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INTERNATIONAL CENTER
ON SMALL HYDROPOWER

World Small Hydropower Development Report 2022

# Northern Europe

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# Northern Europe

## **Countries:** Denmark, Estonia, Finland, Iceland, Ireland, Latvia, Lithuania, Norway, Sweden, United Kingdom

### INTRODUCTION TO THE REGION

The electricity sectors of countries in Northern Europe are highly integrated due to the membership of most countries in the region in the European Union (EU), with the exception of Norway and the United Kingdom, as well as the participation of all countries in the region with the exception of the United Kingdom in the Energy Community, which seeks to harmonize the legal and regulatory frameworks governing the electricity sectors of member countries. Additionally, all countries in Northern Europe are connected to the European Network of Transmission System Operators for Electricity (ENTSO-E), which ensures the synchronous operation of their national electricity grids. Other countries' electricity sector integration with the United Kingdom, previously significant, decreased following the latter's exit from the European Union.

Electricity access in Northern Europe is universal and the electricity sectors of the countries in the region are some of the most diversified in the world with a high degree of integration of renewable energy sources (RES). At the same time, regional countries have adopted different strategies with regard to developing their national energy mixes. Among non-renewable energy sources, gas-fired thermal power plants are the leading source of electricity generation in the United Kingdom, and thermal power forms the mainstay of electricity generation in Estonia and Ireland. The main source of generation in Finland is nuclear power, which also accounts for a significant share of generation in the United Kingdom and Sweden. RES in the region are represented by wind power, hydropower, solar power, geothermal power and bioenergy. Wind power plays a particularly important role in the region. In contrast to many other parts of the world, in Northern Europe wind power outpaces solar power, in terms of both installed capacity and generation, by a significant margin. Wind power is the single-largest source of electricity generation in Denmark and Lithuania, while the United Kingdom leads the region in wind power generation and Sweden in installed wind power capacity. Geothermal power is a major energy source in Iceland, which derives approximately one third of its annual generation from geothermal power.

Hydropower is the leading source of electricity generation in Sweden, Iceland, Latvia and Norway, and plays an important supplementary role in the electricity sectors of other countries in the region with the exception of Denmark and Estonia, where its share of total installed capacity and generation is minor.

An overview of the electricity sectors of countries in the region is provided in Table 1.

Table 1. **Overview of Northern Europe**

| *Country* | *Total population (million people)* | *Electricity access, total (%)* | *Electricity access, rural (%)* | *Total installed capacity (MW)* | *Electricity generation (GWh/year)* | *Hydropower installed capacity (MW)* | *Hydropower generation (GWh/year)* |
|---|---|---|---|---|---|---|---|
| Denmark | 6 | 100 | 100 | 15,489 | 28,273 | 7 | 17 |
| Estonia | 1 | 100 | 100 | 2,506 | 5,957 | 8 | 30 |
| Finland | 6 | 100 | 100 | 17,732 | 66,043 | 3,273 | 12,239 |
| Iceland | 0.4 | 100 | 100 | 2,923 | 19,489 | 2,096 | 13,462 |
| Ireland | 5 | 100 | 100 | 11,021 | 31,977 | 235 | 933 |
| Latvia | 2 | 100 | 100 | 3,100 | 5,720 | 1,586 | 2,598 |
| Lithuania | 3 | 100 | 100 | 3,699 | 11,100 | 128 | 324 |
| Norway | 5 | 100 | 100 | 37,688 | 154,200 | 33,011 | 141,593 |
| Sweden | 10 | 100 | 100 | 43,669 | 165,800 | 16,286 | 70,600 |
| United Kingdom | 67 | 100 | 100 | 75,810 | 311,997 | 4,372 | 8,156 |
| **Total** | - | - | - | **213,637** | - | **61,002** | - |

Source: *WSHPDR 2022*[1]

Note: Data in the table are based on data contained in individual country chapters of the *WSHPDR 2022*; years may vary.

## REGIONAL SMALL HYDROPOWER OVERVIEW

The definition of small hydropower (SHP) universally adopted by the countries in Northern Europe is in line with that used by the EU, which defines SHP as hydropower plants with an installed capacity of up to 10 MW.

A comparison of installed and potential SHP capacities in the region is provided in Table 2.

Table 2. **Small Hydropower Capacities by Country in Northern Europe (MW)**

| *Country* | *Local SHP definition* | *Installed capacity (local def.)* | *Potential capacity (local def.)* | *Installed capacity (<10 MW)* | *Potential capacity (<10 MW)* |
|---|---|---|---|---|---|
| Denmark | Up to 10 MW | 7.0 | 9.8 | 7.0 | 9.8 |
| Estonia | Up to 10 MW | 8.0 | 10.0 | 8.0 | 10.0 |
| Finland | Up to 10 MW | 297.5 | 585.5 | 297.5 | 585.5 |
| Iceland | Up to 10 MW | 66.1 | 3,742.0 | 66.1 | 3,742.0 |
| Ireland | Up to 10 MW | 58.5 | 70.7 | 58.5 | 70.7 |
| Latvia | Up to 10 MW | 28.0 | 96.0 | 28.0 | 96.0 |
| Lithuania | Up to 10 MW | 26.9 | 57.9 | 26.9 | 57.9 |
| Norway | Up to 10 MW | 2,924.0 | 7,162.0 | 2,924.0 | 7,162.0 |
| Sweden | Up to 10 MW | 961.0 | N/A | 961.0 | 961.0* |
| United Kingdom | Up to 10 MW | 405.0 | 1,179.0 | 405.0 | 1,179.0 |
| **Total** | - | - | - | **4,782.0** | **13,873.9** |

Source: *WSHPDR 2022*[1]

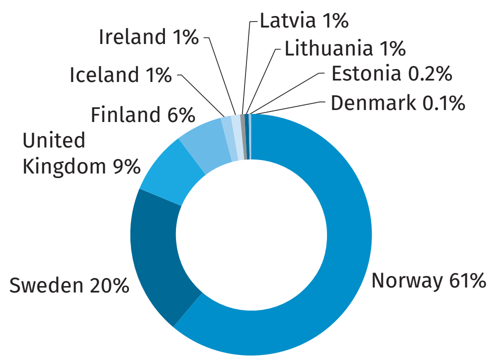
Note: *Based on installed capacity.

The total installed capacity of SHP of up to 10 MW in Northern Europe is 4,782 MW, while the total potential capacity is estimated at 13,873.9 MW. Relative to the *World Small Hydropower Development Report (WSHPDR) 2019*, the installed capacity has increased by nearly 9 per cent, mainly due to a significant expansion of the SHP capacity in Norway. Potential capacity has increased by 28 per cent, mainly due to a newly-available assessment of SHP potential in Iceland.

Apart from Norway, some recent SHP development has taken place in Finland, Ireland, Iceland and the United Kingdom. In other countries in the region, SHP development has stalled due to the saturation of SHP potential as well as fluctuations in river flow and occasional public opposition to SHP development, which have resulted in stricter environmental standards for SHP plants. In Finland, a slow process of decommissioning existing SHP plants has accelerated over the last few years in the wake of policies aimed at preserving fish migration routes through the removal of barriers, and the installed SHP capacity of the country has been declining accordingly. Additional restrictions on water impoundment have been adopted in Latvia and Lithuania. As a consequence, activity in the SHP sector in many countries of the region has been focused primarily on the refurbishment of existing plants. While regional hydropower generation, and SHP in particular, is expected to receive some short-term benefits from increased snowmelt due to climate change, these benefits are likely to be short-term, while long-term climate trends project an increase in the interannual variability of runoff.

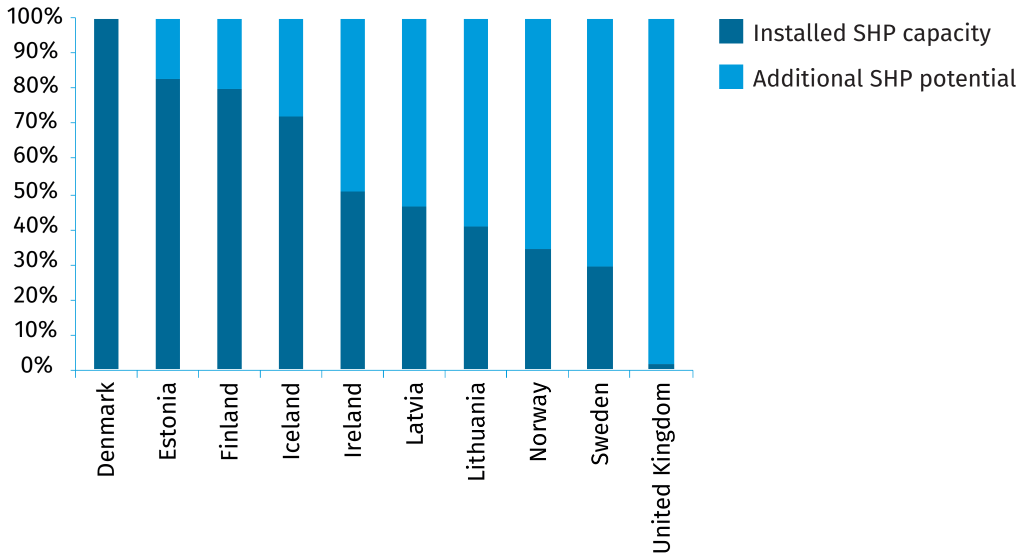
The national share of regional installed SHP capacity of up to 10 MW by country is displayed in Figure 1, while the share of total national SHP potential utilized by countries in the region is displayed in Figure 2.

Figure 1. **Share of Regional Installed Capacity of Small Hydropower up to 10 MW by Country in Northern Europe (%)**




Source: *WSHPDR 2022*[1]

Figure 2. **Utilized Small Hydropower Potential up to 10 MW by Country in Northern Europe (%)**




Source: *WSHPDR 2022*[1]

Note: SHP potential of Sweden is assumed to be fully utilized due to a lack of reliable data on SHP potential.

The installed capacity of SHP of up to 10 MW in **Denmark** is 7 MW, provided by two operational SHP plants. A third SHP plant was undergoing restoration as of 2021. Potential SHP capacity in the country is estimated at 9.75 MW on the basis of the total installed capacity of the three plants. With one plant out of operation, approximately 72 per cent of the total potential capacity is being utilized. Further SHP development in the country is unlikely due to unfavourable topographic conditions.

**Estonia** has approximately 50 operational SHP plants of up to 10 MW with a total installed capacity of 8 MW. Potential SHP capacity in the country is estimated at 10 MW, indicating that 80 per cent has been developed. The potential for further SHP development in Estonia is limited and there are no ongoing projects or specific plans for the construction of additional SHP plants.

**Finland** has an installed capacity of 297.5 MW for SHP of up to 10 MW from approximately 80 plants, while potential capacity is estimated at 585.5 MW, suggesting that 51 per cent has been developed. Some activity has taken place in the SHP sector in the country recently, with one new plant commissioned in 2021. However, overall installed capacity for SHP of up to 10 MW has declined as some plants have been decommissioned and others refurbished to exceed the 10 MW threshold and therefore excluded from the total. Additional new stream development in Finland is unlikely, and much of the remaining unutilized potential capacity comes from existing but non-operational SHP sites.

The installed capacity of SHP of up to 10 MW in **Iceland** is 66.1 MW, while potential capacity has been recently estimated at 3,724 MW, indicating that approximately 2 per cent has been developed. However, the estimate of potential capacity is theoretical, and the technically and economically feasible SHP potential of the country is unknown. SHP construction in Iceland is actively ongoing, with six new SHP plants commissioned between 2018 and 2019, while several additional projects are in the planning stages.

**Ireland** has an installed capacity of 58.5 MW for SHP of up to 10 MW, while potential capacity is estimated at 70.7 MW, indicating that nearly 83 per cent has been developed. There are 66 operational SHP plants in addition to hundreds of identified potential SHP sites in the country. Three new SHP projects were under development as of 2021.

There are 147 SHP plants of up to 10 MW in **Latvia** with a total installed capacity of 28 MW. Potential SHP capacity in the country is estimated at 96 MW, indicating that 29 per cent has been developed. No new SHP development has taken place in Latvia in recent years, in part due to negative formal assessments of their environmental impact and public opposition. On the other hand, a total of 367 old water mill sites have been identified in the country that are suitable for the construction of SHP plants.

The installed capacity of SHP of up to 10 MW in **Lithuania** is 26.9 MW, provided by 97 plants. Potential capacity is estimated at 57.9 MW, indicating that 46 per cent has been developed. There has been no new SHP construction in Lithuania in recent years, and there are no ongoing or planned SHP projects in the country. However, a 2019 change in the country's Water Law has opened 170 rivers and streams that had been previously off limits to SHP development.

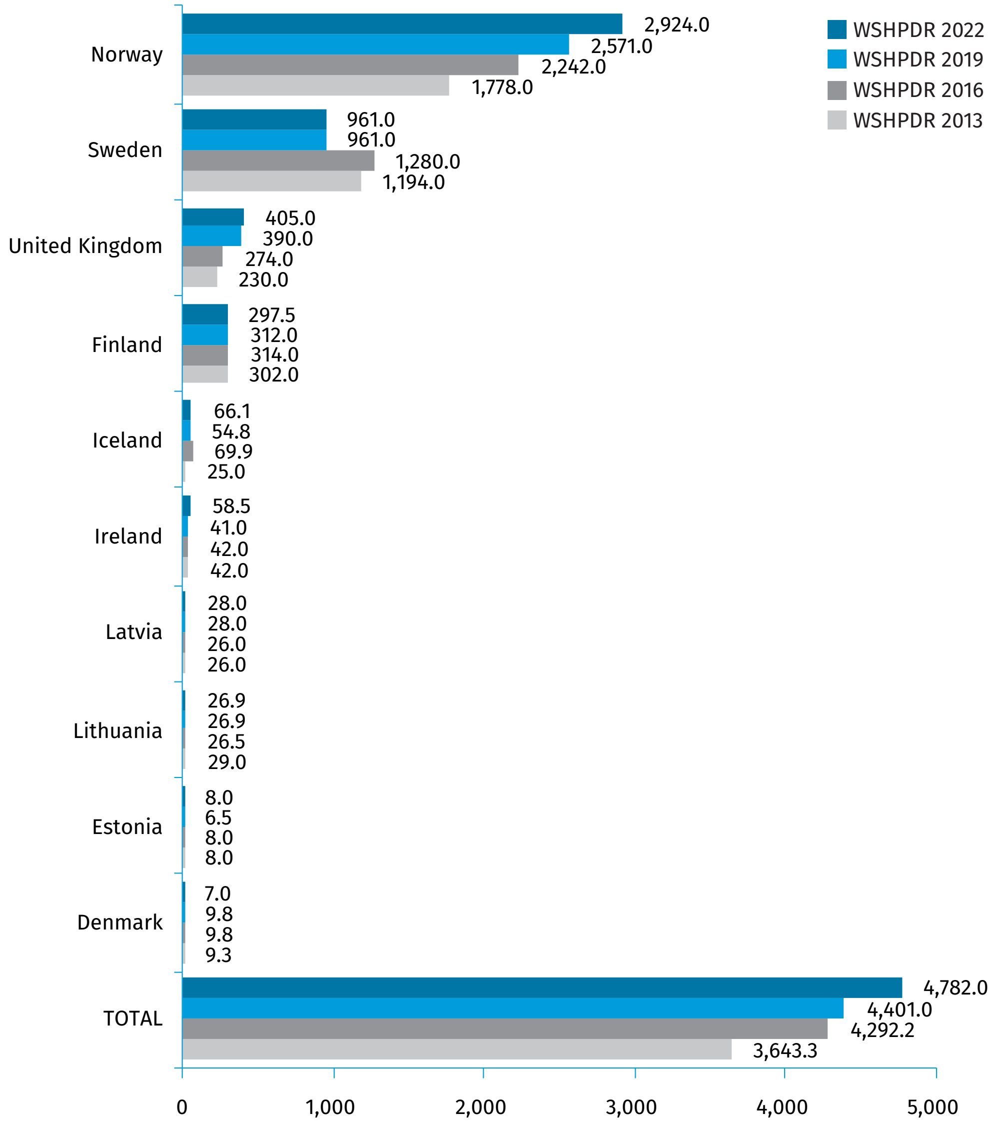
**Norway** has an installed capacity of 2,964 MW for SHP of up to 10 MW, accounting for 61 per cent of the region's total installed SHP capacity. The potential capacity is estimated at 7,162 MW, indicating that 41 per cent has been developed. The SHP sector of Norway has been expanding rapidly and consistently over the last two decades, with 70 per cent of the country's existing SHP plants constructed between 2000 and 2020. As of 2020, there were 64 SHP plants under construction in the country in addition to another 267 licensed projects.

The installed capacity of **Sweden** for SHP of up to 10 MW is 961 MW. No reliable estimates of potential SHP capacity are available and it is assumed to be fully or almost fully developed, although some evidence suggests it may be double that of current installed capacity. The installed capacity of the country has not changed in several years and any further development is expected to focus on the modernization of existing plants.

The **United Kingdom** has an installed capacity of 405 MW for SHP of up to 10 MW, while the potential capacity is estimated at 1,179 MW, indicating that 34 per cent has been developed. The SHP sector in the country is actively growing with 1,216 new SHP plants commissioned between 2010 and 2019, although the pace of new construction has slowed in recent years. Tens of thousands of potential SHP sites have been identified across the country, with the large majority of potential sites as well as existing SHP plants located in Scotland.

Changes in the installed SHP capacities of up to 10 MW of countries in the region compared to the previous editions of the *WSHPDR* are displayed in Figure 3.

Figure 3. **Change in Installed Capacity of Small Hydropower up to 10 MW from *WSHPDR 2013* to *WSHPDR 2022* by Country in Northern Europe (MW)**




Source: *WSHPDR 2022,*[1] *WSHPDR 2013,*[2] *WSHPDR 2016,*[3] *WSHPDR 2019*[4]

## Climate Change and Small Hydropower

An increase in winter runoff as a result of earlier snowmelt has already been observed in Norway and Finland, and additional increases are expected in the future. The increase of inflow to rivers has been beneficial for hydropower production in these countries. However, the interannual variability of inflow is also expected to increase, with the difference between the driest and wettest winters potentially doubling by 2090. In the Baltic countries, precipitation has been decreasing, although the impact on hydropower has varied. Some negative impacts of increased variability in river flow on SHP production in Latvia and Lithuania have included water impoundment being banned during low-flow periods, as well as SHP operations being suspended entirely in certain cases.

# BARRIERS AND ENABLERS FOR SMALL HYDROPOWER DEVELOPMENT

The main barrier to further SHP development in **Denmark** is the country's flat topography. Taking existing operational and non-operational SHP plants into account, all identified feasible SHP potential in the country is fully developed. Further activity in the SHP sector of the country is likely to be limited to repairs and refurbishment of existing plants.

The potential for additional development of SHP in **Estonia** is limited due to the country's flat topography and strict environmental requirements for new plants. However, some potential exists in the form of abandoned water mills, some of which could be refurbished and converted into SHP plants.

Barriers to SHP development in **Finland** include strict environmental and other regulations, limited profitability and declining snowmelt, which could reduce river flow. However, the latter issue may be offset by projected increases in precipitation. There are a large number of potential SHP sites available for development in the country, many of which are formerly operational plants in need of rehabilitation or comprehensive reconstruction.

Additional SHP development in **Iceland** is complicated by a degree of public resistance to hydropower development in general. Although the country's estimated theoretical SHP potential is enormous, it remains unclear how much of this potential is technically and economically feasible. Enablers for SHP development include rising demand for electricity, a comprehensive framework for hydropower development coupled with specific government initiatives in support of SHP development and projections of increased precipitation as a result of climate change that may benefit hydropower.

One important barrier to the development of SHP in **Ireland** is the lack of recent data on SHP potential, with estimates based on potential sites identified several decades ago, which could have already been developed or no longer feasible for development due to reduced flow or other factors. Some more recent assessments suggest that few undeveloped economically feasible SHP sites remain in the country. Additional barriers include strict environmental regulations, high start-up costs and opposition to SHP from fishing communities. Support for SHP in the form of RES auctions is available, although SHP projects have historically been outcompeted at such auctions by wind and solar power projects. Considerable potential remains in the country for the development of micro-scale hydropower.

Barriers to SHP development in **Latvia** include a negative perception of SHP by both the public and authorities, both due to environmental impacts and the perceived excessive cost to the public of feed-in tariffs (FITs) applied to SHP. Licensing procedures are lengthy and complicated and SHP development in many areas in the country is prohibited entirely. Enablers include the FITs and other incentives, which remain in place despite opposition, and considerable untapped SHP potential, with hundreds of identified sites.

