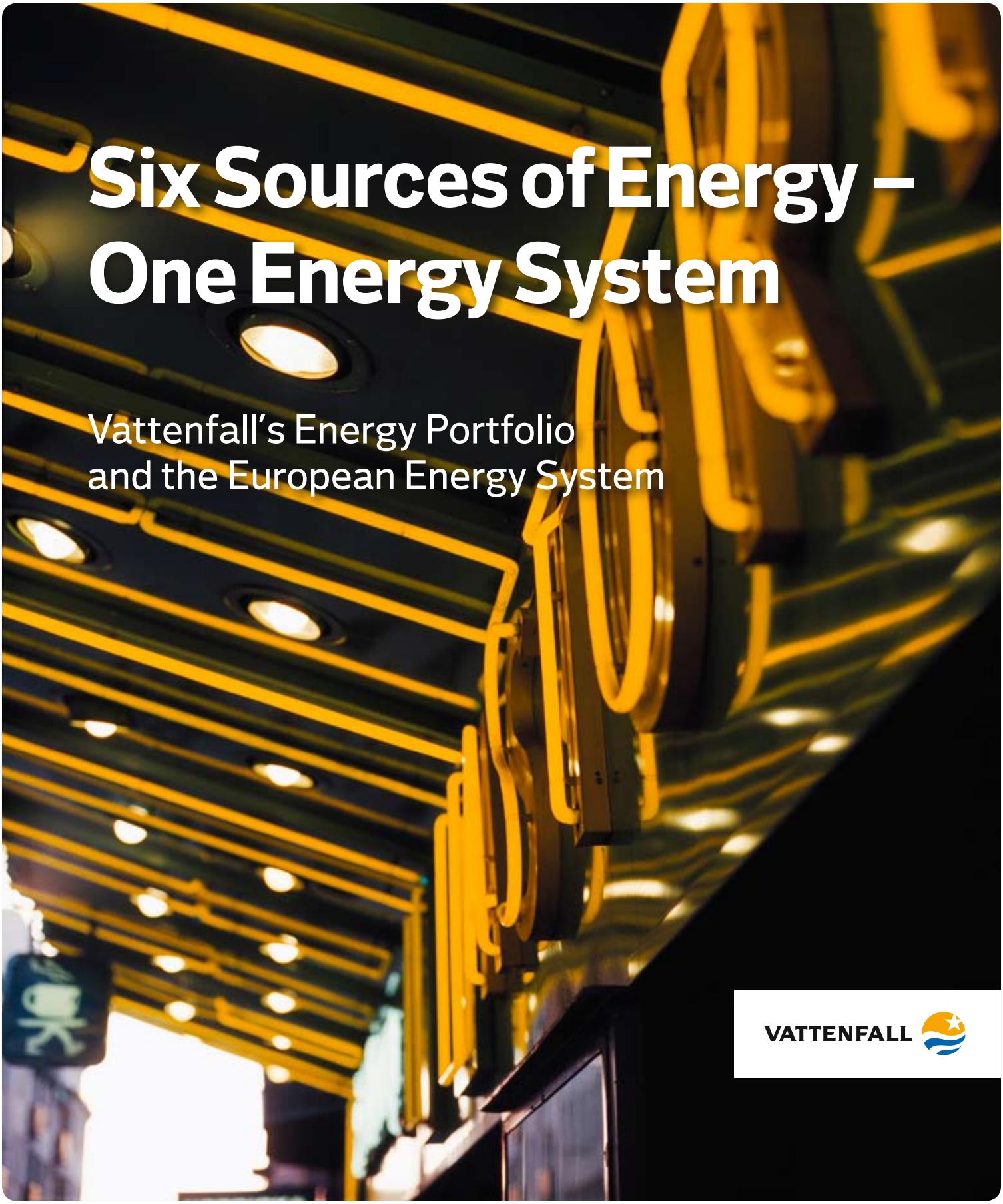

Six Sources of Energy – One Energy System

Vattenfall's Energy Portfolio and the European Energy System

VATTENFALL

Hydro Power

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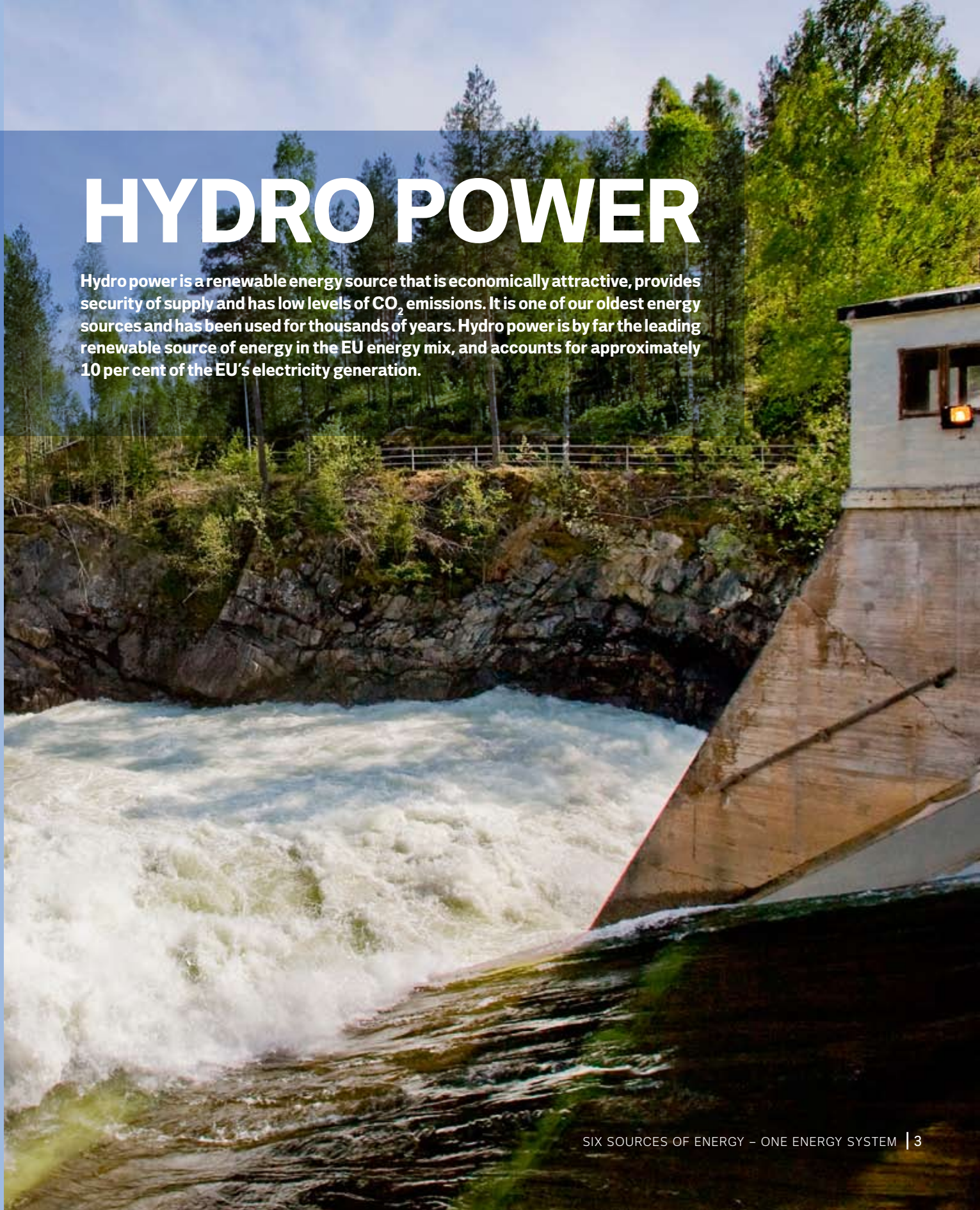
HYDRO POWER

Hydro power is a renewable energy source that is economically attractive, provides security of supply and has low levels of CO_2 emissions. It is one of our oldest energy sources and has been used for thousands of years. Hydro power is by far the leading renewable source of energy in the EU energy mix, and accounts for approximately 10 per cent of the EU's electricity generation.

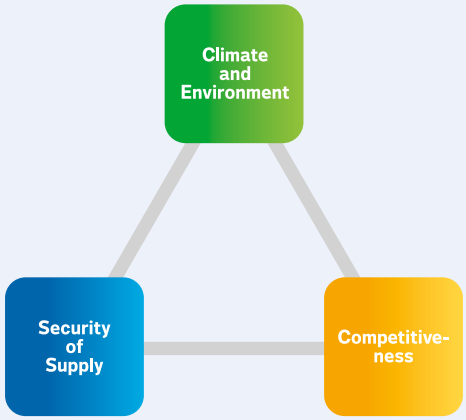


The Energy Triangle – Hydro Power

Climate and environment

All energy sources have environmental impact during their life cycles. Combustion of energy sources, particularly fossil fuels, generates CO_2 emissions and contributes to global warming. In the long run, emissions from power production will need to be close to zero if greenhouse gas levels in the atmosphere are to be stabilised.

Hydro power is a renewable energy source that causes almost no emissions that impact the climate or the environment. However, power plants are a significant encroachment on the landscape and impact river ecosystems. A power plant may also affect animal and plant life in the vicinity.



Security of supply

Fuel shortages and unreliable electricity systems cause societal and economic problems. Securing supply means guaranteeing that primary energy is available, and that delivered energy is reliable, essentially 100 per cent of the time. This is a major political and technical challenge.

Hydro power plants provide large-scale and stable electricity generation which can often be controlled domestically. But sustained high generation levels are dependent on precipitation. Hydro power also functions as balancing power, since capacity can be rapidly changed to compensate for differences in generation and consumption in the mains supply.

