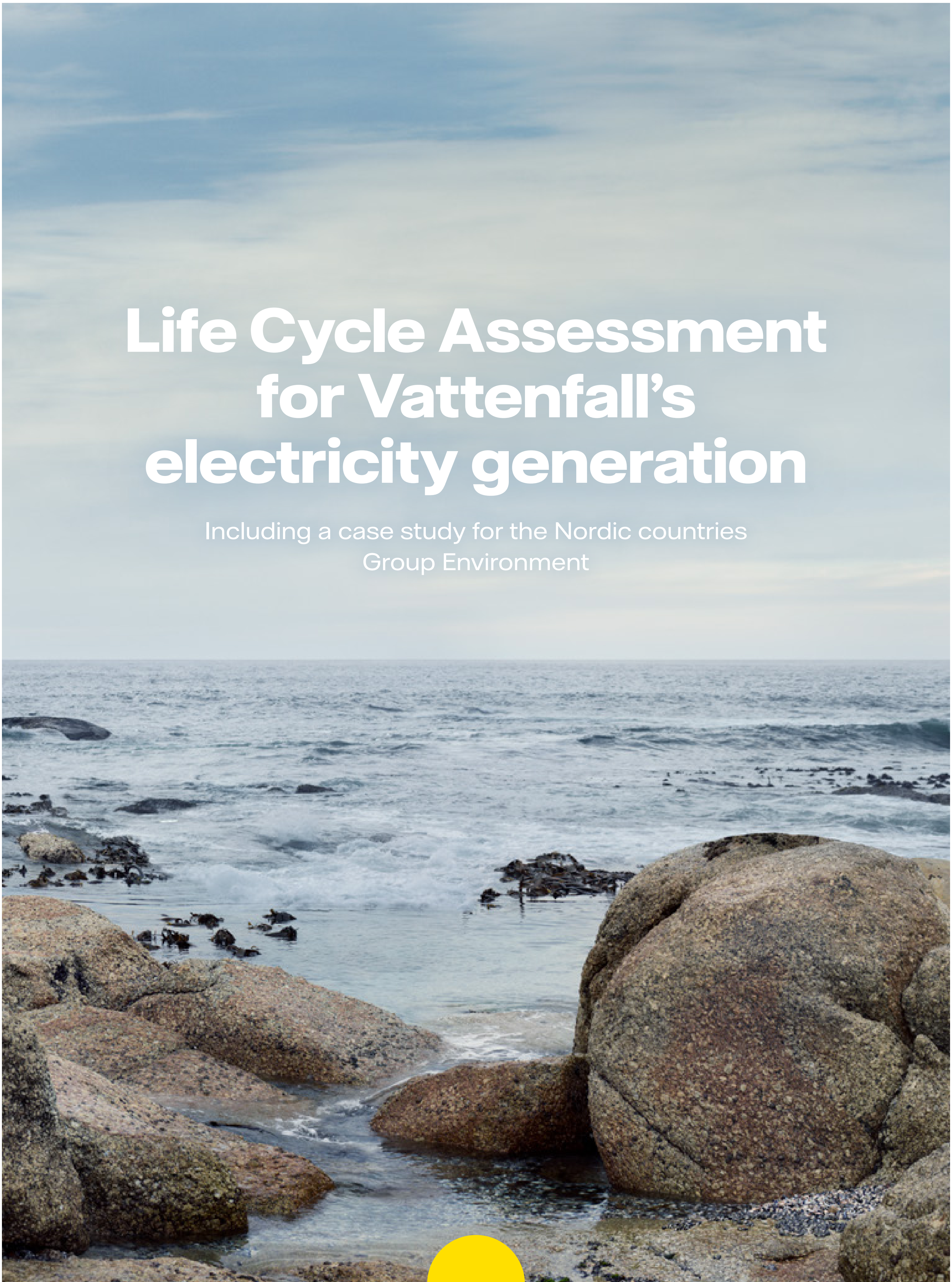


Life Cycle Assessment for Vattenfall's electricity generation

Including a case study for the Nordic countries
Group Environment

VATTENFALL

Contents

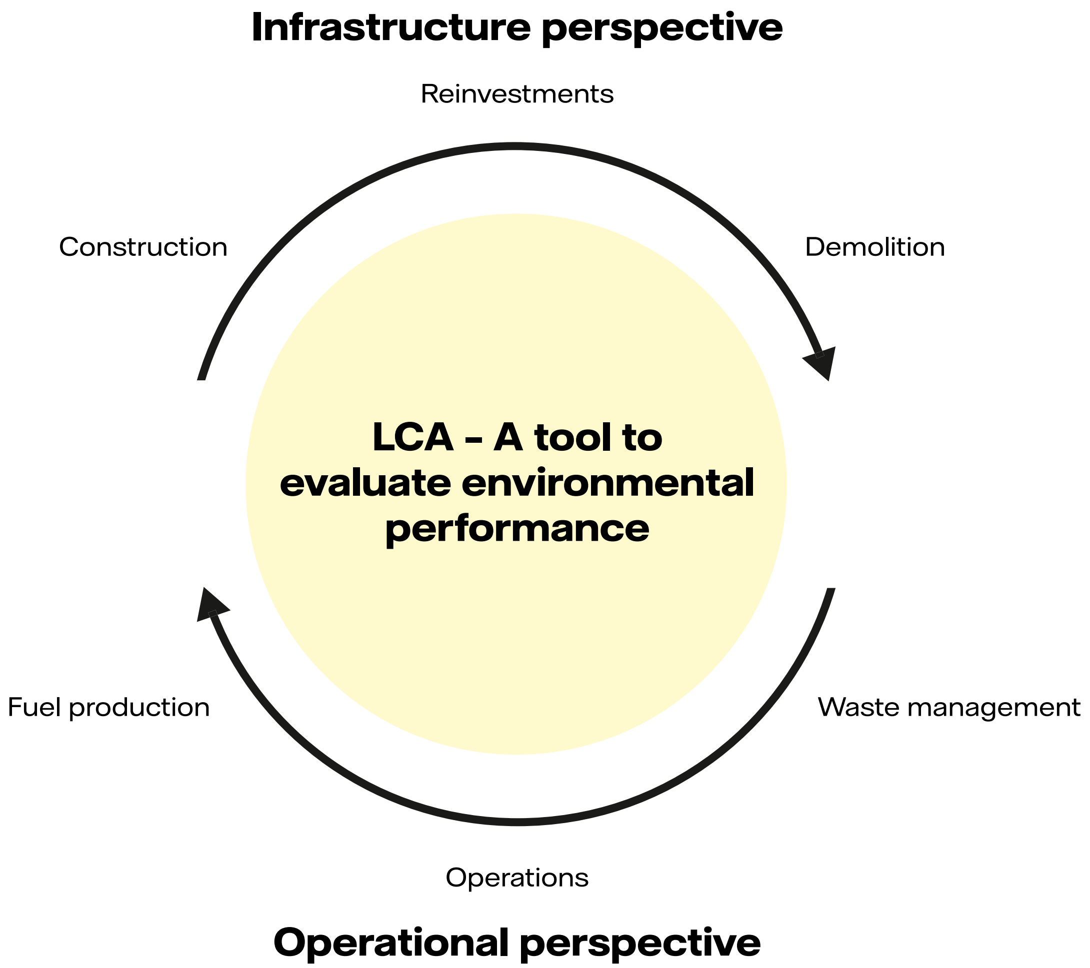
Summary

Vattenfall has been using Life Cycle Assessment (LCA) as a tool for evaluating and mapping the environmental impact of its electricity generation activities since the early 1990s. The environmental impact of generating electricity 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 LCA approach helps Vattenfall to set priorities by identifying where environmental impacts arise and where measures need to be applied to reduce them.

The main environmental impact does not always occur as direct emissions during plant operation. For some technologies indirect emissions from the construction phase are crucial, while for others indirect emissions from fuel production dominate.

As more renewable technologies are introduced into the electricity system indirect emissions will become more in focus, A life cycle perspective will therefore be even more important when evaluating the environmental performance of new energy solutions to ensure high environmental performance throughout the value chain.

These activities are in line with Vattenfall's strategy and vision – to be leading towards sustainable production and sustainable consumption and fulfil our purpose to "Power Climate Smarter Living".



The electricity system

Energy systems around the world are built up by different power sources, both using renewable and fossil energy resources.

The prerequisites are different in different countries and depending on factors such as topography, climate and political acceptance the electricity generation must be adapted to these specific circumstances.

Every step in the process of generating and distributing electricity has impacts on 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. In order to have a holistic view when showing the impacts 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 as it is consumed. Hence, to form a reliable electricity system that provides the flexibility needed to respond to variations in demand a mix of energy sources with varying generating properties is required.

