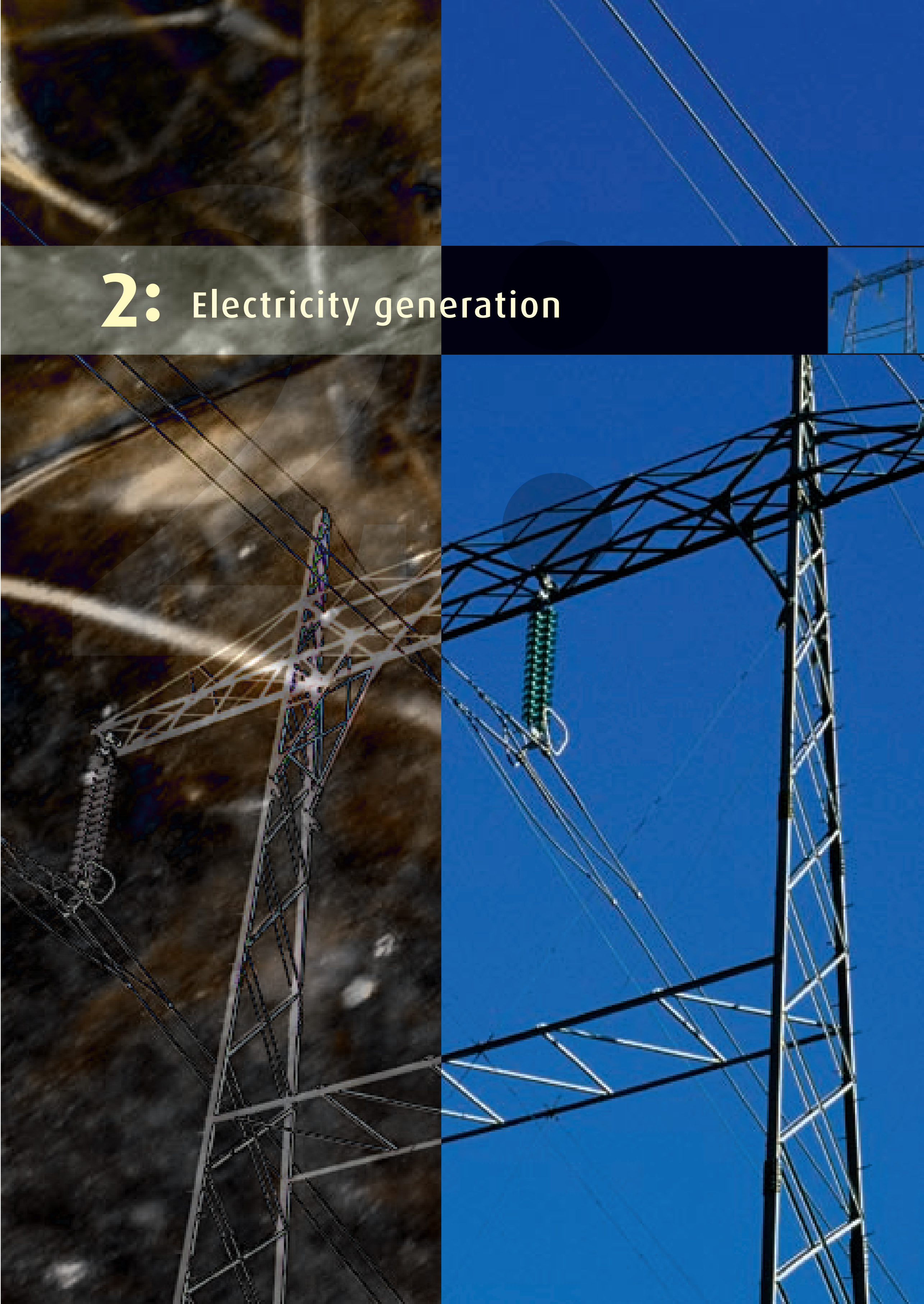
# 2: Electricity generation



## 2.1 Total electricity production

In 2007, electricity production was over 137 TWh. This high production level is due to high levels of precipitation. Approximately 135 TWh was generated from hydropower, 0.9 from wind power and 1.5 in gas-fired power plants and other thermal power stations.

The relationship between installed production capacity and consumption varies from region to region. Most of the hydropower is produced in western Norway and Nordland county, whereas in eastern Norway, energy consumption is far higher than local production. This means power has to be transmitted from the west to the east and from north to south. between the various parts of the country is also affected by the exchange with Denmark, Sweden, Finland and the Netherlands. Current transmission capacity from Norway to its neighbours is more than 5,000 MW. These connections are used for both import and export of energy (see Chapter 7).

### Norwegian power generation capacity changing

Traditionally, Norway's production of electricity has come almost exclusively from **hydropower**. We have defined a 'normal year' to describe a year with a normal amount of precipitation, which we use to calculate expected annual power production. 30 years is the standard length of normal periods for meteorological and hydrological data.

**Inflow** is the amount of water that flows to a power plant from its local catchment area. Hydropower plants' **mean production capacity** is calculated on the basis of installed output and the expected annual inflow in a year with normal precipitation. Norwegian power generation varies broadly from year to year (see figure 2.4), and precipitation is the main uncertainty factor.

However, this situation is changing. In recent years, Norway has developed new production capacity, such as wind power and gas-fired power. **Uncertainty linked to annual power generation is therefore more complex now.** However, Norwegian power generation will continue to depend greatly on precipitation levels, as hydropower will continue to dominate in the foreseeable future.

Like hydropower, **wind power** is characterised by low operating costs. This means that the price of electricity has to be extremely low for wind power to be unprofitable, once the power stations have been built. A wind power plant needs wind of a certain speed to be able to produce electricity. If the wind speed is too low or too high, production is not possible.

**Gas-fired power plants** are productive as long as the price they receive for the power is greater than the cost of generating it. Future power price, the price of gas and the price on $CO_2$ emissions are therefore new variables that affect annual power production.

**Other thermal power*** is produced in small power stations often situated next to and owned by large industrial concerns. The energy resources used for power generation include municipal waste, industrial waste, waste heat, oil, natural gas and coal (on Svalbard). The operating time of these plants is usually closely linked to the general level of activity in the companies, but also depends on the price of fuel. Power plants that use waste as fuel usually have a more even output.

* 'Thermal power station' is a general term used for power stations that produce electricity from fossil fuels, biofuels or nuclear power.

