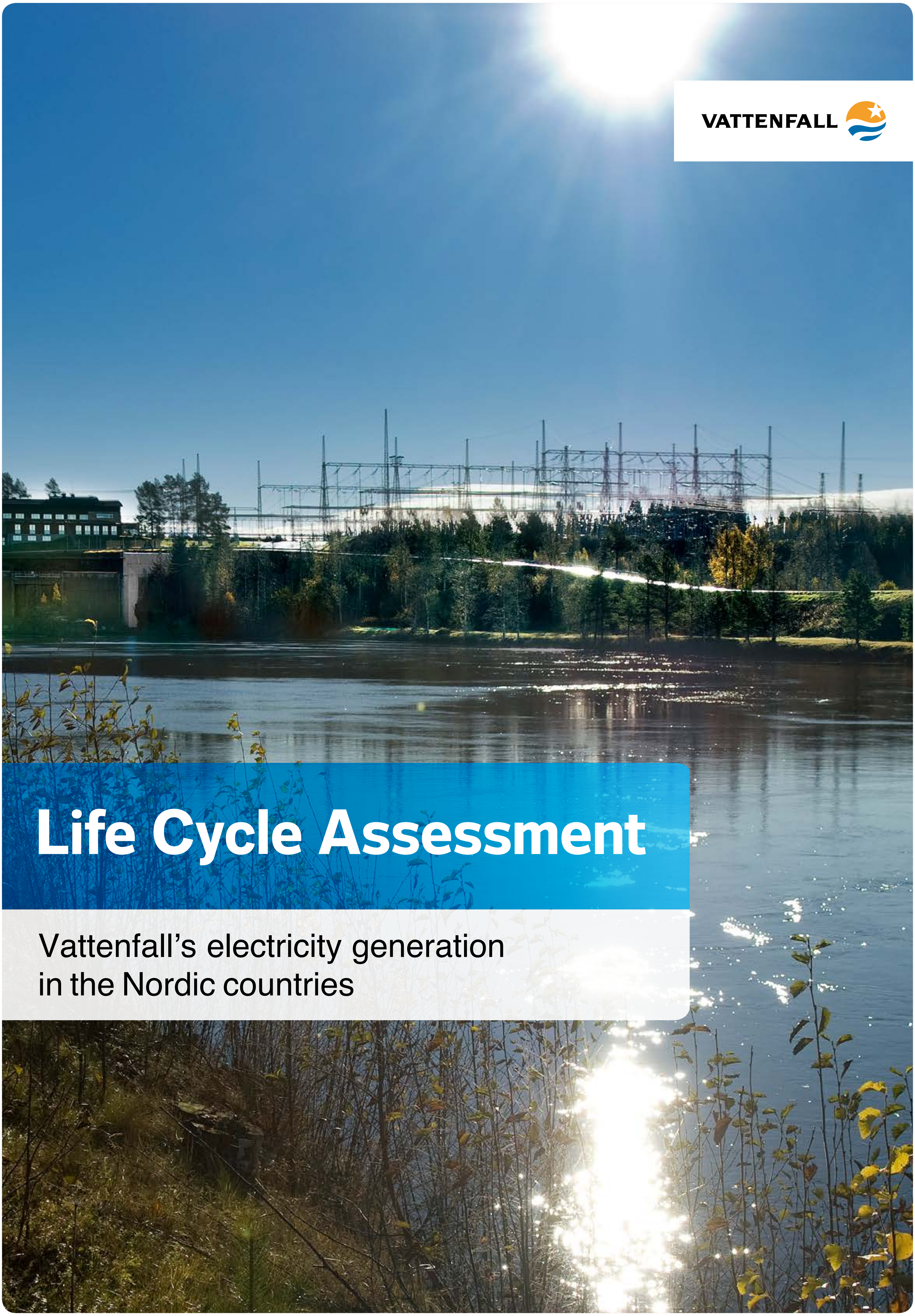


VATTENFALL

Life Cycle Assessment

Vattenfall's electricity generation in the Nordic countries

Content

Cover picture: The hydro power plant at Stornorrfors, Sweden.

The distribution network for electricity generated at the Stornorrfors hydro power plant in Sweden.

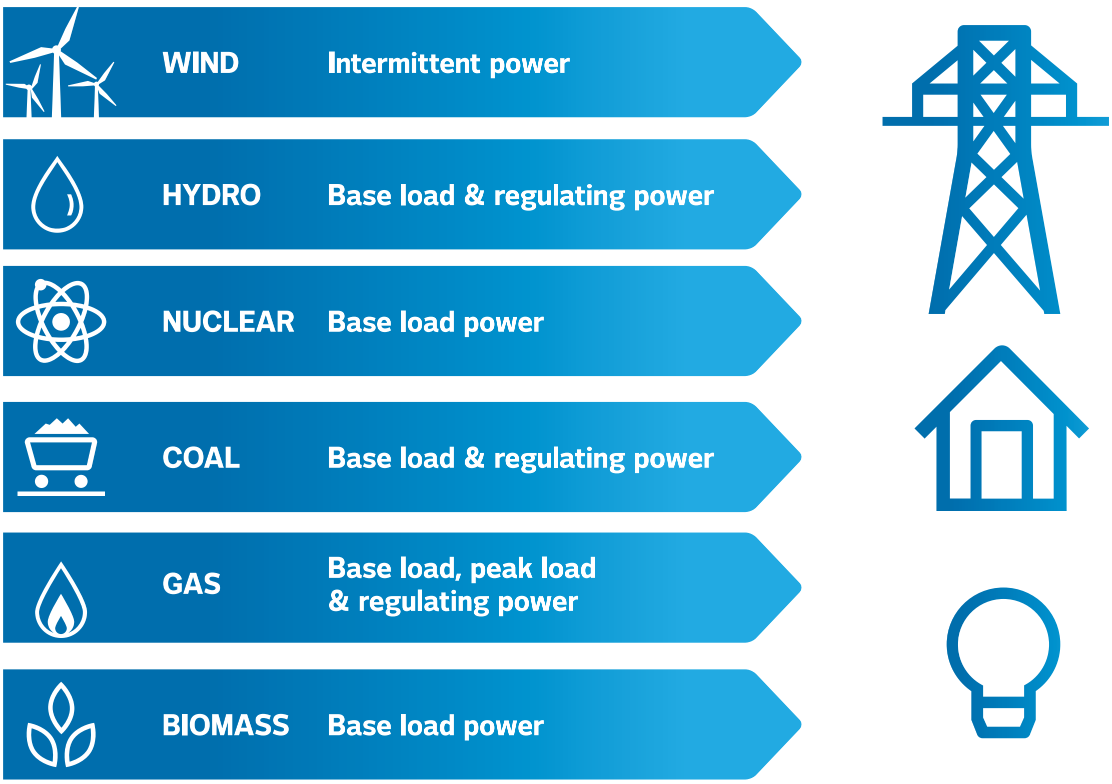
The Nordic electricity system

The demand for energy, and specifically electricity, is increasing on a global level, particularly in growing economies. The supply of electricity becomes increasingly important for an industrial sector that is still at the development stage. Steady economic growth requires reliable access to electricity at reasonable cost. It is therefore necessary to provide a safe and secure electricity system with low vulnerability

Every step in the process of generating and distributing electricity affects the environment in one way or another, regardless of the energy source. Examples include emissions to air and water, various kinds of residual products, and exploiting vulnerable terrain. To see the whole picture showing the impact of various energy sources on the environment, we need a life cycle perspective. Such an approach includes the entire value chain of electricity generation, from fuel production and the construction of plants to the handling of waste. A life cycle perspective also allows us to see to which extent the choice of supplier affects the results.

As it is difficult to store large amounts of electricity efficiently, it has to be generated at the same time that it is consumed. A mix of energy sources with varying generating properties forms the basis of a reliable electricity system and provides the flexibility needed to respond to variations in demand.

Figure 1: The use and properties of different energy sources.



The turbine hall at Stornorrfors hydro power plant in Sweden.

Different energy sources have different properties

The basis of any electricity generating system is its *base load power*. It is typically generated by nuclear power plants, certain combustion plants and hydro power plants designed specifically for this purpose.

In addition to this, *regulating power* is needed in order to meet variations in electricity consumption. This power is also important for maintaining high quality in the electricity grid. Energy sources used for regulating power are primarily hydro and combustion plants. Combustion plants are also used for generating *peak load power* at times when the demand for electricity is particularly high.

Renewable energy sources, such as wind, solar or wave power, often have an intermittent or irregular output depending on weather and wind conditions.

The conditions for generating electricity are different in different countries, depending on factors such as topography, climate, and political acceptance and electricity generation must be adapted to these specific circumstances. Thus the Nordic countries benefit from good conditions for hydro power thanks to the large number of rivers.

Any increase in the use of *intermittent power* in the electricity system often leads to an increased need for regulating power.