Today Vattenfall and others are looking into battery storage as a supplement. However, it will take time before this can be a real game changer for regional or national energy systems.

Different power sources have different properties

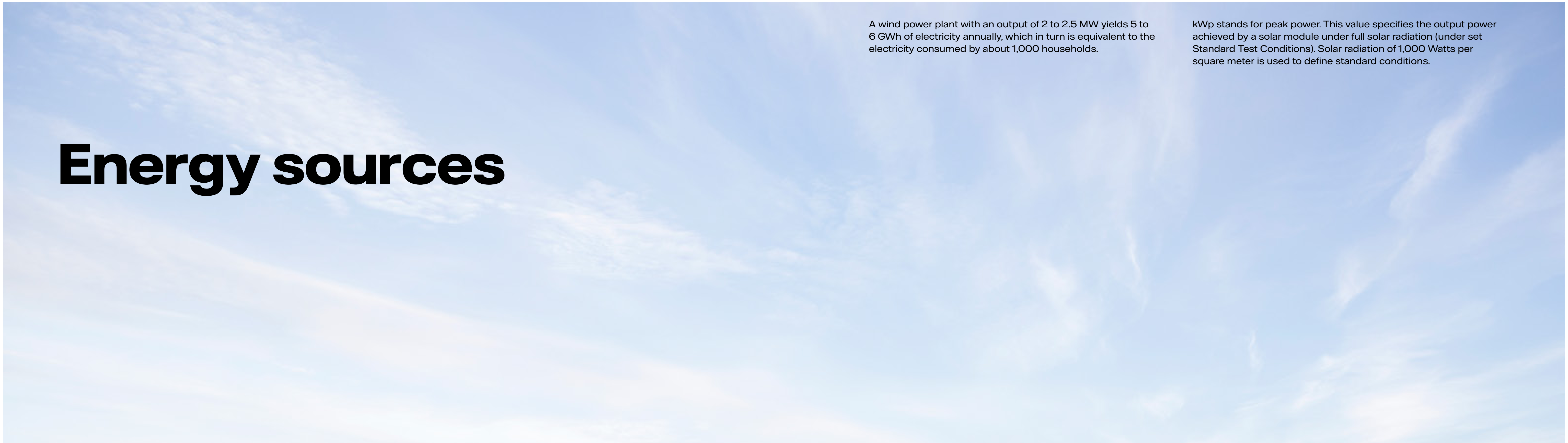
The basis of any electricity generating system is its base load power.

It is typically generated by nuclear power plants, large combustion plants, and/or hydro power plants designed specifically to generate electricity at a steady level.

In addition to this, regulating power is needed in order to meet variations in electricity consumption and variations from e.g. intermittent power sources. This power is also important for maintaining high quality in the electricity grid. Energy sources used for regulating power are primarily combustion and hydro plants. With an increasing share of wind power, Vattenfall is developing ways to also use wind farms as regulating power. Combustion plants are also used for generating peak load power at times when the demand for electricity is particularly high. For example during cold winter days, hot summer days or if ordinary plants are not supplying for certain reasons.

Renewable power sources, such as wind and solar power, often have an intermittent or irregular output depending on weather and wind conditions. Any increase in the use of intermittent power in the electricity system often leads to an increased need of regulating power. To balance the system, there are ongoing activities in research and development of smart grids, which connects to e.g. electrified transports and the use of battery storages.

Figure 1. Transformer station.



Energy sources

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 re-cultivated once the mine is exhausted. Once used, the spent nuclear fuel will be forever placed in final repositories. The design of the final repository may vary between different countries.

Hydro

Hydro power in its modern form has been used for more than 100 years, and is still an important renewable resource for generating electricity. The availability of water varies during the year and does not coincide with the demand for electricity. But since 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. 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.

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.