Following a cancellation of existing FITs, there are no incentives for SHP development in **Lithuania**. This has extended the payback period of SHP projects and made investments in the SHP sector less attractive. Additionally, extensive environmental restrictions are in place on SHP construction in protected areas. The major enabler for SHP development in Lithuania is the partial lifting of these restrictions on certain watercourses following amendments to the country's Water Law.

Some challenges faced by the SHP sector in **Norway** include difficulties with grid connections in parts of the country as well as increasing competition from wind power. Nonetheless, the overall atmosphere for SHP development in the country is positive due to favourable market conditions, rising electricity demand and support for RES in the form of electricity certificates, as well as very significant undeveloped potential.

Barriers to SHP development in **Sweden** include a lack of identified undeveloped potential, costly licensing procedures and strict environmental requirements. However, support is available in the form of an electricity certificate scheme shared with Norway and the recognized need for modernizing existing plants.

SHP development in the **United Kingdom** has been hampered by insufficient interest from investors, cessation of FIT support in 2019 and the complicated documentation required for licensing and operation of SHP projects. Enablers for development in the sector include a liberalized electricity market favourable towards small producers, ambitious carbon reduction targets, and very significant remaining undeveloped potential, particularly on old water mills that could be repurposed as SHP plants.

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# Denmark

International Center on Small Hydro Power (ICSHP)



## KEY FACTS

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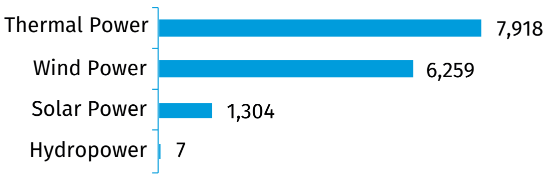
| **Population** | 5,831,404 (2020)[1] |
| **Area** | 43,094 $km^2$[2] |
| **Topography** | Denmark is made up of the Jutland Peninsula connected to the European continent and numerous islands varying in size. It has a predominately low-lying, flat terrain with an average elevation of 30 metres above sea level. The landscape features rocky coastlines, several fjords and the presence of various bogs and marshes. The highest peak in the territory is Yding Skovhøj, an old burial mound reaching 173 metres, while the highest natural peak is Møllehøj at 171 metres.[2] |
| **Climate** | The climate is temperate with Atlantic, Artic and continental influences. While below-freezing temperatures and snowfall commonly occur in the winters, the gulf stream from the Atlantic maintains the average temperature in January and February at 0 °C, which is considerably warmer than average for the same latitude. Summers are mild and cool, with an average temperature of 16 °C in July, the warmest month.[2] |
| **Climate Change** | For a country with low elevation and many islands, an important concern are the rising sea levels, which would cause coastal erosion and floods. In addition, precipitation is expected to increase by up to 40 per cent in the winters, which would intensify the perceivable flooding. As a result of flooding, some bogs, which are naturally efficient at storing carbon, may become too deep, releasing the carbon back into the atmosphere.[3] |
| **Rain Pattern** | The average annual precipitation for the country is approximately 640 mm but varies between regions. The southern Jutland region receives an average of 810 mm per year, whereas the islands in the north receive an average of 405 mm per year.[2] |
| **Hydrology** | Although Denmark is a country rich in water resources, most of the plentiful rivers are small and slow due to the low elevations. The longest river is the 160-kilometre Gudenåen, which begins in the eastern-central Jutland region and flows north-east to empty into the Randers Fjord. There are also several lakes in the territory with a region of large lagoons in the north-west.[2] |

## ELECTRICITY SECTOR OVERVIEW

In 2020, the total installed capacity in Denmark was 15,489 MW. Thermal energy including both renewable and non-renewable (biomass, oil, coal and natural gas) accounted for 7,918 MW, or 51 per cent, which comprised 5,544 MW of large-scale units, 1,788 MW of small-scale units and 586 MW of auto-producers. Wind power has been the fastest growing source of energy since 1990 and accounted for 6,259 MW, or over 40 per cent. The remaining 9 per cent was largely solar power with 1,304 MW and some 7 MW of hydropower (Figure 1).[4]

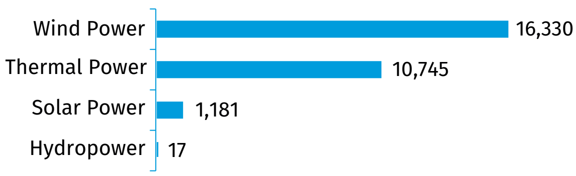
Figure 1. **Installed Electricity Capacity by Source in Denmark in 2020 (MW)**




Source: Danish Energy Agency[4]

In 2020, the total net electricity generation was 28,273 GWh. Wind power generated 16,330 GWh (just under 58 per cent), thermal power including renewable and non-renewable sources generated 10,745 GWh (38 per cent), solar power 1,181 GWh (4 per cent) and hydropower 17 GWh (Figure 2). Denmark both imports and exports electricity, with Norway, Sweden and Germany among the largest trade partners. In 2020, 18,594 GWh of electricity was imported and 11,711 GWh was exported.[4]

Figure 2. **Annual Electricity Generation by Source in Denmark in 2020 (GWh)**




Source: Danish Energy Agency[4]

The electricity access rate is 100 per cent. The electricity system of Denmark is separated into two areas. Western

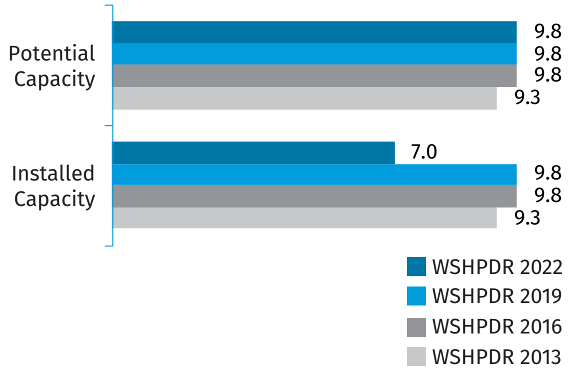
Denmark (DK1) is connected to the electricity system of Continental Europe through Germany and Eastern Denmark (DK2) is connected to the Nordic electricity system through Sweden and Norway. Any company can generate or distribute electricity in Denmark. The Danish Energy Agency acts as the overseeing body, responsible for granting authorizations to plants over 25 MW. The transmission system within the country is fully owned by Energinet. Transmission lines connect to Germany, Norway, Sweden and the Netherlands and are managed jointly by Energinet and the respective country's transmission company. Similar lines are planned to connect Denmark to the United Kingdom in the next few years.[5]

The electricity market of Denmark is integrated with Sweden and Norway though the Nord Pool power market, which coordinates trade in electricity as well as the spot and future markets between 20 countries. Prices in Norway and Sweden tend to be strongly influenced by rainfall due to the heavy reliance of these two countries on generation from hydropower. Final electricity prices for households are composed of approximately 39 per cent electricity prices, 41 per cent electricity taxes and 20 per cent value added taxes (VAT). In 2020, the electricity price for households was 2.11 DKK/kWh (0.30 USD/kWh).[4]

## SMALL HYDROPOWER SECTOR OVERVIEW

The definition of small hydropower (SHP) in Denmark is up to 10 MW. In 2020, installed capacity of SHP was 7 MW that generated 16.7 GWh.[4] There have been three main hydropower plants in operation in Denmark: Tangeværket, Holstebro and Karlsgårdeværket, however, the Karlsgårdeværket plant was out of operation for restoration as of 2021.[6,7] The Tangeværket plant, built in 1921, is the largest with 3 MW installed.[8] Due to low elevations and slow flowing rivers, total potential in the country is 9.75 MW.[9] Given the flat nature of the country's terrain, further SHP development is unlikely. Compared to the *World Small Hydropower Development Report (WSHPDR) 2019*, potential capacity remains unchanged and total installed capacity has decreased due to access to new data (Figure 3).

Figure 3. **Small Hydropower Capacities in the WSHPDR 2013/2016/2019/2022 in Denmark (MW)**




Sources: Danish Energy Agency,[4] *WSHPDR 2019*,[9] *WSHPDR 2016*,[10] *WSHPDR 2013*[11]

## RENEWABLE ENERGY POLICY

Denmark has expressed commitments to expanding renewable energy for several decades. It was one of the very first countries to invest in wind power technology in the 1970s with government subsidies and subsequently introduced feed-in tariffs (FITs) and preferential prices shortly after. In the 1980s, the first renewable targets were set to have 1,000 MW of wind power by 2000, and once reached in 1999, the target was increased to 5,500 MW by 2030 which has already been reached.[12] Targets set in the 2012 Energy Policy included sourcing 70 per cent of electricity and 35 per cent final energy consumption from renewable energy by 2020, and 100 per cent renewable energy in final consumption by 2050.[13] The 2020 final energy consumption target has been reached with over 40 per cent in 2020, but the target for the electricity sector has fallen short.[4]

The Promotion of Renewable Energy Act passed in 2008 provides legal framework for the development of renewable energy, including SHP. It also provides a basis for FITs, which vary according to when the plant was connected to the grid and for how many years thereafter.[14]

## BARRIERS AND ENABLERS FOR SMALL HYDROPOWER DEVELOPMENT

The situation for SHP in Denmark has remained unchanged, for these main reasons:

- Potential capacity is small and has been almost fully developed;
- Residual flow requirements are judged individually for each project;
- Natural barriers and the flat nature of the country.[9]

Due to the lack of potential, there are no enabling factors to develop further traditional SHP. For further SHP development, unconventional technologies, such as in-conduit projects, could be considered.

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# Estonia

International Center on Small Hydropower (ICSHP)

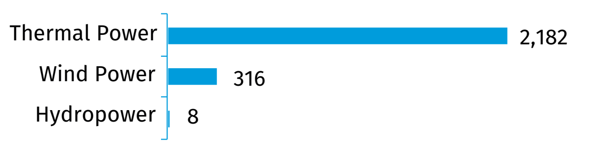
## KEY FACTS

| | |
|---|---|
| **Population** | 1,329,479 (2020)[1] |
| **Area** | 45,227 km$^2$ [2] |
| **Topography** | Estonia has a predominately flat terrain alternating between uplands and lowlands. The average elevation in the country is approximately 50 metres with only less than 10 per cent of the country reaching elevations above 90 metres. The western region of the mainland and islands off the west coast are mostly lowland plains, with some swampy plateau areas. The major upland areas include the Pandivere Uplands in the north-east, the Otepää Uplands in the central south-east region and the Haanja Uplands in the extreme south-east. The highest point in the country is Suur Munamägi Hill at 317 metres, situated in the Haanja Upland.[2,3] |
| **Climate** | Estonia has a humid, temperate climate in the transition zone between maritime and continental climates. The northern and western coastal areas typically have a milder, maritime climate than the southern interior's continental climate. The country experiences all four seasons of nearly equal length. Average temperatures in July vary between 16 °C and 17.4 °C, in which the warmer temperatures are at the coasts. The winters are also slightly warmer near the coasts, with average temperatures between –2 °C and –4 °C. Winters in the eastern uplands are colder with average temperatures closer to –7 °C.[2,3] |
| **Climate Change** | A major concern regarding climate change in Estonia is the rise in sea levels. Due to the country's extensive low-lying coastline, a sea level rise could cause severe flooding by the end of the century. Average temperatures have risen by more than 1 °C in the past century and are expected to continue warming, especially during the winter months. There has been a significant decrease in annual snow coverage, with an average of almost 26 less days of coverage per year than before the 1960s.[4] |
| **Rain Pattern** | The rate of precipitation in Estonia is much higher than that of evaporation, causing the country to have a very damp climate. Average rainfall varies between regions and seasons. February and March are the driest months throughout the country and July and August are the wettest. Annual rainfall is approximately 520 mm on the islands and coastal regions and 740 mm in the eastern uplands, with some parts experiencing over 1,000 mm. The average duration of snow coverage per year is approximately 109 days.[4] |
| **Hydrology** | Estonia has an extensive network of rivers and streams, though the large majority of them are small springs that seasonally dry up. The major drainage basins are the Gulf of Finland, the Gulf of Riga, Lake Peipsi and the western islands. The country's longest river is Pärnu at 145 kilometres flowing south-west from the Pandivere Uplands. The largest river by discharge is the Narva flowing northwards from Lake Peipsi. Other important rivers include the Emajõgi, Riisa, Kasari and Pirita. Some of these rivers have great seasonal variation in flow with large areas of flooding during spring. There are approximately 1,200 natural lakes, which combined cover almost 5 per cent of the country's territory. The majority of the lakes are located in the south-western upland region and the largest is Lake Peipsi with an area of 3,550 km$^2$ located along the western border with Russia.[2,3] |

## ELECTRICITY SECTOR OVERVIEW

In 2020, the total installed capacity in Estonia was 2,506 MW. The large majority was with thermal power, which includes both non-renewable and renewable sources, with 2,182 MW (87 per cent). The remaining 13 per cent was with 316 MW of wind power and 8 MW of hydropower (Figure 1).[5] There is also some solar power installed in the country, but an official value of total capacity is unavailable.[6] Thermal power capacity has been steadily decreasing since its peak of 2,807 MW in 2012, while wind power has been steadily increasing, but at a slower rate, during the same years.[5]

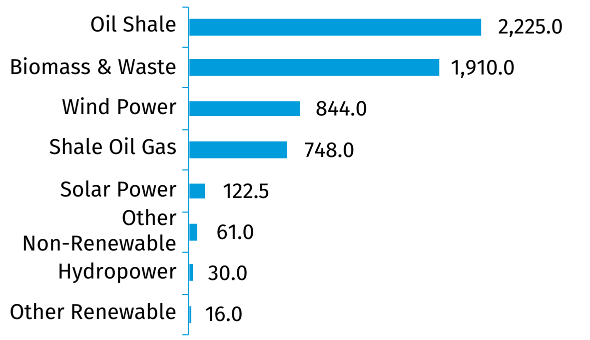
Figure 1. **Installed Electricity Capacity by Source in Estonia in 2020 (MW)**




Source: Statistics Estonia[5]

In 2020, total electricity generation was 5,956.5 GWh (Figure 2). Oil shale generated 2,225 GWh (37 per cent), biomass and waste 1,910 GWh (32 per cent), wind power 844 GWh (14 per cent), shale oil gas 748 GWh (13 per cent), solar power 122.5 GWh (2 per cent), hydropower 30 GWh (0.5 per cent), other renewable energy 16 GWh (0.03 per cent) and the remaining 2 per cent comprised other non-renewable energy which generated 61 GWh.[5] Estonia was net importer of electricity in 2020, having imported 7,367 GWh and exported 3,723 GWh. In the last few years, total electricity generation has been declining because of a sharp decrease in oil shale generation after 2018. The share of renewable energy in final energy consumption has been steadily increasing and was just over 30 per cent in 2020.[7]

Figure 2. **Annual Electricity Generation by Source in Estonia in 2020 (GWh)**




Source: Statistics Estonia[5]

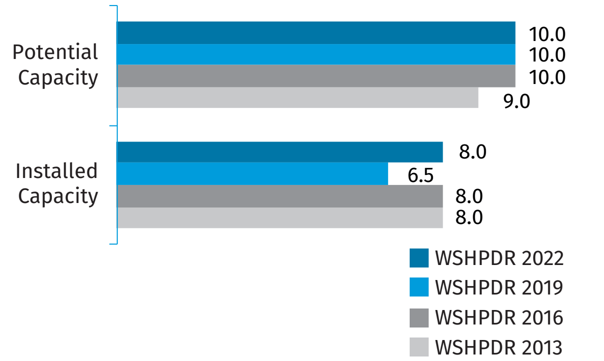
The electrification rate in Estonia is 100 per cent. The electricity sector has been liberalized since 2013, meaning that customers can choose their suppliers. While there are several privately-owned companies in the country, the supplier with the single largest market share continues to be the state-owned company, Eesti Energia AS.[8] Likewise, distribution is also liberalized but Elektrilevi, a subsidiary of Eesti Energia AS, holds approximately 95 per cent of the market share, recently acquiring the second largest distribution company in 2021.[9] Electricity transmission is fully operated by Elering. The transmission system has international interconnections with Finland and Latvia and is part of a synchronous area that also includes Lithuania. There is also transmission line infrastructure that remains in place between Estonia and Russia, but no trade of electricity has taken place between the two countries since 2005.[8,10]

In 2013, Estonia joined the Nord Pool market system, which determines the base price of electricity on the spot market. The Estonian Competition Authority approves the consumer prices in the country.[8] At the end of 2021, the electricity tariffs for industrial consumers ranged between 0.13 EUR/kWh (0.14 USD/kWh) and 0.19 EUR/kWh (0.20 USD/kWh), depending on usage, and tariffs for domestic consumers ranged between 0.16 EUR/kWh (0.17 USD/kWh) and 0.18 EUR/kWh (0.19 USD/kWh), depending on usage.[5]

## SMALL HYDROPOWER SECTOR OVERVIEW

The definition of small hydropower (SHP) in Estonia is up to 10 MW. The installed capacity of SHP in Estonia in 2020 was 8 MW that generated a total of 30 GWh.[5] The total estimated potential capacity is approximately 10 MW, indicating that 80 per cent has been developed.[11] There are approximately 50, mostly privately owned, SHP plants, ranging from 4 kW to 1.2 MW, connected to the national grid.[12] Compared to the *World Small Hydropower Development Report (WSHPDR) 2019,* installed capacity has regained its prior level to 8 MW and the estimated potential has remained the same (Figure 3). The reason for the increase in installed capacity is not known.

Figure 3. **Small Hydropower Capacities in the WSHPDR 2013/2016/2019/2022 in Estonia (MW)**




Sources: Statistics Estonia,[5] *WSHPDR 2019,*[11] *WSHPDR 2016,*[13] *WSHPDR 2013*[14]

Estonia has a long history of hydropower, beginning with centuries-old water mills that were transformed into hydropower plants during the 19th and early 20th centuries. By 1940, there were over 900 sites in operation, ranging from simple waterwheels to modern turbines, with a combined capacity of 9.3 MW. However, almost all of these were destroyed during World War II and the rest were closed while the country was part of the Soviet Union. Starting from zero plants in 1990, hydropower capacity was steadily built back up until 2010 when it reached its current level of approximately 50 plants.[15]

There is 30 MW of overall theoretical hydropower potential in Estonia.[11] Due to the flat terrain and slow rivers, overall potential of hydropower in Estonia is low and hydropower is not considered an important renewable energy resource to develop much further. Nonetheless, there is a considerable number of old water mill sites that could potentially be modernized and incorporated into the grid, as long as they are not located in a protected river and would comply with new environmental standards. A number of standards that aim to protect fish migration and the natural ecosystems of waterways have been enforced in recent years. This includes 125 rivers throughout the country that have been legally protected against any dam construction within them. The Narva River, the country's largest by discharge, does not appear on the list of protected rivers, which opens up the possibility for large hydropower to be developed, however, with strict regulations on dam construction and the lack of importance put on hydropower in general, development of such potential is unlikely.[15]

## RENEWABLE ENERGY POLICY

As a member of the European Union, Estonia has prioritized increasing the share of renewable energy in both production and consumption in order to reduce environmental pollution and cut greenhouse gas emissions. In compliance with the European Union Renewable Energy Directive (2009/28/EC), the Government of Estonia published its National Renewable Energy Action Plan in 2010. This plan set targets such as for 1,913 GWh of electricity to be generated with renewable energy sources as well as 30 per cent of final consumption by 2020.[16] Both targets were reached, although by different means than those of the original plan, which expected wind power to have a much higher importance in the energy mix and for biomass to be slightly lower. The National Energy and Climate Plan for 2030, with the final version published in 2019, provided a set of goals for the following decade. By 2030, the country intends for 4,300 GWh of electricity to be generated by renewable energy along with 42 per cent of final energy consumption. According to this plan, hydropower generation and installed capacity are expected to remain at their current levels of 30 GWh and 8 MW, respectively, to 2030, and the overall increase is planned to come mostly from wind power, but also some solar power and biomass.[17]

In Estonia, energy production from renewable energy sources has been mainly promoted through subsidies and more recently, reverse auctions. As stated in 2009 amendments to the Electricity Market Act, the national transmission company is to provide subsidies to renewable energy producers under 100 MW. This includes electricity generated from any type of renewable source as well as cogeneration of heat and power (CHP) using biomass.[18] The financing costs of the subsidy is passed on to consumers in the form of a renewable energy charge relative to consumption. Elering announces the costs each year, and for 2021 it was 0.0136 EUR/kWh (0.014 USD/kWh).[19] As of 2019, these subsidies had begun phasing out to be replaced by reverse auctions. The first reverse auction took place in 2019 and will take place annually.[20]

## BARRIERS AND ENABLERS FOR SMALL HYDROPOWER DEVELOPMENT

The key barriers to SHP development in Estonia include:

- Low overall potential due to flat terrain;
- Residual flow values are fixed in the water use licensing procedure and are set on the 95 per cent fraction of the flow duration curve;
- Fish pathways are often requested, making projects more expensive.