Different types of power

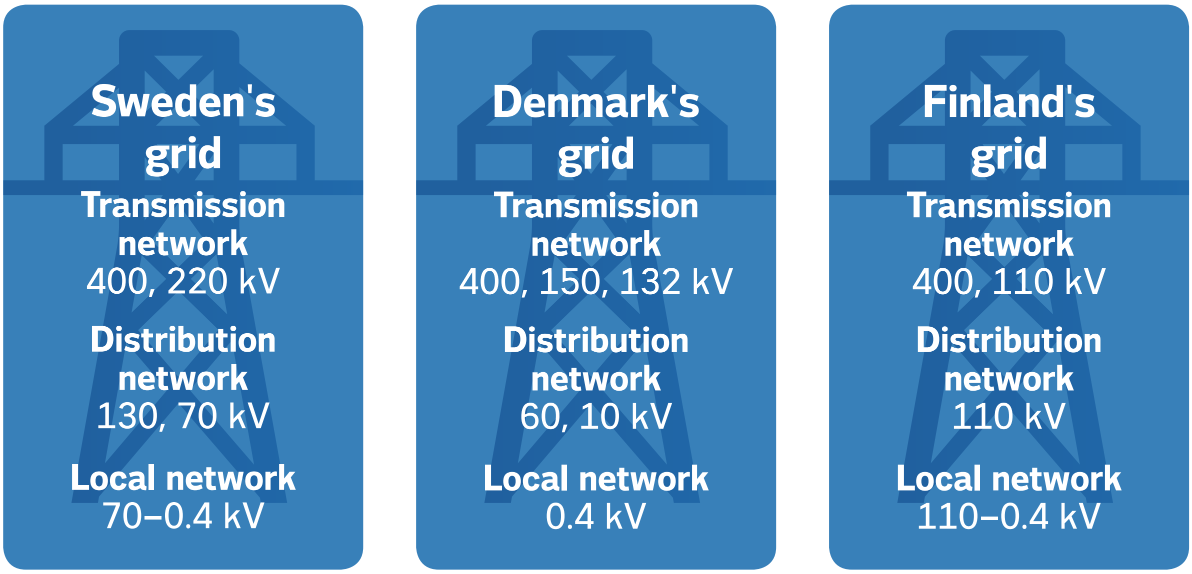
Base load power – generated at a steady level by our largest plants.

Intermittent power – electricity generated when weather conditions are suitable. The output can vary rapidly, regardless of the demand for electricity.

Regulating power – making it possible to regulate output rapidly to meet both variations in electricity consumption over time and variations in other plants such as intermittent energy sources.

Peak load power – to handle peaks in the demand for electricity caused by, for instance, low temperatures on very cold days or because an ordinary generating plant is not supplying electricity at all.

Figure 2: Transmission and distribution networks in the Nordic countries.



Distribution

The generating plants are connected to the national grid, which in turn supplies consumers with electricity. There are several types of networks with different voltage levels and of diverse designs. The *transmission networks* deliver high-voltage electricity over great distances. This minimises losses. Electricity generated in the large power plants is stepped up to the voltage level needed by the transmission networks to deliver electricity all over the country. From the transmission networks the voltages are again stepped down to lower levels before the electricity can be delivered to major consumers such as cities and large industries via *distribution networks.*

Low voltage *local networks* supply electricity to minor consumers in towns. Small plants can supply electricity directly to local networks. The networks in the Nordic countries are interconnected and integrated with each other, and electricity is traded across borders.

Vattenfall's electricity mix

Vattenfall generates electricity using various technologies based on several energy sources such as hydro, nuclear, wind, coal, natural gas and biomass. In Sweden, Vattenfall generates electricity mostly from hydro and nuclear, in Denmark from coal, wind and biomass, while the generation in Finland is dominated by hydro, biomass and peat.

Vattenfall's electricity output in the Nordic countries used in this report is based on the plants owned by Vattenfall on 1 January 2012, although the relevant figures are from 2011.

Table 1: Electricity mix in Vattenfall's operations in the Nordic countries.

Energy source	Percentage of total output			
	Nordic countries	Sweden	Finland	Denmark
Nuclear	51.9	56.4	0.0	0.0
Hydro	39.0	41.9	75.0	0.0
Coal	5.5	0.0	0.0	73.1
Wind	2.1	1.0	0.0	15.6
Biomass	1.2	0.4	14.4	11.2
Gas	0.0	0.0	2.4	0.0
Peat	0.2	0.2	8.2	0.0
Peak load plants	0.0	0.0	0.0	0.0
Total electricity generation	81.9 TWh	75.3 TWh	0.5 TWh	6.1 TWh

Nuclear

In a nuclear power plant, electricity is generated by utilising the energy released when atoms are split. When an atomic nucleus is split by nuclear fission, heat is generated. This is used to heat water to produce steam to drive a turbine which in turn drives a generator to produce electricity. This operation results in the use and release of cooling water that warms up the sea near the power plant, thereby affecting plants and animals.

The fuel used is uranium, which is extracted from mines, often outside Europe. After being extracted, the uranium is converted and enriched in several stages until it arrives at the power plant as fuel (uranium dioxide). The extraction of uranium, like all mining, has an impact on the landscape, even if the mining area is recultivated once the mine is exhausted.

The spent fuel is stored for about 40 years in an interim storage facility (CLAB) next to the Oskarshamn nuclear power plant and is then placed in the final repository near the Forsmark nuclear power plant. The spent fuel must be encapsulated in copper and steel and will then be kept embedded in bentonite clay deep underground forever. The low and medium active nuclear waste is placed in a final storage repository in rock caverns near the Forsmark nuclear power plant.

Hydro

Hydro power has been used for more than 100 years, and is still the most important renewable resource for generating electricity in the Nordic countries. The availability of water varies during the year and does not coincide with the demand for electricity. But because water can be stored in large quantities in reservoirs, the hydro power plants can be run to generate electricity when there is a demand, and they can therefore be used for both base load and regulating power. Some of the reservoirs are huge, and regulation of flows means that the water level may vary by as much as 30 metres in some cases.

The construction of reservoirs, dams and power plants leads to a substantial intrusion of the landscape. Enormous reservoirs have an impact on plants and animals over a wide area by forming obstacles in the rivers, by changing the flow of water and by drying up river beds.

In a normal year, about 200 TWh of electricity from hydro power is generated in the Nordic system, but it may vary by as much as 70 TWh between an extremely wet year and a dry year. Vattenfall has about 50 large-scale hydro power plants and 50 small-scale plants in the Nordic countries with a total installed capacity of 8.6 GW. In a normal year, they generate about 32 TWh of electricity.

Fluctuations in water levels also have an impact on the river banks, and bank environments situated between the highest and lowest water levels lose some of their biodiversity. The construction of hydro power plants also affects reindeer husbandry, agriculture and forestry.

Wind

A wind turbine exploits the wind's kinetic energy. As wind speeds can fluctuate very much, electricity generation is intermittent, and regulating power is needed as a complement to maintain the quality in the electricity grid. Fortunately winds are strongest during the winter months – just when the need for energy is at its peak. Wind turbines can generate electricity when the wind speed is between 4 and 25 metres per second. In stronger winds, the load on the wind turbines is so great that they must be shut down to avoid being exposed to excessive wear and tear.

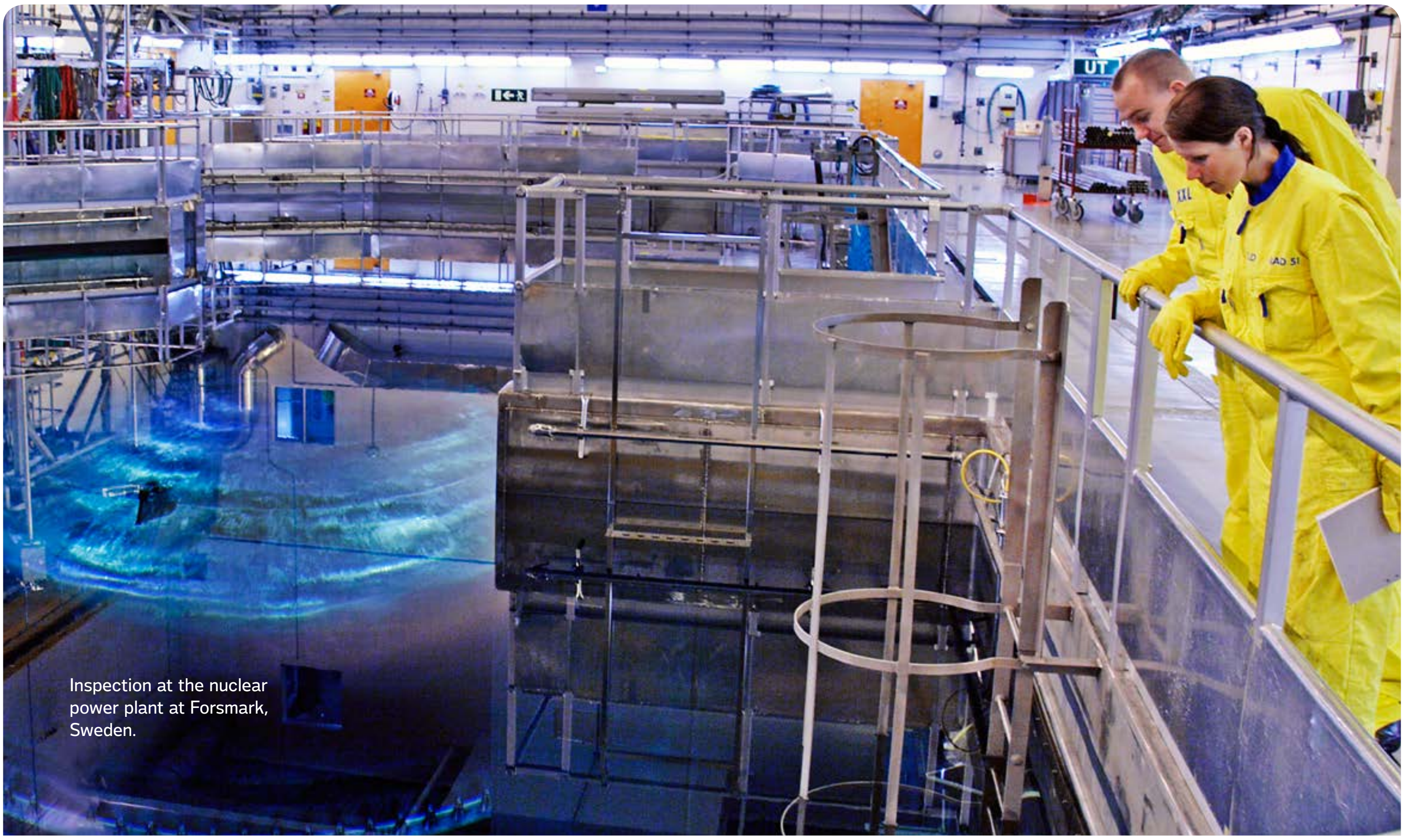
The construction of wind turbines changes the landscape, affecting plants, animals and human beings. In some cases delicate biotopes are disturbed by the turbines. They can also disturb birds, which also run the risk of colliding with the rotor blades. The foundations of offshore wind power plants have been found to work well as artificial reefs, thus having a positive effect on the local biodiversity.