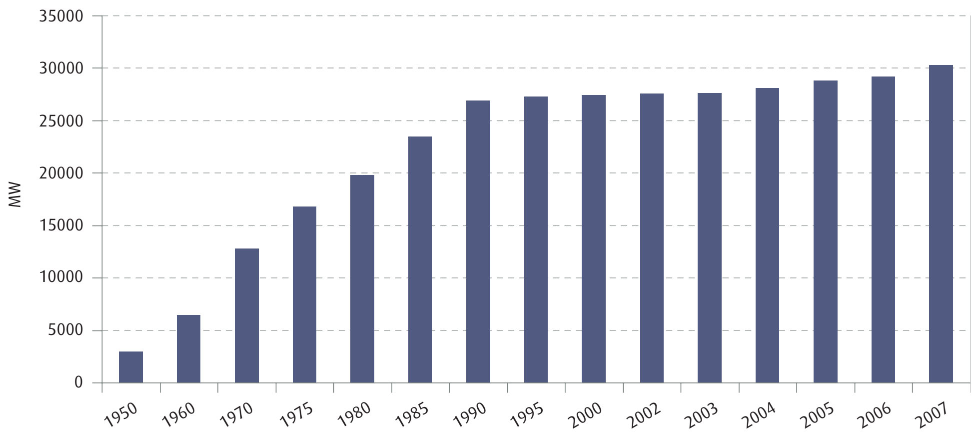



**Figure 2.1 Installed output capacity up until 1 January 2008.**
*Source: Norwegian Water Resources and Energy Directorate (NVE)*

### 2.1.1 Power generation capacity in 2008

At the beginning of 2008, hydropower production in a normal year in Norway was calculated to be 121.8 TWh. In addition, Norway now has a installed capacity of 385 MW from wind power stations,, 645 MW from gas-fired power plants and 240 MW from other thermal power plants. 215 MW of the installed gas-fired power capacity comes from the gas-fired power plant in Melkøya, whose production is dedicated to and specially adapted for the energy needs of the Snøhvit field. Hydropower currently constitutes some 96 per cent of Norway's production capacity.

Figure 2.1 shows developments in production capacity. The largest hydropower projects were built between 1970 and 1985, when installed capacity increased by 10,730 MW, or an average of 4.1 per cent per year. Towards the end of the 1980s, Norway's rate of hydropower development tapered off. Since the beginning of the 1990s, the growth of new production capacity has been consistently low. Capacity increased by 800 MW from 1993 to 2005. The increase in the 1990s was primarily due to refurbishment and upgrading of old power stations, which resulted in better utilisation of existing power stations. New wind power plants also account for a growing proportion of this increase. In 2007, the gas-fired power plants at Kårstø and Melkøya added to a considerable increase in production capacity.

## 2.2 Hydropower

Norway's river systems are very important both for commercial interests and public interests – in connection with outdoor recreation, for instance. Electricity generation is the most important commercial use of Norwegian watercourses.

A river system comprises a river and all its tributaries from source to sea, including lakes, snowfields and glaciers in the catchment area. There are about 4,000 river systems in

**Table 2-1 Norway's highest waterfalls (height calculated by virtually vertical head).**
*Source: Watercourse Act Committee*

| Waterfall | Height (m) | Phase | Licensed/protected |
|---|---|---|---|
| Tyssestrengen | 300 | Built | 1964 Tyssefaldene A/S |
| Ringdalsfossen | 300 | Built | 1964 Tyssefaldene A/S |
| Skykkjedalsfossen | 300 | Built | 1973 Statkraft |
| Vettisfossen | 275 | Permanently protected | 1923 Natural Environment Protection Act |
| Austerkrokfossen | 256 | Built | 1966 Elektrokjemisk A/S |
| Søre Mardalsfossen | 250 | Built | 1973 Statkraft |
| Storhoggfossen i Ulla | 210 | Built | 1973 Statkraft |
| Vedalsfossen | 200 | Permanently protected | 1980 Protection plan II |
| Feigefossen | 200 | Permanently protected | 1986 Protection plan III |
| Glutrefossen | 171 | Partly built | 1973 Statkraft |

Norway. In some counties, almost all the larger rivers have been developed. Seven of Norway's ten highest waterfalls have been developed, and the remaining three are permanently protected against such developments (see table 2.1). To increase the electricity production, water is commonly transferred from one part of a river system to another or even between neighbouring river systems. In many cases, several power stations have been built in the same river system.

There are a wide range of different types of watercourses in Norway as a result of the great variations in topography, precipitation and climate. Rivers in western Norway, Nordland county and parts of Troms county are generally short and steep, with large waterfalls, while eastern Norway, the Trøndelag region and Finnmark county have much longer systems that carry a large water volume but drop more gently to the sea.

Volume and head of water determine the potential energy of a waterfall.

The head of water is the height difference between reservoir intake and power station outlet. Water is directed into pressure shafts leading down to a power station, where it strikes the turbine runner at high pressure. The kinetic energy of the water is transmitted via the propeller shaft to a generator, which converts it into electrical energy.

Low-head power stations often use a large water volume but have a small head, as in a run-of-river power station. Since regulating the flow of water is difficult, it is generally used as and when available. The amount of electricity generated therefore rises considerably when the river is carrying more water during the spring thaw or when precipitation is very high. Most run-of-river power stations are situated in lowland areas, particularly in eastern Norway and Trøndelag. Several run-of-river power stations stand along the Glomma river. Solbergfoss power station at Askim in Akershus county has the largest low-head turbine in Norway.

High-head power stations are generally constructed to utilise a large head but smaller volume of water than run-of-river installations. Many of these types of power stations store water in reservoirs and are referred to as reservoir power stations. The reservoirs allow water to be retained in flood periods and be released in drought periods, typically in winter. Reservoirs allow a larger proportion of the runoff to be used in power production. They usually have a larger installed capacity than run-of-river stations, but a shorter utilisation period. High-head power stations are often built inside the mountain, near the reservoirs used to regulate the volume of its water supply. The power station and reservoirs are connected by tunnels through the rock or by pipes down the mountainside.

Power stations with an installed capacity of up to 10 MW are designated as small, and usually sub-divided into the following categories:

- micro (installed capacity below 0.1 MW)
- mini (installed capacity from 0.1–1 MW)
- small (installed capacity from 1–10 MW)

Small power stations are often installed on streams and small rivers without regulation reservoirs. Their output will then vary with the level of water inflow.

### 2.2.1 Water inflow

Water inflow is the volume of water flowing from the entire catchment area of a river system into the reservoirs. The catchment area is the geographical area that collects the precipitation that runs into a particular river system. Useful inflow is the amount of water that can be used for hydropower generation.