The key enabler for SHP development in Estonia is:

- Numerous old water mill sites could be assessed to be transformed and made operational again.

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# Finland

Kristian Dahl Larsen, Samfunnsbedriftene Energy

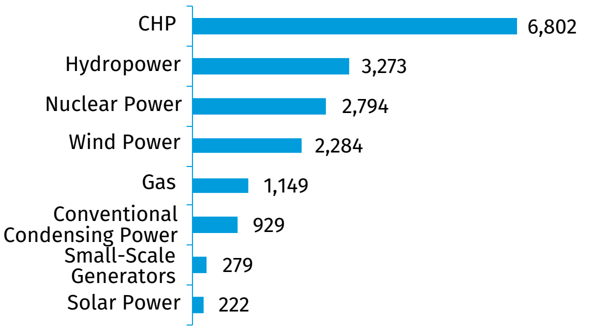
## KEY FACTS

| | |
|---|---|
| **Population** | 5,533,793 (2021)[1] |
| **Area** | 338 462 km$^2$ [2] |
| **Topography** | The topography of Finland is largely flat land with almost 70 per cent of the area covered by forest, while numerous lakes occupy a large part of the remaining area. While the southern regions terrain is dominated by lakes and flatland, low hills and mountains characterize the northern region. The highest mountain, Haltitunturi (1,328 metres) is located in the north-western tip of Finland, on the border with Norway.[3,4] |
| **Climate** | The average annual temperature is approximately 5.5 °C in the south and somewhat lower towards the north. Temperatures differ between seasons and regions. The average difference between the southern and northern regions is greatest in winter, when the difference can reach up to 12 °C. The recorded average high temperature was 31.8 °C, while the low temperature was estimated at 39.9 °C.[5,6] |
| **Climate Change** | The climate is defined by major yearly variation, although the longer climate trend shows more persistent changes. Annual average temperature has increased by over 2 °C since the 1850s and is forecasted to continue to rise. Depending on the level of global greenhouse emissions, climate models predict that average temperature in Finland could increase by between 2.6 °C and 8.5 °C before the end of the century. As a result of the higher annual temperature, precipitation is estimated to increase and intensify further. Estimations of annual precipitation predict an increase of between 6 and 11 per cent by 2050 and of up to 20 per cent by 2100. Extreme rainfall events are estimated to increase significantly, highest runoffs to turn from spring to winter and risk of frazil ice formation to increase in many rivers due to shorter time of ice cover.[7,8,9] |
| **Rain Pattern** | Average annual precipitation ranges from 500 mm to 650 mm. Rain patterns are infrequent and created by swift temperature changes. Summer periods record more regularity in showers and thunderstorms. The precipitation varies between the different regions and seasons. In the southern and central regions, annual precipitation is between 600 mm and 700 mm, while in the northern region and along the coast annual precipitation is lower. The long winter causes approximately half of the annual 500–600 mm of precipitation in the north to fall as snow. The lowest recorded annual precipitation is 200–300 mm and highest annual precipitation recorded is 900–1,100 mm. Spring is categorized as the lowest annual season for precipitation, where March is considered the month with the least precipitation of the season. Precipitation slowly increases following spring and levels out in the summer months of July–August, then decreases gradually towards winter and spring.[5] |
| **Hydrology** | Finland has large water resources in its many lakes and rivers. Inland water covers almost 10 per cent of the country's area. The largest lake, Saimaa, stretches over 4,400 km$^2$. Lake Saimaa forms a lake system that connects over 120 other rivers and lakes. Several hydropower plants are located along the lake system. Many of the rivers flow into the inland lakes. The major rivers in the country are Kemijoki, Tornion-Muonionjoki, Oulujoki, Teno, Vuoksi, Kymijoki and Kokemäenjoki. Kemi is the longest river, stretching almost 550 kilometres.[4,10] |

## ELECTRICITY SECTOR OVERVIEW

The electricity produced in Finland mainly comes from nuclear power, combined heat and power (CHP), hydropower and wind power.[11] In 2019, Finland produced 66,043 GWh domestically.[12] Of the total domestic production, nuclear power accounted for 22,915 GWh, hydropower for 12,239 GWh and wind power for 6,025 GWh. Conventional condensing power accounted for 3,147 GWh, while CHP from industry, district heating and small-scale generation together accounted for 21,576 GWh (Figure 1). Wind and solar power continued to ramp up to become a bigger part of the country's power generation. From 2016 to 2019 electricity generation from solar power increased by more than five times. However, the overall contribution in 2019 was a mere 0.2 per cent of the country's supply.[11] The role of wind power has also developed quickly in Finland. In 2019, electricity generation from wind power almost doubled from 2016.[13] In the same year, wind power made up almost 9 per cent of the total electricity production in Finland, up from less than 5 per cent in 2016. Hydropower generation declined from 2016 levels, but shows some historic variance and previous production on similar levels as in 2019.[11] The share of hydropower will naturally vary due to weather fluctuations and water supply in a given year.[14]

Figure 1. **Annual Electricity Generation by Source in Finland in 2019 (GWh)**

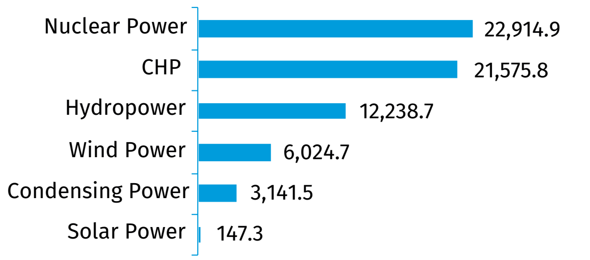



Source: Statistics Finland[11]

Electricity imports also play an important part in the country's supply and amounted to approximately 22,000 GWh in 2020.[12] The majority of electricity imports came from Sweden, while the majority of exports went to Estonia.[15]

In terms of capacity, total installed capacity of Finland amounted to 17,732 MW in 2020. Largest installed capacity was found from CHP (district heating and industry) with 6,802 MW, while hydropower had 3,273 MW of installed capacity, nuclear power 2,794 MW, wind power 2,284 MW and gas-powered plants 1,149 MW (Figure 2).[13]

Figure 2. **Installed Electricity Capacity by Source in Finland in 2020 (MW)**




Source: Statistics Finland[13]

The electricity market in Finland was deregulated and open to competition with the Electricity Market Act in 1995. The act led to changes such as freedom for customers to choose their electricity supplier. Private households can today produce their own electricity and sell it to the market.[16] The electricity market has several players, although Fortum remains the largest by far.[17] Fortum is a publicly traded company, although the majority shareholder with over 50 per cent remains the Finnish state.[18] Additionally, Finland is part of the Nordic wholesale electricity market, where electricity is traded freely across bidding zones in the Nordic and Baltic countries.[19] Finland currently has one bidding zone.[20]

In terms of prices and tariffs Finland is competitive compared to its European peers. In the second half of 2020, household prices constituted EUR 0.177 (USD 0.20) (including taxes) per kWh, which ranked in the middle among the European Union (EU) member states.[12] The same ranking of electricity prices for industry shows a price of EUR 0.094 (USD 0.11) per kWh, which is the second lowest among the EU27.[12] The transmission grid of Finland is also highly competitive in terms of pricing. A recent study found the main grid tariff to be the second cheapest among the EU members, only beaten by Slovenia.[21]

Finland has a well-developed electricity system and has enjoyed an overall 100 per cent electrification rate for the total population since before 1990.[22] In Finland, there is three grid levels: high voltage, medium voltage and low voltage.[23] High-voltage networks (110–400 kV) measure approximately 22,500 kilometres long.[23] The medium-voltage (1–70 kV) networks reach over 150,000 kilometres, while the low-voltage network (up to 1 kV) expands over 250,000 kilometres.[24] To further develop and upgrade the grid, the Finnish transmission system operator (TSO), Fingrid, has plans to invest EUR 1,200 million in the grid between 2015 and 2025.[25] Fingrid has set a target to build 3,000 kilometres of new transmission lines in that period.[25] Furthermore, the Swedish TSO Svenska Kraftnät and Fingrid are planning to develop an 800 MW alternating current connection between the northern regions of the two countries. The connection is to be finished by 2025.[26]

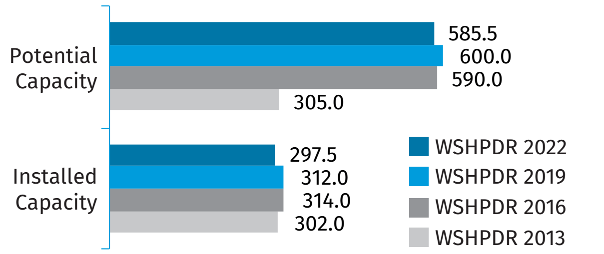
The regulator in Finland, Energiavirasto, is a licensing and supervisory body that monitors the operations and implementation of the electricity markets.[27] In addition, an important role of the regulator is to regulate monopoly situations of the transmission companies.[28] As the licence-providing body, Energiavirasto also maintains a register of power plants exceeding 1 MVA.[17]

The Government of Finland has set in motion plans for developing the electricity sector to decrease import dependencies. For instance, Finland is currently building two new nuclear power plants to replace electricity imports.[26] The Government also introduced feed-in tariff (FIT) subsidy schemes to increase renewable energy. The scheme applied to wind power, biogas, forest chips and wood-based fuels (not hydropower) starting from 2010, but has been discounted since 2021.[29]

## SMALL HYDROPOWER SECTOR OVERVIEW

Finland defines small hydropower (SHP) as plants of up to 10 MW in capacity. The regulator, Energiavirasto, publishes an official registry of the power plants in Finland.[21] According to the data of 2021, the installed capacity of SHP plants in Finland was approximately 297.5 MW from approximately 80 power plants.[21] Approximately 120 MW of small-scale plants was connected to the grid in 2015, which suggests that many SHP plants are decentralized (Table 1).[30] The installed capacity in 2021 was approximately 5 per cent lower than the installed capacity reported in the *World Small Hydropower Development Report (WSHPDR) 2019* (Figure 3). The decrease in capacity could be due to the refurbishment done in the three-year period, which could have brought some power plants above the 10 MW threshold. Another possibility is the discontinuation of operation of some plants. The trend of discontinuation of SHP operation has increased in recent years.[31] State support for the decommissioning of SHP plants is both available and promoted through the national NOUSU programme, which aims to slow down the loss of biodiversity by removing barriers for fish migration.[32] Notably, sentiment towards new hydropower in Europe has decreased in recent years, mostly driven by environmental groups focused on improving and restoring the biodiversity of rivers.[33]

Figure 3. **Small Hydropower Capacities in the WSHPDR 2013/2016/2019/2022 in Finland (MW)**




Source: Energiavirasto,[21] Motiva,[31] *WSHPDR 2013*,[34] *WSHPDR 2016*,[35] *WSHPDR 2019*[36]

According to Motiva, a state-owned sustainable development company, the undeveloped potential of SHP in Finland is estimated to be approximately 288 MW and the total undeveloped potential of all hydropower is estimated to be 663 MW.[31] A significant part of the undeveloped potential is found by the modernization and capacity upgrades of old plants.[37] Combined with the current installed capacity, total potential capacity of SHP can therefore be estimated to be close to 585.5 MW. It is worth noting that the undeveloped potential does not take into account protected waters or border rivers.[30] Furthermore, the Finnish authorities report that no new SHP initiatives are planned in the near future, seeing as the majority of undeveloped potential is not from new sites but rather from repowering of existing sites.

Table 1. **List of Selected Operational Small Hydropower Plants in Finland**

| *Name* | *Location* | *Capacity (MW)* | *Operator* | *Launch year* |
|---|---|---|---|---|
| Maavesi | Joroinen, Katajamäentie 1461, Maavesi | 2.0 | Savon Voima Oyj | 2021 |
| Korkeakoski | Korkeakosken voimalaitos Kotka | 10.0 | Kolsin Vesivoimantuotanto Oy | 2016 |
| Myllykosken vesivoimalaitos 1 | Myllykosken vesivoimalaitos 1 | 6.9 | Pato Osakeyhtiö | 2012 |
| Koivukoski | Koivukosken voimalaitos Kotka | 1.8 | Kolsin Vesivoimantuotanto Oy | 2001 |
| Liunankoski | Joroinen, Liunantie 79 | 1.2 | Savon Voima Oyj | 1995 |
| Juankoski | Juankoski, Juankoskentie 7A | 5.5 | Savon Voima Oyj | 1995 |
| Vääräkoski | Tohmajärvi, Vääräkoski | 1.8 | Pohjois-Karjalan Sähkö Oy | 1992 |
| Tammerkoski | Tammerkoski | 8.6 | Tampereen Sähkölaitos | 1992 |
| Kuokkastenkoski | Nurmes, Kuokkastenkoski | 2.0 | Pohjois-Karjalan Sähkö Oy | 1990 |
| Sälevä | Lapinlahti, Itäkoskentie 53, Paloinen | 3.0 | Savon Voima Oyj | 1988 |
| Sallila | Sallila (Vampulan kunnassa) | 1.2 | Sallila Energia Oy | 1986 |
| Långfors | Långfors | 1.2 | Oy HERRFORS Ab | 1985 |
| Saario | Tohmajärvi, Saario | 1.6 | Pohjois-Karjalan Sähkö Oy | 1984 |
| Hamari | Hamari, Ylivieska | 2.5 | Korpelan Voima kuntayhtymä | 1984 |
| Stadsforsens Kraftverk | Stadsforsens Kraftverk | 4.6 | Nykarleby Kraftverk | 1984 |
| Klåsarö | Klåsarö | 4.5 | Oy Mankala Ab | 1983 |
| Kiltua | Sonkajärvi, Kiltuantie 1129 A, Jyrkkä | 5.6 | Savon Voima Oyj | 1982 |

Source: Energiavirasto[21]

## RENEWABLE ENERGY POLICY

The National Energy and Climate Plan (NECP) outlines the country's climate and energy goals in the future and supports the overall targets of the EU. According to the NECP, the Government aims to reduce emissions in non-ETS (Emissions Trading System) by 39 per cent by 2030.[26] To add to the ambition, the Government has set a goal to be carbon-neutral by 2035.[38] Moreover, the plan sets a national renewable energy target of 51 per cent in gross final energy consumption by 2030.[26] The target of Finland is part of its contribution to the binding renewable target for the EU of 32 per cent by 2030. This target was proposed to be increased to 40 per cent by the European Commission in July 2021.[39] This could indicate that Finland will need to revise the national renewable target in the coming years.

Bioenergy plays an important role in renewable energy production in Finland, due to the vast and rich forest resources in the country.[26] According to the International Energy Agency (IEA), biofuels and waste contribute over 50 per cent of total domestic energy production.[40] This share continues to increase. Nuclear power is the second most dominant source, while hydropower and wind power account for a lesser share.[40]

## SMALL HYDROPOWER LEGISLATION AND REGULATIONS

Hydropower is heavily regulated in both Finland and the EU. In Finland, the Water Act (587/2011) is very important for hydropower because permits for the construction and operation of a plant are issued in accordance with the act.[41,42] In 2019, the Government made plans to update the Water Act and extend the tight regulations for fisheries, which toughens the environmental regulations for SHP plants and limits profitability.[31]

Several other domestic legislations are also essential for SHP in Finland. For instance, it is necessary to comply with the Act on the Protection of Rapids (35/1987) to build a hydropower plant. Furthermore, an environmental impact assessment (EIA) according to the Environmental Impact Assessment Procedure Act (468/1994) must be performed where hydropower is planned.[43,44] In addition, it is necessary to comply with the Nature Conservation Act (1096/1996), which constitutes the framework for biodiversity and sustainable use of natural resources, and the Environmental Protection Act (579/2014), which regulates environmental pollution.[45,46] On the EU level, the EU Water Framework Directive (2000/60/EC) sets the overall framework for hydropower regulation for member states.[47]

## COST OF SMALL HYDROPOWER DEVELOPMENT

The cost of SHP projects depends largely on their type, size and location.[48] Therefore, many hydropower plants have a location-specific cost. Generally, the cost allocation of SHP plants is divided somewhat differently than for large plants.[50] For instance, the IEA estimates that civil works account for a smaller cost share for SHP, while the cost share of electrical and mechanical equipment is larger than for large plants.[50] Some of the main economic barriers for SHP are high investment and audit costs, but electricity transmission prices and tax also dampen profitability.[30] The latter could explain why many small-scale plants choose to stay disconnected from the grid. According to the state-owned sustainable development company, Motiva, one reason why construction of SHP plants is predicted to slow down is heavy labour cost and poor economics.[31]

## FINANCIAL MECHANISMS FOR SMALL HYDROPOWER PROJECTS

Finland has previously had several support schemes for renewable energy. For instance, production support, such as FITs, for certain renewable energy sources, including wind power, biogas, wood fuel and wood chips, have been available.[29] The FIT system has decreased over time and finally closed in March 2021.[29] Another tender scheme called "Bonus system" was introduced in 2018.[42] The Bonus system is a technology-neutral subsidy scheme for up to 12 years.[42] Green certificates or Guarantees of Origin are available for all renewable energy producers of electricity and would serve as additional revenues for the producers.[49] No new support schemes for renewable energy production appear to be planned in Finland.[29]

Energy support can also be granted in the form of investment support, specifically for small-scale renewable production, new technologies and research projects.[50] However, SHP is excluded from the investment aid scheme.[42] In recent years, the trend has moved towards discontinuing SHP because of more stringent environmental policy due to biodiversity impacts and state support for the decommissioning of SHP plants has rather been made available.[32]

## EFFECTS OF CLIMATE CRISIS ON SMALL HYDROPOWER DEVELOPMENT

Temperature in Finland has risen by almost 2 degrees since the 1850s and is estimated to increase further if greenhouse gas emissions continue to increase.[8] A higher temperature will lead to more annual precipitation as well as more intensified and extreme episodes of rainfall.[9] Thus, increased temperatures from climate change could improve profitability for SHP due to the increased and more intensive rainfall. However, the ability to utilize the increased precipitation depends on the location of the additional rainfall and the available capacity of nearby SHP plants. Other effects of a warmer climate contribute to less snow accumulation in winter, leading to less snow melting in spring and therefore smaller capacity factors for hydropower.[51] In addition, the risk of frazil ice formations—ice that does not float—increases due to thinner ice cover and could lead to clogging of the water intake for SHP plants. Reduced water from snow melting and increased risk of clogging could have strong negative effects on the business case of SHP plants. However, estimates of the amount of reduced snow in Finland vary largely and depend on global emission reductions in the coming years.[51]

## BARRIERS AND ENABLERS FOR SMALL HYDROPOWER DEVELOPMENT

The following points summarize the main barriers to SHP development in Finland that have been identified:

- Heavy regulatory framework for hydropower plants;

- Government policies prioritize biodiversity concerns such as rehabilitation of watersheds and fish migration more than adding new SHP capacity;
- Limited profitability for new SHP projects and few financial support incentives available for SHP;
- Reduced water from snow melting and increased risk of frazil ice formations as a result of a warmer climate.

The following points summarize the main enablers that have been identified:

- Rich water resources available;
- Precipitation estimated to increase and intensify due to increased temperatures from climate change.

**Disclaimer:** The opinions, statistical data and estimates contained in this chapter are the responsibility of the author and should not be considered as reflecting that of the author's affiliated organization. By extension the author's affiliated organization is not liable for the information or the views presented in this chapter.