A wind power plant with an output of 2 to 2.5 MW yields 5 to 6 GWh of electricity annually, which in turn is equivalent to the electricity consumed by about 1,000 households.

Coal

Coal is a fossil energy source which still forms the base of the European electricity system. Coal power plants generate about 28% of the total electricity in the EU, and a large proportion of global carbon dioxide emissions. Coal is formed when fossil plants and animal remains are subjected to high pressures and temperatures over long periods of time. The process takes several million years, and is similar to the way oil is formed. There are several different types of coal, two of which are used for generating electricity – lignite (brown coal) and hard coal. Lignite has a lower energy content and is used only in power plants located adjacent to lignite mines.

Coal mines often have a major impact on the surrounding landscape. There are two basic ways of mining coal – underground mining and surface mining, also called open-cast mining. The method used depends on the geology around the coal deposits. Today about 60% of the world's coal production comes from underground mining.



Inspection at the nuclear power plant at Forsmark, Sweden.

Biomass

Biomass is matter originating from photosynthesis. The various uses of biomass have expanded considerably in recent decades. By using biomass for power generation instead of fossil fuels, we can considerably reduce carbon dioxide emissions. Numerous methods are available for producing different types of biomass such as energy crops, farming and forestry residues and waste. In a biomass-fired power plant, biomass is converted to electricity and heat by combustion.

Peat

There are various types of peat, depending on the type of vegetation dominating the location where it was formed. Peat is formed by incomplete decomposition of biological material, meaning that a large proportion of the energy content is retained.

Both in Sweden and internationally, peat is regarded as a fossil fuel or equivalent. In the Nordic countries, peat has been characterised as a slowly renewable biomass fuel. According to the UN's climate panel, IPCC, peat is classified as neither a biomass nor a fossil fuel, and has therefore been assigned to a category of its own.

Natural gas

Natural gas deposits are formed in the Earth's crust, for instance in porous rock such as sandstone, into which the gas has oozed and remained in place, or where a layer of hard rock above the gas deposits has sealed the gas in. Natural gas is a fossil fuel formed by the slow decomposition of biological material over millions of years. Natural gas is formed under the same conditions as oil and is therefore often found in the same places.

The gas is extracted on land and at sea, either in conjunction with extracting oil or from separate natural gas deposits. In more recent deposits, the gas is often released through a borehole under its own pressure. In older deposits, where the pressure has fallen, carbon dioxide or water is pumped down in order to increase the pressure and thus force the gas out. Gas is often transported via pipelines, and some leakage may occur: in modern systems, this is estimated at no more than 1%.

In a gas turbine, the gas is fired under pressure. This results in the formation of combustion gases at high temperatures and pressures. The combustion gases drive a turbine that in turn drives a generator. Often the gases are then piped to a flue gas boiler where the residual heat and pressure can be used to generate more electricity and heat, for example to be utilised in a district heating network.

Peak load plants

Oil condensing/gas turbine

Peak load plants consist mainly of oil condensing plants or gas turbines, which can be started up at short notice to supply electricity. These plants are only used for relatively short periods when the demand for electricity is particularly high. Their environmental impact is often relatively high as they burn fossil fuels.

Maintenance of power plants at the Horns Rev offshore wind power park, Denmark.

Life Cycle Assessment (LCA) –Methodology

Vattenfall's Life Cycle Assessments are based on the international ISO 14040 and ISO 14044 standards. The environmental impact of generating power is described from a life cycle perspective covering the areas of construction and dismantling of power plants, fuel production, operations and handling of residual products. The life cycle assessment provides information about emissions during normal operation, which means that breakdowns or accidents are not taken into account.

The main environmental impact does not always occur during plant operation. For some technologies, the construction phase is crucial, while for others fuel production dominates. Our life cycle assessments are conducted in accordance with the international EPD® system (Environmental Product Declaration) and its methodology. The aim is to provide accurate information derived by using conventional methods.

The definition of the goals and scope of the life cycle assessment is followed by an inventory analysis where the life cycle is mapped out and the use of resources and emissions from all sub-processes is summarised. The result is divided by the electricity generated during the plant's service life, which gives the environmental impact per kWh generated.

We have chosen here to only report the results of the life cycle assessment without any deeper interpretation.

Figure 3 describes how a life cycle assessment is conducted. The arrows in the figure indicate that this is an interactive process which is continuously improved by the feedback from its results.

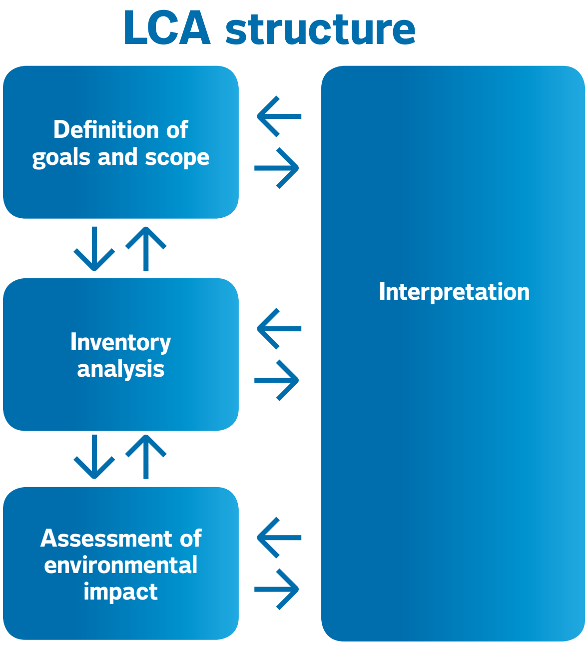


Figure 3: The different stages of the life cycle assessment as defined by the international ISO 14040 and 14044 standards.

The international EPD® system
Vattenfall's life cycle assessments form an important part of our Environmental Product Declarations. Today we have EPDs for almost 100% of our electricity generation in the Nordic countries.

The international system for Environmental Product Declarations is an information system for describing the environmental properties of a product or service in quantified terms. The EPD® system was founded by the Swedish Environmental Management Council in response to demands by industry for comparability and rules for the implementation and presentation of life cycle assessments.

The system is open to all products and services and complies with international standards for life cycle assessments and environmental declarations (ISO 14040, 14044 and 14025).

For each category of products there are a set of rules, Product Category Rules (PCR), describing what must be include in the environmental declaration. The declarations for electricity include not only life cycle assessments; there are also reporting requirements regarding the impact on biodiversity as well as any environmental risks. For further information, please refer to our Environmental Product Declarations at www.environdec.com.