Precipitation levels vary from one part of the country to another, between seasons, and between years. Precipitation is highest in coastal and central parts of western Norway. There is also a clear tendency for precipitation to increase with elevation above sea level. Mean annual precipitation is lowest in the upper Otta valley (300 mm) and in inland parts of Finnmark county (mean annual precipitation 250mm and 300 mm respectively). The mean annual precipitation in large parts of western Norway is 3,000–3,500 mm.

Inflow is high during the spring thaw, but normally decreases during summer. High rainfall in autumn generally results in an increase before the onset of winter, when inflow is normally very low. It also varies during the year, depending on local geographical and climatic conditions. The spring thaw is later in inland regions and in the mountains than near the coast and in lowland areas. In much of lowland eastern Norway, western Norway and Trøndelag, the rivers run highest in May. The highest water levels near the coast occur at the end of April, but are delayed until June or July in inland and upland regions. In northern Norway, discharge volumes reach a peak in June, or somewhat earlier in coastal areas.

Precipitation varies substantially from year to year and is more than twice as high in the wettest years as in the driest ones.

Inflow was relatively high in the period 1996–2000, particulary in 2000 when the high inflow to the power stations led to high electricity generation (see figure 2.4). Inflow in both 2002 and 2003 was slightly below the normal level. However, variations through the year were considerable in 2002, with high inflow in spring, followed by very low inflow in autumn. Taken as a whole, 2004 had normal inflow. An early thaw and a lot of precipitation resulted in a higher than normal inflow in spring, but the summer was relatively dry. Inflow was very high in 2005.

Like 2002, inflow varied greatly through the year in 2006. A relatively dry late summer was followed by an exceptionally wet autumn. 2007 had high inflow, especially during the summer. Inflow was 142 TWh, i.e. 22 TWh higher than normal.

Variations in actual power generation from year to year over the past decade can be attributed primarily to differences in inflow, as generating capacity increased very little.

In addition to variations in water inflow through the year, consumption fluctuates over the year and is much higher in winter than in summer. In fact, the pattern of demand – and thus the amount that must be generated – is generally the opposite of inflow variations. When inflow is high, consumption is often low – and vice versa. Figure 2.2 shows the relationship between mean output and useful inflow over a year. Consumption can also vary considerably between years because temperature changes affect the amount of electricity needed for heating.

### 2.2.2 Regulation reservoirs

The potential energy of water can be stored in regulation reservoirs constructed either in natural lakes or in artificial basins created by damming a river. Water is collected in the regulation reservoirs when water inflow is high and consumption is low. When inflow is low and consumption is high, stored water can be drawn from the reservoirs and used to generate electricity. Regulation reservoirs are generally situated in sparsely populated areas, and usually at high altitudes in the mountains in order to make the fullest possible use of the head of water. The difference between the highest and lowest permitted water levels in a reservoir is stipulated in a watercourse regulation licence (rules for reservoir drawdown), which takes into account such factors as topography and environmental considerations.

Dry-year or multi-year regulation is made possible by large reservoirs that can store water in wet years for use in years when precipitation is low. Short-term regulation involves a daily or weekly filling and emptying cycle. Storing water in summer for use in winter

## Power and capacity balance

In a power market, there must always be a balance between the power supplied to the power grid (power availability) and the power demand (consumption). Domestic power balance is defined as the relationship between annual production and total annual consumption of power. The power balance is often evaluated on the basis of the ratio between consumption and normal-year production (production in a year with normal precipitation).

Where inflow to domestic hydropower plants is high, domestic production is often greater than consumption. The situation will be the reverse in years with low inflow. Cross border transmission capacity makes consumption less affected by fluctuations in domestic production.

The capacity balance represents the ratio between availability and utilisation of power at a specific point in time. Developments in the power balance and the capacity balance are interlinked. A gradual tightening of the power balance due to little new production capacity increases the risk of a short-term power shortage. The highest peak demand in several years was set on the morning of 5 February 2001. The consumption maximum was 23,054 MW between 9 and 10 am.

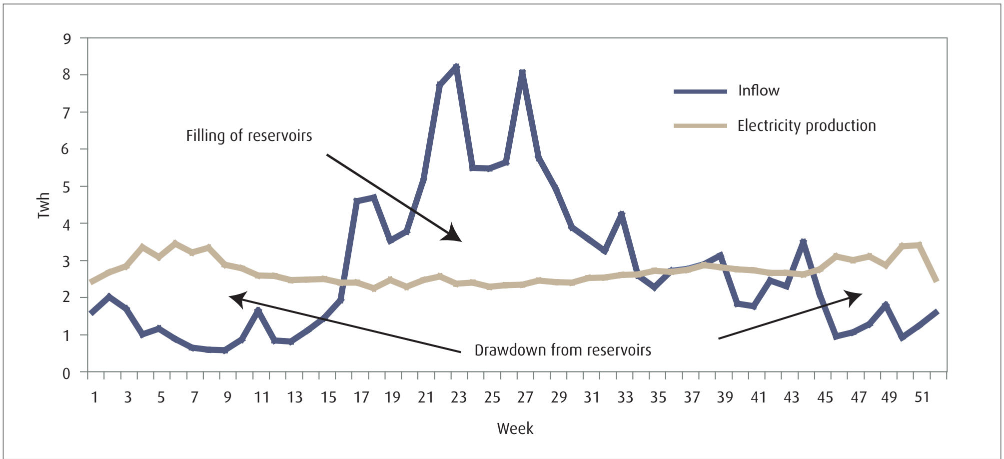



**Figure 2.2 Variations in water inflow and electricity output in 2007.**
*Source: Nord Pool*

months, when the demand for power peaks, is known as seasonal regulation.

A reservoir's energy capacity is the amount of power that can be generated when the reservoir is full. An upper and lower regulation limit is usually set for reservoirs. Since 1980, the energy capacity of Norway's reservoirs has risen by just over 29 TWh. At the start of 2008, total energy capacity was about 84.3 TWh, which is equivalent to around two thirds of the annual electricity consumption. The degree of filling of the reservoirs is a measure of how much water (potential energy) they contain at any given time. Figure 2.3 shows changes in the degree of filling during 2007, and the minimum, median and maximum degree of filling in the 1990–2007 period, expressed as a percentage of the total energy capacity of the reservoirs.

Normally, water will be drawn off during the autumn and winter when electricity demand is highest. Demand reaches its lowest level in spring and summer, and the reservoirs refill. Changes in the degree of filling of the reservoirs reflect variations in electricity generation and water inflow through the year.