In a normal year, about 200 TWh of electricity from hydro power is generated in the Nordic system in total, 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 40 small-scale plants in the Nordic countries with a total installed capacity of 8.6 GW. In a normal year, they generate about 31 TWh of electricity.

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.

kWp stands for peak power. This value specifies the output power achieved by a solar module under full solar radiation (under set Standard Test Conditions). Solar radiation of 1,000 Watts per square meter is used to define standard conditions.

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 – 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 big that they must be shut down to avoid being exposed to excessive wear and tear. Modern turbines are not as sensitive to high wind speeds and can thus harvest more of the wind. The modern wind turbines, especially those built off-shore, are also bigger and can thus generate more electricity. This means that the environmental footprint becomes lower per every kilowatt hour generated.

The construction of wind turbines changes the landscape, affecting plants, animals and human beings. In some cases delicate biotopes are disturbed by the turbines or so called green corridors are cut of, which means that the animals face more difficulties moving in a larger area. They can also disturb birds and bats, 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.

Solar

A solar photovoltaic (PV) system converts approximately 10-15 % of the incoming solar energy into electricity. Efficiency is dependent on solar radiation, location, shading and the orientation and tilt of the supporting structure (often roof) as well as keeping the panels clean. In order to use the electricity in the household or transfer it to the local network, it must be converted from DC (Direct Current) to AC (Alternating Current).

This is done by means of an inverter coupled to the photovoltaic system and the house wiring. Installation of solar panels on both private houses and industrial buildings is popular in many European countries.

The surplus electricity generation can be sold and distributed to the local grid. Today profitability is making it interesting to construct large solar power plants. Vattenfall is doing this in connection to some wind power plants. The environmental impacts occur mainly during the production of the solar panels.

In the Nordic countries, the annual production varies between 800 and 1000 kWh per kWp installed, for a system directed towards the south and without shading.

The Nordic PV market is still very small and represents only a tiny fraction of the total electricity production.

Biomass

Biomass is matter originating from photosynthesis. The various uses of biomass have expanded considerably in recent decades.

Numerous methods are available for producing different types of biomass such as energy crops, farming and forest residues and waste. By using biomass for power generation instead of fossil fuels, carbon dioxide emissions can considerably be reduced. In a biomass-fired power plant, biomass is converted to electricity and heat by combustion. Biomass is usually co-fired with fossil fuels but can also be used as a single fuel in biomass-only plants.

Coal

Coal is a fossil energy source which still forms the base of the European electricity system. Coal power plants generate about 27% 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. 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.

Gas and Oil

Natural gas and oil are fossil fuels formed by the slow decomposition of biological material over millions of years. Natural gas and oil are formed under the same conditions and are therefore often found in the same places.

Natural gas is extracted on land and at sea, either in conjunction with extracting oil or from separate natural gas deposits. 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.

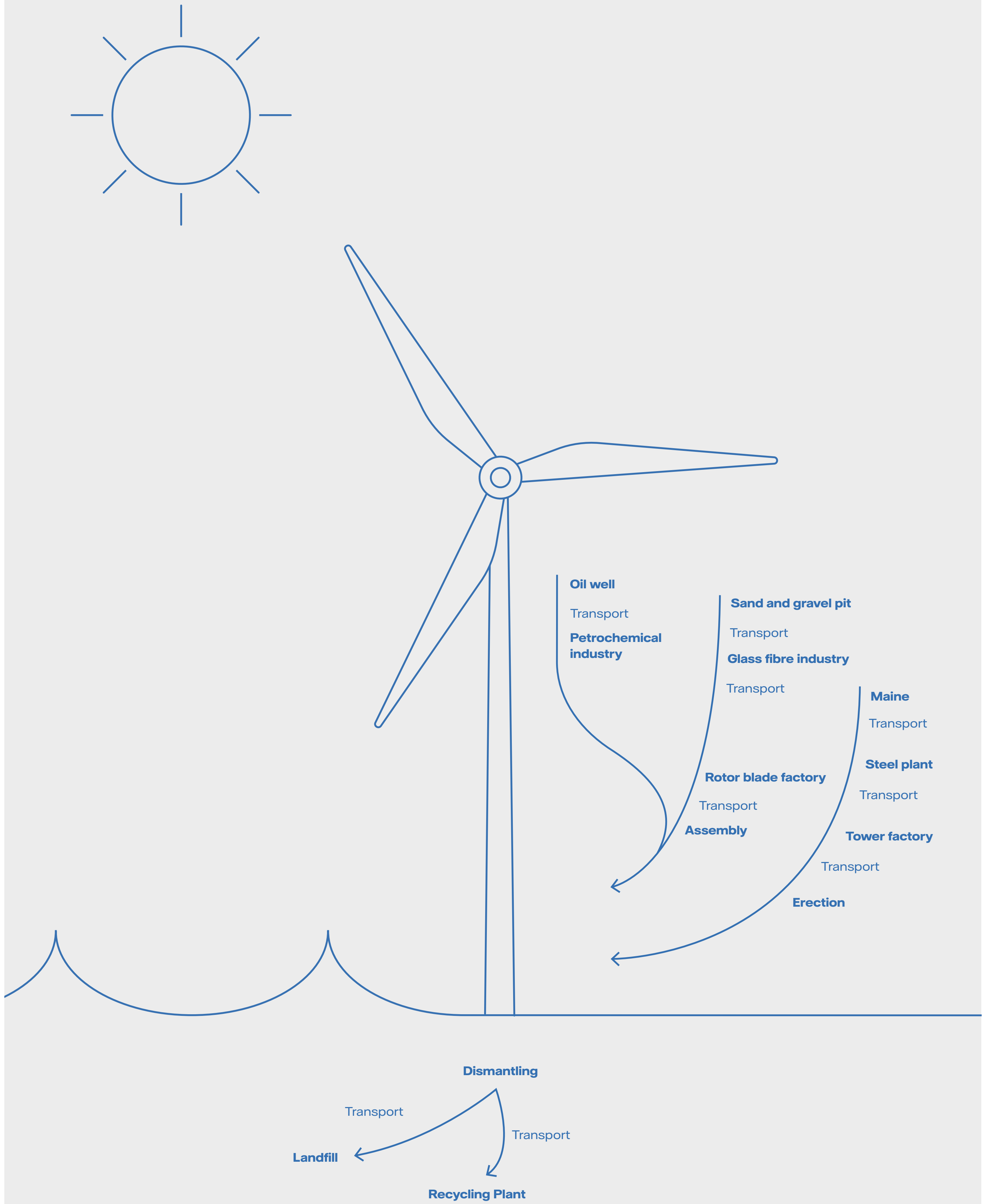


Figure 2. Examples of flows within a life cycle. The figure shows a number of flows in the lifecycle of a wind turbine. The entire life cycle also includes manufacturing and scrapping of generators, gearboxes and foundations, reinvestments, and operations and maintenance.