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# Iceland

Kristian Dahl Larsen, Samfunnsbedriftene Energy

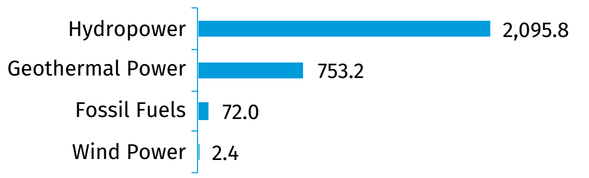
## KEY FACTS

| | |
|---|---|
| **Population** | 368,792 (2021)[1] |
| **Area** | 103,000 km$^2$ [2] |
| **Topography** | Iceland is a volcanic island containing over 200 volcanoes, with glaciers and cold lava covering roughly 10 per cent of the country's land area. The elevation differs largely. The highest point in Iceland is the top called Hvannadalshnjúkur, which rises to 2,199 metres above sea level. The average elevation of the land is approximately 500 metres above sea level, yet one quarter of the land is below 200 metres above sea level.[3,4] |
| **Climate** | The weather in Iceland is mild coastal despite the northern location, largely because of the Gulf Stream. Average temperatures in summer are approximately 10 °C and can reach highs of 24 °C. Average winter temperatures are approximately 0 °C. In general, the weather can be unstable and change quickly.[3] |
| **Climate Change** | Climate change will likely have a large impact on the island country of Iceland, most notably because of the melting of glaciers in the country. Estimates by the national meteorological institute suggest that all glaciers might vanish in the next 100–200 years. This will have major impacts on the marine ecosystem because of the acidification of the ocean. However, the melting of glaciers could also create new lakes or add to the capacity of existing ones. Estimates from climate models suggest the temperature could increase by approximately 1.3-2.1 °C by 2050. Similarly, precipitation is estimated to increase by 1.2–4.3 per cent by the middle of the century.5 |
| **Rain Pattern** | Average precipitation varies largely depending on the region of the country. In the south of Iceland, annual precipitation is estimated at approximately 5,000 mm, while in the mountainous areas it ranges between 1,000 mm and 3,000 mm and in the northern part is as low as 1,000 mm. Precipitation is greatest during the winter months (December–January) and lowest in the summer months (May–June). The difference can also be rather large, where precipitation in winter months can be twice the monthly average of summer months. The Icelandic regulator estimates the energy flow from precipitation to be approximately 220–285 TWh annually.[5,6] |
| **Hydrology** | Iceland has access to several good water sources through many lakes and waterfalls, numerous rivers, large glaciers and heavy rainfall. The main rivers are Pjorsa, Jokulsa a Fjollum, Olfussa, Jokulsa a Bru, Lagarfljot, Skjalfandafljot, Skeidara and Kudafljot. Pjorsa is the longest river stretching approximately 237 km in length.[4] |

## ELECTRICITY SECTOR OVERVIEW

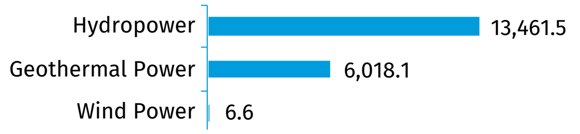
In 2019, Iceland generated a total of 19,489 GWh of electricity from hydropower, geothermal power, wind power and fossil fuels.[7] Of the total production, hydropower contributed 13,461.5 GWh, while geothermal power produced 6,018.1 GWh. Wind power and fossil fuels accounted for 6.6 GWh and 2.7 GWh, respectively (Figure 1).[7] In the same year, total installed capacity reached 2,923 MW.[7] This represents an increase of approximately 157 MW from 2017.[8] In terms of installed capacity, over 71 per cent of the total was from hydropower, while geothermal power was the second largest source (Figure 2). Access to electricity in the country is 100 per cent in both rural and urban areas.[9] In fact, the electrification rate in Iceland has been 100 per cent since the 1990s, according to the World Bank.[9]

Figure 1. **Annual Electricity Generation by Source in Iceland in 2019 (GWh)**




Source: Orkustofnun[7]

Figure 2. **Installed Electricity Capacity by Source in Iceland in 2019 (MW)**




Source: Orkustofnun[7]

With nearly 100 per cent of electricity coming from renewable sources, Iceland is a world leader in clean electricity production. In addition, Iceland tops the list of per capita energy production producing 53,832 kWh per person annually.[10] The heavy industry plays an important part in the country's electricity sector as it makes up much of the electricity demand. In 2018, this share was 81 per cent.[11]

In 2003, a new electricity act was introduced for the electricity sector in Iceland. The act was significant in that it separated production and sale of electricity transmission and distribution. The aim of the law was to introduce more competition in the sectors of electricity production and sale, mirroring the model used in the European Union.[12] The national regulator, Orkustofnun, was given the power to supervise the implementation of the act.[13] Additionally, as Orkustofnun is responsible for issuing licences for new power plants, monitoring compliance of the licensed plants and overseeing tariff calculations of the income cap for distribution and transmission companies.[14] The major electricity producers in Iceland are Landsvirkjun, Orka náttúrunnar and HS Orka. Landsvirkjun is by far the largest of the producers, responsible for approximately 71 per cent of total electricity production, while Orka náttúrunnar and HS Orka produce 19 and 7 per cent, respectivly.[12] The public sector has a strong presence in the electricity sector of Iceland. Most of the large power producers are either owned directly by the state or by municipalities, with the one exception being HS Orka.[15] For instance, Landsvirkjun is 100 per cent owned by the state, while Orka náttúrunnar is owned by several municipalities.[16,17]

The main grid is operated by the Icelandic transmission system operator (TSO), Landsnet.[12] The grid is comprehensive with over 75 substations, 85 delivery points for power plants and large users and 59 delivery points for distribution utilities.[18] Additionally, the gird consists of more than 3,000 kilometres of transmission lines.[19] The majority of the grid is overhead, while only a small part in urban areas is laid underground.[18] According to the TSO, the grid is constantly upgraded and expanded to keep up with the growing demand.[18]

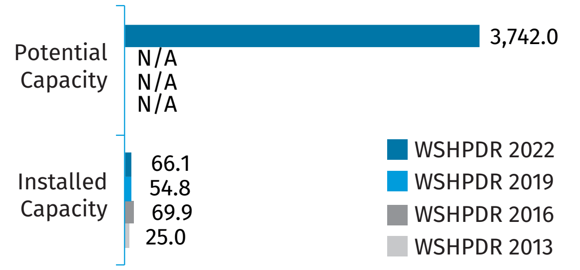
The electricity market of Iceland is highly liberalized, heavily based on renewable generation, although with no integration or interconnectors to other power systems.[14] Overall, Iceland enjoys very competitive electricity prices compared to other Northern European countries.[20] However, since there is no power exchange in Iceland, over 80 per cent of energy sold to large consumers is done through power purchase agreements (PPAs).[14]

The average price of electricity for households increased by 8.7 per cent since January 2021, reaching 0.1356 EUR/kWh (0.15 USD). The price excluding taxes was 0.1071 EUR/kWh (0.12 USD).[21]

## SMALL HYDROPOWER SECTOR OVERVIEW

In Iceland, small hydropower (SHP) plants are defined as hydropower plants of up to 10 MW. According to the register of the regulator Orkustofnun, existing SHP plants produced 332.2 GWh of electricity in 2019 and had a total installed capacity of 66.1 MW.[7] Compared to the *World Small Hydropower Development Report (WSHPDR) 2019*, this indicates a 21 per cent increase in capacity (Figure 3), which could be due to new projects coming online, as Iceland is pushing for innovation to build and utilize more SHP in rural areas. In addition, several power plant licences have been issued for SHP in Iceland in recent years.[22] From 2018 to 2021, at least seven licences for SHP were issued, indicating that the SHP sector in Iceland is in continuous development.[23] A list of selected existing SHP plants is displayed in Table 1.[7]

Figure 3. **Small Hydropower Capacities in the WSHPDR 2013/2016/2019/2022 in Iceland (MW)**




Source: Orkustofnun,[7,26,27,28,29,30] *WSHPDR 2013*,[31] *WSHPDR 2016*,[32] *WSHPDR 2019*[33]

In terms of grid connectivity, the Government has decided that power plants larger than 1 MW must be connected to the grid.[24] As in most of Europe, some public resistance towards new hydropower exists in Iceland, which is exemplified by the environmental group Save Þjórsá River.[25]

Table 1. **List of Selected Operational Small Hydropower Plants in Iceland**

| *Name* | *Location* | *Capacity (MW)* | *Operator* | *Launch year* |
|---|---|---|---|---|
| Setbergsvirkjun | Setbergsvirkjun | 0.04 | Smávirkjun | 2019 |
| Hólsvirkjun | Hólsvirkjun | 5.50 | Smávirkjun | 2019 |

| *Name* | *Location* | *Capacity (MW)* | *Operator* | *Launch year* |
|---|---|---|---|---|
| Úlfsárvirkjun | Úlfsárvirkjun | 0.20 | Smávirkjun | 2019 |
| Bugavirkjun | Bugavirkjun | 0.04 | Smávirkjun | 2014 |
| Glerárvirkjun II | Glerárvirkjun II | 3.30 | Fallorka | 2018 |
| Urðarfells-virkjun | Urðarfellsvirkjun | 1.15 | Smávirkjun | 2018 |
| Þverárvirkjun - Önundarfirði | Þverárvirkjun - Önundarfirði | 0.40 | Smávirkjun | 2018 |
| Köldukvíslar-virkjun | Köldukvíslar-virkjun | 2.79 | Smávirkjun | 2013 |
| Gúlsvirkjun | Gúlsvirkjun | 3.40 | Smávirkjun | 2009 |
| Bjólfsvirkjun | Bjólfsvirkjun | 6.40 | Smávirkjun | 2008 |
| Djúpadals-virkjun I/II | Djúpadalsvirkjun I/II | 2.80 | Fallorka | 2004/ 2006 |
| Múlavirkjun | Múlavirkjun | 3.10 | Smávirkjun | 2005 |
| Gönguskarðsá | Gönguskarðsá | 1.80 | Smávirkjun | 2015 |
| Árteigsvirkjun | Árteigsvirkjun | 1.22 | Smávirkjun | 2005/ 2009 |
| Þverárvirkjun | Þverárvirkjun | 2.20 | Orkubú Vestfjarða | 1953 |
| Grímsá | Grímsá | 2.80 | Orkusalan | 1958 |
| Skeiðfoss | Skeiðfoss | 4.80 | Orkusalan | 1945 |
| Andakíll | Andakíll | 8.20 | Orka Náttúrunnar | 1947 |

Source: Orkustofnun[7]

The maximum theoretical potential of SHP has been estimated using geospatial water catchment and stream flow analysis. An analysis was conducted for each of the five main regions of the country (Table 2). This represents an enormous potential compared to the current installed capacity. However, it remains to be seen how much of this potential is technically and economically feasible.

Table 2. **Summary of Theoretical Potential of Small Hydropower by Region in Iceland**

| | *Eastfjords* | *North-land* | *West-fjords* | *West Iceland* | *South Iceland* | *Total* |
|---|---|---|---|---|---|---|
| Number of sites | 883 | 532 | 401 | 246 | 444 | 2,506 |
| Potential capacity (MW) | 1,603 | 829 | 447 | 215 | 648 | 3,742 |

Source: Orkustofnun[26,27,28,29,30]

Planning applications can be viewed on the Orkustofnun website, and the known SHP projects in planning are displayed in Table 3.[23] Table 4 shows selected SHP projects available for investment.[34]

Table 3. **List of Known Planned Small Hydropower Projects in Iceland**

| *Name* | *Location* | *Capacity (MW)* | *Developer* | *Stage of Development* |
|---|---|---|---|---|
| Þjóðbrókargil | Strand-abyggð | 9.9 | N/A | Exploration licence issued in 2021 |
| Hólsvirkjun | Fnjóskadalur | 5.5 | Arctic Hydro ehf. | Licence to build and operate issued in 2019 |
| Eyjafjarðarsveit | Eyjafjarðará | 1.0 | Tjarnavirkjun ehf. | Power plant licence issued in 2019 |
| Köldukvíslar | Austur Hérað | 2.0 | Orkusalan ehf. | Exploration permit issued in 2018 |
| Ódáðavötn | Fljótsdalshérað | 4.0 | Orkusalan ehf. | Exploration permit issued in 2018 |
| Úlfsárvirkjun | Dagverðardalur | 0.2 | AB-Fasteignir ehf. | License to build and operate issued in 2018 |
| Gilsár | Hérað | 2.0–3.0 | Orkusalan ehf. | Exploration permit issued in 2018 |

Source: Orkustofnun[23]

Table 4. **List of Selected Small Hydropower Projects Available for Investment in Iceland**

| *Name* | *Location* | *Potential capacity (MW)* | *Head (m)* | *Type of site (new/refurbishment)* |
|---|---|---|---|---|
| Fitjá-neðri | Húnaþing Vestra | 2.9 | 207 | New |
| Fitjá-efrl | Húnaþing Vestra | 1.8 | 180 | New |
| Giljá | Húnavatn-shreppur | 1.8 | 190 | New |
| Vatnsdalsá | Húnavatn-shreppur | 5.6 | 95 | New |
| Álftaskálará-neðri | Húnavatn-shreppur | 5.4 | 230 | New |

Source: SSNV & Mannvit[34]

## RENEWABLE ENERGY POLICY

In its Climate Action Plan, Iceland states the aims to reduce its emissions by at least 40 per cent by 2030 and reach carbon neutrality by 2050.[35] Due to the low carbon intensity of electricity production in Iceland, much of the attention to further reduce emissions is given to road transport, agriculture, fisheries and waste management, on the one hand, and to carbon sequestration through afforestation and land restoration, on the other hand.[36] In general, new renewable power plants are regulated through the Master Plan for Nature Protection and Energy Utilization, which sets a framework to reconcile competing interests in regards to the use of natural resources.[37] Options for power plants are to be evaluated by a committee in each phase, categorized by vote in the Parliament. The Master Plan is currently in its fourth phase, but has been halted for some years due to the unfinished Parliament resolution of the third phase.[38]

In late 2016, Orkustofnun presented the idea of a small power plant project. The project aims to incentivize power production in rural areas to help with the national security of supply issues.[39] The concern over the security of supply originates from a number of factors, including an increase in electricity consumption from a growing population, the halted Master Plan with few new power projects and the large cost and time of building a new grid.[39] One key aspect of the project is to map suitable possibilities for new SHP production. A grant for Master's degree research in SHP is offered.[40] However, SHP plants must compete on the open market for sale and production of electricity as other actors.[39]

## SMALL HYDROPOWER LEGISLATION AND REGULATIONS

In Iceland, the national regulator is responsible for granting licences for new power plants, however, power plants with an installed capacity below 1 MW do not need a permit unless the electricity will be delivered to the grid.[41] In addition, hydropower plants must comply with two main pieces of legislation, namely the Water Law of 1923 and the Act on Exploration and Utilization of Ground Resources of 1998.[42,43]

## FINANCIAL MECHANISMS FOR SMALL HYDROPOWER PROJECTS

There are several financial mechanisms available for SHP projects. All producers of electricity from renewable energy sources are eligible to receive green certificates or Guarantees of Origin (GOs) from the TSO, Landsnet.[44] These certificates can be traded on the market and contribute as additional revenue for power plants. In addition, Iceland distributes grants and loans through its Energy Fund for projects that utilize renewable energy sources and reduce the use of fossil fuels.[45] Furthermore, SHP plants are eligible for green loans, which enjoy benefits such as lower interest rates and a possibility of interest payment only for the first three years.[46] Grants for the study and research of SHP are also available.[40]

## EFFECTS OF CLIMATE CRISIS ON SMALL HYDROPOWER DEVELOPMENT

Climate change is expected to have a significant effect on Iceland and SHP development most notably in terms of increased precipitation and melting of glaciers.[5] The glacier melting is estimated to happen over the next 100–200 years.[5] The national regulator estimated that the country's glaciers hold significant amounts of energy, of up to 7,600 TWh, that will be released.[6] Not all the melted glacier water can be utilized due to the distribution and localization of the existing hydropower plants; however, SHP can be built to optimize the water resources from the new streams.[6]

## BARRIERS AND ENABLERS FOR SMALL HYDROPOWER DEVELOPMENT

The following points summarize the main barriers to SHP development in Iceland that have been identified:

- Some public resistance, particularly from environmental groups, towards more hydropower development;
- Uncertainty over the amount of SHP potential that is technically and economically exploitable.

The following points summarize the main enablers that have been identified:

- Strong determination from the Government to research and utilize more SHP. Examples include financial mechanisms, increased research and mapping of SHP opportunities from the regulator;
- Comprehensive legislative framework for hydropower compared to wind and solar power.
- Increased predicted precipitation as an effect of climate change is expected to create strong business opportunities for SHP projects;
- Growing electricity demand from an increasing population offers an opportunity for SHP, especially due to the limited gird capacity available for supply from other major power plants.

**Disclaimer:** The opinions, statistical data and estimates contained in this chapter are the responsibility of the author and should not be considered as reflecting those of the author's affiliated organization. By extension, the author's affiliated organization is not liable for the information or the views presented in this chapter.

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# Republic of Ireland

Tamsyn Lonsdale-Smith, International Center on Small Hydro Power (ICSHP)

## KEY FACTS

| | |
|---|---|
| **Population** | 5,011,500 (2021)[1] |
| **Area** | 70,290 $km^2$ [2] |
| **Topography** | The country's terrain has been described as bowl-shaped, with low-lying interior plains surrounded by rugged hills and low mountains and with sea cliffs on the west coast. The mean elevation is 118 metres, while the highest point is Carrauntoohil at 1,041 metres in the Macgillycuddy's Reeks situated in the south-west. Other key mountain ranges include: the northern Blue Stack Mountains, the eastern Wicklow Mountains (which house the Lugnaquillia at 926 metres), the southern Knockmealdown and Comeragh mountains and the western Twelve Pins. The lowest point is North Slob in County Wexford, at 4 metres below sea level.[3] |
| **Climate** | The climate is maritime temperate, modified by the warm North Atlantic Drift, particularly on the Atlantic coast, and by the prevailing south-westerly Atlantic winds. The climate is humid, yet the hills and mountains, many of which are near the coast, provide shelter from strong winds and from direct oceanic influence. Winters are cool and windy. From February to June, there is less rainfall due to continental anticyclones. Temperatures can range from 2 °C to 10 °C in the winter months and from 10 °C to 20 °C in the summer months, depending on the region.[4,5] |
| **Climate Change** | The average annual surface air temperature in Ireland has increased by over 0.9 °C over the last 120 years, with a rise in temperatures being observed in all seasons. Annual precipitation was 6 per cent higher in the period from 1989 to 2018, compared to the 30-year period from 1961 to 1990. Sea level rise and higher oceanic temperatures have also been observed in the ocean and coastal areas. By mid-century, Ireland could see increased frequency of heavy rainfall events, while annual precipitation is expected to decrease overall, by 1–3 per cent in the medium-to-low scenario and by 3–20 per cent under the high emission scenario.[6] |
| **Rain Pattern** | Most of the eastern half of the country receives between 750 mm and 1,000 mm of rainfall per year. Rainfall in the west generally averages between 1,000 mm and 1,400 mm. In many mountainous districts, rainfall exceeds 2,000 mm per year. The wettest months in almost all areas are December and January. April is generally the driest month across the country. However, in many southern regions, June is the driest.[4,5] |
| **Hydrology** | There are over 70,000 km of waterways made up of 3,192 different water bodies including rivers, streams and tributaries. There are an estimated 12,000 lakes, covering an area of more than 1,200 $km^2$. The largest lake by area is Lough Neagh, which is estimated to be of the order of 18,870 $km^2$, with an unknown distribution among the different geological formations.[7] |

## ELECTRICITY SECTOR OVERVIEW

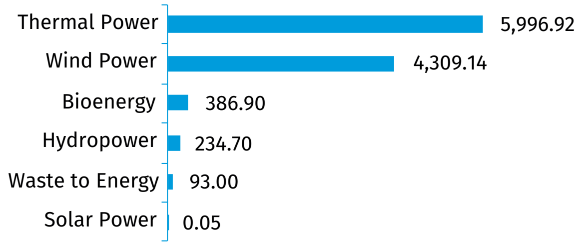
Electricity in Ireland continues to be dominated by non-renewable sources, with coal and peat, until recently, still prominent in electricity generation. However, the share of renewable energy sources in the energy mix is gradually increasing, both in terms of installed capacity and demand, mainly due to an increase in wind power. As a result, carbon intensity of the grid decreased by 14 per cent from 2018 to 2019, reaching 324 g $CO_2e$/kWh in 2019.[8] In contrast, the carbon intensity of electricity generation in 1990 was 896 g$CO_2$/kWh.[9]

Total installed capacity in 2021 amounted to 11,020.7 MW, of which 5,996.9 MW (55 per cent) was thermal power capacity (Figure 1). Wind power made up 4,309.1 MW (39 per cent), of which 2,074.1 MW was connected to the transmission system operator (TSO) and 2,235.1 MW to the distribution system operator (DSO).[10,11] Hydropower installed capacity in 2020 was 234.7 MW, or 2 per cent, not including the 292 MW pumped-storage hydropower plant at Turlough Hill.[11] Of the total hydropower capacity, 212.2 MW was TSO-connected and 22.5 MW DSO-connected.[11,12] Bioenergy, waste to energy and solar power made up 386.9 MW, 93 MW and 0.05 MW respectively.[10,11,12]

No new hydropower plants above 3 MW have been installed in the country since the 1950s. However, a large-scale hydropower project, 360 MW Silvermines in County Tipperary, has been deemed a Project of Common Interest by the European

Union, with an expected commissioning date of December 2028.[13]

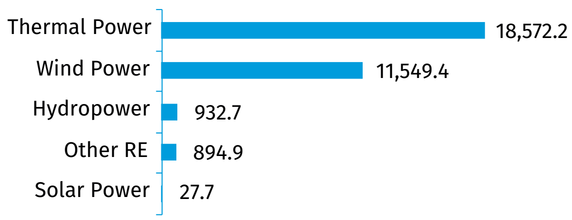
Figure 1. **Installed Electricity Capacity by Source in Ireland in 2021 (MW)**




Source: EirGrid Group[10,11,12]

A total of 31,976.9 GWh of electricity was generated in Ireland in 2020. The main sources of production were thermal, at 18,572.2 GWh (58 per cent) (Figure 2). Natural gas met the majority of demand at 16,250.1 GWh (51 per cent), with contributions in decreasing amounts from peat at 960.4 GWh (3 per cent), coal at 669.2 GWh (2 per cent) and oil 393.5 GWh (1 per cent). Wind power was the dominant contributor to the renewable energy mix for the year 2020 (11,549.4 GWh; 36 per cent), followed by hydropower (932.7 GWh; 3 per cent) and solar power (27.7 GWh; 0.1 per cent). Other renewable sources, including renewable biomass, contributed 894.9 GWh (3 per cent). The remaining 299 GWh (1 per cent) of generation was met by waste to energy, diesel and combined heat and power (CHP) plants.[14] Imports and exports play a very small role via interconnectors linking the country to Northern Ireland and Wales. The net export in 2020 amounted to 0.5 per cent of electricity generation in 2020.[14]

Figure 2. **Annual Electricity Generation by Source in Ireland in 2020 (GWh)**




Source: EirDrid Group[14]

EirGrid is the TSO in Ireland, while further transmission and distribution functions are under the control of the Electricity Supply Board (ESB) Networks Ltd. The Commission for Regulation of Utilities (CRU) is responsible for regulating the electricity market as well as other utilities. An Integrated Single Electricity Market (I-SEM) is in operation on the island of Ireland, facilitated by the North-South interconnector to Northern Ireland.