It can be profitable to pump water uphill to a reservoir with a greater head of water, because the potential energy of water increases in proportion to its head. If electricity prices are low, it may be profitable for operators to use power to move water to a reservoir at a higher altitude, so that the water can be used for generation when prices rise again.

### 2.2.3 Hydropower output

Power output was generally above average in the second half of the 1980s and the beginning of the 1990s because inflow was high. It was below the mean level in both 1996 and 1997. In the period 1998–2001, hydropower output was generally relatively high. Precipitation was above normal for several years in a row, with hydropower output high as a result. A new production record was set in 2000 at 143 TWh. Production in 2007 was almost 137 TWh. Figure 2.4 shows trends in mean annual generating capacity and actual hydropower output in Norway from 1980 to 2007. On 1 January 2008, Norway had a total instal-

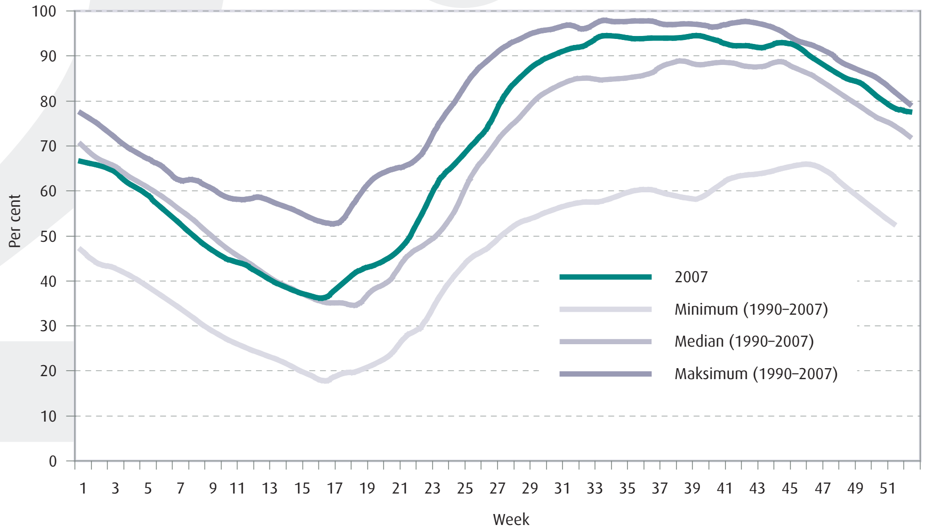



**Figure 2.3 Reservoir filling 2007.**
*Source: Norwegian Water Resources and Energy Directorate (NVE)*

led capacity of 29,030 MW at 699 hydropower stations larger than 1 MW. The mean generating capacity of hydropower stations is calculated on the basis of installed capacity and expected annual inflow in a year of normal precipitation (see box). Thirty years is the standard period used to calculate normal values for meteorological and hydrological variables. At the start of 2008, generation in a normal year from the Norwegian hydropower system was calculated to be about 121.8 TWh.

The ten largest power stations in Norway account for about a quarter of the country's generating capacity. Statkraft SF is Norway's largest power producer providing around 30 per cent of total production capacity. Table 2.2 lists the 10 largest power stations in Norway at 1 January 2008.

Kvilldal hydropower station in Rogaland county is Norway's largest, with a maximum generating capacity of 1,240 MW. This corresponds to almost 4 per cent of Norway's total hydropower generating capacity. Table 2.3 shows the numbers and installed capacity of hydroelectric power stations in various size groups at 1 January 2008.

### 2.2.4 Hydropower potential

Norway's hydropower potential is the amount of energy in its river systems that is technically and financially available to generate electricity, and was calculated to be 205 TWh per year at 1 January 2008. These calculations are based on the 1970–1999 inflow period.

Around 45.5 TWh per year of the total hydropower potential is located in protected watercourses, see figure 2.5. This potential is therefore not available for development. This means there is currently a remaining potential of around 37.7 TWh per year that is not protected against development of power stations. Developed mean annual generating capacity is 121.8 TWh. In addition, projects

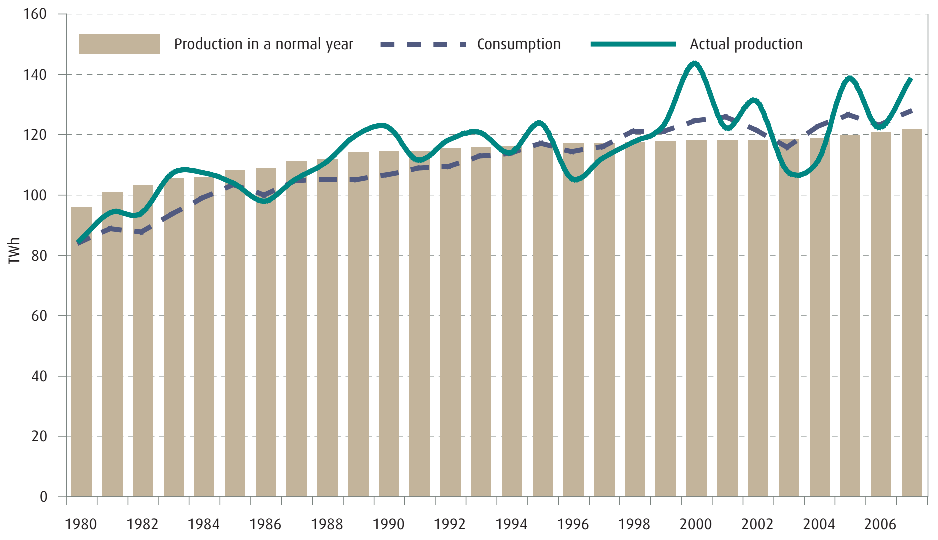



**Figure 2.4 Hydropower output, total electricity consumption and mean annual generating capacity for hydropower stations 1980–2007.**
*Source: Norwegian Water Resources and Energy Directorate (NVE)*

with a capacity of 1.3 TWh is under construction, and the development of a further 1 TWh is licensed.