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 electricity 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. Vattenfalls' life cycle assessments are conducted in accordance with the International EPD® system and its methodology.

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 generated kWh. In this brochure results from the life cycle assessment is reported without any deeper interpretation. Figure 2 describes how a life cycle assessment is conducted. The arrows in the figure indicate that this is an iterative process which is continuously improved by the feedback from its results.

Environmental impact - various categories

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

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

The effects of these emissions are further described in Table 1 below.

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.

The international EPD® System

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 included 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 environdec.com

Emissions	Formation affected by	Impact on health and environment
Carbon dioxide equivalents (CO_2 eq.)Greenhouse gases	• The carbon content of the fuel. • Methane and carbon content in the soil released when mining coal.	• A contributor to global warming (only fossil fuels increasing the net release of carbon dioxide is accounted for).
Nitrogen oxides (NO_x)	• 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.

Table 1: Environmental impacts arising reported emissions.

Delimitations for the various power 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 is based on the applicable PCR for electricity generation. For more details see Appendix 1.

In the diagrams (Figure 3 – Figure 5) shown in this report, the data for nuclear, hydro, and wind power are based on EPD results for each power source. Data for solar power doesn't fulfil all requirements in the EPD category rules since more generic upstream data have been used. For other power sources shown in the diagrams Vattenfall operational data has been used but upstream data is generic.

Results

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

Result per generated kWh and power source

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

- Fuel production – Production and transportation of fuel.
- Operations – Operation of the power plant including conventional waste management
- Infrastructure - Construction, maintenance and dismantling of power plant
- Radioactive waste management - Handling of radioactive waste from nuclear power plants

Note that the reported results in Figures 3, 4 and 5 only apply under the conditions stated in this document. They cannot be considered representative of electricity generation in general. It should also be noted that different power sources cannot be entirely substituted by each other, as they have different functions in the electricity system.

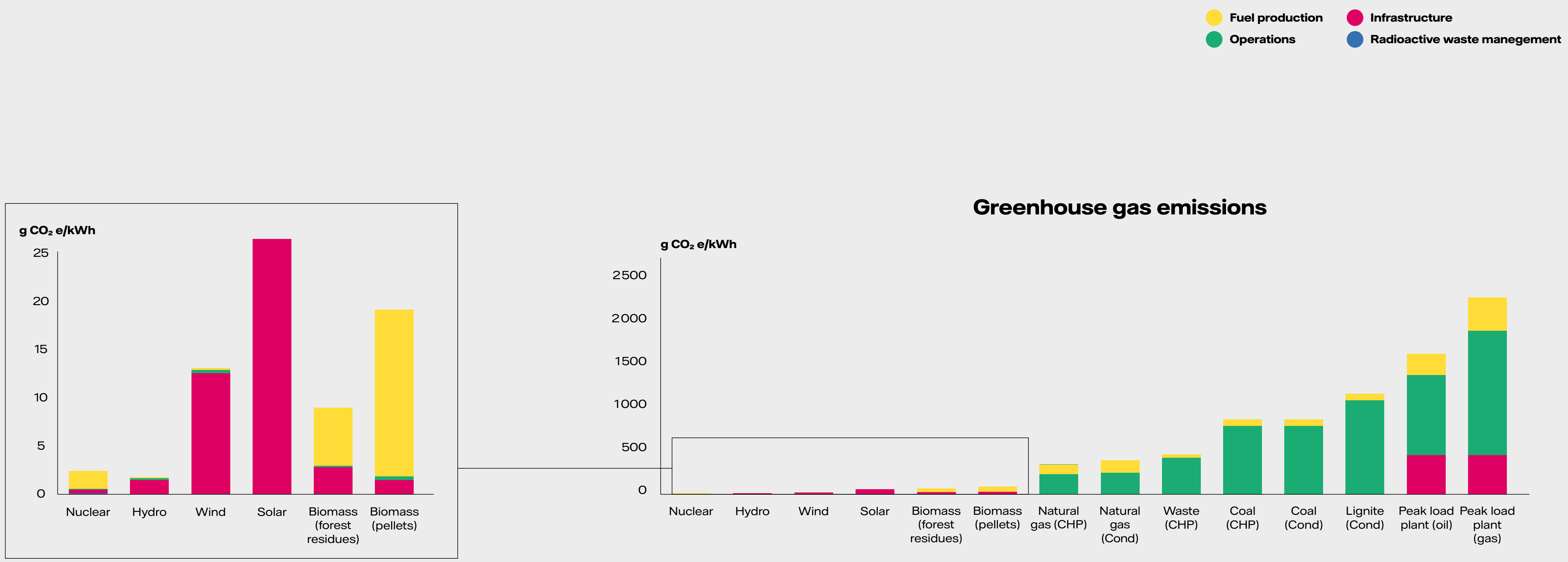


Figure 3. Emissions of fossil greenhouse gases (carbon dioxide equivalents) from a lifecycle perspective, for different electrical power sources.