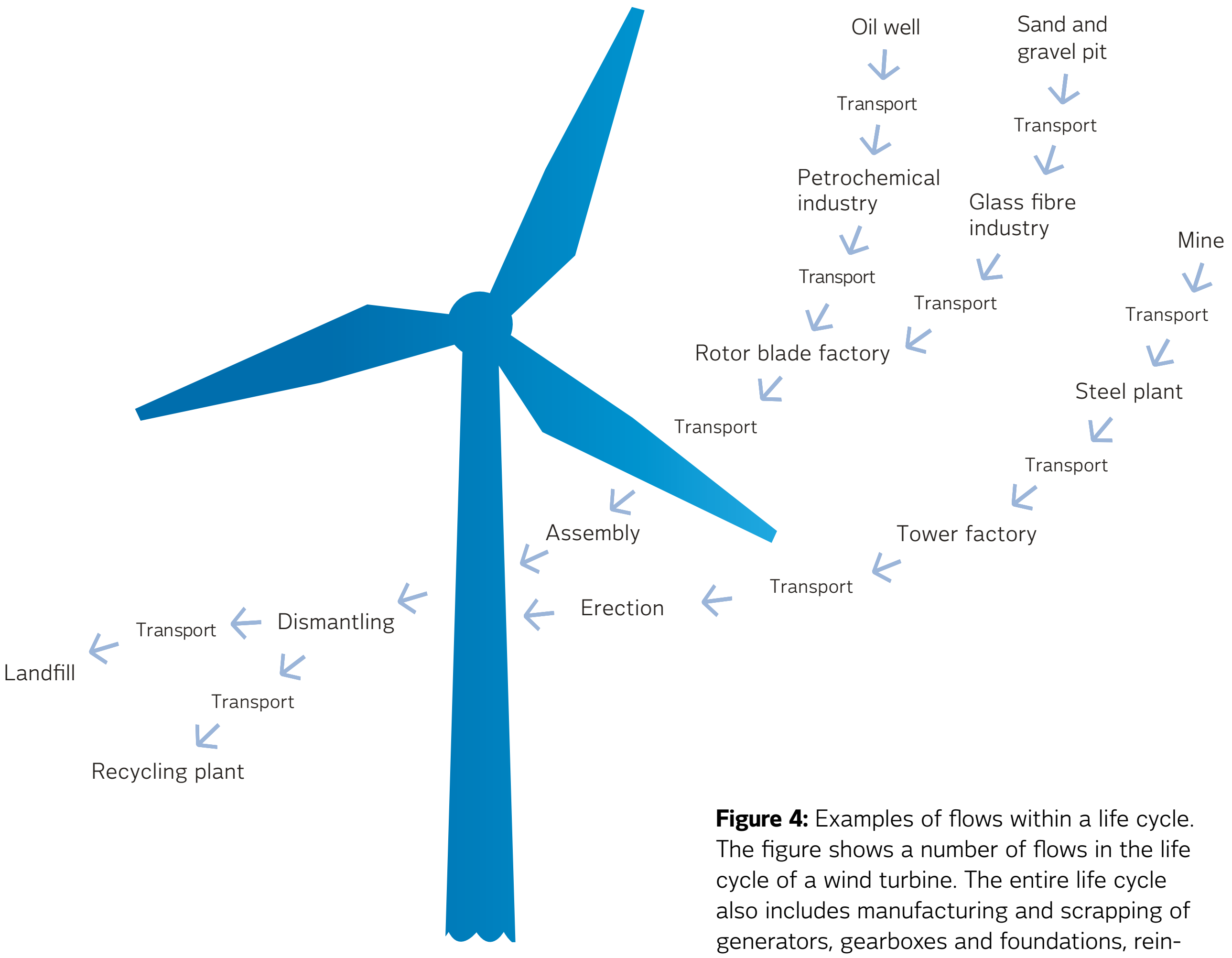
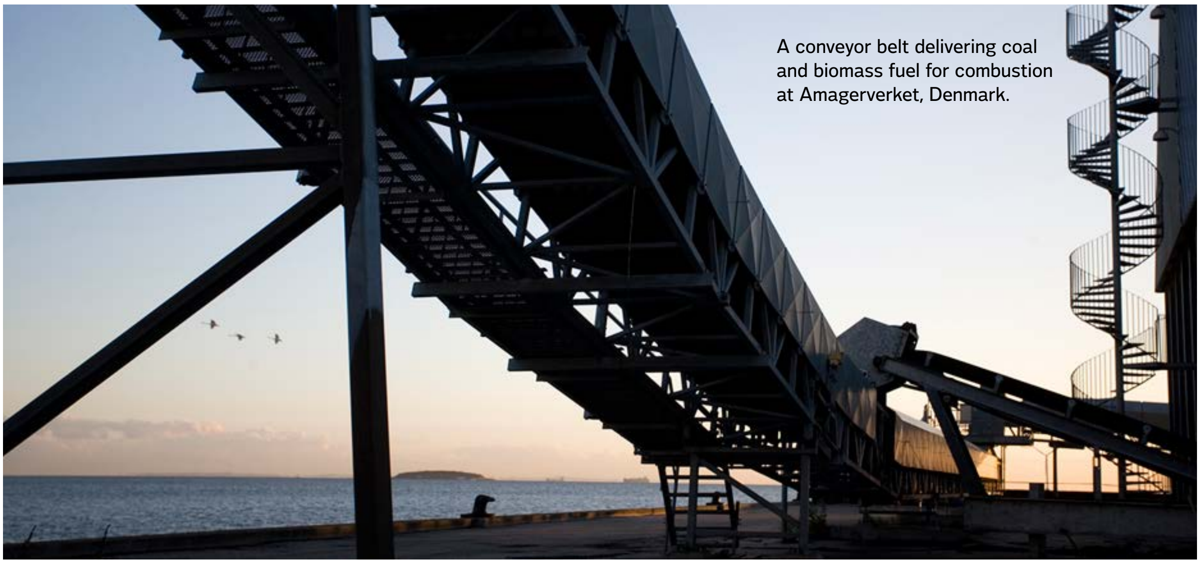


Figure 4: Examples of flows within a life cycle. The figure shows a number of flows in the life cycle of a wind turbine. The entire life cycle also includes manufacturing and scrapping of generators, gearboxes and foundations, reinvestments, and operations and maintenance.

Coal and biomass fuel being transported on barges via water to Amagerverket, Denmark.



A conveyor belt delivering coal and biomass fuel for combustion at Amagerverket, Denmark.

Environmental impact – various categories

In this summary the environmental impact is reported in terms of emissions of:

- Greenhouse gases *(expressed in terms of carbon dioxide equivalents, see below)*
- Nitrogen oxides
- Sulphur dioxide

The greenhouse gases have been weighted together using conventional weighting factors to form carbon dioxide equivalents. This term considers the various contributions that different greenhouse gases make to global warming and specifies how much carbon dioxide would need to be emitted to produce the same climate impact. Methane, for example, contributes 25 times more to global warming than carbon dioxide. The effects of electricity generation on the landscape, animals and plant life are difficult to summarise in a conventional life cycle assessment. For information about the impact on biodiversity, see Vattenfall's EPDs at www.environdec.com

Table 2: Emissions included in this life cycle assessment, how they arise and their impact on the environment and health.

Emissions	Formation affected by	Impact on health and environment
Carbon dioxide equivalents (CO_2e) **(Greenhouse gases)**	• The carbon content of the fuel • Methane and carbon content in the soil released when mining coal or when land is inundated.	• A contributor to global warming. (only fossil fuels increase the net release of carbon dioxide)
Nitrogen oxides, (NO_x)	• The nitrogen content of the fuel • Combustion conditions: temperature, duration and excess air	• Acidification • Eutrophication • Harmful to health if inhaled • Contribute to the formation of ground-level ozone
Sulphur dioxide (SO_2)	• The sulphur content of the fuel	• Acidification • Health effects on people with breathing difficulties

Delimitations for the various energy sources

System boundaries and allocation principles for Vattenfall's life cycle assessments are based on the international regulations found in the Product Category Rules (PCR) defined in the international system for Environmental Product Declarations (EPD®). The allocation between electricity and heat was based on the applicable PCR for electricity generation.

Table 3: Describes what this means for the different energy sources.

Energy source	Data source	Life cycle coverage	Technical service life
Nuclear	Vattenfall's EPDs for Forsmark and Ringhals.	All processes from the uranium mine to the underground repository, including the construction, operation and dismantling of power plants and facilities for handling radioactive waste. Also included are reinvestments and transportation of fuel.	The technical service life of the nuclear power plants has been set at 50 years
Hydro	Vattenfall's EPD for hydro power (based on a representative selection of 14 Vattenfall hydro power plants in eight different rivers).	The life cycle assessment covers resource consumption and emissions from construction, reinvestments and operations. The dismantling of dams and power plants is not included, as the chosen reinvestment model implies that the power plants are as new at the end of their assumed service life.	The technical service life for machinery is assumed to be 60 years, and for concrete structures and dams 100 years.
Wind	Vattenfall's EPD for wind power (based on a representative selection of ten wind power farms in the Nordic countries, UK and Poland).	Construction of wind turbines and foundations, including reinvestments, operations and the dismantling of the plants. Manufacturing and transportation of materials for components and machinery, including components such as towers, rotor blades, gearboxes, generators etc. Reinvestments mainly apply to gearboxes and generators. During operations, travelling is required for maintenance work and for topping up various lubricating oils. These factors have also been included in the assessment.	The technical service life for a wind turbine is assumed to be 20 years. turbines etc. Reinvestments are estimated at 1% of the total construction work per year. Dismantling of power plants is included.
Coal	Vattenfall's EPD for coal power (based on the Vattenfall coal-fired CHP plants in Denmark). The selection is representative (2008) for Vattenfall's coal power in Denmark.	The life cycle covers coal mining, transportation of coal to the power plant, its operation, construction, dismantling and reinvestments in the plant. Machinery and vehicles used in coal mining and transportation are included in the life cycle. The hard coal is transported to the power plant by ship, as the distances between coal mines and power plants are often long. The construction of the power plant includes the actual building, boilers, generators	The technical service life of power plants is based on the estimated service life of selected plants in Denmark, and is around 30 years.