The future electricity plans for Ireland are guided by the European Commission's National Energy and Climate Plans 2021–2030. Under this plan, 70 per cent of electricity is to be generated from renewable sources by 2030.[15] However, none of the planned or projected increases in renewable electricity production is expected to be met by new hydropower capacity, suggesting that most cost-effective sites have already been exploited. Furthermore, from 2005 to 2018 hydropower only experienced a growth rate of 10 per cent, which was the lowest growth rate of any renewable generation technology in the country.[15]

Ireland has reached a 100 per cent electrification rate. Imports are supported by the East-West Interconnector to Wales with a 500 MW high-voltage direct-current submarine cable.[16] From 2018 to 2019, net electricity imports increased by 673 GWh, representing a shift from Ireland being a net exporter to a net importer of electricity.[8] Further interconnections are being explored through the Celtic Interconnector project, which could link the country to the French transmission grid.[17]

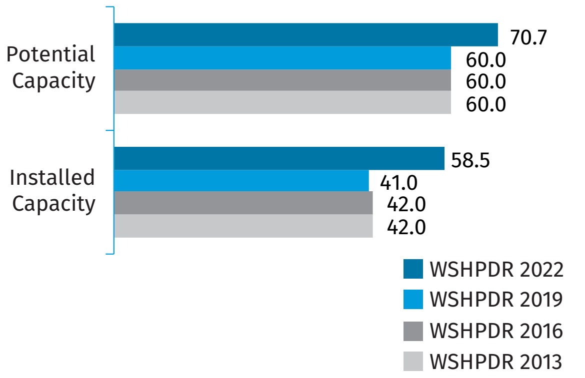
Electricity tariffs in the country are competitive, yet regulated by Electric Ireland, which has the power to enact such mechanisms as price freezes to limit price increases for consumers. In 2021, prices were increased by 9 per cent due to increased wholesale costs and supplier prices, equating to an average of EUR 8.20 (USD 9.70) per month on the electricity bill.[18] Electricity prices are higher than the prices of gas generation, which represents a price distortion and disincentive for consumers to switch to electrified heating solutions. Nonetheless, the average domestic price of electricity (consumption band DC) in the first semester of 2019 was 2 per cent below the Euro Area average.[19]

## SMALL HYDROPOWER SECTOR OVERVIEW

This chapter takes the ICSHP definition of SHP as plants up to 10 MW in capacity, which is in line with the common definition used in the country.[20] In 2021, SHP contributed 58.5 MW to the total installed capacity, or 0.5 per cent.[11,12] This indicates an increase in SHP installed capacity of 43 per cent compared to the *World Small Hydropower Development Report (WSHPDR) 2019* (Figure 3). This change is due to access to more accurate data sources, plus 0.56 MW of new installed capacity since 2019. In Ireland, the SHP sector comprises 6 TSO-connected plants, with capacities ranging from 0.15 MW to 10.0 MW, and 61 DSO-connected plants, with capacities ranging from 0.02 MW to 4.3 MW (Table 1).[11,12] As of April 2021, there were three new contracted DSO micro-hydropower plants with capacities between 0.04 MW and 0.87 MW under development (Table 2).[21]

Potential capacity in Ireland for small-to-micro-scale hydropower generation is still underexploited, with many sites of less than 1 MW still available for development.[20] According to a report published in 1985, there are 592 potential sites, including those already exploited, with a total of 39.04 MW of potential capacity.[22] Sites with the largest potential are listed in Table 3. The undeveloped potential as of this 1985 report was 34.50 MW. At the same time, in 1985, there was at least 36.18 MW of operating grid-connected SHP capacity.[11,12] Therefore, the total SHP potential in the country, including operational SHP plants is equal to at least 70.68 MW. However, this is likely to be a conservative estimate. The increase in potential capacity compared to the *WSHPDR 2019* is due to access to this more detailed information and improved calculation.

Figure 3. **Small Hydropower Capacities in the WSHPDR 2013/2016/2019/2022 in Ireland (MW)**




Source: EirGrid Group,[11] ESB Networks,[12] Irish Hydropower Association,[22] *WSHPDR 2013*,[23] *WSHPDR 2016*,[24] *WSHPDR 2019*[25]

Table 1. **List of Selected Operational Small Hydropower Plants in Ireland**

| *Name* | *Location* | *Capacity (MW)* | *Launch year* |
|---|---|---|---|
| Erne Cliff (1) | Donegal | 10.00 | 1950 |
| Erne Cliff (2) | Donegal | 10.00 | 1955 |
| Lee Inniscarra (2) | Cork | 8.00 | 1952 |
| Clady | Clady | 4.30 | N/A |
| Lee Carrigadrohid (3) | Cork | 4.00 | 1952 |
| Liffey Hydro (4) | Wicklow | 4.00 | 1944 |
| Rockygrange Hydroel | Collooney | 2.19 | N/A |
| Anarget Hydro | Donegal | 2.10 | N/A |
| Trewel Cottoners | Milltown | 1.20 | N/A |
| Owenbeg Natural Power | Bantry | 0.80 | N/A |
| Curramore mini-hydro | Bantry | 0.77 | N/A |
| Mahon Hydro Scheme 2 | Kilmacthomas | 0.70 | 2008 |
| Lough Eske | Donegal | 0.66 | N/A |
| Lowerymore Hydro | Donegal | 0.60 | 2001 |
| Ashgrove Mill | Kilgarvan | 0.60 | N/A |
| Collooney Manufacuring | Collooney | 0.50 | N/A |
| Slaheny River Hydro | Bantry | 0.49 | 2002 |
| Barnsbridge Hydro | Donegal | 0.48 | 2001 |
| Nadirkmore Hydro | Westport | 0.41 | N/A |
| Parteen Weir | Birdhill | 0.40 | N/A |

Source: EriGrid Group,[11] ESB Networks[12]

The SHP sector is largely run by private developers and small companies. One main deterrent to developing SHP under the current market conditions is due to the lack of a default electricity purchaser for renewable energy supplied into the network since the market decoupling in 1994. This represents a financial risk to new market players.[20]

Table 2. **List of Planned Small Hydropower Projects in Ireland**

| *Name* | *Location* | *Capacity (MW)* | *Planned launch year* | *Stage of development* |
|---|---|---|---|---|
| Glasha Hydro | County Doon | 0.87 | N/A | Contracted |
| The Mill | County Laois | 0.04 | N/A | Contracted |
| Avonmore House Hydro | County Wicklow | 0.07 | N/A | Contracted |

Source: ESB Networks[21]

Note: As of April 2021.

According to EriGrid Group, there is limited potential for the expansion of SHP in the country, since it is viewed as a mature technology and there is lack of suitable locations.[26] The sites listed in Table 3 come from a study conducted in 1985 and should be considered as preliminary information on sites that were viable at the time of the chapter writing.

Table 3. **List of Selected Potential Small Hydropower Projects in Ireland**

| *Name* | *Location* | *Potential capacity (MW)* | *Head (m)* | *Type of site (new/refurbishment)* |
|---|---|---|---|---|
| 32(i) | Ballisodare | 0.88 | 5.8 | New |
| 32(ii) | Ballisodare | 0.74 | 7.25 | New |
| L11/r48 | Cottoners | 0.53 | 335 | New |
| 57(ii) | Corrib | 0.47 | 3.9 | New |
| 17 | Boyle | 0.40 | 3.3 | New |

Source: Irish Hydropower Association[22]

## RENEWABLE ENERGY POLICY

Compared to the neighbouring United Kingdom, in Ireland renewable energy support schemes and policies in general have been lagging behind, with little in the way of planning and policy support. This lack of a clear policy direction and regulatory uncertainty have had an obvious impact on renewable energy penetration in the country, with large producers such as Equinor pulling out of the offshore wind sector as a direct result.[27]

The renewable energy policy is primarily driven by European Union obligations and is described in the National Energy and Climate Plan (NECP) 2021–2030.[15] The related ambitions include: an early and complete phase-out of coal- and peat-powered electricity, an increase in renewable power generation up to 70 per cent by 2030 and meeting 15 per cent of electricity demand with renewable sources contracted under corporate power purchase agreements. There is no specific target for hydropower under the NECP due to the small number of potential sites viable for development.[20]

Apart from this, Ireland has a Transition to a Low Carbon Energy Future 2015–2030 White Paper, which set the target to reduce electricity sector emissions by 80–95 per cent by 2050 and achieve net zero by 2100. This policy provided a target for renewable energy within the electricity consumption of 40 per cent for 2020.[28]

## SMALL HYDROPOWER LEGISLATION AND REGULATIONS

The licensing procedure for SHP in Ireland suggests that potential developers should consult with planning and fishery board authorities in the early stages of the assessment of sites to assess planning friendliness and determine if these actors are likely to contest such a project. In this way, developers can assess the riskiness of pursuing a project in an area based on how friendly they can expect authorities in the area to be, before putting down any funds for the project. Local authorities are responsible for deciding if an environmental impact assessment (EIA) is required. This is usually the case where the project is likely to change at least 30 per cent of the mean river flow. In some cases, an environmental impact statement (EIS) is also required.[20] There are no SHP-specific policy mechanisms in Ireland.

## COST OF SMALL HYDROPOWER DEVELOPMENT

The cost of operating SHP in Ireland is high due to initial installation costs, but this is generally recovered over time due to the “free fuel” and low operating costs.[20] Estimates of production costs (OPEX) range from EUR 0.0007 to EUR 0.0015 (USD 0.00083–0.0018) per kWh, depending on the proximity to the electricity grid. Investment cost is estimated to be between EUR 3 million and EUR 12 million (USD 3.54–14.18 million) per MW.[29] The cost is also dependent on the type of generator used, which itself is dependent on the nature of water resources available.[20]

## FINANCIAL MECHANISMS FOR SMALL HYDROPOWER PROJECTS

Until 2015, the main incentive for the development of renewable energy in Ireland was the feed-in tariff (FIT), which has now been replaced by the Renewable Electricity Support Scheme (RESS), operated by the Department of Communications, Climate Action and Environment.[30] The programme provides support to renewable energy projects over a 15-year period. The policy objectives of the scheme include: provision of support for communities to participate in renewable energy projects; broadening the renewable electricity technology mix; delivering the renewable energy required under the ambitious Transition to a Low Carbon Energy Future 2015–2030 White Paper; increasing energy security and energy sustainability; and ensuring the cost effectiveness of the energy policy. The first RESS auction occurred in July 2020, with only solar and wind power projects qualifying in the results.[31] To date, hydropower projects have not benefited from either the RESS or the previous FIT scheme.

## EFFECTS OF CLIMATE CRISIS ON SMALL HYDROPOWER DEVELOPMENT

Future viability of hydropower will depend on the levels of water bodies that are altered by seasonal changes to mean rainfall and on evaporation rates caused by seasonal temperature changes. With no areas of long-term snow or ice cover existing in the country, changes in snow and glacial melt are not considered to be a critical factor. Simulations reported by Met Éireann show projected decreases in mean annual spring and summer precipitation of 0-20 per cent by mid-century, depending on model parameters.[32]

Frequencies of heavy precipitation events are expected to increase during the 2041–2060 time period according to climate simulation models, showing approximately 20 per cent increases during the winter and autumn months.[33] The frequency of extended dry periods are projected to increase substantially by mid-century during autumn and especially summer months, with increases of 12-40 per cent. Temperature projections indicate an increase of 1.0-1.6 °C in mean annual temperatures and up to 2.6 °C on extreme days in summer, with the largest increases to be seen in the east of the country. At the same time, frost days will decrease. The impact of these changes on hydropower generation requires further study for the specific regional hydrological conditions within Ireland.[32]

## BARRIERS AND ENABLERS FOR SMALL HYDROPOWER DEVELOPMENT

Hydropower is not projected for growth by the country’s NECP because it is largely agreed that few sites suitable for development remain.[15] Ireland does have an abundance of water resources and hydropower plants can produce consistent power throughout the day for the entire year if water levels are high enough. However, the 1985 mapping reported by the Sustainable Energy Authority of Ireland (SEAI) indicates that sources of water suitable for hydropower development remain limited to many small-scale capacity sites of below 1 MW.[34] Micro-hydropower could potentially be viable for small villages or businesses using smaller streams or other sources. However, development costs are likely to be high, including civil engineering, manufacturing and equipment installation. There are also strict environmental regulations and the historical trends of renewable support schemes show that wind and solar power have been disproportionately favoured in the past. There can be considerable public opposition to the construction of plants on popular waterways (e.g., a plant turned down in Kerry), often to protect fisheries and sport fishing.

The following points summarize the main barriers to SHP development that have been identified:

- Increase in hydropower capacity is not envisioned within the NECP 2021–2030;
- Lack of a default purchaser for renewable energy supplied to the network;
- According to EirGrid Group, economically feasible sites have largely been exploited;
- High start-up costs;
- Strict environmental regulations;
- Poor history of qualification for financial support mechanisms;
- Public opposition to SHP within fishing communities;
- Larger capacities of over 1 MW have been for the most part developed.

The following points summarize the main enablers that have been identified:

- Considerable unexploited potential at the small-to-micro scale;
- Support via the RESS auction scheme remains possible, despite a track record of favouring solar and wind power;
- Recent Government-level publications aimed at raising awareness for SHP development and providing advice to potential developers.

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# Latvia

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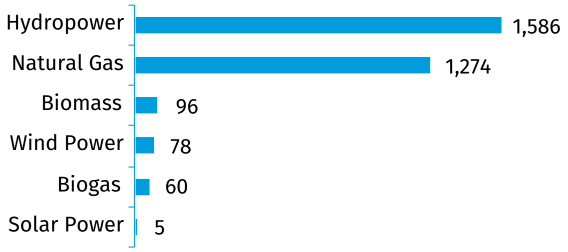
## KEY FACTS

| | |
|---|---|
| **Population** | 1,893,223 (2021)[1] |
| **Area** | 64,589 km²[2 2] |
| **Topography** | Latvia can be divided into two parts: a continental part in the east and the Kurzeme Peninsula (Kurland) in the west. The continental part consists of morainic uplands, which are crossed by several rivers flowing to the lowlands. The highest point of the country, the Gaizinkalns Hill with an altitude of almost 312 metres above sea level, is in the Vidzeme Upland. The continental part is separated from the peninsula in the west by the Lielupe River, which flows through the Zemgales Plain. The peninsular part is characterized by the Kurzeme Upland, which is lower than the continental upland and is crossed by several rivers, of which the Venta River is the most important. The highest point in these uplands is at 184 metres above sea level. Overall, approximately 57 per cent of the country lies below 100 metres above sea level and only 2.5 per cent lies above 200 metres.[2] |
| **Climate** | Latvia has moderately cold winters, while summers are moderately hot. In the summer (June–August) the average temperature is 17 °C but can occasionally reach 30 °C. During spring and autumn, the weather is relatively mild, but variable and generally humid, with an average temperature of 10 °C. Winters in Latvia usually start in mid-December and last until mid-March. The average temperature in winter is approximately -6 °C but can sometimes reach -25 °C.[3] |
| **Climate Change** | Over the last 30 years, the average annual air temperature in Latvia has increased by 0.7 °C. It is becoming increasingly difficult to predict weather with cold waves in winter and heat waves in summer.[4] |
| **Rain Pattern** | The average annual precipitation in Latvia is 667 mm. Rainfall is generally higher in hilly regions, on slopes facing moist air masses. The western slopes of the Vidzeme Upland receive 700–800 mm of rainfall annually and the western slopes of the Kurzeme Upland receive 650–700 mm, however, rainfall decreases along the eastern slopes. Much of the rain (70 per cent) falls from April to October, with maximum rainfall (>100 mm) occurring in August. Rainfall is lower in spring. Precipitation, as a constant snow cover, usually starts between the 30th of December and the 5th of January. The thickness of the snow cover exceeds 30 cm in most parts of Latvia; in eastern regions with a hilly topography, the snow cover is 40–50 cm deep.[2,3] |
| **Hydrology** | There are 12,500 rivers in Latvia with a total combined coverage of approximately 37,500 km². The biggest rivers are the Daugava, Lielupe, Venta, Aiviekste and Gauja. Depending on the physical and geographical conditions, a large share of river discharge comes from either snowmelt, groundwater or direct surface runoff. Approximately 50–55 per cent of the waters of the Daugava, Venta, Lielupe and Musa Rivers is melted snow, while for the Gauja and Amata Rivers it is 35–40 per cent. The total renewable surface water resources are estimated at 16.5 km³/year and incoming surface water resources at 18.7 km³/year.[2] |

## ELECTRICITY SECTOR OVERVIEW

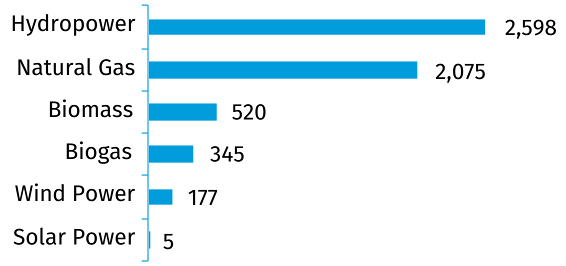
Electricity generation in Latvia is based mostly on large hydropower and combined heat and power plants (CHP) with the rest of the demand being provided for through imports. In 2020, electricity generation in Latvia totalled 5,720 GWh (Figure 1), which is considerably less than in 2016 (6,425 GWh).[5,6] Installed capacity in 2020 was approximately 3,100 MW (Figure 2).[6,7] In the same year, total electricity consumption amounted to 7,138 GWh and total imports reached 4,173 GWh while exports were 2,546 GWh (Figure 3).[8]

Figure 1. **Annual Electricity Generation by Source in Latvia in 2020 (GWh)**



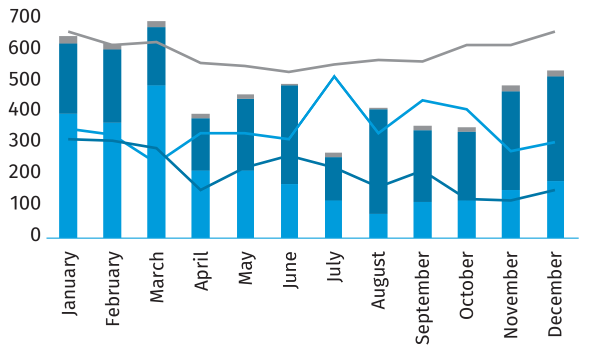

Source: Central Statistical Bureau[5,6]

