = 1 000 kWh
1 GWh (gigawatt hour) = 1 000 000 kWh
1 TWh (terawatt hour) = 1 000 000 000 kWh

Voltage
1 kV (kilovolt) = 1 000 volt (V)

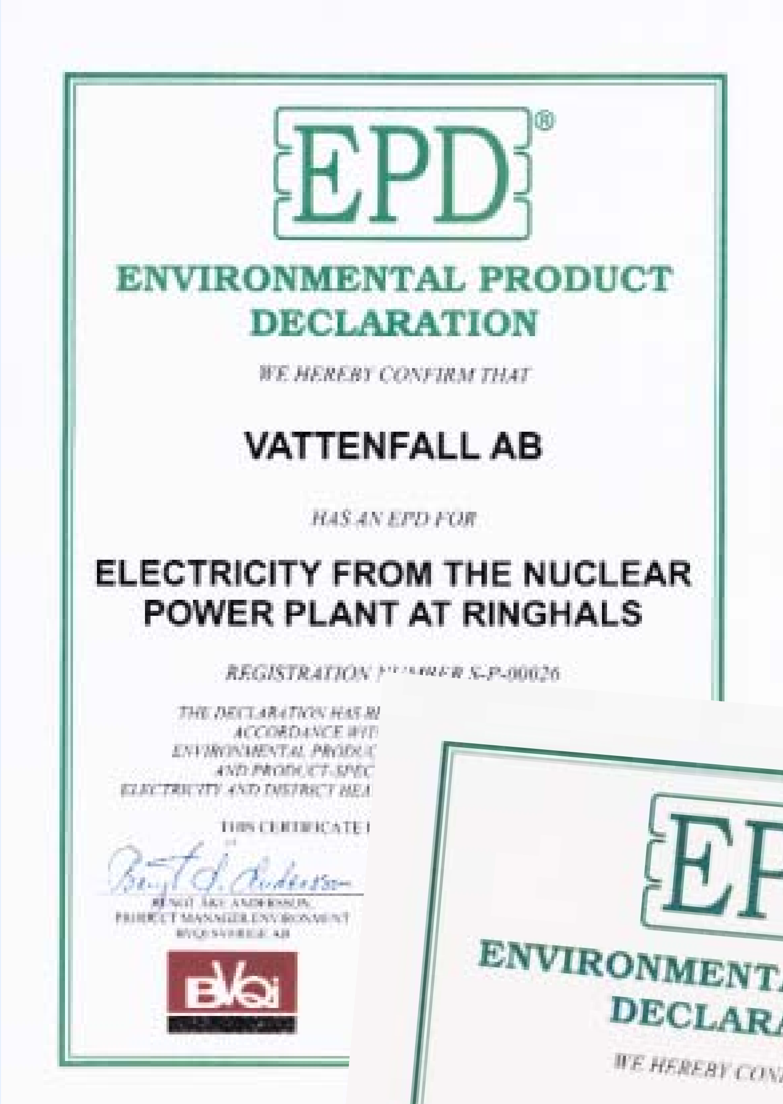
Rules of thumb for energy

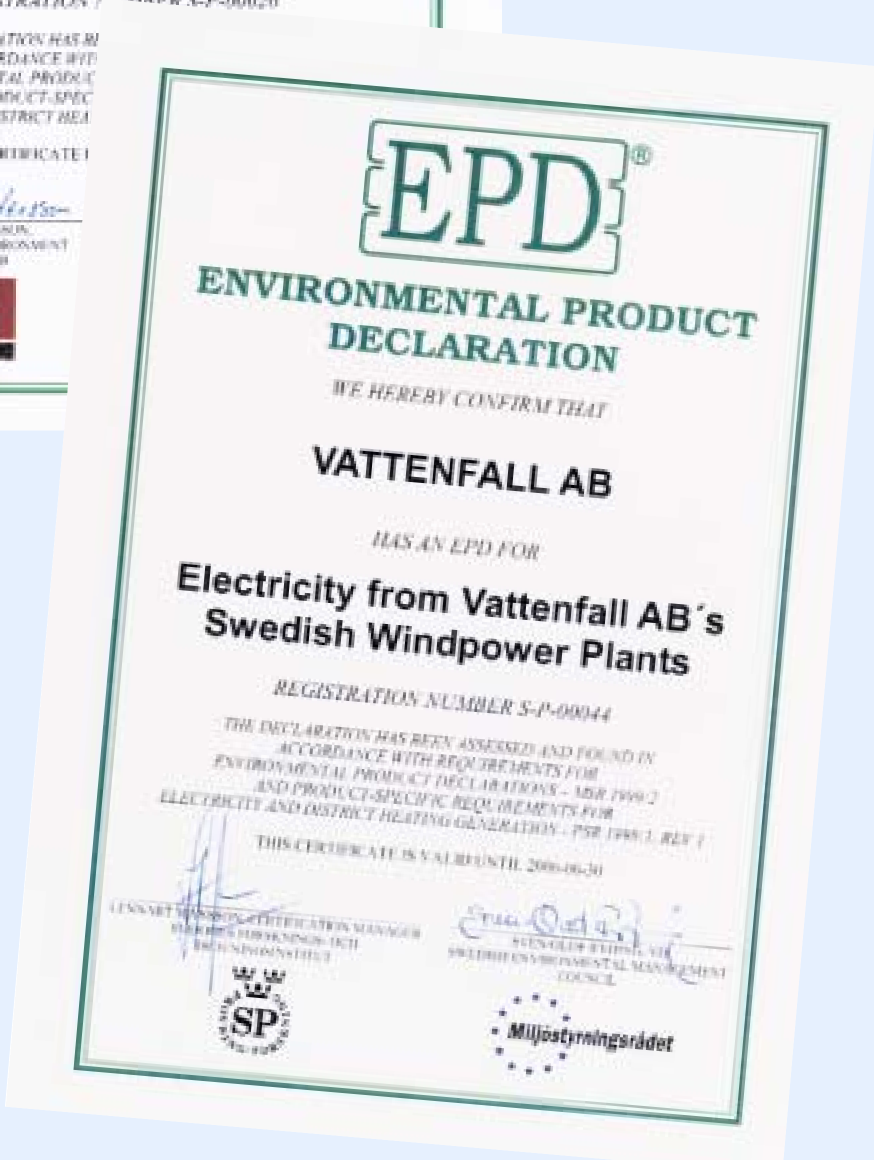
1 kWh is enough to run a normal car heater for approximately 1 hour or an 11 W low-energy light bulb for almost four days.

1 MWh is enough to heat a house for a few weeks and can be generated in 20 minutes in Vattenfall's largest wind-power plant, during good winds.

1 GWh covers the electricity needs of a city of about 100 000 inhabitants for 8 hours, and can be generated in the Harsprånget hydropower plant in one hour, or in the Forsmark nuclear power plant in 20 minutes.

1 TWh can run two large newspaper machines for one year. It is enough to run all the trains, undergrounds and trams in Sweden for five months. It is generated by the Ringhals nuclear power plant in 12 days.


EPD®
ENVIRONMENTAL PRODUCT DECLARATION
WE HEREBY CONFIRM THAT
VATTENFALL AB
HAS AN EPD FOR
ELECTRICITY FROM THE NUCLEAR POWER PLANT AT RINGHALS
BVQI


EPD®
ENVIRONMENTAL PRODUCT DECLARATION
WE HEREBY CONFIRM THAT
VATTENFALL AB
HAS AN EPD FOR
Electricity from Vattenfall AB´s Swedish Windpower Plants
REGISTRATION NUMBER S-P-00044
SP
Miljöstyrningsrådet

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