Competitiveness

Energy is a fundamental input to economic activity, and thus to human welfare and progress. The costs of producing energy vary between different energy sources and technologies. A competitive energy mix will keep overall costs as low as possible given the available resources.

Hydro power has no fuel costs and competitive generation costs. Constructing a new plant requires a substantial investment, but the economic life of a plant is long.

The History of Hydro Power

Hydro power is one of our oldest energy sources and has been used for several thousand years. In ancient India, Rome and China, water wheels were built to operate mills and timber saws. Hydro power was developed over the centuries, and was used in the early industrial era to power spinning machines and looms in textile factories in England and other countries. But modern, large-scale hydro power as we know it today first came into being with the invention of the electric motor and electric generator.

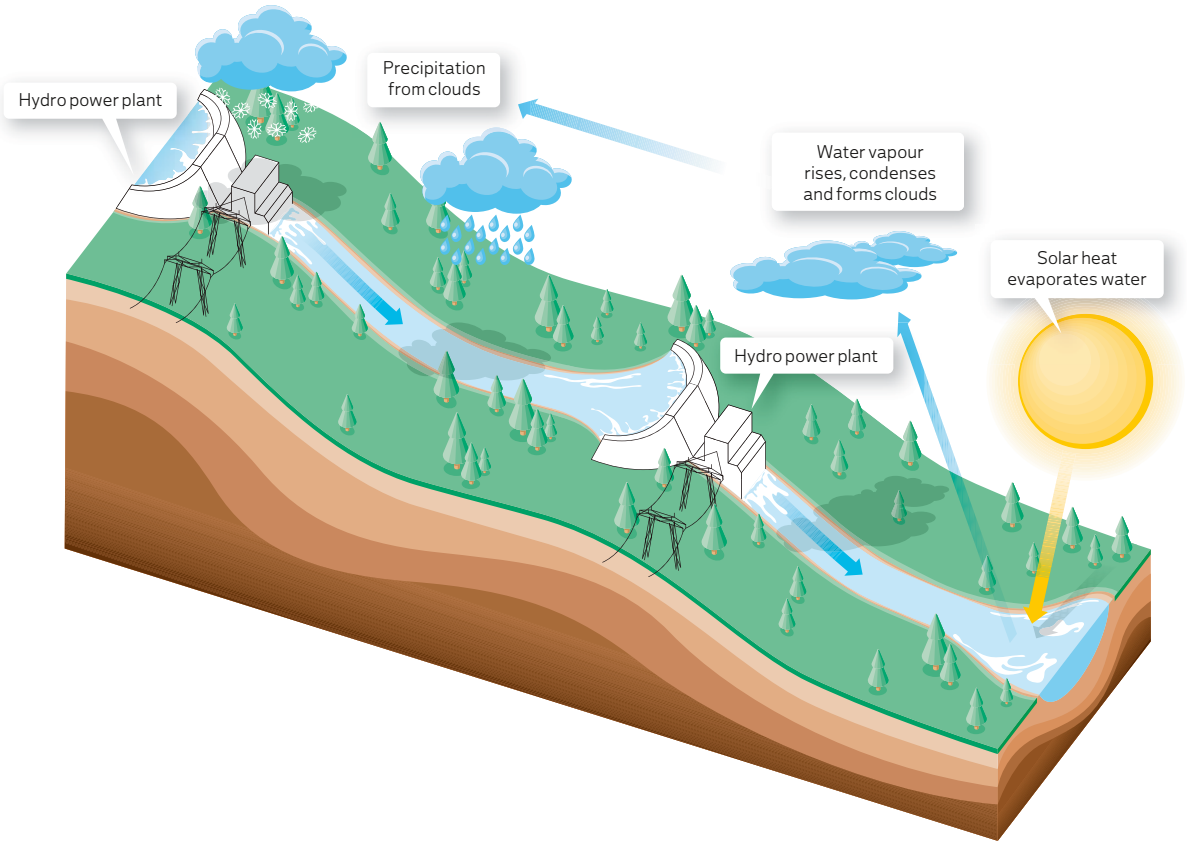
Hydro power involves harnessing the energy present in the movement of water to generate electricity. Water movement occurs in many different ways. The movement of water through its natural cycle creates streams and rivers. Winds and ocean currents create waves, and the moon's gravitational force creates tidal flows. Hydro power can also be found in the energy created in the mixture of fresh and salt water as rivers and streams flow into the sea.

Glaciers and lakes are created through evaporation and precipitation, and water flows back to the sea via rivers and streams. In order to harness the energy of running water, watercourses are altered so that the flow can be controlled and the water can be directed from dams to a lower level via a turbine. As water from the dam flows through the turbine, the water's potential energy is converted to mechanical energy which is then converted to electric energy via a generator.