Figure 2. **Installed Electricity Capacity by Source in Latvia in 2020 (MW)**



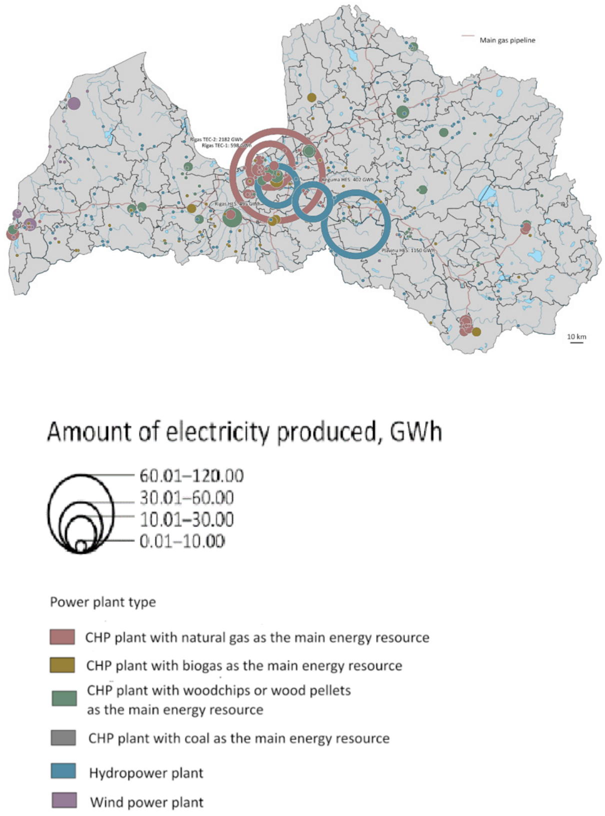

Source: Central Statistical Bureau[6,7]

Figure 3. **Electricity Generation, Consumption, Imports and Exports by Month in Latvia in 2020 (GWh)**




Source: Central Statistical Bureau[8]

Figure 4. **Electricity Production in Latvia in 2019**




Source: Central Statistical Bureau[10]

The greatest share of electricity produced from hydropower was in 2017 reaching 80 per cent (4,386 GWh), while in 2020 it decreased to 45 per cent (2,598 GWh) due to a dry year. At the same time, the installed hydropower capacity in 2020 (1,586 MW) increased by less than 7 per cent compared to 1990 (1,487 MW). There are three large hydropower plants with a capacity of over 10 MW: Kegums at 248 MW, Pļaviņas at 908 MW and Riga at 402 MW (Figure 4).[9] The Latvenergo Group continues the gradual refurbishment of hydropower plants on the Daugava River, which is planned to be completed by 2022.[4]

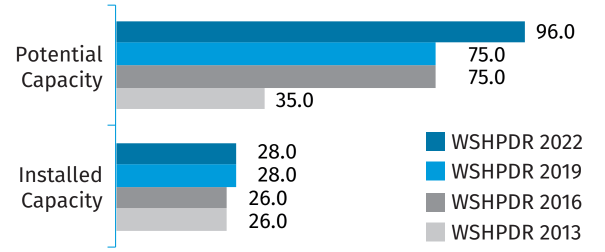
The electricity market is dominated by two state-owned companies: Latvenergo and Enefit (affiliated with the Estonian state enterprise Eesti Energia). The legal framework for the electricity market in Latvia is defined by the Electricity Market Law, which stipulates that the transmission system operator should facilitate the operation of the internal electricity market and cross-border trade, including the support of electricity exchange development.[11] The country is fully electrified and has a distribution network with a total length of 92,656 km.[12] The electricity price in Latvia in 2021 was 61.37 EUR/MWh (72.82 USD/MWh).[13]

Latvia is part of the European Union's (EU) internal electricity market, which operates in accordance with the principles of EU policy and laws. The integration of the Latvian electricity market into the EU market began in 2009. In order to ensure the stability of the electricity market, in November 2020 the Latvia-Russia border was opened for electricity exports from Russia to the Baltic countries. The decision was made following the closure of the Belarus-Lithuania border for electricity trading after the launch of the Astravjec nuclear power plant in Belarus on 3 November 2020.[14]

## SMALL HYDROPOWER SECTOR OVERVIEW

The definition of small hydropower (SHP) in Latvia is up to 10 MW. The installed capacity of SHP in the country is 28 MW, with generation of 70 GWh in 2020. The potential is estimated to be at least 96 MW (280 MWh of potential annual generation), indicating that 29 per cent of the available potential has been developed.[6,15] Compared to the *World Small Hydropower Development Report (WSHPDR) 2019*, the installed capacity has remained unchanged, while the estimated potential increased by 22 per cent based on more accurate data (Figure 5).

Figure 5. **Small Hydropower Capacities in the WSHPDR 2013/2016/2019/2022 in Latvia (MW)**




Source: *WSHPDR 2019*,[2] Central Statistical Bureau,[6] MHEA,[15] *WSHPDR 2013*,[16] *WSHPDR 2016*[17]

In 2020 there were 147 SHP plants with a total installed capacity of 28 MW and only one SHP plant exceeding an installed capacity of 1 MW (Table 1).[6] The Latvian Renewable Energy Association aimed to have 180 SHP plants with a total installed capacity of 48 MW and generating 140 GWh by 2020, however due to negative social attitudes towards SHP, these plans have been postponed.[19] The theoretical untapped hydropower potential of small and medium-sized rivers in the country is estimated at approximately 1,160 GWh, of which 260 GWh is located on unusable parts of the Venta, Lielupe, Salaca and Gauja Rivers. The economically feasible potential was estimated to be between 450 GWh and 500 GWh, but considering all the possible constraints, environmental hydropower potential could be approximately 250–300 GWh.[20]

Table 1. **List of Selected Existing Small Hydropower Plants in Latvia**

| *Name* | *Location* | *Capacity (MW)* | *Operator* | *Launch year* |
|---|---|---|---|---|
| Staškeviču dz. | Aglonas county, Šķeltovas parish, "Staškeviču dzirnavas", Dubnas River | 0.17 | AG 21 | 2002 |
| Karļu aizspr. | Amatas count, Drabešu parish, "Kārļi", Amatas River | 0.60 | AMATAS | 2002 |
| Billes | Amatas county, Drabešu parish, Amatas River | 0.38 | BILLES | 2002 |
| Prūšu | Priekuļu county, Virgas pagast, Virgas River | 0.20 | FIRMA-GABRO | 2002 |
| Bikstriver | Jaunpils county, Jaunpils parish, "Bikstriver", Bikstupes | 0.12 | GA 21 | 2002 |
| Aiviekstes | Aiviekstē, Kalsnavas parish, Madonas county | 0.80 | Latvenergo | 2002 |
| Viduskroģeru | Jelgavas county, Platones parish, "Viduskroģeri", Platones River | 0.15 | NOVATORS | 2002 |
| Lobes dz. | Ogres county, Lēdmanes parish, Lobes River | 0.15 | Oserviss | 2002 |
| Vizlas | Valkas county, Grundzāles parish, Vizlas River | 0.32 | S&E Management | 2002 |
| Rauskas | Mazsalacas county, Ramatas parish, Ramatas River | 0.05 | SL PLUS | 2002 |
| Spridzēnu | Pļaviņu county, Aiviekstes parish, Aiviekstes River | 1.20 | SPRIDZĒNU | 2002 |
| Jaunannas | Alūksnes county, Jaunannas parish, Pededzes River | 0.14 | ENERGO 2000 | 2001 |
| Gravas | Ventspils county, Usmas parish, Engures River | 0.5 | EZERSPĪĶI | 2001 |
| Galgauskas dz. | Gulbenes county, Galgauskas parish, Tirzas River | 0.52 | GALGAUSKAS DZIRNAVU | 2001 |
| Ropažu | Ropažu county, Ropažu parish, Lielās Juglas River | 0.20 | HYDROENERGY LATVIA | 2001 |
| Ziedlejas | Jelgavas county, Lielplatones parish, "Ziedlejas", Platones River | 0.17 | NOVATORS | 2001 |
| Krievciema | Pļaviņu county, Aiviekstes parish, "Krievciema ūdensdzirnavas", Viesatas River | 0.18 | VIORA PLUSS | 2001 |
| Zilriver | Zilupe, Raiņa iela 27, Zilupes River | 0.12 | ZILRIVER | 2001 |
| Variņu | Gulbenes county, Rankas parish, Gaujas River | 0.32 | RANKA HIDRO | 2000 |
| Neretas | Neretas county, Neretas parish, Dienvidsusējas River | 0.15 | NERETAS DZIRNAVAS | 1999 |

Source: Gaujmala[18]

In the late 19th century, Latvia had more than 700 watermills, which were originally powered by wooden waterwheels. SHP plant construction started to expand and by the end of 1926 there were 26 hydropower plants with a total installed capacity of 1.5 MW. During the Soviet period, SHP started to be unprofitable and between 1963 and 1977 all plants were dismantled, even those that were still working efficiently.[20] According to the Latvian Small Hydropower Association, using old watermill locations for SHP development is the best opportunity for development.[21] A total of 367 old watermill sites have been identified.

The public perception of SHP has been negative due to the fact that electricity produced by SHP plants was relatively expensive because of feed-in-tariff (FIT) and mandatory procurement. Furthermore, some SHP plans were badly planned and caused environmental damage.[21] Thus, the EU-funded ECOFLOW project reviewed the situation in Latvian rivers and identified that many SHP plants are damaging the river ecosystems.[22] Those planning mistakes shaped the negative public attitude towards hydropower technology.

## RENEWABLE ENERGY POLICY

Directive 2009/28/EC established an obligation for Latvia to increase its share of renewable energy sources in the gross final energy consumption up to 40 per cent by 2020.[23,24,25,26] In order to help reach this target, the Latvian Renewable Energy Federation has estimated feasible development of renewable energy sources for 2020 (Table 2).[27]

Table 2. **Renewable Energy Potential in Latvia in 2020**

| *Source* | *Potential capacity (MW)* | *Potential generation (GWh)* |
|---|---|---|
| Biomass | 150 | 760 |
| Biogas | 90 | 720 |
| Wind Power | 500 | 1,500 |
| SHP | 75 | 220 |
| Large hydropower | 1,522 | 3,000 |
| **Total** | **2,337** | **6,200** |

Source: Latvian Renewable Energy Federation[27]

The Regulations on Electricity Generation from Renewable Energy Sources (Cabinet of Ministers Regulation No. 198, initially adopted in July 2007 as Regulation No. 503) prescribes conditions for electricity production using renewable energy sources (wind power, SHP, biomass, biogas and solar power). According to this regulation, producers can sell their electricity under the mandatory procurement component (MPC) at fixed purchase prices (FIT system). For hydropower, the price is calculated based on the following formulae, depending on the type of the plant: price = 188 × $c$ × 0.8 × $s$ or price = 159 × $c$ × $s$, where $c$ stands for coefficient (Table 3) and $s$ for the adjustment value in case of overpay.

Table 3. **Coefficient Values by Installed Capacity**

| *Capacity (MW)* | *Coefficient (EUR(USD))* |
|---|---|
| < 0.08 | 1.240 (1.47) |
| 0.08–0.15 | 1.231 (1.46) |
| 0.15–0.20 | 1.202 (1.43) |
| 0.20–0.40 | 1.131 (1.34) |
| 0.40–0.60 | 1.086 (1.29) |
| 0.60–0.80 | 1.072 (1.27) |
| 0.80–1.00 | 1.055 (1.25) |
| 1.00 –1.50 | 1.035 (1.23) |
| 1.50–2.00 | 1.008 (1.20) |
| 2.00–2.50 | 0.992 (1.18) |
| 2.50–3.00 | 0.982 (1.17) |
| 3.00–3.50 | 0.974 (1.16) |
| 3.50–10.00 | 0.965 (1.14) |
| 10.00–20.00 | 0.950 (1.13) |
| 20.00–40.00 | 0.920 (1.09) |
| 40.00–60.00 | 0.890 (1.06) |
| 60.00–80.00 | 0.860 (1.02) |
| 80.00–100.00 | 0.830 (0.98) |
| > 100.00 | 0.800 (0.95) |

Source: Legal Acts of The Republic of Latvia[28]

To achieve the targets set in Directive 2009/28/EC and promote the production of electricity from renewable energy sources and high-efficiency cogeneration, the MPC is used as a support instrument. It is covered by electricity users as well as by targeted subsidies from the Government.[29] In order to prevent a rapid growth of electricity prices for households, the Ministry of Economics has undertaken a number of actions, including:

- Since 2012 no new licences have been issued to sell electricity under the MPC framework;
- In 2021 the MPC was fixed at 17.51 EUR/MWh (20.8 USD/MWh);
- A support mechanism was created for energy intensive processing companies;
- Overcompensation for power plants was eliminated by setting a maximum allowable profit margin of 9 per cent;
- A differentiation of the MPC as per the connection power was introduced in January 2018.[30]

On 1 January 2018, a new financing model for the MPC entered into force, which was one of the solutions developed by the Ministry of Economics as part of the Industrial Support Programme, whose objective is to increase the volume of the industrial sector by 30 per cent in three years, with a view to improve the international competitiveness of the Latvian industrial sector and reduce the costs of manufacturing for companies. This was one of the reasons why the MPC financing model changed, being divided into two parts — the fixed power component, which depends on the voltage of the electricity connection, and the variable component, which is proportionate to the electricity consumed.[31]

## LEGISLATION ON SMALL HYDROPOWER

On 1 January 2014, new Natural Resources Tax Law amendments came into force, stating that owners of hydropower plants with a capacity below 2 MW have to pay a natural resources tax. The tax rate was set at EUR 0.00853 (USD 0.01006) per 100 $m^3$ of the water flow through the hydrotechnical structure. Previously, the natural resources tax did not apply to SHP plants. Another contested provision deals with the regulation of the Cabinet of Ministers on the procedure for calculating the amount of water flowing through a given plant. In 2015, the Constitutional Court ruled that these amendments are not anti-constitutional and they have therefore remained in force. Moreover, the Court found that the said provisions were not only meant to ensure more efficient and responsible use of natural resources, but also increase budget revenue, which, in turn, could be used to finance environmental protection measures.[15,32,33,34,35]

The development of SHP in Latvia is also limited due to legislative requirements, including the Cabinet of Ministers Regulation No. 27, which protects fish populations and forbids dam construction for SHP plants.[36,37,38]

## EFFECTS OF CLIMATE CRISIS ON SMALL HYDROPOWER DEVELOPMENT

As a result of climate change, unusual weather conditions, such as low rainfall, have been observed in recent years in Latvia. Operators of SHP plants are obliged to take these changes into account in their activities. They must ensure the ecological flow and, if the flow decreases below the ecological level, electricity production must be stopped. In such a case, the incoming water in the inflow mode must be discharged downstream. The Government has banned SHP operation in the water storage mode during low water periods. Also, water level fluctuations that may affect the spawning of fish are not allowed.[39]

## BARRIERS AND ENABLERS FOR SMALL HYDROPOWER DEVELOPMENT

The key factors hindering SHP developing in Latvia are as follows:

- The administrative procedures required for SHP projects are very complicated and time consuming;
- There is a negative public attitude against SHP, including a strong opinion that the previous terms for SHP development were too generous and have harmed the environment;
- Most of the smaller rivers are listed as no-go areas for SHP development;
- A tax for the water flowing through the hydrotechnical structure applies to SHP plants.

The following factors can be considered as enablers for SHP development in the country:

- Available untapped potential, including old watermill sites;
- Incentive system (FIT, MPC) available for SHP plants.

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# Lithuania

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## KEY FACTS

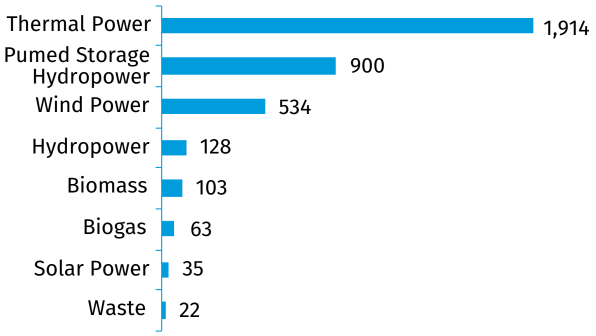
| | |
|---|---|
| **Population** | 2,793,694 (2020)[1] |
| **Area** | 65,286 km² [1] |
| **Topography** | The country's terrain is characterized by lowlands and plains with the highest peak, Aukštojas Hill, reaching 293.8 metres above sea level. Agricultural land covers 52.4 per cent of the total land area; woodland occupies 33.5 per cent of the country's territory and protected areas account for 17.6 per cent. Four per cent of the country's territory is covered with water.[2] |
| **Climate** | Climate varies from marine to continental, with moderate winters and summers and sufficient precipitation. The average temperature is lowest in January (-4.2 °C) and highest in July (18.6 °C). The average annual temperature is 6.9 °C.[2] |
| **Climate Change** | In the 2011–2016 period compared to 1981–2010 the average annual temperature increased by 0.7 °C, indicating a change of local climate.[2] |
| **Rain Pattern** | Precipitation patterns are mostly conditioned by the relief, the position of slopes in relation to the dominating airflows and the distance from the sea. The average annual precipitation rate in Lithuania varies from 800–900 mm on the windward Samogitian Highland slopes to 550–590 mm in the lowlands of central Lithuania. The average annual precipitation rate is approximately 675 mm. The rate of precipitation is sufficient during all seasons and is more intensive during the warm season.[3] |
| **Hydrology** | There are 22,200 rivers in Lithuania, with an average density of 1.18 km/km². The highest density of rivers is in the central part of the country at 1.45 km/km², while the lowest is in the south-eastern part at 0.45 km/km². The largest rivers in the country are the Nemunas (length in Lithuania 475 km, average discharge 540 m³/s), the Neris (235 km, 180 m³/s) and the Šešupė (209 km, 34.2 m³/s). There are 2,585 lakes in the country. The greatest number of lakes can be found in the north-eastern part. Furthermore, there are 1,039 reservoirs (ponds) with an area exceeding 0.5 ha, 340 artificial ponds with a combined area of more than 50 ha and a few canals, which are distributed quite equally across the country.[2,4] |

## ELECTRICITY SECTOR OVERVIEW

The electricity consumption of Lithuania has been growing by a couple of per cent annually. However, this was not the case in 2019, when the annual amount of consumed electricity dropped by 0.3 per cent (to 11.1 TWh) due to an unusually warm winter.[5] The total generated electricity in the same year grew by 13 per cent, amounting to 3.6 TWh (Figure 1).[5] Therefore, almost 68 per cent of consumed electricity was imported. Of the electricity generated domestically in 2019, 58 per cent originated from renewable sources.

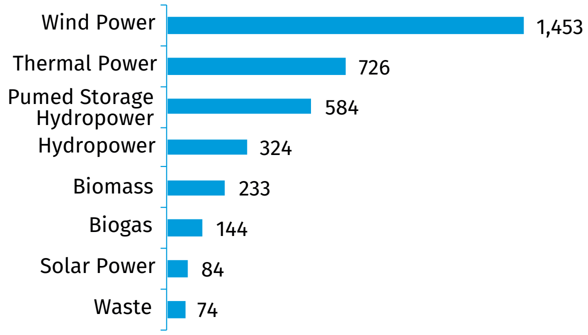
The total installed capacity was 3,699 MW in 2019.[6] More than half of the total, 52 per cent, came from thermal power plants, 24 per cent from pumped storage hydropower, 14 per cent from wind power, 3 per cent from hydropower, 3 per cent from biomass, 2 per cent from biogas, 1 per cent from solar power and 1 per cent from waste incineration (Figure 2). Lithuania is fully electrified.

Figure 1. **Annual Electricity Generation by Source in Lithuania in 2019 (GWh)**




Source: Litgrid[5,6]

Figure 2. **Installed Electricity Capacity by Source in Lithuania in 2019 (MW)**




Source: Litgrid[5,6]

The reliability and security of the energy system of Lithuania is guaranteed by the state-owned company Ignitis Gamyba. It owns and develops strategic electricity generation capacities in Lithuania: the Kruonis pumped storage hydropower plant, the combined cycle unit and reserve power plant in the Elektrėnai Complex, the Kaunas hydropower plant and the Vilnius Power Plant-3.[7] All renewable energy power plants of smaller capacity are owned by the private sector.