Energy source	Data source	Life cycle includes	Technical service life
Biomass	Vattenfall's straw-fired boiler at the Amager power plant in Denmark. The result for wood chips is based on the actual fuel consumption and emissions from a small power plant in Sweden.	Two different types of biomass have been studied: straw pellets and wood chips from forestry waste. Straw pellets include the agricultural work, the pelletisation process and transportation. Wood chips include extraction, transportation and chipping. Carbon dioxide for combustion of biomass has not been included in the calculations. Emissions from extraction and transportation have been included.	The technical service life is estimated at 20 years for straw pellets and 40 years for wood chips.
Peat	Vattenfall's EPD for the Uppsala combined heat and power plant, reference year 2005.	The life cycle for peat covers the production of fuel (processing and transportation) combustion, handling of ash, as well as the construction, reinvestments in and dismantling of the power plant.	The technical service life is assumed to be 40 years.
Natural gas	The results are based on the actual use of fuel and emissions during 2011 from Vattenfall's plant at Myllykoski in Finland.	The life cycle covers the production of natural gas, transportation via pipeline to the power plant and the operation of the power plant. The construction, reinvestment in and dismantling of power plants are included in the calculations. The production of natural gas and the transportation to the power plant are obtained from generic data and are assumed to be from Russia. The transport distance from the production site to the power plant is estimated at 3,000 km. Data for the construction, reinvestment in and dismantling of the power plant are obtained from generic data and are assumed to represent typical values. In the generic data used for natural gas production and transportation, some leakage is assumed.	The technical service life is assumed to be 40 years.
Peak load plant *Oil condensing*	The underlying data for the life cycle assessment of oil condensing comes from Stenungsund. The efficiency is based on actual operational data from 2007.	The life cycle studies for oil condensing power plants cover the production of crude oil, refining, transportation and combustion in the power plant. For the fuel oil (a light oil with a low sulphur content), average figures for Europe have been used. The assessment includes the construction and dismantling of the power plant. The reinvestment rate is low due to the short annual operational period.	The technical service life has been set at 60 years.
Peak load plant *Gas turbines*	Data has been obtained from a gas turbine power plant in Slite. It runs on jet fuel with a low pollution content.	The assessment includes the extraction of crude oil, refining and transportation as well as combustion in the gas turbines. Production data corresponds to the European average for paraffin. Vattenfall's annual operational time for gas turbines in the Nordic countries is very short, even when compared to oil condensing.	The technical service life has been set at 60 years.

Result – emissions per kWh and energy source

The environmental parameters for the various energy sources are expressed in grams per kWh of electricity generated. Presentation of the emissions per kWh generated allows different energy sources to be presented independently of the electrical output of the plants.

Result per kWh

In the figures below, the emissions are divided up according to four stages in the life cycle.

- Fuel (production and transportation)
- Operations
- Infrastructure *(construction, maintenance and dismantling)*
- Handling of radioactive waste

Note that the reported results only apply under the conditions stated in this document. They cannot be considered representative of electricity generation in general. It is also worth remembering that different energy sources cannot be entirely substituted for each other, as they have different functions in the electricity system.

Figure 5: Emission of greenhouse gases (carbon dioxide equivalents) from an LCA perspective for different energy sources.

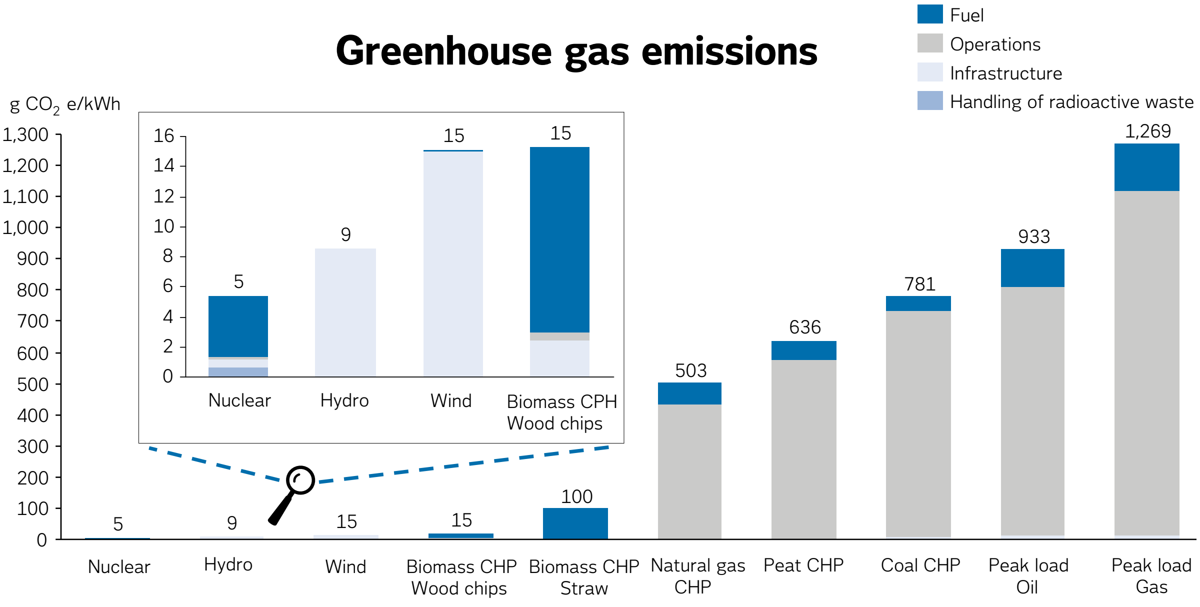


Figure 6: Emission of nitrogen oxides from an LCA perspective for different energy sources.

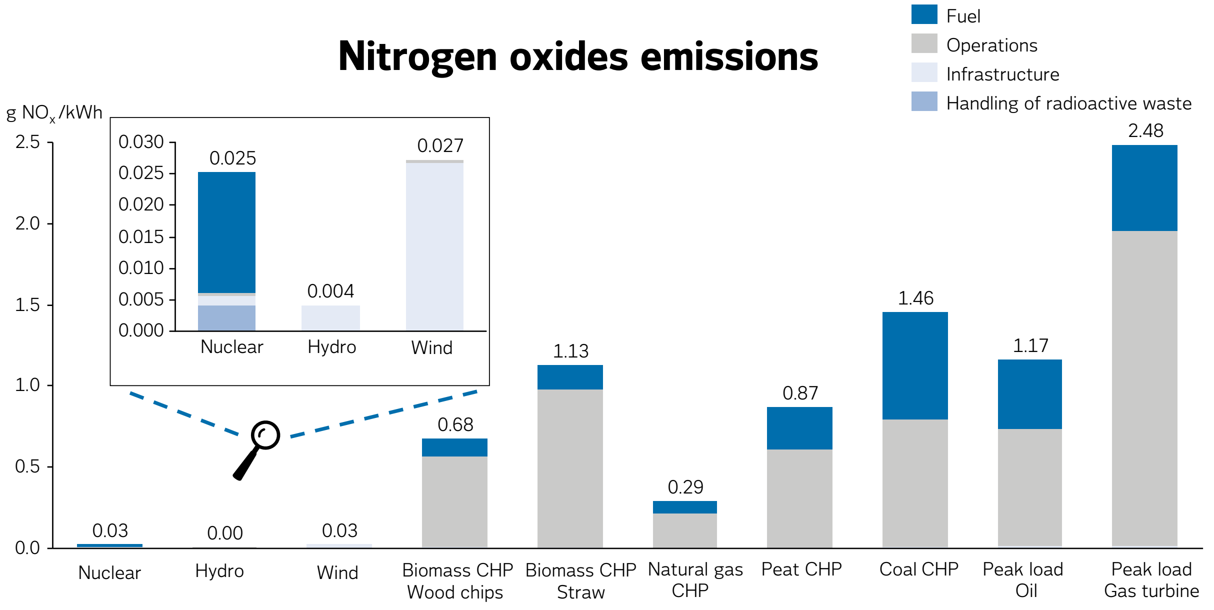
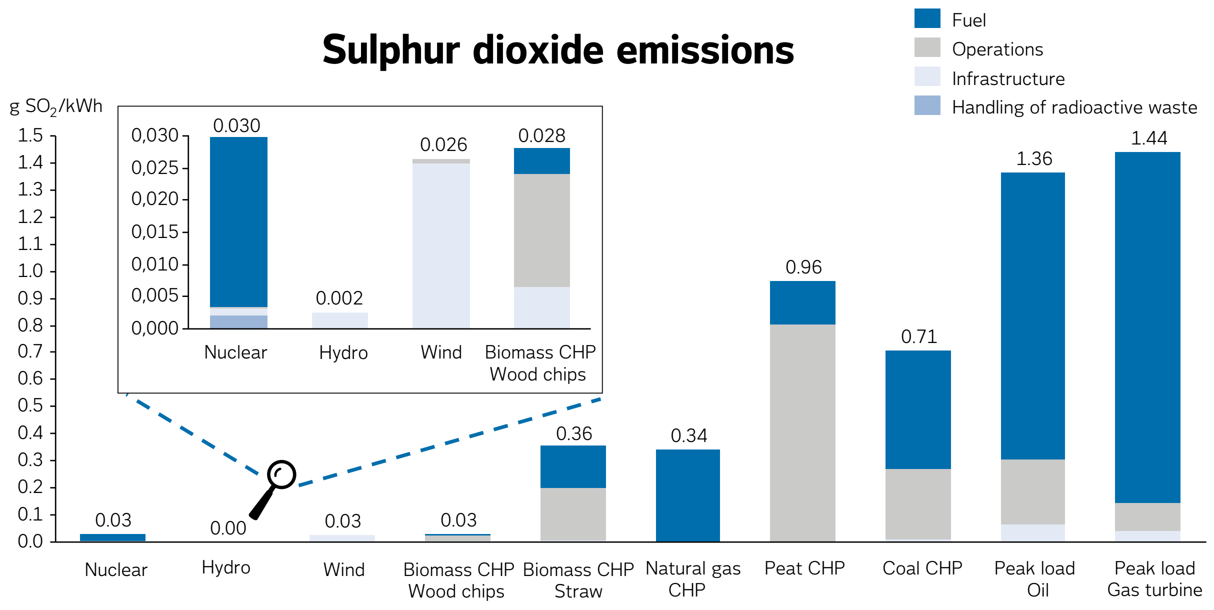