Sweden – an example of the significance of hydro power

Hydro power played a decisive role in Sweden's transformation from a poor exporter of raw materials to a rich country with high-tech, electricity-intensive manufacturing industries. This industrial development placed enormous demands on the energy supply, and the Swedish state recognised early on the potential presented by Swedish rivers.

The natural water cycle



Sweden became a world leader in the development of large-scale hydro power during the 1900s. The hydro power plant in Porjus, officially opened in 1915, was built to provide electricity to the ore railway (Malmbanan) in northern Sweden and was one of the largest, most highly advanced hydro power projects that had been carried out to date. The 1930s saw the development of the technology necessary to send electricity over longer distances, and the major rivers in northern Sweden could thereby be used in earnest to process Swedish natural resources such as timber and ore. The Harsprång power line was opened in 1952. Running from the Harsprång power plant (one of the world's largest hydro power plants, located outside Jokkmokk) to Hallsberg, nearly 1,000 kilometres to the south, the power line linked the entire Swedish power network.

The inexpensive, secure electricity provided by hydro power enabled the emergence of Swedish base industry and served as the foundation for rapid Swedish economic growth in the mid-1900s. The mining industry, iron and steel mills, chemical industries and paper and pulp mills all developed thanks to their interplay with hydro power, and this remains true today. Sweden's exports still consist to a great degree of products from energy-intensive industries[1], and access to inexpensive, secure electricity is therefore of great importance to the Swedish economy.

Global and local considerations conflict

Hydro power on the whole receives strong support from nearly all sections of society, and attitudes towards hydro power do not appear to be affected to any significant degree by political orientation, educational level or age. Negative views are generally targeted at expansion of hydro power and usually not at existing hydro power plants.

Large-scale hydro power has very little impact on the climate and environment in the wider perspective. But hydro power does have a major impact on the environment in direct proximity to the plant and watercourse. The impact of hydro power is accordingly location-specific, which results in distinct conflicts of interest. From a climate perspective, hydro power is a very advantageous type of energy. But for people living near a planned hydro power plant and for the adjacent environment, the impact is more tangible than for almost any other type of energy. Given that large-scale hydro power plants represent a significant encroachment on the surrounding natural environment, the preservation of unspoiled watercourses has often been an argument against the expansion of hydro power.

Public opinion on hydro power has not been entirely positive throughout the hundred plus years of hydro power's history. Until the 1950s, hydro power was viewed as something positive and a necessary part of a functioning electricity generation system in countries that possessed the appropriate natural resources. A counter-movement emerged, however, in the 1950s and '60s, including in Sweden. Nearly all Swedish rivers were developed at that time, and an activist movement to preserve the last unspoiled rivers from development gained momentum. Despite the location-specific environmental impact of hydro power, protests against its expansion were initiated from throughout the country.

During recent decades, growing concerns about the greenhouse effect and global warming have boosted the general public's perception of hydro power and it is now viewed as part of the solution to the climate change problem. Support for hydro power remains essentially strong and intact. The issue is not whether hydro power is positive or negative, but rather how many unspoiled watercourses should be preserved.