The electricity network in Lithuania is modern, able to provide electricity to all consumers also in the event of an accident. Currently, the 400-330-110 kV power transmission grid of Lithuania includes 236 transformer substations and switchyards as well as 7,029 km of power transmission lines.[8] The transmission grid of Lithuania is also well connected to the neighbouring power systems of Latvia, Belarus and the Kaliningrad Region of Russia. During the last decade, two strategic projects were finished, creating international electricity interconnections with Sweden (NordBalt) and Poland (LitPol Link).[8]

A historic change aiming to synchronize the grids between the Baltic States and Continental Europe is planned for 2025. Currently the Lithuanian electricity system is synchronized with the IPS/UPS system that joins Belarus, Russia, Estonia, Latvia and Lithuania into the so-called BRELL ring. The frequency of the Baltic electricity system is centrally managed and coordinated by a centre in Moscow, as a result, in the context of energy integration in Europe, Lithuania, Latvia and Estonia remain an isolated energy island. This energy isolation of the Baltic States in the European Union (EU) will be eliminated once the electricity system has become a full participant in the EU electricity infrastructure and market with synchronous operation with the grid of Continental Europe. After the desynchronization from the IPS/UPS and the synchronization with the Continental Europe Synchronous Area (CESA) via the already existing NordBalt and LitPol links, the Baltic States will start joint operation of a Baltic load-frequency control block.[9]

As a member of the EU, Lithuania follows the European Green Deal objectives and has new goals set by the National Energy and Climate Plan (NECP) for 2030. These include a 45 per cent share of renewable energy in the final energy consumption and a 45 per cent share of renewable electricity.[10] Such an encouragement from the EU is well-timed as the energy strategy currently pursued by the Ministry of Energy of the Republic of Lithuania does not restrict the reliance of the country on electricity imports as long as importing is more cost-effective.[11] However, within the new EU energy policy framework, Lithuania will have to fulfil its obligations to the EU, even if electricity generation from renewable energy sources is more expensive.

In line with the EU Directive 2009/72/EC outlining the common rules for the internal electricity market, the electricity sector in Lithuania has been liberalized. The public companies responsible for the production, transmission and distribution of electricity were established in 2010. Currently, all electricity consumers have the right to freely choose from, and change, independent electricity suppliers as well as to enter into contracts with several suppliers to meet their electricity needs.[12]

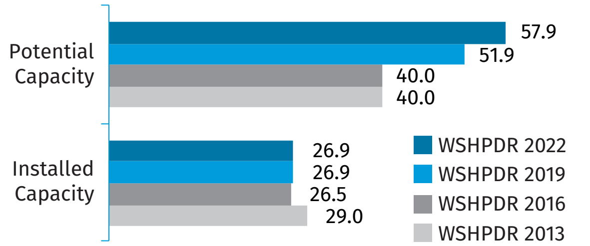
The supervision of the state energy sector in Lithuania is carried out by the National Energy Regulatory Council (VERT). VERT is an independent national regulatory authority (in the EU law sense) regulating activities of entities in the field of energy. Every six months VERT announces the electricity tariffs. The components of the electricity price include the purchase price, the transmission cost, the Public Service Obligations (PSO) tax, the distribution cost, the differential between the public supply price and the actual electricity purchase price as well as the forecasted electricity price from the previous period.[12] In 2021, electricity for end users cost 0.104 EUR/kWh (0.126 USD/kWh) including VAT.[13]

## SMALL HYDROPOWER SECTOR OVERVIEW

In Lithuania, hydropower plants with an installed capacity of less than 10 MW are classified as small hydropower (SHP) plants.

In 2020, there were 97 SHP plants in operation and one non-operational plant in Lithuania, with a total installed capacity of 26.9 MW.[6] These plants generated 53,600 MWh of electricity in 2020.[14] The environmental potential of SHP is estimated at 58 MW, indicating that 46 per cent of known SHP potential in the country has been developed. Compared to the *World Small Hydropower Development Report (WSHPDR) 2019*, the installed capacity remained unchanged, whereas the potential increased by 6 MW (Figure 3). The remaining undeveloped potential of SHP in the country increased from 25 MW to 31 MW as a result of an amendment to the Water Law, which lifted the ban on hydropower development for 170 rivers and their stretches. This amendment implies that the river stretches that were previously not in the protected areas but listed as no-go areas are now open for SHP development.[15]

Figure 3. **Small Hydropower Capacities in the WSHPDR 2013/2016/2019/2022 in Lithuania (MW)**




Source: Kasiulis et al.,[16] *WSHPDR 2013,*[17] *WSHPDR 2016,*[18] *WSHPDR 2019*[19]

The most recently commissioned SHP plant was launched in 2017 (Table 1). As of 2020, no plans for new SHP projects were announced in Lithuania.

Table 1. **List of Selected Recently Commissioned Small Hydropower Plants in Lithuania**

| *Name* | *Location* | *Capacity (MW)* | *Head (m)* | *Plant type* | *Operator* | *Launch year* |
|---|---|---|---|---|---|---|
| Kesiai | Akmenė distr., Agluona River, 56.349267, 22.689263 | 0.05 | 6.2 | Run-of-river | "Viekšnių malūnas" | 2017 |
| Kelmė | Kelmė, Kražantė River, 55.628389, 22.941944 | 0.06 | 3.1 | Run-of-river, old watermill site | A. Jankauskas | 2013 |
| Liubavas | Vilnius distr., Žalesa River, 54.850694, 25.341389 | 0.02 | 3.6 | Run-of-river, old watermill site | "Europos parkas" | 2012 |
| Pagryžuvis | Kelmė distr., Gryžuva River, 55.610111, 23.152444 | 0.10 | 6.4 | Run-of-river | "Gryžuvos vandenys" | 2012 |
| Žerkščiai | Akmenė distr., Venta River, 56.189861, 22.670722 | 0.03 | 1.6 | Run-of-river, old watermill site | K. Stupuras | 2012 |

Source: BALTPOOL,[14] Bilys et al.[20]

The theoretical potential of SHP in Lithuania is estimated at 417 MW, technical at 172 MW, economic at 121 MW and environmental at 58 MW (Table 2). The estimates are based on a scientific study published in 2004, which calculated the primary hydropower resources for all Lithuanian rivers.[21] The protected areas were screened out and excluded using GIS during the Stream Map project funded by the European Commission's Intelligent Energy Europe programme and published in 2017.[22]

Table 2. **Small Hydropower Potential in Lithuania**

| *Potential* | *Capacity (MW)* | *Generation (GWh/year)* |
|---|---|---|
| Theoretical | 417 | 2,093 |
| Technical | 171 | 853 |
| Economic | 121 | 617 |
| Environmental | 58 | 287 |

Source: Kasiulis et al.[16]

There are no off-grid SHP plants in Lithuania. Every new plant must sign an agreement to sell electricity to the national grid. The SHP market in Lithuania is relatively small; nevertheless, some of the owners of SHP plants also have a secondary SHP plant refurbishment business. Many of these business people established the Lithuanian Hydropower Association over 20 years ago.

The public perception of SHP in Lithuania is becoming slightly negative. It is influenced by environmental non-governmental organizations and the Ministry of Environment of the Republic of Lithuania, which encourage removing in-stream hydraulic structures in Lithuania. Thus, the Bražuolė old watermill weir was removed in 2020 and the removal of the Salantai spillway was scheduled for 2021.[23] These structures did not have SHP plants installed, however, due to this movement the future for SHP can become uncertain.

## SMALL HYDROPOWER PROJECTS AVAILABLE FOR INVESTMENT

No inventory of potential sites for SHP development has been made available on the governmental level. Therefore, there is no specific list of SHP sites that are available for development in Lithuania.

A recent scientific study following the recommendations of the European Commission to first upgrade existing hydropower plants or use existing in-stream structures for hydropower development revealed that there are over 700 historic and currently non-powered dam sites in Lithuania that could be utilized for electricity generation. The drawback is that most of these sites can be classified as micro-hydropower (potential capacity of less than 100 kW). Therefore, a feasibility study is needed before recommending them as suitable sites for development. Furthermore, many of such sites are in environmentally protected areas, which limits their retrofitting potential.[16]

## RENEWABLE ENERGY POLICY

Until 2020, the renewable energy policy in Lithuania was shaped by its commitment to the EU, outlining these commitments and initiatives to develop renewable energy in the National Renewable Action Plan (NREAP). In 2015, Lithuania reached its NREAP 2020 target share of energy from renewable sources in final energy consumption ahead of time.

The next step will be the targets for 2030 set in the NECP, as outlined above. As Lithuania has no plans for the development of large hydropower, all strategies, laws and other documents concerning possible hydropower development as well as an environmental approach to hydropower development mainly concern SHP.

Lithuania reached and exceeded its NREAP targets for 2020 for the installed capacity from solar and wind power but did not reach the target set for SHP due to the strict environmental laws. The Government's prioritization of the development of other than SHP renewable energy sources is demonstrated by the fact that the country's target for the installed capacity of SHP set for 2020 in NREAP was 40 MW and the target set for 2030 in NECP is only 27 MW.[10,16]

The support scheme for electricity generation from renewable energy sources in Lithuania can be called a sliding feed-in premium. The monthly average market price of electricity, determined by VERT, is applied to producers of electricity from renewable energy sources via the support mechanism through PSO. The budget of PSO provides the producer with a payment for the difference between the fixed feed-in-tariffs (FITs) for electricity from renewable energy sources and the price of the sold electricity. This means that the level of support from the state depends on the electricity market conditions.[16]

Until 31 December 2020, the fixed tariff for existing SHP plants was 0.059 EUR/kWh (0.071 USD/kWh).[24] Since 2021, existing SHP plants are not being supported by the state via the FIT and are selling generated electricity at market prices. Additionally, the introduction of a water tax for SHP plants is planned.

For new SHP plants, the fixed tariff and promotional quotas are distributed via reverse auctions. At present, promotional quotas are exhausted in Lithuania and the current fixed tariffs for new power plants are no longer applicable. A new support scheme will likely be implemented in the future based on an approved NECP.[16] It is likely that SHP will have to compete for further support with other renewable energy technologies in reverse auctions.

## SMALL HYDROPOWER LEGISLATION AND REGULATIONS

There are no specific governmental plans and programmes targeting SHP. In general, the current legislation and regulations are discouraging for SHP developers.

The Renewable Energy Resources Law of the Republic of Lithuania that came into force in 2011 guarantees a simplified authorization for new renewable energy plants with an installed capacity below 350 kW, except for hydropower.[25] This simplified procedure is available only for damless hydropower plants. Currently, there are no such hydrokinetic power plants operating in Lithuania.

The National Energy Independence Strategy was renewed in 2018 and it sets ambitious targets for 2050.[26] This includes a 100 per cent share of consumed electricity to be generated domestically and an 80 per cent share of renewable energy in final consumption. The goal for 2050 is to generate all electricity from renewable energy sources. To reach this goal, significant development of wind power, biomass and solar power is predicted.

The 2019 amendment to the Water Law prohibits dam construction in protected areas and forbids such constructions if they do not meet the good water status requirements according to Directive 2000/60/EB. According to this law, construction of any SHP plant using an existing in-stream structure in a protected area is also prohibited.[15]

## COST OF SMALL HYDROPOWER DEVELOPMENT

No dam was built for SHP development since the country regained its independence in 1990. Only existing in-stream structures have been retrofitted for electricity generation. The typical cost per kW of installed capacity for such a type of development ranges from EUR 1,000 to EUR 2,000. This cost includes a technical pre-study, permitting and environmental assessment. Additionally, the investor must take into account if a fish pass is needed. Construction of a fish pass increases the cost of the project by up to 20 per cent.[27]

## FINANCIAL MECHANISMS FOR SMALL HYDROPOWER PROJECTS

Subsidies and public support schemes are limited in Lithuania. Therefore, most funding of SHP projects is undertaken by the private sector. For example, in 2013, out of the total investment into the renewable energy sector, 47.3 per cent were loans from banks, 2.4 per cent was support from the EU and 0.2 per cent came from regional and governmental subsidies.[28] Furthermore, it is possible to obtain funding from the EU's structural funds for heritage sites, such as old water mill refurbishments. Still, if this mill is located in an environmentally protected area, there is no possibility to rebuild the old water mill's dam.

## EFFECTS OF CLIMATE CRISIS ON SMALL HYDROPOWER DEVELOPMENT

The already clearly felt impacts of climate change affect SHP now and may affect SHP development in the future. Draughts caused by hot and dry summers are becoming a common phenomenon. During extensive dry periods, SHP plants cease operations due to the lack of water. Such hot and dry periods alternate with flash floods caused by excessive rain. Since Lithuanian SHP plants are all of the run-of-river type, most of the flash flood water cannot be retained in the reservoir and used for electricity generation.

Winters in Lithuania are now warmer, which means that a long-term snow cover does not form, the peak of spring floods is shifting to the winter months and is in decline. All these climate change impacts cumulate and cause inefficient groundwater levels, which in turn reduces the total amount of water in rivers. Currently, there are no estimations carried out to assess how much electricity is not generated due to the impact of climate change and what adaptation measures will be needed in the future.

## BARRIERS AND ENABLERS FOR SMALL HYDROPOWER DEVELOPMENT

Lithuania is a lowland country with modest hydropower resources; however, large parts of the hydropower potential remain untapped. Over more than 100 years of operation, hydropower in Lithuania has proven to be a reliable, efficient and safe source of electricity. Nevertheless, the development of SHP in Lithuania is hindered by strict environmental regulations.

The main barriers for SHP development in Lithuania are:

- Political: There are no governmental incentives, plans or programmes targeting SHP development. Strategies and regulations for the development of renewable energy in Lithuania prioritize other renewable energy sources. Since 2021, the Government does not support SHP plants via the FIT scheme. Additionally, a water tax for SHP plants is planned.
- Environmental: The environmental laws in the country are strict. Retrofitting in-stream structures for electricity generation is prohibited if they are located in protected areas or if they will not ensure a good water status (in line with Directive 2000/60/EC). It was calculated that 39.4 per cent (40.3 GWh/year) of the remaining SHP potential in Lithuania cannot be developed due to the fact that existing in-stream structures are in protected areas.[16] Furthermore, the process of removal of existing in-stream structures has begun in Lithuania.
- Financial: The majority of investments into the SHP sector come from bank loans. Combined with the cancellation of the FIT, this prolongs the payback period, which can make it unsuitable for investors. In the future, it is very likely that hydropower will have to compete for further support with other renewable energy technologies in reverse auctions.

The only enabler in the recent years for SHP in Lithuania that can be listed is:

- Environmental: The amendment to the Water Law that listed 170 rivers and their stretches as no-go areas for hydropower development in Lithuania was lifted in 2019. This implies that the river stretches that were not in the protected zones but were listed as no-go areas are now open for SHP development. Consequently, the remaining untapped potential for SHP in Lithuania increased from 25 MW to 31 MW.[15]

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# Norway

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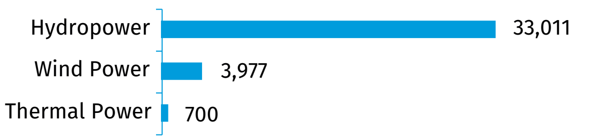
## KEY FACTS

| | |
|---|---|
| **Population** | 5,391,369 (2021)[1] |
| **Area** | 323,808 $km^2$ [2] |
| **Topography** | The terrain is rugged and mountainous, with the Scandes Mountains spanning the length of the country. The highest mountains are in the south with many summits over 2,000 metres above sea level. In many areas the mountains have characteristic steep sides and flat or rounded tops, particularly in the south and far north where the mountains form a high and relatively flat plateau. On the western coastal sides of the plateau the mountains drop precipitously into deep fjords, whereas the eastern inland slopes of the mountains tend to be more gradual. The highest point is Galdhøpiggen at 2,469 metres.[3] |
| **Climate** | Norway covers 13 degrees of latitude and therefore has a large variety in climate and temperature. Temperatures are generally warmer along the south-western coast and colder further inland. The winter period lasts between December and February when mean temperatures can reach as low as -15 °C. Summer lasts from June to August, with average temperatures between 20 °C and 22 °C. During the summer months, the northern regions experience 24-hour sunlight and temperatures can reach above 30 °C.[3] |
| **Climate Change** | In Norway, temperatures are predicted to increase, especially in the winter and in the northern parts of the country. The average annual precipitation will increase by 7–23 per cent by 2100. Whether there is an increase, no change or a slight decline in precipitation will vary according to the season and region. There will be more frequent localized, extreme precipitation events, more rapid onset floods in small rivers and more flooding in densely populated and urban areas. River flow in the winter months will generally increase, while river flow in the summer months will generally decrease. The glacial areas will be reduced and glacial melt and discharge from the glaciers will increase in the short term but decrease in the long term as the glaciers melt away.[4] |
| **Rain Pattern** | There are large differences in the normal annual precipitation in Norway. Western Norway experiences the largest amounts, in excess of 4,000 mm annually. In these areas, frontal and orographic precipitation dominate and most of the precipitation is received during the autumn and winter months (from September to Autumn). Convective precipitation occurs most frequently in the inner districts of Østlandet (south-east) and Finnmark (north-east). Here summer is the wettest part of the year and winter and spring are the driest.[3] |
| **Hydrology** | Depending on the topography, there is a wide variety of water courses in Norway, from larger river basins in eastern and middle regions to smaller and steeper river basins in the mountainous western regions. The longest river is the Glomma, 604 km, and the largest lake is Mjøsa, 362 $km^2$.[3] |

## ELECTRICITY SECTOR OVERVIEW

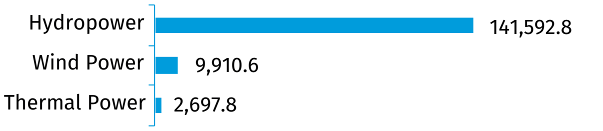
As of 1 January 2021, the installed capacity in Norway was approximately 37,688 MW. Hydropower is the largest source of power generation in the country, with an installed capacity of 33,011 MW (Figure 1). Wind power accounts for 3,977 MW of capacity and thermal power for 700 MW. The country has seen a large increase in development of wind power. In 2020, the total electricity generation in Norway was 154.2 TWh, of which 141.6 TWh, or 92 per cent, was generated from hydropower, with a combination of wind and thermal power generating the remainder (Figure 2).[5]

Figure 1. **Installed Electricity Capacity by Source in Norway in 2021 (MW)**




Source: Statistics Norway[5]

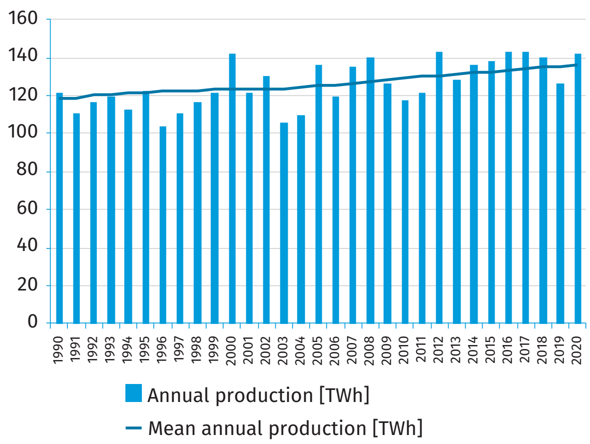
Figure 2. **Annual Electricity Generation by Source in Norway in 2020 (GWh)**




Source: Statistics Norway[5]

Due to the large share of hydropower in the energy mix, the exploitable inflow, i.e., the total amount of the inflow that can be utilized for power production each year, is the most important input factor in the Norwegian power system.[6] The mean annual production of all the hydropower plants installed before the beginning of 2021 was 136,6 TWh. However, there is a significant interannual variation in exploitable inflow for hydropower production in the order of ±20 per cent, affecting the output of the plants (Figure 3).

Figure 3. **Annual Hydropower Generation in Norway in 1990–2020 (TWh)**




Source: Norwegian Ministry of Statistics,[6] NVE

In Norway, both power production and power consumption peak during January. The inflow, however, peaks between April and May. About half of the total hydropower reservoir capacity of Europe, approximately 87 TWh, is located in Norway. Much of this reservoir capacity is used to capture inflow from the summer season for power production during the winter season, to meet the variability of the demand.[7]

In 2021, the total power trading capacity of Norway with other countries increased to approximately 9,000 MW. In May 2021 a new cable to Germany was put in operation and in October 2021 another cable to the United Kingdom, the North Sea Link, became operational.[8] In 2020, Norway imported 4,5 TWh of power and exported 25 TWh.[5]

The electrification rate is 100 per cent. Gross electricity consumption was 133.7 TWh in 2020. The Norwegian Water Resources and Energy Directorate (NVE) estimated in a new report from 2020 that electricity consumption can increase to 163 TWh in 2040.[9] The industry and transport sector will be the largest contributors to the growth.