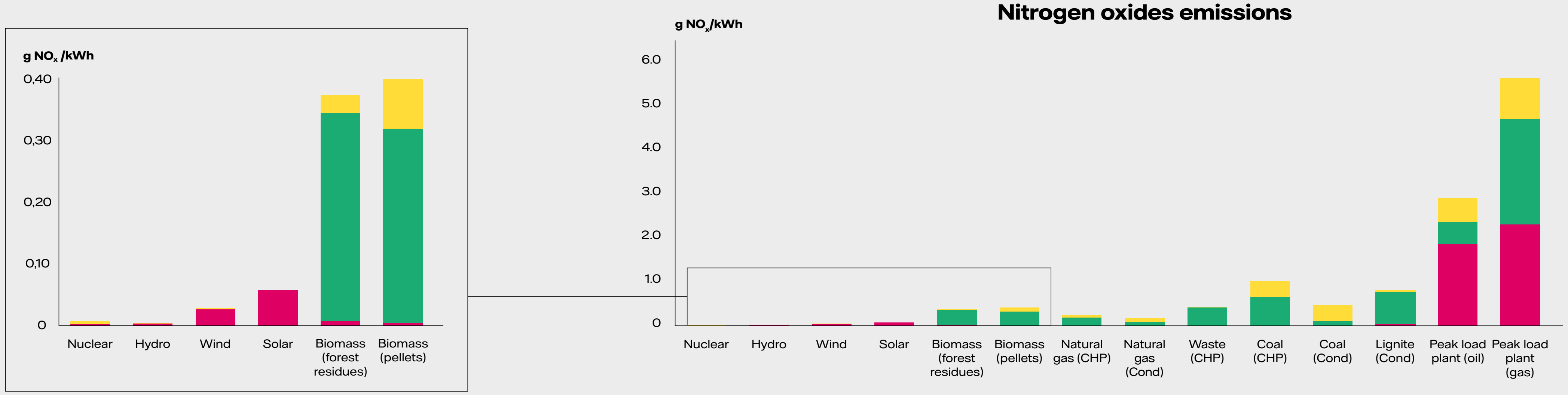


Figure 4. Emissions of nitrogen oxides from a lifecycle perspective, for different electrical power sources.

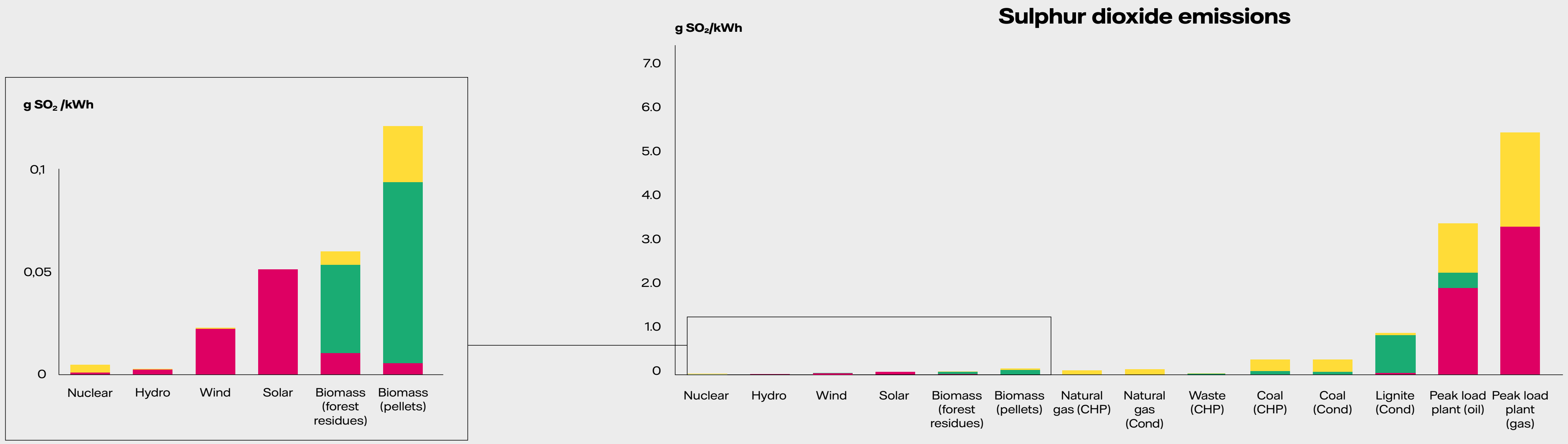


Figure 5. Emissions of sulphur dioxide from a lifecycle perspective, for different electrical power source

Impacts per power 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 environmental impact from hydro power 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. Operations of the hydro power plants result in low emissions. Those that do occur are caused mainly by transportation in conjunction with inspections and maintenance. When expanding the scope to include other greenhouse gases than those of fossil origin, emissions from changes in land use such as flooded land, makes a significant contribution. The soil contains organic carbon compounds and nutrients that are gradually broken down and released as a consequence of inundation. More about these impacts can be found in Vattenfall's EPD for electricity from Hydro power.

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.

Solar power
Solar power is a renewable energy source that causes very low emissions during the operation phase of the life cycle. The environmental impacts mainly occur during the construction phase and the production of the photovoltaic cell and its components is the main contributor to the emissions. The impact per generated kWh is also a result of where the panels are located.

Coal
The carbon dioxide emissions of a coal-fired power plant come mostly from the operational phase as a result of the combustion of coal. Coal mining and transportation also have an impact. Coal mining uses machines and a variety of vehicles to transport the coal from the mining area. Mining operations can also result in the release of relatively large quantities of methane but this varies a great deal from mine to mine. Hard coal is often carried on ships running on heavy fuel oil which results in emissions of sulphur dioxide and nitrogen oxides while lignite usually is transported using conveyor belts directly from the mine to the power plant.

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.

Natural gas
The combustion of natural gas causes lower levels of carbon dioxide emissions compared to other fossil sources of energy. The environmental impact from natural gas 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. Natural gas is often transported via pipelines where a certain leakage may occur.

Peak load plants
Oil condensing/Gas turbine
For oil-condensing and gas-turbine power plants, both the operations and the infrastructure show high environmental impact. The high impact from the infrastructure is due to the very limited number of operating hours per year and since the results are normalized per generated kWh the impact becomes significant.

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, wind, solar).
- → 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.