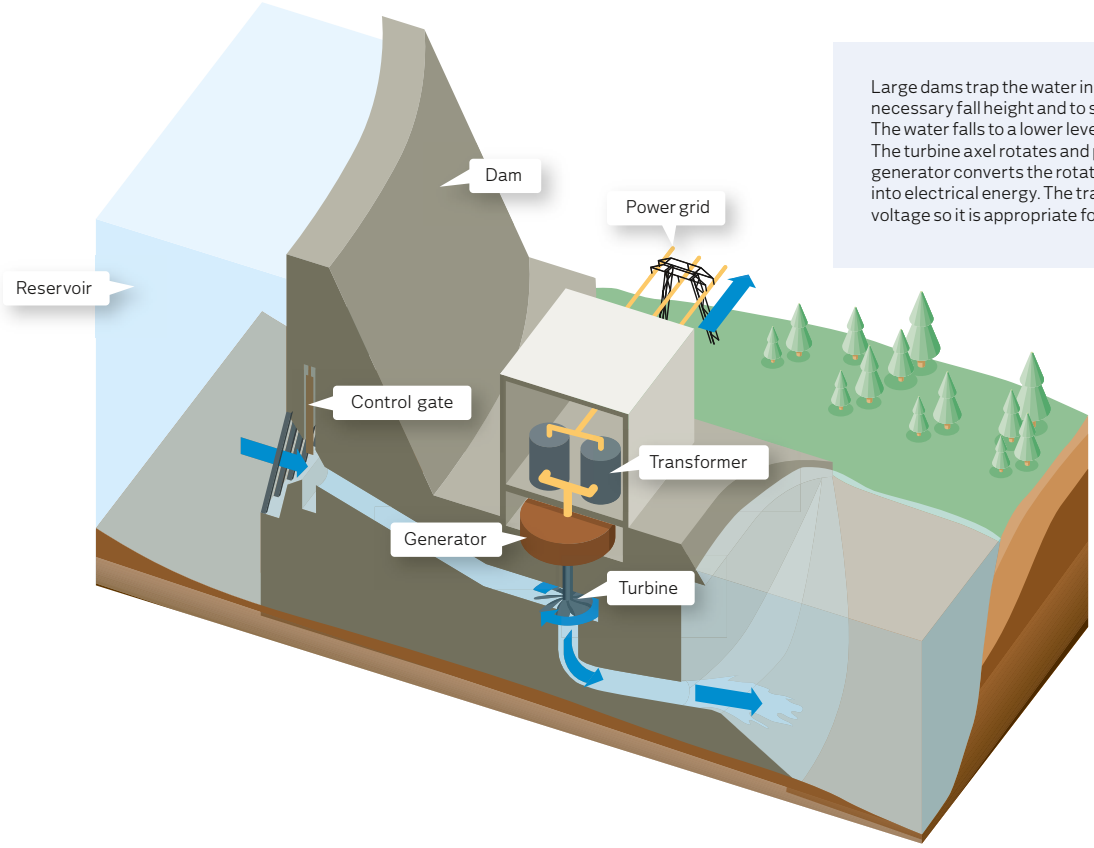
How a Hydro Power Plant Works

Anyone who has ever seen a large waterfall understands the enormous amount of energy present in rushing water. Harnessing a natural force of this magnitude requires advanced engineering skill and colossal constructions. Modern hydro power plants are therefore immense structures with dams that may be over one hundred metres high, huge man-made lakes and turbines weighing hundreds of tonnes. The technology behind hydro power is fairly simple, but taming the power of water is a major challenge.

Utilising water's natural cycle by harnessing the energy of rivers and streams is the most common and significant form of hydro power. Generally speaking, it works by using flowing water to power a generator that generates electricity. Dams create reservoirs that allow for greater heights of fall and also serve to regulate energy withdrawal; i.e., water is stored and used when electricity demand is the greatest. The water is directed from the reservoir to a lower level through tunnels, passing a turbine on the way. The type of turbine used depends on the size of the power plant, height of fall and other conditions. The Francis turbine is the most common type, used chiefly in hydro power plants with medium heights of fall. Hydro power plants with higher heights of fall (in the Alps and Norway, for example) normally use a Pelton turbine. A generator then converts the mechanical energy generated by the rotating turbine shaft into electrical energy, a transformer increases the voltage and the electricity is transmitted to the grid.

Hydro power plants are surrounded by various types of dams, pools, infrastructure and other things necessary to keep a power plant running. Various types of research equipment and research stations are in place, and fish ladders are sometimes used to make it easier for migratory fish to pass through the power plant. The look and design of hydro power plants can vary widely depending on natural conditions, the watercourse where the plant is built and the surrounding natural environment. A hydro power plant built high on a steep mountainside in the Alps calls for a completely different design than a plant built in a flat river valley.

Hydro power plant



Large dams trap the water in reservoirs to create the necessary fall height and to store some water for later use. The water falls to a lower level, passing through the turbine. The turbine axel rotates and powers the generator. The generator converts the rotating movement of the turbine into electrical energy. The transformer regulates the voltage so it is appropriate for the power grid.

Hydro power's significance as balancing power

One problem with electricity as an energy carrier is that it cannot be stored to any great extent. Water, on the other hand, can be. Water reservoirs next to hydro power plants can therefore be thought of as large batteries: water is stored and can be used as needed. Energy can thus be stored during the times of the year when water inflow is high and electricity demand is low, and the energy can then be used when demand is greatest.

Hydro power plants can be used both to generate baseload power (the amount of electricity that is always needed) and as balancing power (electricity output that can quickly be turned on to meet variations in demand). An important characteristic of hydro power is that it generates a great deal of electricity as soon as the water is released, and is not dependent on weather, wind or long, complicated start-up processes, a characteristic not shared by many other types of energy. Hydro power generation can be increased, for instance, to cover shortfalls from wind power and other types of energy that cannot be directly controlled, or from nuclear and coal power plants which take longer to get started.

Long useful life and low operating costs

Hydro power plants are large structures and relatively expensive to build. But once the plant is in operation, hydro power is extremely inexpensive. The plants are almost entirely automated, no fuel needs to be purchased and maintenance costs are relatively low. In addition, the useful life of a hydro power plant is long; many of the plants in operation today were built over 50 years ago and their useful life will continue for many years to come. Hydro power plants may seem expensive in terms of construction, but investment costs are quickly recouped once the plant is in operation.

Environmental consideration and fish conservation

Hydro power is a renewable energy source that produces almost no emissions that impact the climate or the environment. But construction of hydro power dams does meet resistance due to the fact that the dams have a significant impact on the water flow of the rivers where they are built and on animal and plant life in the vicinity.