In 2007 licences were issued for 57 small hydropower stations with a total production of roughly 640 GWh per year. In addition,

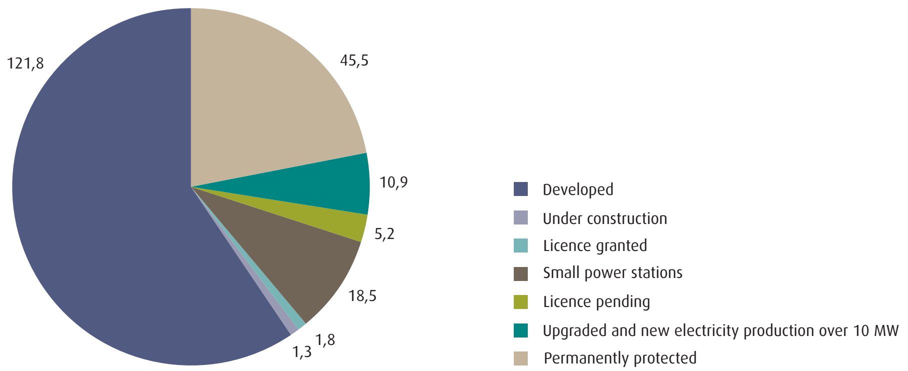



**Figure 2.5 Norway's hydropower potential on 1 January 2008. TWh/year.**
*Source: Norwegian Water Resources and Energy Directorate (NVE)*

**Table 2-2 The 10 largest power stations in Norway at 1 January 2008.**
*Source: Norwegian Water Resources and Energy Directorate (NVE)*

| Power station | Power type | County | Max capacity MW | Mean annual production GWh/year |
|---|---|---|---|---|
| Kvilldal | Hydropower | Rogaland | 1 240 | 3 517 |
| Tonstad | Hydropower | Vest-Agder | 960 | 4 169 |
| Aurland I | Hydropower | Sogn og Fjordane | 675 | 2 407 |
| Saurdalm * | Hydropower | Rogaland | 640 | 1 291 |
| Sy-Sima | Hydropower | Hordaland | 620 | 2 075 |
| Rana | Hydropower | Nordland | 500 | 2 123 |
| Lang-Sima | Hydropower | Hordaland | 500 | 1 329 |
| Tokke | Hydropower | Telemark | 430 | 2 221 |
| Kårstø | Thermal power | Hordaland | 420 | 3 400** |
| Tyin | Hydropower | Sogn og Fjordane | 374 | 1 398 |

* Pump-fed power station
** For gas-fired power stations, the figure quoted is maximum production capacity (see the box on page 18)

licences were granted by royal decree for four new hydropower projects, corresponding to an increase in generating capacity of 140 GWh per year. In 2007, the Ministry ruled on 17 appeals, granting a licence in 12 of the cases, corresponding to 150 GWh per year. Five major refurbishment and upgrade projects have also been cleared for construction, representing a total production of 360 GWH per year. In addition, licence

## Installed capacity, mean output and utilisation period for hydropower stations

The maximum power output (MW) of a hydroelectric power station increases in proportion to the product of the head of water and the water volume per unit time, but is limited by the installed machine capacity. The amount of electricity generated (MWh) in a given time period is equal to the product of the average power output and the time. For example, a power station that operates on average at an installed capacity of 1 MW for one year (8,760 hours) will generate 8,760 MWh (8.76 GWh).

Variations in water inflow and electricity consumption imply that a hydropower station does not operate continuously at maximum capacity. The average utilisation period for a power station is defined as the number of hours required to generate electricity equivalent to mean annual output when operating at maximum capacity. Thus, a power station with a mean annual inflow of 200 GWh and an installed capacity of 50 MW has a utilisation period of 4,000 hours. The average utilisation period for most Norwegian power stations is between 3,500 and 5,000 hours.

**Table 2-3 Hydropower stations in operation on 1 January 2008 by size and total installation.**
*Source: Norwegian Water Resources and Energy Directorate (NVE)*

| MW | Quantity | Total output, MW | Mean annual production GWh/year |
|---|---|---|---|
| 0 – 0.1 | 201 | 8 | 41 |
| 0.1 – 1 | 231 | 110 | 490 |
| 1 – 10 | 368 | 1 247 | 5 640 |
| 10 – 100 | 253 | 9 223 | 41 348 |
| 100 – | 78 | 18 440 | 74 345 |

exemption is granted for for 58 mini and micro power stations (approximately 85 GWh per year). Altogether, the energy authorities have approved hydropower projects with a total annual production of approximately 1.2 TWh in 2007.

Most large hydropower projects were classified in the Report to the Storting on a Master Plan for Water Resources. The various categories used in this Master Plan indicate the order in which river systems should be developed, giving first priority to the lowest-cost projects and those with the fewest conflicts of interest. This is discussed in more detail in Section 4.2.1.

Refurbishment of hydropower stations involves modernising them to use more of the potential energy of the water. In addition, operating costs can be reduced and operating reliability improved. The head loss can be reduced by widening water channels and increasing tunnel cross section, for instance. Utilisation rates can also be improved by using more modern turbine and generator technology.

Upgrades are major projects. Examples of upgrades are the transfer of water from other catchment areas, enlarging existing regulation reservoirs or constructing new ones, increasing the head of water or expanding technical installations to increase the available power output. Refurbishment combined with upgrading generally yields a bigger increase in electricity generation and better profitability than refurbishment alone.

Most refurbishment and upgrade projects are classified as category I in the Master Plan for Water Resources. Some fall into category II, while others are not dealt with in the Master Plan or were exempted from it.

Developers themselves take the initiative on new projects, and also bear the economic risk. The latter can be particularly high for hydropower developments because projects are very capital intensive. In addition, the future price of electricity is uncertain, and the costs of developing hydropower projects vary widely.

### 2.2.5 Small hydropower plants

Small hydropower plants include power plants with installed capacity of up to 10 MW and can be subdivided into the following subgroups: micro power stations (installed capacity up to 0.1 MW), mini power stations (installed capacity up to 1 MW) and small power stations (installed capacity up to 10 MW).

Conventional small power stations are not regulated and are therefore only handled in accordance with the Water Resources Act.

Micro and mini power stations can have so little impact that they do not require a licence. The NVE may to issue licences to develop up to 10 MW installed capacity, if the undertaking is only subject to the Water Resources Act. A power station with an installed capacity of up to 10 MW is also exempt from the Master Plan for Water Resources.

In June 2007, the Ministry of Petroleum and Energy issued the Guidelines for Small Hydropower Stations. The guidelines provide recommendations for how the planning authorities (county administrations) can devise regional plans for small hydropower stations. The NVE uses these guidelines when handling licence applications. The purpose of the guidelines is to strengthen the foundation for a coordinated assessment of licence applications for small hydropower stations and to make the process more efficient and predictable for developers, authorities and the general public.

The NVE has mapped all the potential small hydropower resources in Norway. It estimates that the remaining potential on 1 January 2008 is around 18.5 TWh. It is stressed that this is a theoretical potential that does not take into consideration environmental impacts and other factors that reduce development opportunities.