Impacts from other factors

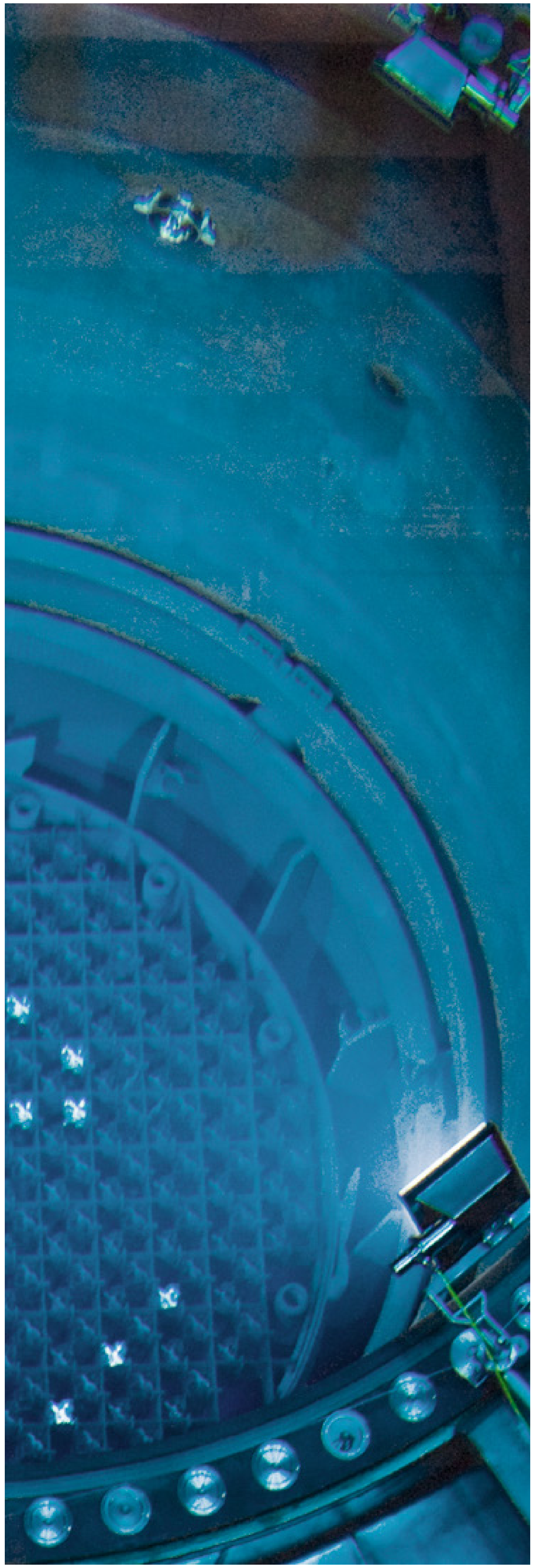
The production of fuel represents more than half the emissions to air in the nuclear power life cycle. The choice of supplier in the fuel chain is of great importance, particularly regarding uranium mining and enrichment. The content of uranium in the ore is important. Mines with low uranium content, 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 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 by installed capacity is a key parameter for the environmental profile of power types utilizing 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 running on fossil 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 influence 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. A combined heat and power plant has a higher efficiency compared to a power or heat plant only and thus has a positive influence on the environmental impact.

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.



Case study

Vattenfall's Nordic electricity from a life cycle perspective

This is a summary of the environmental impact of an average kWh generated by Vattenfall in the Nordic countries during the reference year 2020, based on:

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

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 wind, and in Finland from hydro.

Vattenfall's electricity output[1] in the Nordic countries used in this report is based on the total production during 2020.

Distribution

In order to distribute electricity 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. 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.

Result for an average generated 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 fossil greenhouse gases, sulphur dioxide and nitrogen oxides from a life cycle perspective. A simplified diagram of the electricity mix is shown in each figure as a reference. The bars are divided into four life cycle stages:

- Fuel production – Production and transportation of fuel.
- Operations – Operation of the power plant including conventional waste management.
- Infrastructure - Construction, maintenance and dismantling of power plant.
- Radioactive waste management - Handling of radioactive waste from nuclear power plants.

The results for Vattenfall's Nordic electricity mix are also shown in relation to the results for some of the other energy sources described in Chapter 3 Results.

[1] Based on Vattenfall's annual electricity output in pro rata terms.

Energy source	Nordic Countries	Sweden	Finland	Denmark
Nuclear	41,0%	43,1%	0,0%	0,0%
Hydro	53,3%	55,3%	100%	0,0%
Wind	5,5%	1,5%	0,0%	100%
Biomass, peat, waste	0,2%	0,2%	0,0%	0,0%
Fossil-based power	0,0%	0,0%	0,0%	0,0%
Total electricity generation	65,1 TWh	61,9 TWh	0,5 TWh	2,7 TWh

Table 2: Electricity mix in Vattenfall's operations in the Nordic countries.

Figure 6. Transmission and distribution voltage differ between countries.

The residual mix in the Nordic countries

The residual mix in the Nordic countries is calculated based on the volumes of energy from different energy sources that are used in the Nordic countries each year, after deducting the electricity sold with guarantees of origin from the mix. The Swedish Energy Markets Inspectorate provides results on the environmental impact of this electricity mix. For 2020 the greenhouse gas emissions for the Nordic residual mix (operation phase only) was 365.27 g/kWh. If this is compared to the operation phase for Vattenfall's Nordic electricity mix (0.70 g/kWh), the difference is extensive. The result for Vattenfall's mix is as low as 0.2% of the residual mix. Note that these numbers are not comparable because of differences in the calculation methods, but the order of magnitude is correct to compare.

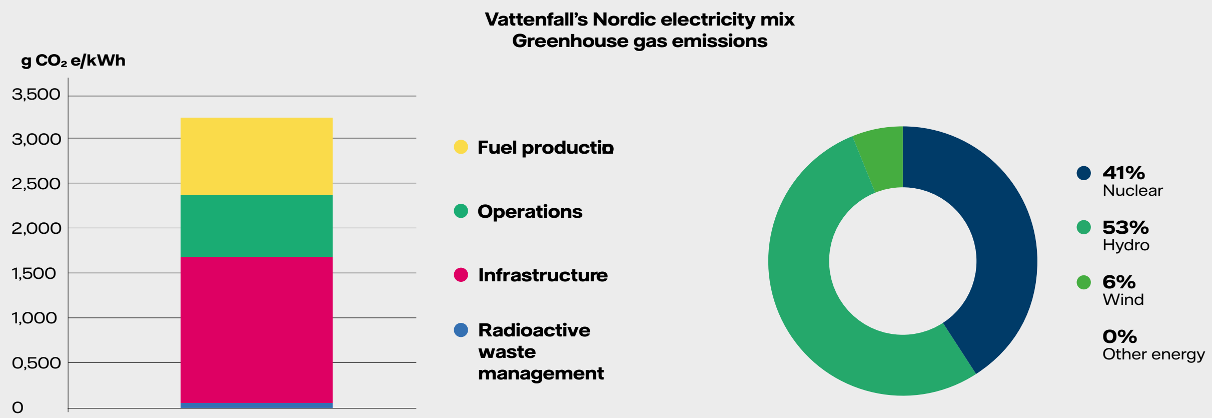


Figure 7. The figure shows energy sources and fossil greenhouse gas emissions connected to the different life cycle stages.