Figure 7: Emission of sulphur dioxide from an LCA perspective for different energy sources.



Impact of each energy source

Nuclear

Nuclear power gives rise to low carbon dioxide emissions over the entire life cycle. The largest proportion of its environmental impact arises from fuel production– more than half of the emissions to air during the life cycle are produced at this stage. Fuel production covers transportation, uranium mining, conversion, enrichment and fuel fabrication in plants all over the world.

The testing of backup power, the production of chemicals and the transportation of radioactive waste are the main contributions to the emissions from the operation of the nuclear power plant.

Hydro

The emissions contributing to global warming come mainly from the soil under water as a consequence of inundation. The soil contains organic carbon compounds and nutrients that are gradually broken down and released. The carbon compounds are broken down to carbon dioxide assisted by the acid in the water.

Besides this, the environmental impact is highest during construction and reinvestments, primarily from the production of steel and concrete which results in the emission of carbon dioxide, sulphur dioxide and nitrogen oxides. Operation of the hydro power plants results in low emissions. Those that do occur are caused mainly by transportation in conjunction with inspections and maintenance.

Wind

Wind power is a renewable energy source that causes very low emissions during its life cycle. The environmental impact during the construction phase dominates the wind power life cycle. The production of steel, concrete and composites is the main contributor to the emissions. About half of the emissions of greenhouse gases arise from the production of steel for the turbines.

Coal

The environmental impact of a coal-fired power plant comes mostly from the operational phase as a result of the combustion of coal. Coal mining and transportation also have a relatively large impact. Coal mining uses machines and a variety of vehicles to transport the coal from the mining area, and it can also result in the release of relatively large quantities of methane, however this varies a great deal from mine to mine. Coal is often carried on ships running on heavy fuel oil which results in large emissions of sulphur dioxide and nitrogen oxides.

Biomass

The combustion of biomass results in the emission of carbon dioxide, sulphur dioxide and nitrogen oxides. However, the carbon dioxide is not considered to contribute to global warming, as the biomass binds carbon dioxide by photosynthesis during its growth. In contrast, fuel production gives rise to fossil carbon dioxide emissions of various types. The emissions occur primarily during the transportation and processing phases, but also from forestry or agriculture, depending on the origin of the fuel.

Peat

Drying peat is an energy-intensive process that consumes a great deal of energy. It is therefore important to understand what energy mix is being used. The combustion of peat also gives rise to high emissions of carbon dioxide, sulphur dioxide and nitrogen oxides. In some countries, peat is classified as a slowly renewable fuel, while the EU and many international bodies classify it as a fossil fuel. Vattenfall regards the carbon dioxide emissions from peat as of fossil origin and includes them with greenhouse gas emissions.

Natural gas

The combustion of natural gas causes lower levels of carbon dioxide emissions compared to other fossil sources of energy. The environmental impact of a natural gas power plant comes mostly from the operational phase as a result of combustion, which releases carbon dioxide and nitrogen oxides. However, emissions of sulphur dioxide are very limited, as the fuel does not contain any sulphur. This means that no sulpur is released during combustion in the power plant. Gas is often transported via pipelines, and a certain leakage may occur.

Peak load plants

Oil condensing/gas turbine

The operation of oil-condensing and gas-turbine power plants, i.e. the combustion stage, dominates their environmental impact, above all through emissions to air. The production of fuel also releases emissions, while the construction phase accounts for only a small part of the emissions.

Conclusions

- Emissions from the construction phase dominate the environmental impact of those energy sources that do not burn fuel but utilise a flowing source of energy *(hydro power and wind power)*.
- For combustion plants *(biomass, coal, oil, natural gas)* the emissions from the operation phase is dominating, followed by the production of fuel.
- For nuclear power the dominating phase is the production of the uranium fuel.
- The dismantling phase has relatively low impact for all energy sources, partly because metals and concrete can be recycled.

The production of fuel represents more than half the emissions to air in the *nuclear power* life cycle. The choice of supplier in the fuel chain is of great importance, particularly regarding uranium mining and enrichment. The content of uranium in the ore is important. Mines with a low uranium content, or those using fossil-based electricity, have a greater environmental impact. The same applies to the choice of enrichment method. The consumption of electricity and fuels in the various processing phases is crucial. The electricity consumption can vary by a factor of ten between different enrichment methods. Even the generation mix for the electricity used by suppliers is of great importance. A large proportion of fossil-based electricity will result in a higher environmental impact via emissions to air.

The quantity of materials per installed capacity is a key parameter for the environmental profile of types of power that utilise *flowing energy sources* (wind power, hydro power), as is the choice of materials to be used. As a rule, the greater the quantity of materials and the more scarce they are, the greater their environmental impact. Another significant factor is where the materials were produced, and what sort of electricity was used in the production process. Highly fossil-based power generation and long transportation distances result in higher emissions to air. In addition, the efficiency of converting the flowing energy to electricity is significant for the environmental profile, and the availability of flowing energy during the year also has a large impact on the overall results. The longer the plant operates, the lower its environmental impact per kWh. A good wind location increases the turbine's output during its service life and thus results in a lower environmental impact.

For combustion plants run on *fossil, peat or biomass fuels,* the critical factor is efficiency, i.e. how efficiently the energy in the fuel is converted into electricity. The purity of the fuel and the efficiency of the flue gas cleaning also have an effect on the environmental impact. The lower the efficiency, the greater the effect of the fuel production has on the results, as more fuel is used per kWh generated at lower levels of efficiency. In general terms, the transport distances between extraction and combustion are highly significant for the environmental impact of biomass. This is even more the case than for other fuels, as the energy content in biomass is generally lower than in for example coal. In the cases presented here, however, the fuels are extracted locally, and the transportation distances between extraction and use are therefore relatively short.

All the results presented in the figures represent the current situation at Vattenfall. Data for peak load plants (oil condensing and gas turbines) have been obtained from older plants with relatively low levels of efficiency and limited (or no) flue gas cleaning. Because peak load plants are only run for a few hours a year, higher emissions are permitted. The Danish coal power plants have very high technical efficiency, but as they are not used for the base load, and are to some extent regulated by the demand for heat, they appear to be less efficient from a life cycle perspective. This is because their actual efficiency level is far below the theoretical level.

Summary

This is a summary of the environmental impact of an average kWh generated by Vattenfall in the Nordic countries, based on:

- Vattenfall's electricity generating plants.
- The annual output of the plants.
- The environmental impact of the different energy sources per kWh generated (as described in previous chapters).

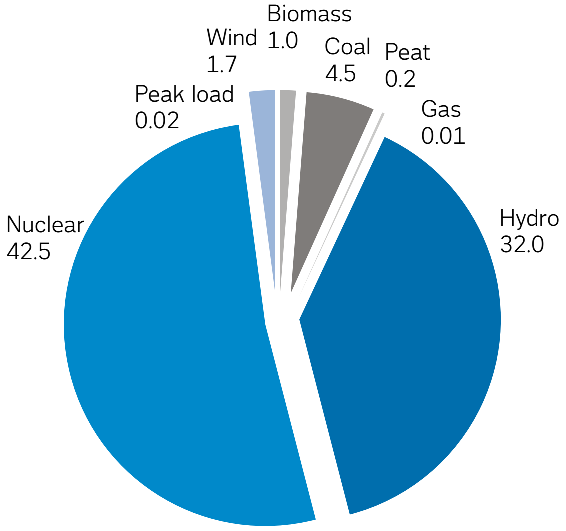
Vattenfall's electricity mix

Vattenfall generates about 82 TWh of electricity per year in the Nordic countries. The table below displays the generation mix used in this life cycle assessment.

Table 4: Vattenfall's electricity generation mix in the Nordic countries.

Energy source	Percentage of total generation in the Nordic countries
Nuclear	51.9
Hydro	39.0
Coal	5.5
Wind	2.1
Biomass	1.2
Gas	0.0
Peat	0.2
Peak load plants	0.0

Figure 8: Vattenfall's mix of electricity in the Nordic countries (TWh).