### 2.2.6 Environmental impact of hydropower development

Converting hydropower to electricity is clean energy production. in Norway accounts for virtually all the generated electricity. This has played and will continue to play a very important part in the global effort to reduce emissions of greenhouse gases. However, the development of river systems does entail changes in the local landscape. Examples include direct interventions in the form of land use, the fragmentation of areas of the natural environment and the regulation of lakes. In addition to the actual generating installations, facilities such as access roads, quarries and rock tips are generally needed. Access roads tend to increase traffic and may result in changes in land use.

The interventions can diminish the attractiveness of the landscape. At the same time, several of the older power stations are now regarded as important cultural and industrial history monuments. Mitigating measures by the developer will help reduce or remove the negative impacts of a development project.

Hydropower development and generation can have various impacts on the flora and fauna in and around river systems. Rapid changes in generation of power and in water volumes discharged are typical of hydropower stations. Changes in discharge volume can affect fish stocks and other freshwater organisms.

The environmental disadvantages, both the aesthetic impact on the landscape and the impact on biodiversity, are the main reasons why many watercourses are protected from power development (see Section 4.2.1).

An application for a licence for power development in watercourses must pass through a comprehensive process. This includes a thorough review of the environmental impacts. An application may be refused on environmental grounds. The authorities may also require measures to mitigate the impact of a development project. Examples include requirements to establish a fund for fish stock enhancement or rules on the minimum permitted rate of flow if regulation harms fish and other flora or fauna in and around the watercourse. The legislative framework for hydropower developments is described in more detail in Chapter 4.

A licence to develop a watercourse protected by the protection plan can only be granted

where the protected object is not harmed. Where the watercourse's unspoilt nature is the basis for the protection order, a licence will not normally be granted. In general, only very careful development with limited water withdrawal will be permitted.

### 2.2.7 Norwegian expertise in the hydropower sector

Norway is the sixth largest hydropower generator in the world and the biggest in Europe. The Norwegian hydropower industry is more than a century old. During this period, Norway has developed expertise covering all stages of hydropower development, from planning and design to the delivery and installation of technical equipment. Throughout, there is always a clear focus on finding efficient, environment-friendly solutions. The authorities and power companies have developed expertise in regulating and managing the hydropower resources, and Norway has also become a world leader in operating an efficient power market.

The companies within the supply industry, except contractors (construction), have a total annual turnover of around NOK 8–10 billion.

These companies provide jobs for around 3,500 people.

Norway has already developed a large proportion of its available hydropower potential, and Norwegian industrial and consulting firms have therefore increasingly started looking abroad for assignments. These include consultancy services within planning, design and engineering and the supply of turbines and electro-mechanical products. In addition, demand for Norwegian expertise in system operation and power market development is growing. There is also increasing interest in investing in hydropower in other countries. Examples include SN Power's widespread activity in Latin America and Asia, and Statkraft's increased investments in central and south-eastern Europe.

The International Centre for Hydropower (ICH) was established some 15 years ago, with the objective of sharing Norway's unique expertise in the hydropower sector. ICH is a consortium consisting of power companies, suppliers and the authorities. Activities target all areas within generation of hydropower and electricity supply, including funding and environmental issues. The ICH has its head office at the Norwegian University of Science and Technology (NTNU) in Trondheim, and receives a grant from Norad (the Norwegian Agency for Development Cooperation) for its international seminars where students from all over the world are taught by Norwegian teachers from NTNU, the power industry and the authorities. The ICH regularly organises large international hydropower conferences in Norway, and occasionally holds regional conferences in other parts of the world.

The ICH's central strategic goals include raising the level of competence of the people working in this sector and gathering and sharing technical, financial, social and environmental knowledge.

## 2.3 Wind power

A wind power station comprises one or more wind turbines and the necessary electrical installations. When several turbines are installed, it is often called a wind farm.

The wind turbine consists of a tower, rotor and blades, and a turbine head containing a generator and control system. The turbine blades are driven by the wind in the same way as an aircraft wing in motion provides lift to an aircraft. Energy is transmitted from the turbine via the propeller shaft to a generator inside the turbine head. The generator converts kinetic energy to electrical energy, which is then transmitted to transformers out on the power grid.

A modern wind turbine generates electricity when the wind speed at hub height reaches 4 to 25 metres per second (m/s) – from gentle breeze to storm. At wind speeds exceeding 25 m/s, the blades are slowed down, and at very high wind speeds, the blades lock and the turbine shuts down. The available wind power is proportional to the cube of the wind speed. Energy production therefore depends largely on the wind conditions. Normally, a wind turbine utilises up to 40 per cent of the kinetic energy of the wind that passes across the blades. Wind power is a variable energy source and unlike hydropower, cannot be regulated. Since such facilities have to operate when the wind is blowing, they can only cover a part of the electricity required.

Norway has fairly good wind resources in general, compared with many other countries. However, we also have other climatic conditions, such as snow and ice, which pose challenges for development of wind power. The annual utilisation period for a wind turbine in Norway is expected to exceed 3,000 hours at favourable sites. However, empirical data show that recorded production from Norwegian windmills is slightly lower than this at present. In 2007, average utilisation period was approx. 2,600 hours. In many places, the average annual wind speed over a year period is more than 8 m/s at a height of 10 m above ground. The wind speed will typically be 10–20 per cent higher at the relevant operating height for wind turbines, depending on the local topography. See the box in Section 2.2.3 for a more detailed explanation of utilisation period.

At the end of 2007, there was 385 MW of wind power installed in Norway, distributed across 184 turbines at 18 registered wind power stations. Total production was 899 GWh. In addition, at 1 January 2008, the NVE awarded licences to another 18 projects with a combined installation of approx. 1,400 MW (see table 2.4). In Europe, significant investments are being made in wind power and other renewable energy, to reduce pollution from electricity generation from non-renewable energy sources. The wind power 0industry has experienced significant growth. Global installed power has increased from 2,500 MW in 1992 to over 93,900 MW in 2007, which represents an annual growth of around 30 per cent. More than 50 per cent of this capacity is installed in Europe. Germany is currently the leading wind power nation, with 24 per cent of the total global wind power 0capacity. In second place is the US with 18 per cent, followed by Spain with 16 per cent.

Technology development and industrialisation within wind power production has increased unit performance. There has been a marked increase in the investment costs for wind power in recent years; however, wind mills have also become more efficient. Production costs are estimated to currently be between NOK 0.45 and 0.60/kWh at sites with good wind conditions and where costs linked to the construction of the plant and associated infrastructure are moderate. Today, wind power development is not commercially viable, and therefore continues to require some form of financial support.