The surface and depth of a dam varies greatly since the water level is determined by electricity output needs and the amount of water that is allowed to pass through the power plant. Water level fluctuations cause nutrient transfer from the productive riparian zone, and the biological richness is largely lost. Fish have a harder time finding food and laying eggs in the riparian zone, and hydro power plants present migratory obstacles for many fish species. Also, there is a carbon effect as a reservoir is made and carbon in the inundated soil reacts with oxygen in the water to form carbon dioxide. This effect is milder in Northern European boreal regions than in southern tropical regions, where methane is also formed. Efforts are being made to minimise this impact and research is being conducted to identify additional ways to protect the ecosystem from the effects of dam construction.[2]

> *Water reservoirs next to hydro power plants can be thought of as large batteries: water is stored and can be used as needed.*

Various types of waterways are sometimes built around the power plants to facilitate fish migration. Whenever possible, spawning grounds that are affected by dam construction are re-created in locations where they are not impacted by the power plant in the same way. Different fish have different migratory patterns: species such as perch and pike need relatively calm water without too much of a slope, while full-grown salmon need to be able to fight upstream and can jump up to two metres. Therefore, several types of steeper fish ladders are normally combined with flatter fish byways; i.e., man-made brooks and small waterways. There is extensive research on the ways different species of fish are impacted by changes in watercourses. Tagging fish with radio transmitters is a new method being employed to learn more about fish migration.[3]

Old river channels are often not drained completely. Rather, to make the environment more conducive for plant and animal life, attempts are made to maintain a natural, though lower, water flow. Areas containing particularly important habitats, biotopes and species are protected and many energy companies are working to restore environments that have been damaged by previous dam construction.

Most countries have legislation in place that obliges hydro power operators to raise and release fish to compensate for the impact of hydro power plants on the fish stock. Many of the largest European fish farms are therefore operated by energy companies.

Hydro Power in Europe

Hydro power is by far the leading renewable energy source in the EU energy mix. According to the IEA, hydro power accounted for approximately 10 per cent of the EU's electricity generation and about 60 per cent of total renewable electricity generation in 2008.[4]

In global terms, hydro power accounted for 16 per cent of total electricity generation in 2008, as compared to other types of renewable energy which in aggregate accounted for barely three per cent.[5] The world's largest hydro power producers are China, Canada, Brazil and the US.[6]

Hydro power in European countries

All countries that have had the option of utilising hydro power have considered it obvious to do so. The wide variations in the amount of hydro power used by different countries are due primarily to geographic, geological and economic factors, not to political decisions.

The construction of a large-scale hydro power plant requires the right kind of watercourse, and these are not present in equal measures throughout the world. The proportion of hydro power in the energy mix of countries such as Sweden, France and Austria, which have large differences in altitude and suitable watercourses, is therefore very high. Hydro power comprises over 98 per cent of total electricity generation in Norway, Europe's largest hydro power producer with annual generation of approximately 140 TWh.[7] Countries such as Denmark, Germany and Poland, on the other hand, do not possess the conditions conducive for hydro power and therefore rely heavily on other energy sources.

Much of the work associated with traditional hydro power focuses on increasing the safety of dams and minimising adverse effects on the surrounding natural environment.

Safety and environmental considerations

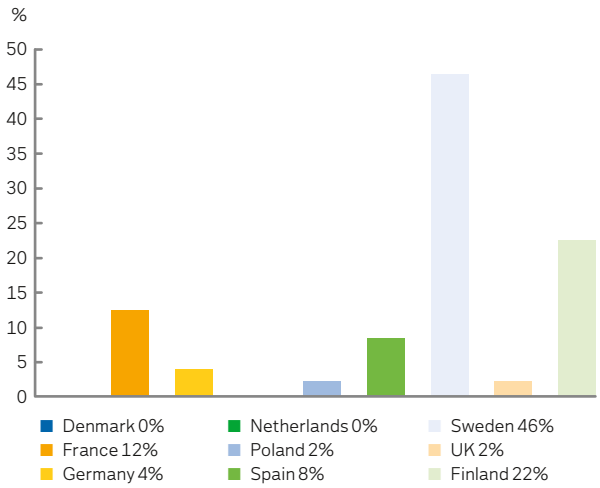
Much of the work associated with traditional hydro power focuses on increasing the safety of dams and minimising adverse effects on the surrounding natural environment. Safety aspects are primarily aimed at preventing dam leakage and rupture. Risks of leakage (e.g., of oil) into water bodies are carefully monitored and preventive measures are taken. Advances in meteorology and hydrology have increased hydro power plant risk awareness, and investments are currently being made in many older plants to improve dam safety. Several of these plants have been fortified to handle water flows that are so high that, statistically speaking, they are expected to occur once every 10,000 years.

New technology brings more hydro power to Europe

Due to the fact that European hydro power is so well-developed, investments in hydro power in Europe consist primarily of the modernisation and capacity expansion of existing plants.

There are also opportunities to expand small-scale hydro power plants (plants with a capacity of up to 10 MW).