Result for an average kWh

The bar charts below display some examples of environmental impact parameters for Vattenfall's Nordic electricity generation. The figures show the total emissions per kWh in the categories of greenhouse gases, sulphur dioxide and nitrogen oxides from a life cycle perspective, and how much each energy source contributes to the total emissions.

The bars are also divided into four life cycle stages:

- Fuel *(production and transportation)*
- Operation
- Infrastructure *(construction, maintenance and dismantling)*
- Handling of radioactive waste

Figure 9: The relative contributions from different energy sources to Vattenfall's emissions of greenhouse gases (carbon dioxide equivalents) in the Nordic countries.

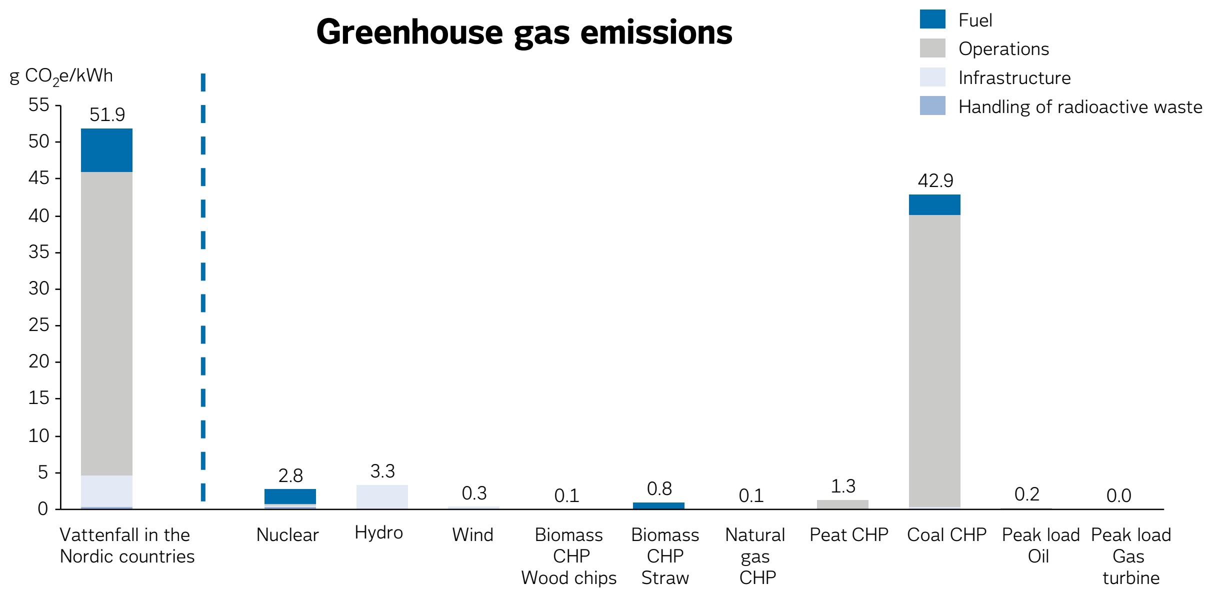


Figure 10: The relative contributions from different energy sources to Vattenfall's emissions of nitrogen oxides in the Nordic countries.

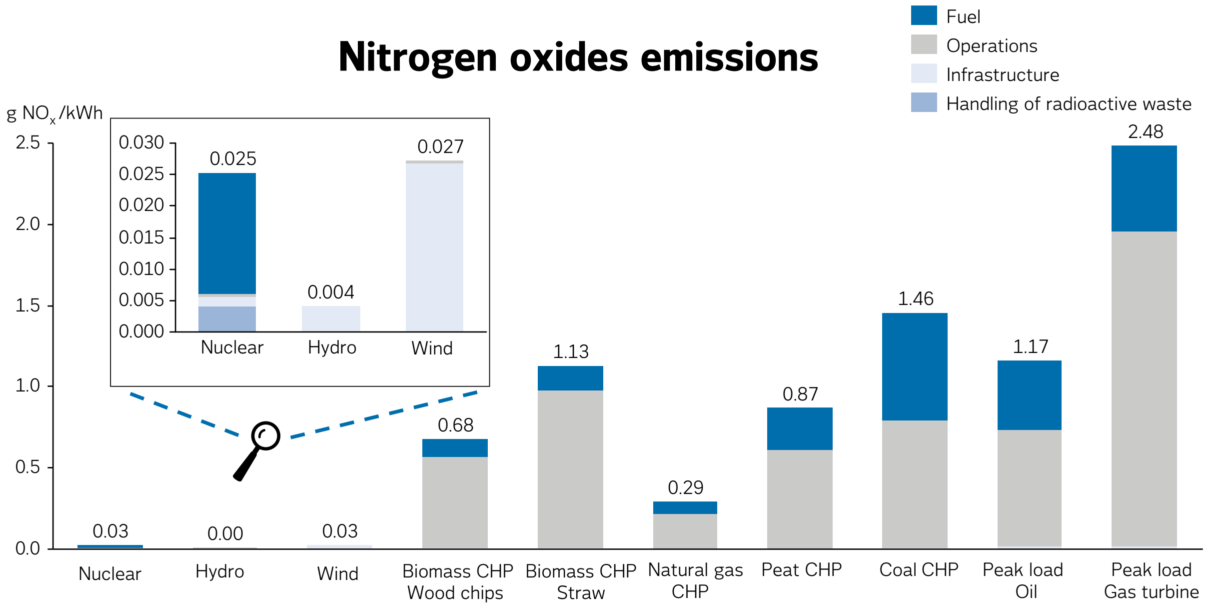
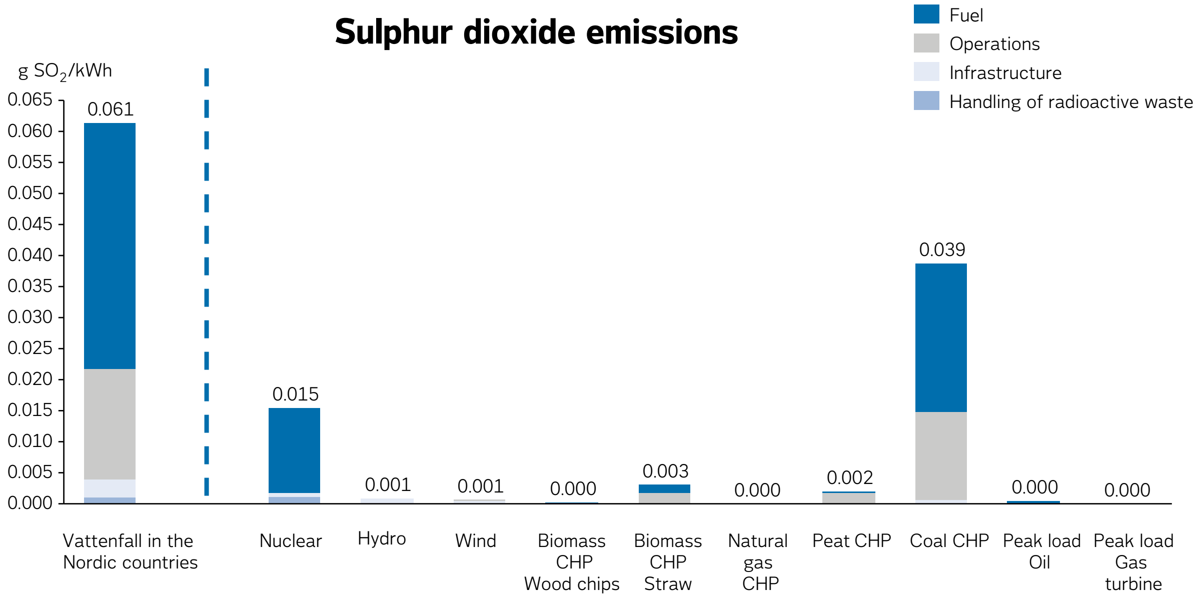


Figure 11: The relative contributions from different energy sources to Vattenfall's emissions of sulphur dioxide in the Nordic countries.

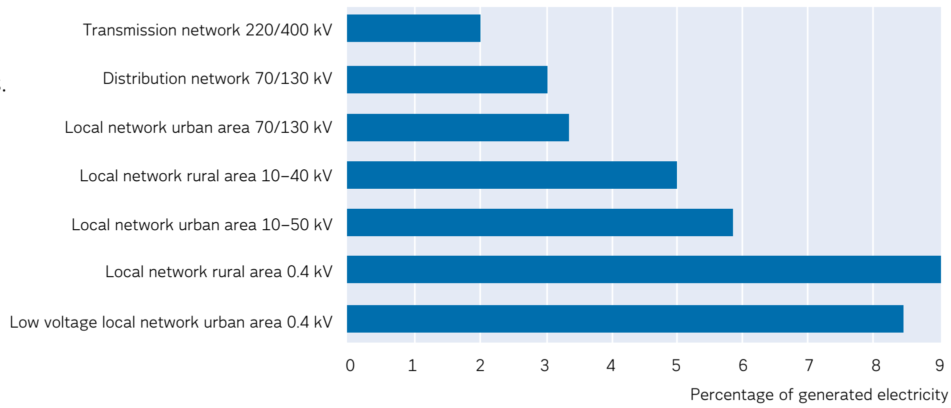


Results including distribution

In previous chapters, the results have been presented per kWh of electricity generated, but in order to show the entire life cycle perspective all the way to the customer, the distribution must also be taken into account. The environmental impact from distribution of electricity can be divided into two components; distribution losses and construction and reinvestments of the distribution networks. The distribution losses are assumed to be compensated for by additional generation in the respective plant and they are expressed as a percentage of the total results. Environmental impact from construction and reinvestments are presented separately in table 5 and must also be added to the overall results.