Development of wind power plants and associated infrastructure can conflict with other business interests, such as tourism, reindeer husbandry and other interests such as military radar installations. These conflicts are considered in the NVE's licence processing.

Report no. 29 (1998–1999) to the Storting on Norwegian energy policy sets a target of building wind power stations with a generating capacity of 3 TWh by 2010. See also Section 3.4 on Enova SF.

### 2.3.1 Environmental impact of wind power developments

Wind power is a renewable energy source that does not result in the release of pollutants such as greenhouse gases or particles. However, development of wind power and associated infrastructures does lead to land use changes and environmental impacts. The environmental impact primarily relates to visual effects, changes to the landscape, fauna and flora. Wind power plants are often located in an open landscape near the coast, where wind resources are best. This make wind farms exposed and visible in the landscape. A licence to build and operate a wind farm is granted for a period of 25 years. Wind park construction is to a certain extent a reversible intervention in the landscape.

The environmental consequences revealed in an impact assessment report and associated consultative statements will be included in the licence process. Through the licensing

**Table 2-4 Wind power projects licensed by the NVE as at 1 January 2008 but not on line***

*Source: The Norwegian Water Resources and Energy Directorate (NVE)*

| | Power MW | Annual production GWh/year | Licence |
|---|---|---|---|
| ANDMYRAN | 160 | 620 | December 2006 |
| BESSAKERFJELLET, Sør-Trøndelag | 57 | 150 | November 2004 |
| FAKKEN, Troms | 60 | 200 | December 2006 |
| BESSAKERFJELLET, Sør-Trøndelag | 90 | 200 | November 2004 |
| HUNDHAMMERFJELLET-3, Nord-Trøndelag | 51 | 160 | February 2002 |
| HØG-JÆREN, Rogaland | 73 | 260 | September 2004 |
| KARMØY (OFFSHORE), Rogaland | 3 | N.A.** | September 2006 |
| KVALVÅG, Hordaland | 6 | 1 | February 2007 |
| KVITFJELL, Troms | 200 | 660 | February 2002 |
| Vest-Agder | 102 | 280 | December 2006 |
| MIDTFJELLET, Hordaland | 150 | 450 | February 2007 |
| NYGÅRDSFJELLET – STAGE 2, Nordland | 40 | 120 | December 2006 |
| SELBJØRN Hordaland | 40 | 110 | February 2007 |
| SKALLHALSEN, Finnmark | 65 | 190 | October 2004 |
| STOLMEN, Hordaland | 6 | 1 | February 2007 |
| STORE KALSØY, Hordaland | 9 | 1 | February 2007 |
| TYSVÆR, Rogaland | 39 | 110 | December 2006 |
| YTRE VIKNA, Nord-Trøndelag | 249 | 870 | October 2004 |
| **TOTAL** | **1400** | **4383** | |

* This includes licences that have been appealed to the Ministry of Petroleum and Energy (pending and processed).

** Trial operation

process, the intention is to arrive at countermeasures that reduce the negative impacts of wind farm construction. If the environmental impacts are too large, a licence will not be granted.

## 2.4 Gas-fired power

The term 'gas-fired power station' is often used as a general designation for all facilities that use natural gas to generate electricity and/or heat. There are several different types of gas-fired power stations. One in which gas turbines generate all the electricity is known as a simple-cycle gas turbine station. Such facilities can be started up and closed down at short notice, and are therefore suitable for providing power at times of high overall demand. Running costs are relatively high. Plants of this type are currently found on fixed installations in the North Sea.

Electricity generation using gas turbines also produces heat. Combined cycle gas turbine stations (CCGT) and cogeneration (combined heat and power – CHP) stations exploit this heat, making them considerably more efficient than simple-cycle gas turbine stations.

In CCGT stations, steam turbines are used to generate electricity from the waste heat given off by the steam turbines. Used together, these turbines can give a net efficiency for electricity generation of up to 60 per cent.

A cogeneration facility produces both electricity and heat – for space heating, for example. Surplus heat from steam turbines or in gas turbine flue gases is carried to a heat distribution system. A cogeneration plant produces less electricity than a CCGT plant for the same level of gas consumption. However, it converts a larger proportion of the energy content of the gas to usable energy (more than 80 per cent) in the form of both electricity and heat.

Norway generally has a limited potential for using heat from electricity generation. The district heating infrastructure is not as well developed in the large cities in Norway as in other European countries. A high concentration of users is required to make a district heating network or industrial utilisation of the heat profitable. However, cogeneration stations could be relevant for industrial applications in Norway.

Naturkraft's gas-fired power station (CCGT) at Kårstø was completed in autumn 2007. It has an installed capacity of about 420 MW, corresponding to an annual output of about 3.5 TWh.

The energy requirements for the Snøhvit gas liquefaction project are to be met by an integrated gas-fired power station, providing 215 MW of electricity and 167 MW of heat, which was licensed in 2003. An annual output of about 1.5 TWh is planned. The gas-fired power station was completed before the Snøhvit gas liquefaction plant came on stream in 2007 and is specially adapted to the energy requirements of the Snøhvit facility.

In addition, Statnett SF is building two 150 MW gas-fired back-up power stations at Tjeldbergodden and Nyhamna in Møre og Romsdal. These power stations will only be used in the event of severely stressed power situations where there is a risk of rationing. Statnett SF must apply for special permission from the the NVE every time these power stations are to be used.

Small quantities of electricity are generated by gas turbines at petroleum plants along the Norwegian coast. These are dedicated power stations that are not linked to the power grid in Norway and are therefore not part of the power system.

Some sites also produce small amounts of electricity using gas turbines and gas engines. Gas from the Grønmo landfill in Oslo is used to generate electricity, for instance.

Power generation based on fossil fuels results in emission of greenhouse gases. In accordance with the new Greenhouse Gas Emission Trading Act, compulsory quotas apply to gas-fired power stations. A quota will be allocated to Kårstø, which was built before 2008. The Snøhvit energy plant is subject to the rules for oil and gas operations and will be included in the new quota system (see Section 3.3.2).

However, emisssions of greenhouse gases from gas-fired power stations can be reduced by capturing and storing $CO_2$. This is discussed in more detail in Section 3.3.3.

## 2.5 Other forms of electricity generation

Production processes in many industrial companies generate waste heat that can be used to generate electricity. The opportunities for and costs of this vary from company to company, depending on process technologies and location.

A proportion of the heat generated in district heating plants can be used for power production, called co-generation. About 100 GWh was generated in this way in 2006. Total heating production was just under 1.2 TWh in 2006.