Share of hydro power in electricity generation (2008)



Source: IEA Statistics, Electricity Generation, 2010

The Future of Hydro Power

Hydro power will play a crucial role in achieving a sustainable energy system in the future. The climate change issue has altered our view of what power generation should look like, and efforts to switch over to a carbon neutral energy mix are in full swing at all levels throughout the world. The EU has established a number of climate targets to serve as the basis for its climate change efforts through the year 2020. The attainment of these targets requires an increased use of renewable energy sources, such as hydro power.

European hydro power is currently well-developed. Although European hydro power electricity generation will increase in absolute terms, its share of total electricity generation will decrease slightly. Future European hydro power investments will chiefly be made in efficiency measures and improvements at existing hydro power plants, expanded use of small-scale hydro power and new hydro power technology. The capacity of hydro power to store energy and act as balancing power will be increasingly important as renewable but intermittent types of energy, such as solar and wind, gain significance. Modern hydro power will therefore be an essential component in future energy systems and in achieving the EU's climate goals.

Great potential for small-scale hydro power

During recent years, small-scale hydro power has been discussed more and more often. The scientific community agrees on the great potential presented by small-scale and tidal stream hydro power plants (plants that utilise natural water flows but have no dams or regulation capabilities). Like large-scale hydro power, electricity generation in small-scale plants is renewable and inexpensive. Moreover, these plants have only a minor impact on the surrounding natural environment and are often well-received by public opinion. The disadvantage of small-scale as compared to large-scale hydro power plants is that they do not offer the same level of security of supply, since they often lack regulation or storage capabilities and therefore cannot be used as balancing power.

At present, however, several regulatory obstacles must be resolved before a more comprehensive expansion of small-scale hydro power plants can be achieved. The general view on increasing the use of this renewable energy source is positive.

Waves generated by wind and currents carry enormous amounts of energy which, if harnessed, would be a major contributor to a carbon neutral energy system.

Pumping power increases system reliability

Hydro-pumping power stations fill an important role in the energy system as a way of storing energy and equalising electricity supply and demand. When electricity generation is high and consumption is low (e.g., at night or during the summer months) the surplus is used to pump water into a higher reservoir. When electricity demand is higher than generation (e.g., during the day or in winter) the water is released from the higher reservoir and electricity is produced as in a conventional hydro power plant. However, hydro-pumping power stations are net energy consumers, meaning that on average they consume more energy than they produce.

Combining hydro-pumping power stations with solar power stations and wind turbines is a method of producing renewable electricity that offers both security of supply and an even generation rate regardless of weather conditions. This method utilises the renewable energy generated by wind and solar power and combines it with the pumping station's capacity to store energy. In combination, the power stations become a net energy producer. However, these efforts are still in the developmental phase.

Ocean waves are an untapped resource

The new hydro power variant that is considered to have the greatest potential is sea wave power. Waves generated by wind and currents carry enormous amounts of energy which, if harnessed, would be a major contributor to a carbon neutral energy system. So far, wave power is in the developmental stage and harnessing wave energy still presents technical challenges. Wave power plants must be capable of producing a reasonable amount of power in light winds and small waves just as in stormy weather and rough seas. They must also be able to handle the physical strain the ocean exposes them to, and must have a minimal impact on animal and plant life. But progress is rapid and major research projects are underway in several countries.[8]

Tidal energy – a blend of old and new technology

Tidal energy uses the difference in water level height between high and low tides as well as the currents created by tides in bays or along coasts. Tidal currents are extremely predictable, a major advantage in terms of planning generation and maintenance. Tidal power plants have been used on a small scale in places like France since the 1960s, though the potential of tidal power as a large-scale energy source is not entirely certain. The main limitation is that very few locations are suitable for major tidal power plants: the difference in water level must be substantial for the plant to be profitable.

Osmotic power – an innovative idea with great potential

Water can also generate energy in more surprising ways. One hydro power variant considered as having great potential is osmotic power, sometimes called salinity power, a method of harnessing the energy released when fresh water is mixed with salt water. Osmotic power plants use the physical and chemical phenomenon of osmosis.

When fresh water meets salt water (for example, when a river flows out to the sea) enormous amounts of energy are released which can be converted to electricity. In an osmotic power plant, fresh and salt water are directed into separate storage containers. The containers are separated by a semi-permeable membrane which lets through water molecules but not the larger salt molecules. The salt molecules in the salt water draw the fresh water through the membrane, creating osmotic pressure in the salt water container. The pressure built up through this method is equivalent to a water column of over 100 metres, and is then used to power a turbine which generates electricity.

Osmotic power is a renewable energy source and could in theory be used everywhere fresh water flows into salt water. The potential is great, but the technology is still expensive. The greatest challenge lies in improving the membranes and making them less expensive. The world's first osmotic power plant, opened in 2009, is located outside of Oslo, Norway.