The distribution losses are caused by several factors, such as distribution distance, the instantaneous load on the network, the voltage level to which the power plants connect, and the voltage level at which the customer is connected. The figure below shows average losses. The average distribution losses (assuming the power plants feed into the transmission network) for an industrial customer connected to the regional network are around 3%, while the equivalent distribution loss to a household in a sparsely populated area is around 9%.

Figure 12: Distribution losses at different voltage levels.



The emission of greenhouse gases, nitrogen oxides and sulphur dioxide from construction and reinvestments in transmission and distribution networks are presented in Table 5. These emissions must be added to the emissions shown in Figures 5, 6, 7, 9, 10 and 11 in order to obtain the emissions per kWh of distributed electricity.

Emissions	Quantity	Unit
Greenhouse gases	1.0	g CO_2e/KWh (el) distributed
Nitrogen oxides	0.0023	g NO_x/kWh (el) distributed
Sulphur dioxide	0.0038	g SO_2/kWh (el) distributed

Table 5: Emissions from construction of and reinvestments in transmission and distribution networks.

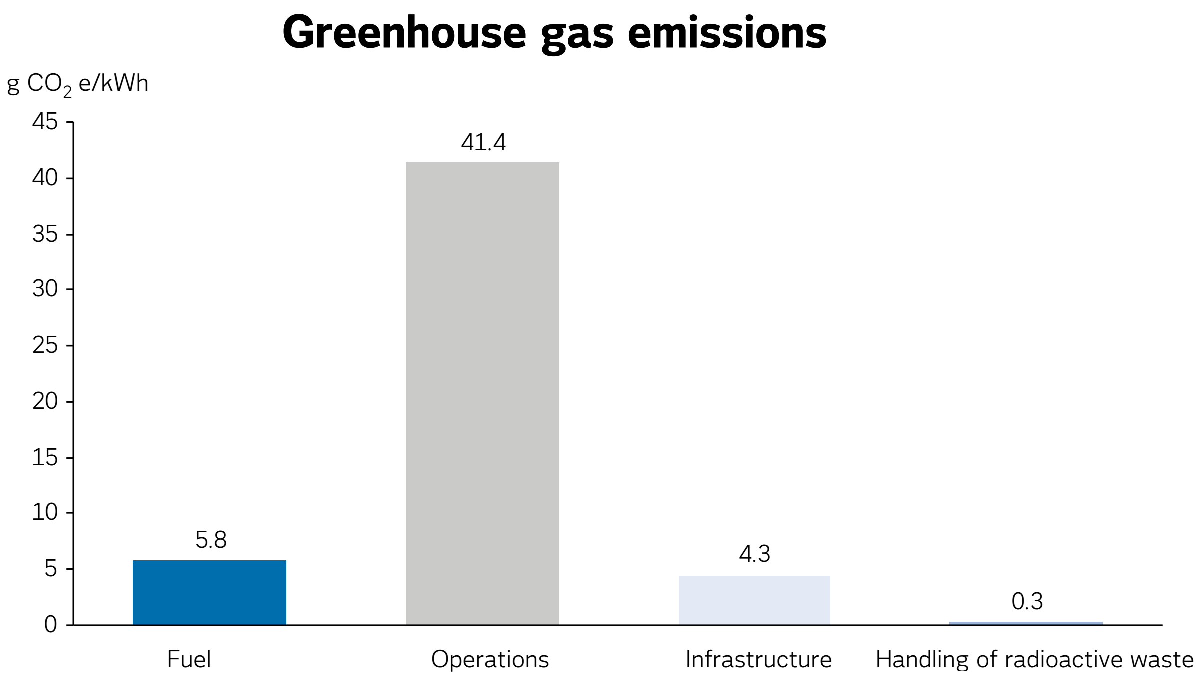
Interpretation of the results

Most emissions of carbon dioxide, from a life cycle perspective, occur in the operational phase, where Vattenfall has operational control. Emissions of sulphur dioxide are on the other hand largely emitted upstream, for instance during the transportation of fuel.

Even though the coal power in Denmark accounts for only 5-6% of Vattenfall's total electricity generation in the Nordic countries, it is a significant factor for all the parameters reported here. This is not solely due to plant operation and the combustion of coal; half of the SO_2 emissions from coal power originate from coal transportation. The two largest contributors to the electricity mix, namely hydro power and nuclear power, generally contribute very little to the overall environmental impact.

Most carbon dioxide emissions from electricity generation occur in the operational phase, over which Vattenfall has operational control. On the other hand, the sulphur dioxide emissions arise mostly upstream, for example during the transportation of fuel. Even though the peak load plants have high emissions per kWh generated, their contribution to Vattenfall's total environmental impact is on the whole negligible, due to the fact that these plants are not run for more than a few hours per year. The emissions of greenhouse gases from Vattenfall's electricity generation in the Nordic countries, divided into the various phases of the life cycle, are shown in figure 13 below. As shown in the figure, most emissions occur in the operational phase, where Vattenfall has operational control. In order to reduce them, we have implemented a range of measures, such as flue gas cleaning, dust cleaning, catalytic converters, flue gas recycling and significant efficiency-boosting techniques.

Figure 13: Greenhouse gases from various phases in the life cycle of an average kWh of electricity.



Fuel production also has a significant environmental impact. It accounts for a considerable part of sulphur dioxide emissions, more than 60%. However, this figure can be influenced by careful selection of suppliers and fuel sources. In some cases, Vattenfall has also imposed requirements on suppliers in order to reduce the environmental impact – such as requiring a change in the electricity mix for its deliveries.

The Pelamis wave power plant project off the Shetland Islands is a joint project between Aegir Wave Power, Scottish Power and Vattenfall.

LCA as a tool in our environmental work

Vattenfall has been using LCA as a tool for evaluating and mapping the environmental impact of its electricity generation activities since the early 1990s. The LCA approach helps Vattenfall to set priorities by identifying where environmental impacts arise and where measures need to be applied to reduce them from a life cycle perspective. This is done partly by implementing the right measures in our own operations and partly, where relevant, by making specific demands on our suppliers.

With the use of LCA, Vattenfall has implemented a number of measures based on a life cycle perspective, to improve its environmental performance. These measures and applications include:

Changes in the electricity mix that our suppliers within the nuclear fuel cycle use, with the aim of reducing the environmental impact of the electricity supplied by Vattenfall's nuclear power plants.

Identification of significant environmental aspects from an LCA perspective in order to make prioritised and well-founded decisions.

Evaluation of new technical solutions, such as generating electricity from wave power, Carbon Capture and Storage (CCS), etc.

Evaluation of biomass fuel chains, with the aim of avoiding fuels with high greenhouse gas emissions in their life cycle, and prioritising fuels with low emissions.

Vattenfall's Environmental Product Declarations (EPD), based on life cycle assessments, are used to demonstrate the environmental impact from Vattenfall's electricity generation and supply environmental data to product-specific electricity in Sweden. The EPDs also act as a basis for reviewing permit applications, and to support public relations activities with various interested parties.

These activities are in line with Vattenfall's strategy and vision – to be a leader in developing environmentally sustainable energy production.

Glossary

B

Base load power – the society's basic need for electricity. Plants designed for generating base load power and supply power at a steady level.

C

Carbon dioxide equivalents – a measure of the emission of greenhouse gases, taking into account that different gases have different capacities to contribute to global warming.
CHP – Combined Heat and Power plant, producing both heat and electricity.

D

Distribution network – a network that delivers electricity to major consumers such as cities and large industries.

E

EPD® – Environmental Product Declaration.

I

Intermittent power – generated when weather conditions are favourable, and the generating volume can consequently fluctuate very much independently of the demand for electricity.

L

LCA – Life Cycle Assessment.
Local network – local networks that supply small consumers.

P

PCR – Product Category Rules that specify how delimitations are made in an EPD®.
Peak load power – needed to handle peaks in the demand for electricity caused by factors such as low temperatures on very cold days or because a regular power plant is not supplying any electricity at all.

R

Regulating power – power that can be regulated quickly to meet both variations in electricity consumption over time and variations in other plants such as intermittent energy sources.
Reinvestment – investments in existing plants that are not included in annual maintenance.

T

Transmission networks – networks that deliver high-voltage electricity over great distances.

Links

The website of the international EPD® system:
www.environdec.com

Vattenfall's Environmental Product Declarations are available at:
www.environdec.com/en/EPD-Search/?query=vattenfall

PCR for electricity, steam and hot water:
www.environdec.com/en/Product-Category-Rules/Detail/?Pcr=5802

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