## 2.6 Taxes and fees in the power sector

Electricity consumption is subject to a consumption tax. For 2008, the consumption tax levied through the grid rent is NOK 0.105 per kWh; including VAT it comes to NOK 0.1313 per kWh. Consumers in the county of Finnmark and some municipalities in the county of Nord-Troms (Karlsøy, Kvænangen, Kåfjord, Lyngen, Nordreisa, Skjervøy and Storfjord) are exempted from this tax. Consumption tax has risen gradually from NOK 0.1023 per kWh in 2007 and NOK 0.1005 per kWh in 2006. Consumption tax added NOK 6.1 billion to the national treasury in 2006. The electricity tax is structured so that it follows the EU directive on tax on energy products (the Monti directive), in which energy-intensive industries are generally exempted from electricity taxes.

Activities at the state-owned Enova company are financed through an energy fund. The fund receives income from a grid tariff supplement of NOK 0.01 per kWh. Enova's tasks are to promote more efficient energy use, the production of new renewable forms of energy, and environment-friendly use of natural gas (see the description of Enova in Section 3.4).

VAT is charged on electricity at the standard rate of 25 per cent levied on other goods and services subject to this tax. Household customers in the Nordland, Troms and Finnmark counties are exempt from VAT on electricity.

As for other industries, a tax of 28 per cent is levied and paid to the State on profits earned by all power companies. In addition a profitability-independent natural resources tax of NOK 0.013/kWh paid to the municipal authority and the county authority is levied on hydropower producers. Of this, NOK 0.011 is allocated to the municipal authority and NOK 0.002 to the county authority. This ensures that municipal and county authorities have a minimum tax income level. The calculation base for the tax on natural resource extraction is determined for each power station, and is the average of the plant's total output of electricity in the income year and the six preceding years. The natural resource tax does not represent an additional financial burden to the companies, as it can be deducted from income tax and, in the event of a difference, can be carried forward with interest. A basic interest tax of 30 per cent is levied on hydropower producers that achieve profits greater than the calculated tax-free income. The purpose of tax-free income is to protect alternative profits. Along with other taxes, the basic interest tax contributes to a large proportion of the potential basic interest being included as public income. The municipal authorities can also levy a property tax on the production plant. This is calculated primarily on a profitability basis intended to reflect the market value of the property. Pro-

perty tax can also be levied on the distribution system. About NOK 5.3 billion was raised from natural resource and basic interest taxes in 2006.

Licence fees represent compensation for damage caused to districts in which water resources are exploited. They are also an instrument for allowing rural areas to share in the financial return on hydropower development. Within specified maximum and minimum limits, fees are determined by assessment. This evaluation attaches importance to such factors as the degree of environmental disturbance and the profitability of the development. As the licensing authority, the NVE is entitled to adjust the licence fee every five years. Licence fees provided NOK 520 million to the municipal authorities and NOK 126 million the central government in 2007.

Municipal authorities affected by hydropower developments are also entitled to buy a proportion of the power generated. The licensee can be required to sell up to 10 per cent of the electricity generated to the municipalities concerned. If this exceeds general power consumption in the municipalities, the county authority is entitled to buy the surplus. The licensee can also be required to sell up to five per cent of the power generated to the central government, but the latter has not exercised this right so far. The price paid by the power recipient must correspond roughly to generating costs or the full cost of delivery. There are currently two price setting regulations. For licences issued before 1959, the price is negotiated between the licensee and the municipal authority, limited to a maximum price. For licences issued after 1959, the price is set by the Ministry of Petroleum and Energy in accordance with full costs for a representative selection of power stations. The financial significance of the obligatory sale of power is equivalent to the difference between the price for the power in the market and the price for

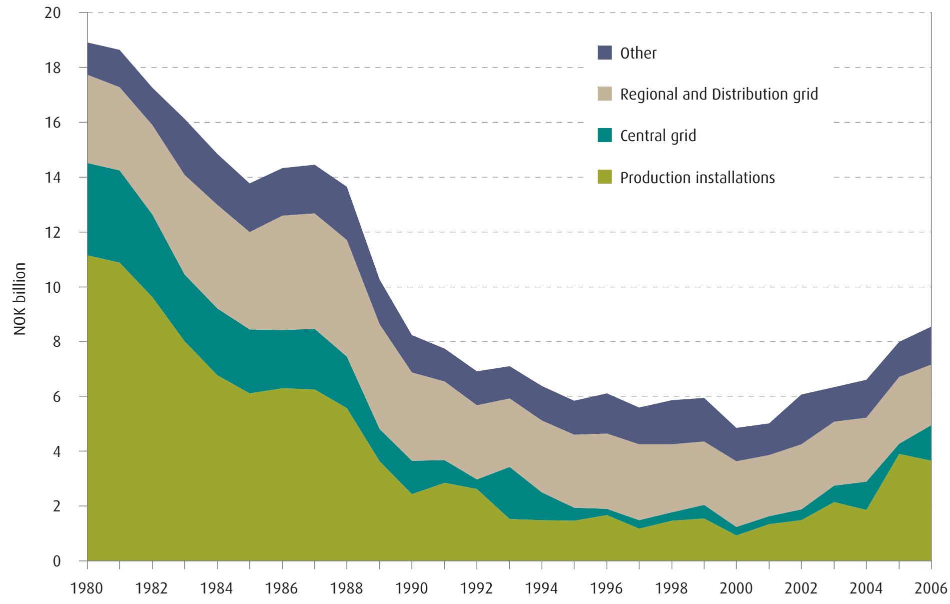



**Figure 2.6 Gross investment in the electricity supply system. Fixed 2006 NOK.**
*Source: Norwegian Water Resources and Energy Directorate (NVE)*

obligatory power including the input tax. Deliveries under these provisions total about 8.5 TWh per year.

## 2.7 The role of the electricity supply sector in the Norwegian economy

The gross product in the electricity supply sector in 2007 was approximately NOK 45.8 billion, or roughly 3.1 per cent of gross domestic product for mainland Norway.

Real capital in the electricity supply system amounted to NOK 238 billion in 2007, corresponding to 5.1 per cent of fixed real capital in mainland Norway.

Investment in the power supply sector totalled about NOK 8.5 billion in 2006. Figure 2.6 shows the development of gross investment in electricity supply since 1980. Net investment in the sector fell towards 2000, but has increased in recent years. Employment in the electricity supply sector rose steadily during the 1980s, and stabilised after 1989. The number of people employed has declined in recent years. About 11,700 people worked in the electricity supply sector in 2007.