New technologies on the way – but the traditional ones remain important

Although new technologies such as wave and osmotic power have great potential, they are still under development. Their significance in future energy systems is hard to predict. In the immediate future, small-scale hydro power will probably be the hydro power variant that will contribute most to increasing the amount of renewable electricity, provided that policy frameworks are developed and administrative processes improved. Meanwhile, large-scale hydro power will remain the most important renewable energy source in the European energy mix.

Vattenfall and Hydro Power

Hydro power is a renewable energy source that is economically attractive, provides security of supply and has low levels of CO_2 emissions. Vattenfall has century-long roots in hydro power and continues to hold a leading position in Sweden. Vattenfall is committed to hydro power and intends to explore growth options through acquisitions in Central and Western Europe.

Vattenfall's hydro power operations

Vattenfall owns and operates more than one hundred hydro power plants, most of which are located in Sweden with some in Finland and Germany. Hydro power accounts for roughly 20 per cent of Vattenfall's total electricity generation and is the most important renewable energy source in terms of both Vattenfall's production and the European energy system.

Hydro power has played an important role in Vattenfall's history. When Vattenfall's predecessor, the State Power Board of Sweden, was founded in 1909, it was tasked with managing the Swedish state's investments in hydro power. Sweden's many rivers and streams comprised an excellent source of energy for Swedish industry, one which grew at a record pace in the early 1900s. Since then, hydro power has played a vital role for both Vattenfall and for Sweden.

Vattenfall also operates a number of fish farms, including those in Indalsälven and Luleälven, to compensate for the impact that the company's power plants have on fish stocks in Swedish rivers. Vattenfall is one of Sweden's largest fish farmers, releasing nearly two million salmon, whitefish and sea trout fry into Swedish rivers each year. For a full list of Vattenfall's hydro power plants, please see the production site at www.vattenfall.com/powerplants.

Akkats power plant located in Jokkmokk, north of the Arctic Circle. Akkats forms the gateway to the Swedish Great Lakes and Laponia World Heritage Site.

Vattenfall's hydro power operations going forward

Hydro power is increasingly attractive, particularly in light of the fact that the French market is opening up to competition. As one of Europe's largest operators, Vattenfall has a clear competitive advantage. Vattenfall will continue to keep hydro power growth options open.

Vattenfall is investing in modernising and upgrading existing hydro power plants, 30 or so of which will be upgraded between 2004 and 2014. Vattenfall is also conducting a comprehensive dam safety programme. The Abelvattnet power plant, in Storuman in northern Sweden, will be Vattenfall's first newly constructed hydro power plant in over 15 years.

The share of hydro power in Vattenfall's electricity generation is expected to fall to just over half of its current level by 2030. This is not due to a reduction in hydro power generation, but to the fact that hydro power is already well-developed. Simply put, there are few opportunities to build more or to expand existing hydro power plants as the demand for electricity rises. Increases in electricity generation will therefore come primarily from other types of energy.

SUMMARY

- **Hydro power is the most important renewable energy source in the EU's energy mix. In 2008 hydro power accounted for approximately 11 per cent of the EU's electricity generation and about 60 per cent of total renewable electricity generation**
- **Hydro power plants can be used both to generate baseload power (the amount of electricity that is always needed) and as balancing power (electricity output that can quickly be turned on and off to meet variations in demand and supply)**
- **A hydro power plant in operation is very inexpensive. The plants are almost entirely automated, no fuel needs to be purchased and maintenance costs are relatively low. Hydro power plants are expensive to build, but the useful life is long**
- **Hydro power produces basically no emissions that impact the climate or the environment. But construction of hydro power dams have a significant impact on the water flow of the rivers where they are built and on animal and plant life in the vicinity. Efforts are being made to minimise this impact and research is being conducted to identify additional ways to protect the ecosystem from the effects of dam construction**
- **The development and increased use of new hydro power technologies, such as wave power, pumping power stations and osmotic power, will be essential elements in achieving a sustainable energy system in the future. However, traditional large-scale hydro power will in all likelihood remain the most important renewable energy source in the European energy mix**
- **Vattenfall has century-long roots in hydro power and currently owns and operates over one hundred hydro power plants. As one of Europe's largest operators, Vattenfall has a clear competitive advantage. Vattenfall will continue to keep its hydro power growth options open**

Footnotes – Hydro power

1 Statistics Sweden, SCB, Trade in Goods and Services, Foreign Trade
2 You can read more about climate effects of land inundation on IPCC's webpage, www.ipcc.ch
3 Read more about Vattenfall's environmental and fish conservation efforts in Vattenfall's 2009 CSR Report
4 IEA Statistics, Electricity Generation, 2010, www.iea.org
5 Ibid.
6 The Royal Swedish Academy of Sciences Energy Committee, About Hydro Power, 2009
7 IEA Statistics, op. cit.
8 Read more about the Lysekil Wave Power Project at: http://www.el.angstrom.uu.se/forskningsprojekt/WavePower/Lysekilsprojektet_E.html