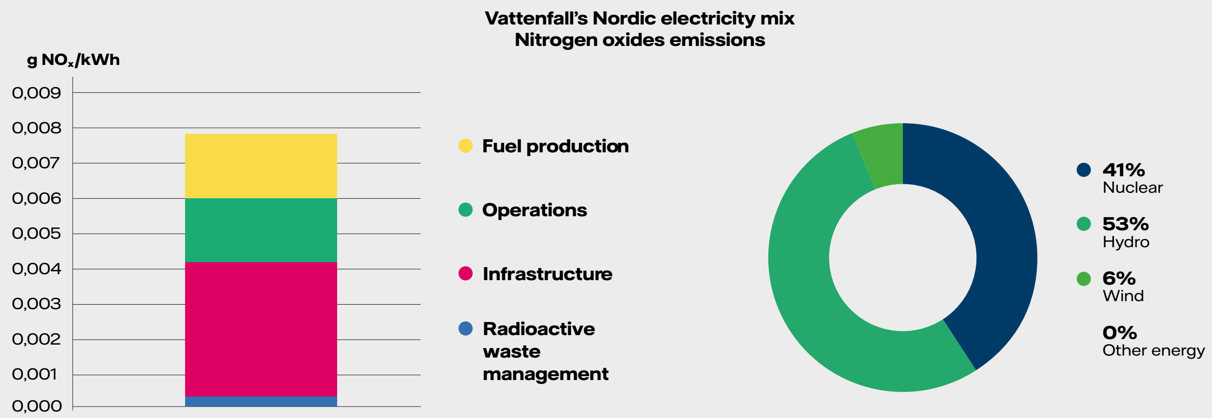


Figure 8. The figure shows energy sources and nitrogen oxides emissions connected to the different life cycle stages.

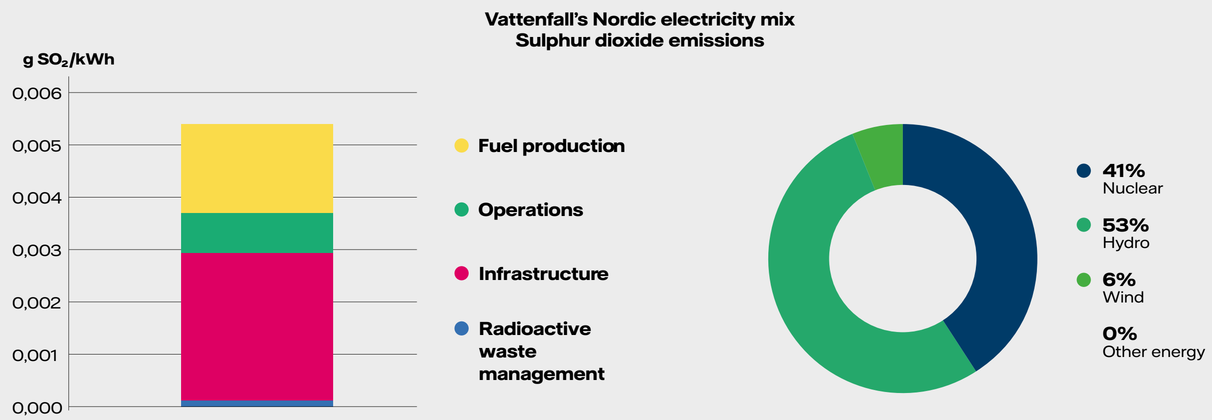


Figure 9. The figure shows energy sources and sulphur dioxide emissions connected to the different life cycle stages.

Results for distribution

In order to show the total environmental impact from electricity delivered to customers, the distribution system 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 3 and must also be added to results per generated kWh. 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 4%, while the equivalent distribution loss to a household in a sparsely populated area is around 8%.

The emission of greenhouse gases, nitrogen oxides and sulphur dioxide from construction and reinvestments in transmission and distribution networks are presented in the table below. These emissions must be added to the emissions shown in Chapters Results and Case study in order to obtain the emissions per kWh of distributed electricity.

Average distribution losses in Sweden

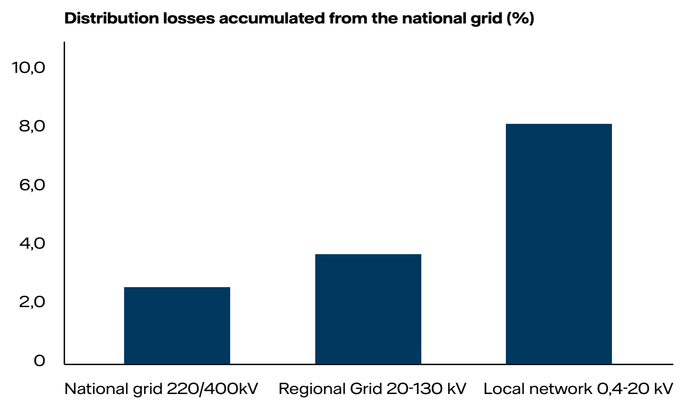


Figure 10. Average distribution losses at different voltages in Sweden.

Emissions	Quantity	Unit
Greenhouse gases	1,6	g CO2 e/kW (el) distributed
Nitrogen oxides	0,0039	g NOX e/kW (el) distributed
Sulphur dioxide	0,0048	g SO2 e/kW (el) distributed

Table 3. Shows the emissions of greenhouse gases of fossil origin, nitrogen oxides and sulphur dioxide from construction and reinvestments in transmission and distribution networks.

Interpretation of the case study results

For Vattenfall's Nordic electricity mix most of the carbon dioxide emissions, from a life cycle perspective, are emanating from the infrastructure, meaning the construction, reinvestment and dismantling of the power plant.

The two largest contributors to the electricity mix, namely hydro power and nuclear power, have a low environmental impact per kWh generated, thus influencing a low overall result. The majority of the carbon dioxide emissions from electricity generation for both hydro and wind power are due to the infrastructure, i.e. construction of power plants. This is a large part part also for nuclear power however the majority of the emissions arise upstream, mainly during uranium extraction. The infrastructure for hydro power and upstream fuel production for nuclear power, are also equally significant contributors to the nitrogen oxides emissions.

Even though the peak load plants have high emissions per kWh generated, their contribution to Vattenfall's total environmental impact on the whole is very low, due to the fact that these plants are run for only a few hours per year.

Fuel production also has a significant environmental impact as it accounts for the second largest portion of both greenhouse gas emissions and of sulphur dioxide emissions. However, these figures can be influenced by careful selection of suppliers and fuel sources. In some cases, Vattenfall has imposed requirements on suppliers in order to reduce the environmental impact – such as requiring a change in the electricity mix for its deliveries. The governance of these indirect emissions is an area of continuous development.

In order to reduce emissions from the operational life cycle stage where Vattenfall has full management control, a range of measures have been implemented. Examples of measures are flue gas cleaning and recycling, dust cleaning, catalytic converters, and significant efficiency-boosting techniques. Transportation has also been in focus, for example in off-shore wind where emissions from vessel fuel are big contributors to the environmental impact in the operational stage.

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 increasingly by setting requirements on our suppliers, or work together with them to lower the environmental impacts.

Vattenfall sees an increased interest for LCA as a tool to improve environmental performance but also when working with social aspects in the supply chain. EU is for example pushing the eco-design directive further and they are also working on requirements on environmental footprints for products and organisations.

With the use of LCA, Vattenfall has so far implemented a number of measures to improve the environmental performance based on a life cycle perspective. Main focus is on greenhouse gases but depending on the circumstances, other environmental impacts are prioritised such as rare earth metals.

The measures and applications include:

- Identification of significant environmental aspects from an LCA perspective in order to make prioritized and legitimate decisions. This is for example used when looking at new business models, before introducing new products, or when looking at construction alternatives.
- Evaluation of new technical solutions, such as generating electricity from solar power. It has also been used for evaluating electricity generation from wave power, battery storage, and Carbon Capture and Storage (CCS).
- Vattenfall's Environmental Product Declarations (EPD), based on LCA, are used to demonstrate the environmental impact from Vattenfall's electricity generation and supply environmental data for product specific electricity in the Nordics. They also act as a basis for reviewing permit applications, and to support public relations activities with various interested stakeholders.
- Influencing Vattenfall's suppliers within the nuclear fuel cycle and wind power to lower their environmental impacts e.g. through looking at the electricity mix they use and how efficiently energy is used. The aim is to reduce the environmental impact of the electricity supplied by Vattenfall's nuclear power plants.
- 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 has also conducted two pilots in social LCA, as an addition to the EPDs for hydro and wind. The pilots tested and evaluated existing methodology. The conclusion is that the methodology has to be developed further before it can be used as an integrated part of Vattenfall's EPDs. Vattenfall will continue to follow the developments in the area. The reports can be found on environdec.com, where all Vattenfall's EPDs are available.

The activities are all in line with Vattenfall's strategy – to be leading towards sustainable production and sustainable consumption, and also in line to become fossil free within one generation. Read more about our strategy on www.vattenfall.com.

Glossary and links

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/vattenfall

PCR for electricity, steam and hot water:
www.environdec.com/PCR

Vattenfall:
www.vattenfall.com

Questions? Send an e-mail to:
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Appendix

Energy source	Data source	Life cycle coverage	Technical service life
Nuclear	Vattenfall's EPDs for Swedish nuclear power.	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: • 44 years: Ringhals 1&2 • 60 years: Ringhals 3&4, Forsmark 1,2,3.
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 rebuilt 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 – Appendix 3: Nordic LCA results (based on a representative selection of seven wind power farms in the Nordic countries)	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. Reinvestments are estimated at 1% of the total construction work per year. Dismantling of power plants is included.
Solar	Based on Vattenfall's Lifecycle assessment of solar energy produced in Italy.	The assessment includes transports and infrastructure such as connections, panels and converters as well as waste management after usage. The panel is based on generic data and it is assumed to be manufactured in Poland and Vietnam.	The technical service life has been set at 30 years.
Biomass and biogenic waste	Based on Vattenfall's CHP plant in Nyköping (forest residues) and Drefviken/Jordbro (pellets)	Two different types of biomass have been studied: wood chips originating from forest residues and wood pellets. Wood chips are considered free from upstream environmental burden and only the transportation an chipping process is accounted for while pellets include the forestry operations, the pelletisation process and transportation. Operation of the power plant and waste handling, as well as building and dismantling of the plant has been included. Carbon dioxide for combustion of biomass has however not been included in the calculations, since it is considered being biogenic.	The technical service life has been set at 40 years.

Energy source	Data source	Life cycle coverage	Technical service life
Natural gas	Based on data from Vattenfall's CHP plant HKW Mitte in Germany, and condensing plant Hemweg in the Netherlands.	The life cycle includes well drilling, natural gas production and processing and transportation via pipeline. Included is also operation of the power plant and waste handling, as well as building and dismantling of the power plant.	The technical service life has been set at 40 years.
Waste	Based on Vattenfall's CHP waste incineration plant in Uppsala, Sweden.	The life cycle starts with transportation of the waste, other upstream emissions are excluded as the fuel itself (waste) is considered to be free from environmental burden. However, emissions and waste generated at the power plant is considered, as well as building and dismantling of the plant.	The technical service life has been set at 40 years.
Coal	Based on data from Vattenfall's coal CHP plant Reuter West and condensing plant Moorburg, both located in Germany.	The life cycle covers coal mining, transportation of coal to the power plant. The hard coal is transported to the power plant by ship, as the distances between coal mines and power plants are often long. Construction, operation and waste handling, as well as dismantling of the power plant, are also included.	The technical service life has been set at 40 years.
Lignite	Based on a lignite power plant in Boxberg, Germany (when owned by Vattenfall).	The life cycle includes extraction of lignite. Since lignite is extracted close to the power plant, no transport is accounted for. Also included are operation of the power plant and waste handling, as well as building and dismantling of the plant.	The technical service life has been set at 40 years.
Peak load plant Oil condensing	Based on Vattenfall's oil condensing plant in Stenungsund.	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 40 years.
Peak load plant Gas turbines	Based on Vattenfall's 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. 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 40 years.

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