All grid owners in Norway are obliged to provide a connection to the grid to all new production units. This obligation applies to the existing grid. In areas with many new producers but limited available capacity, the first producer to make a binding agreement with the grid owner is the one that gets connected. All grid owners have the possibility to require the new production units to pay a connection charge according to prevailing regulations.[10]

Before 1991, power producers in Norway were obliged to cover the power demand in specific regions. The power prices were regulated and reflected the long-term marginal costs of the investments in new production capacity that had to take place in order to cover the forecasted future demand in a specific region. In 1991, a new energy act was introduced deregulating the electricity market.[11]

Since then, the Norwegian power market has opened to competition and today Nord Pool Spot organizes the Nordic marketplace for trading electricity. Nonetheless, the Norwegian power industry is dominated by public ownership and a decentralized organizational structure with approximately 10 per cent of annual production sourced from private ownership in the hydropower sector.[5] The wind power sector has approximately two thirds of foreign and private ownership.

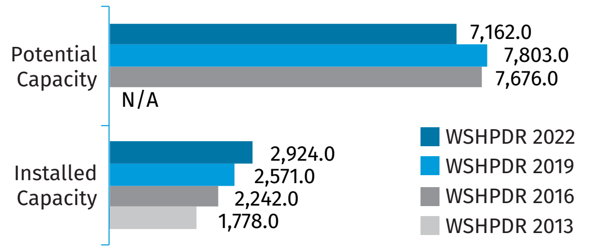
Every day, Nord Pool calculates a day-ahead system price, which is common to the Nordic market. Further Nord Pool calculates prices for the different bidding areas, which takes into account bottlenecks in the transmission system. At the time being, Norway is divided into five different bidding areas and each area can have a different price. The electricity market can be divided into a wholesale market and an end user market. Actors in the wholesale market can be power producers, suppliers and large industrial actors. The suppliers act on behalf of small- and medium-sized end users and industry.[12]

The Government regulates the transmission and distribution tariffs based on the Energy Act and related regulations. The NVE determines annual revenue caps for each individual licence holder. Over a period of time, the revenue shall cover the costs of operation and depreciation of the grid, at the same time giving a reasonable rate of return on invested capital provided effective operation, utilization and development of the network.[13] The total price of electricity for households is made up of the electricity price, grid rent and taxes, with each part constituting approximately one third of the total price.[14] The average price of electricity for households in the first quarter of 2021, excluding taxes and grid rent, was NOK 0.54 (USD 0.06) per kWh. This is 100 per cent higher compared to the same quarter in 2020, which was NOK 0.27 (USD 0.03) per kWh.[14]

## SMALL HYDROPOWER SECTOR OVERVIEW

In Norway, hydropower plants with a total capacity of less than 10 MW are classified as small hydropower (SHP) plants, with some exceptions.[15] SHP installed capacity in 2021 was approximately 2,924 MW. The additional technical potential is estimated to be 4,238 MW, of which approximately 1,209 MW (29 per cent) is calculated from known projects that are under construction, have been given licences or have applied for licences.[7,16] This indicates that almost 60 per cent of the available potential capacity remains untapped and approximately 41 per cent has already been developed. Compared to the *World Small Hydropower Development Report (WSHPDR) 2019*, the installed SHP capacity increased by roughly 14 per cent, whereas the potential decreased by 8 per cent (Figure 4). The decrease in the potential estimate is due to the revised upwards cost of 0.6 USD/kWh for SHP plants and the fact that some areas with hydropower potential have been protected according to nature diversity act.

Figure 4. **Small Hydropower Capacities in the WSHPDR 2013/2016/2019/2022 in Norway (MW)**




Source: NVE[7,16] *WSHPDR 2013*,[17] *WSHPDR 2016*,[18] *WSHPDR 2019*[19]

As of 2021, there were 1,682 hydropower plants in the country, 1,338 (80 per cent) of which were SHP plants (Table 1). More than 80 per cent of these are run-of-river. Combined, they contribute approximately 9 per cent of the installed hydropower capacity in Norway (Table 2). The most significant increase in new hydropower plants in Norway was in the period after World War II and until the mid-1980s. Many of the older SHP plants were closed down due to the interconnection of the grid and the economic viability of new power plants. After the deregulation of the electricity market in 1991 there was more or less a stagnation in the construction of new hydropower plants due to overcapacity and low prices on electricity. This has, however, changed during the last decades, which have seen an increase in the development of new SHP projects. Thus, 936 out of the existing 1,338 (70 per cent) SHP plants in Norway were built during the period from 2000 to 2020.[7]

Table 1. **List of Selected Operational Small Hydropower Plants in Norway**

| *Name* | *Location* | *Capacity (MW)* | *Head (m)* | *Plant type* | *Operator* | *Launch year* |
|---|---|---|---|---|---|---|
| Valdra | Etne | 3.5 | 280.3 | Run-of-river | Valdra Kraftverk AS | 2020 |
| Fivelandselva | Sauda | 3.1 | 244.7 | Run-of-river | Fivelandselva Kraft AS | 2020 |
| Storåvatn 1 | Rødøy | 8.0 | 442.5 | Reservoir | SMISTO Kraft AS | 2020 |
| Storlia | Eidfjord | 8.5 | 84.5 | Run-of-river | Statkraft Energi AS | 2020 |
| Nørlandselva | Masfjorden | 4.9 | 129.1 | Run-of-river | CK Kraftholding Vest AS | 2020 |
| Kjeldalselva | Storfjord-Omasvuotna-Omasvuono | 5.0 | 233.7 | Run-of-river | Kjeldalselva Kraft AS | 2020 |
| Gudåa | Meråker | 4.6 | 248.0 | Run-of-river | Meraker Kraft AS | 2020 |
| Sædalen | Vaksdal | 4.4 | 160.0 | Run-of-river | Sædalen Kraft AS | 2020 |
| Øvre Leiråga | Rana | 8.5 | 183.3 | Run-of-river | MIP Miljøkraft AS | 2020 |
| Nedre Leiråga | Rana | 3.15 | 34.7 | Run-of-river | MIP Miljøkraft AS | 2020 |
| Salhuselva | Steigen | 3.3 | 195.0 | Run-of-river | Salhuselva Kraft AS | 2020 |
| Botna | Sogndal | 1.9 | 332.5 | Run-of-river | Botna Kraft AS | 2020 |
| Tverrdalselvi | Sogndal | 6.0 | 225.3 | Run-of-river | Tverrrdalselvi Kraft AS | 2020 |
| Osdalen | Volda | 4.3 | 176.5 | Reservoir | Tussa Energi AS | 2020 |
| Skeidsflåten | Sogndal | 4.8 | 82.2 | Run-of-river | Skeidsflåten Kraft AS | 2020 |
| Bjørgelva | Sørreisa | 2.4 | 232.3 | Run-of-river | Bjørgelva Kraft AS | 2020 |
| Nessane | Høyanger | 8.6 | 263.2 | Run-of-river | Nessakraft AS | 2020 |
| Mølnåa | Selbu | 1.5 | 131.7 | Run-of-river | Selbu Energiverk AS | 2020 |

| Name | Location | Capacity (MW) | Head (m) | Plant type | Operator | Launch year |
|---|---|---|---|---|---|---|
| Løkkebø | Kinn | 2.2 | 151.9 | Run-of-river | Løkkebø Kraftverk AS | 2020 |
| Liemyr | Sirdal | 1.4 | 31.0 | Run-of-river | Sirdal Kraft AS | 2020 |

Source: NVE[7]

Table 2. **Operational Hydropower Plants by Size and Mean Annual Production in Norway in 2021**

| Plant size | Number of plants | Installed capacity (MW) | Generation (TWh) |
|---|---|---|---|
| <1 MW | 575 | 186 | 0.8 |
| 1–10 MW | 763 | 2,738 | 10.6 |
| 10–100 MW | 261 | 9,814 | 42.9 |
| >100 MW | 83 | 20,273 | 82.3 |
| **Total** | **1,682** | **33,011** | **136.6** |

Source: NVE[7]

At the end of 2020, 64 SHP plants were under construction and further 267 licensed projects had not yet expired or been realized (Table 3). The potential capacity from known projects that are under construction, received licences or have applied for licences is estimated at 1,209 MW.[15] While there is an economic potential for an additional 3,029 MW, this figure may be misleading as a large share of these sites are unlikely to be granted a licence or the developer has withdrawn the application (Table 4).

Table 3. **List of Selected Planned Small Hydropower Projects in Norway**

| Name | Location | Capacity (MW) | Plant type | Developer | Planned launch year | Stage of development |
|---|---|---|---|---|---|---|
| Fennefoss | Evje og Hornes | 9.5 | Run-of-river | Agder Energi Vannkraft AS | 2023 | Under construction |
| Røvatn | Narvik | 5.4 | Run-of-river | Ballangen Energi AS | 2022 | Under construction |
| Dyrkolbotn | Alver | 2.7 | Run-of-river | Nipo Kraft AS | 2022 | Under construction |
| Dalsfos Øst | Kragerø | 1.4 | Run-of-river | Skagerak Kraft AS | 2022 | Under construction |
| Tverrelvi | Voss | 4.5 | Run-of-river | NGK Utbygging AS | 2022 | Under construction |

Source: NVE[16]

Table 4. **List of Selected Small Hydropower Projects Available for Investment in Norway**

| Name | Location | Potential capacity (MW) | Type of site (new/refurbishment) |
|---|---|---|---|
| Vetle Svardalen | Luster | 4.9 | New |
| Storelvi Øvre | Luster | 5.0 | New |
| Elde | Bremanger | 1.2 | New |
| Tokheimselva | Ullensvang | 9.1 | New |
| Lauvstad | Drangedal | 2.2 | New |

Source: NVE[16]

## RENEWABLE ENERGY POLICY

In 2003, the Government prepared a strategy to increase the development of SHP plants to contribute to new power generation and development of rural areas.[20] Many local developers of SHP plants were not familiar with the process of establishing and operating a new power plant. The focus areas in the strategy included simplification of the licensing process, tax-based economic incentives and establishment of a certificate market for new power production.

Since 1 January 2012, Sweden and Norway have had a common market for electricity certificates.[13] It is based upon the Swedish electricity certificate scheme, which has been in place since 2003. The goal was to increase the annual renewable electricity production in both countries combined by 28.4 TWh by the end of 2020, representing approximately 10 per cent of the current electricity production of the two countries. Sweden has set an additional goal of 18 TWh for the 2020–2030 period, while Norway has not set a new goal after 2020. Norwegian projects which are commissioned during 2021 can participate in the market. Between the start of the certificate scheme in 2012 and the end of March 2021, the scheme has contributed 46.4 TWh of new renewable production between the two countries and hence surpassed its goal. There are still 14.1 TWh under construction, planned to be commissioned during 2021.[13]

The common electricity certificate market is due to continue until the end of 2035. Within the electricity certificate scheme, approved power plants receive one certificate for each MWh they produce over a period of 15 years. Hence, owners of approved plants have two products on the market: electricity and certificates that can be sold independently of each other. From 2012 to 2018, Norwegian producers entitled to certificates received an average of approximately 15 EUR (17 USD) per MWh (based on the average spot price of certificates).[21] Due to the large amount of production in the market and the associated quota obligations, the price has fallen to nearly zero in recent years. This support scheme is technology neutral, which means that all energy sources defined as renewable energy qualify for participation in the electricity certificate market. As of May 2021, 269 new SHP plants in Norway were granted the right to participate in the electricity certificate market, which is included in the goal of 28.4 TWh. To be eligible for participation in the market, the hydropower plant must be built in accordance with the licence and commissioned after 1 January 2012.

## SMALL HYDROPOWER LEGISLATION AND REGULATIONS

Licensing procedures differ depending on many variables, with project size and expected impact being the most important ones. All applications for licences must come with a sufficient description of the project's impact on nature. This is often done through an environmental impact assessment (EIA). An environmental report shall be made for SHP projects, which describes the natural conditions in and along the impacted river stretch. Smaller projects with lesser environmental impact may be handled through simplified procedures.

With some exceptions, the municipality issues licences for SHP plants with capacity of up to 1 MW. The Ministry of Petroleum and Energy (OED) has delegated to NVE to license hydropower projects with capacity of up to 10 MW. After the application is received, a public hearing of the application and EIA, or environmental report in case of SHP projects, takes place. The licence decision can be appealed to OED. NVE's environmental section ensures that the construction, operation and maintenance of hydropower plants are in accordance with the regulations established in the concession. NVE is also responsible for the supervision of dams and appurtenant structures, including approval of plans for construction and rehabilitation and administration of the legal framework for dam safety, also including the development of new technical guidelines.

In nearly all business models between developers and owners of water rights for SHP projects, a rental period of 40 years is common. After 40 years, the contracts must be renewed, expired or terminated. The forty-year timeframe corresponds with the normal economic lifetime, although the estimated lifetime of many components in the SHP plant is shorter. In many contracts, the owner of the water rights (e.g., farmers) are given an option of buying the SHP plant for a fixed price. The most frequently used models are:

- Lending the rights: Lending the rights is a clean model where different kinds of risk sharing can be used. Common for both alternatives is the fact that there is no risk for negative cashflow for the owner of the rights:
- Fixed rent per year, normally based on estimated production in GWh;
- Fixed rate per kWh, risk is shared on the electricity price.
- Share the profit: There are many optional fractions when it is decided to share the profit. A commonly used fraction is the 50/50 principle.
- Fraction of sales: An agreed fraction of the income/sales is close to the 'Lending the rights' in principle, but the owner of the rights is fully exposed to the risk in generation and in electricity prices.
- Private developers: Landowners, farmers and groups of such may organize and develop SHP plants as private business.
- Selling the rights: In very rare situations, the rights to waterfalls have been sold.[22]

Hydropower plants are eligible to get guarantees of origin for their production. There is a range of different products in the scheme of guarantees of origin with different prices, e.g., unsubsidized power.

## COST OF SMALL HYDROPOWER DEVELOPMENT

NVE calculates levelized cost of energy (LCOE) for energy projects.[23] For SHP plants, LCOE is calculated at 0.042 USD/kWh and it is expected to remain unchanged in 2030. Operation and maintenance cost is set at 0.005 USD/kWh. The economic lifetime is set at 40 years and discount rate at 6 per cent. In comparison, LCOE for hydropower plants larger than 10 MW of installed capacity is 0.047 USD/kWh.

## EFFECTS OF CLIMATE CRISIS ON SMALL HYDROPOWER DEVELOPMENT

The hydropower system in Norway has in the last decades experienced more inflow due to increased precipitation, which has resulted in more power production. The increased inflow has been highest during winter and the snowmelt flow decreased. In the future, the inflow is expected to further increase.[4] Most of the increased inflow can be utilized for hydropower production. The inflow during winter will increase, but there will be more variations between the years. Towards the end of the century there will be more rain during the winter. But there will also be winters with little inflow compared to present day levels. The gap between the driest and wettest winters will nearly double from today's level towards the end of the century. Areas with glaciers will experience an increase in inflow due to the melting of the glaciers, until it is reduced after the glaciers have melted. The inflow during summer will decrease due to reduced melting of snow and glaciers. With higher temperatures there will be more evaporation.[24]

## BARRIERS AND ENABLERS FOR SMALL HYDROPOWER DEVELOPMENT

While the country is well-known for its efficient SHP projects, there are certain issues that might affect the future development of the sector:

- There are areas in Norway which have problems with access to both to the local grid and to the central transmission system;
- The cost of developing new wind power has decreased in the last years and it is still expected to decrease in the future, making wind a more economically viable option than SHP.

The following points summarize the main enablers for further SHP development that have been identified:

- Norway has experienced a high amount of development of new SHP projects in the last decade due to the re-regulated electricity market and favourable market conditions. Further development of SHP can be expected.
- There are expectations of higher electricity demand due to electrification and new power-intensive industries.

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# Sweden

International Center on Small Hydropower (ICSHP)

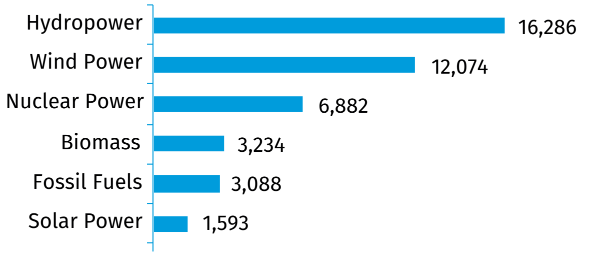
## KEY FACTS

| | |
|---|---|
| **Population** | 10,353,442 (2020)[1] |
| **Area** | 450,295 km$^2$ [2] |
| **Topography** | The terrain of Sweden could be categorized with three major regions. Götaland in the south is characterized with highlands in its interior and low-lying plains along the southern coast. The central region, Svealand, is mostly lowlands historically pushed down by glaciers, with the exception of some highlands to the west along the border with Norway. Norrland in the north, the largest and least populated region, has the highest elevations, predominately covered by the Scandinavian Mountains. This region includes Mount Kebnekaise which, at 2,111 metres, is the highest peak in the country, and is located in the far north beyond the Arctic Circle.[2] |
| **Climate** | The climate in the south of Sweden is temperate and relatively milder than other places on the same latitude. In the summer, average temperatures in the south are between 15 °C and 17 °C and in the winter, temperatures typically remain between -5 °C and 0 °C. The subarctic climate in the north of Sweden is more severe than in the south. Summers are very short and cool and winters are long and very cold. In the interior of the Norrland region, winter temperatures fall to between -40 °C and -20 °C with harsh winds and only a few short hours of daylight.[2] |
| **Climate Change** | Effects of climate change have been experienced in the last few decades in Sweden, with a general warming of average temperatures since the late 1980s. Winter temperatures have increased by between 1 °C and 2 °C, while summer temperatures are also increasing but at a slower rate. Warming temperature trends are expected to continue into the upcoming decades. Additionally, a noticeable increase of precipitation has been occurring since the 1970s with a more dramatic increase since the beginning of the 21st century. In the upcoming decades, continuous increase of precipitation gives concern of increased landslides and erosion.[3] |
| **Rain Pattern** | Precipitation happens throughout the year, however, the seasons with the most precipitation are summer and autumn. Average annual rainfall throughout the country is between 500 mm and 800 mm, but varies between regions. Lower amounts of precipitation are experienced in the eastern part of the country and on the islands along the Baltic Sea with an annual average of 400 mm. In the mountains, especially in the north-west, annual precipitation is the highest, averaging between 1,500 mm and 2,000 mm. In the south-west, most wet areas receive from 1,000 mm to 1,200 mm of rainfall per year.[4] |
| **Hydrology** | Most of the country's many rivers begin in the Scandinavian Mountains in the north and flow to the south or south-east. The longest is the Klar-Göta River, which begins in Norway and crosses the border to flow south-east through Sweden. Other major rivers are the Muonio and Torne in the north, which form the border with Finland, and the Dal, which flows south-east, cutting through the central Svealand region. The country also has many considerable lakes, which rivers drain into, the largest one being Lake Väner at 5,650 km$^2$, located in the south-west.[2] |

## ELECTRICITY SECTOR OVERVIEW

In 2021, total installed capacity in Sweden was 43,669 MW, of which approximately 77 per cent was with renewable energy sources. Hydropower accounted for 16,286 MW (37 per cent), wind power for 12,074 MW (28 per cent), nuclear power for 6,882 MW (16 per cent), biomass for 3,234 MW (7 per cent), fossil fuels, mostly in the form of gas turbines and cogeneration, for 3,088 MW (7 per cent), solar power for 1,593 MW (4 per cent) and waste for 512 MW (1 per cent) (Figure 1). The fastest growing energy sources in recent years have been wind and solar power. Installed capacity of wind power doubled in six years from just over 6,000 MW in 2015 and surpassed nuclear power as the second largest capacity in 2018. In the same six years between 2015 and 2021, solar power grew from 126 MW to 1,593 MW, over 1,100 per cent. In contrast, nuclear power and fossil fuels have been steadily decreasing during the same years.[5]

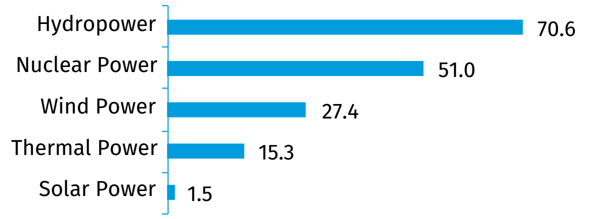
Figure 1. **Installed Electricity Capacity by Source in Sweden in 2021 (MW)**




Source: Swedenergy[5]

In 2021, total electricity generation in Sweden was 165.8 TWh. Hydropower generated 70.6 TWh (42 per cent), nuclear power generated 51.0 TWh (31 per cent), wind power generated 27.4 TWh (17 per cent), thermal power, including biomass and fossil fuels, generated 15.3 TWh (9 per cent) and solar power 1.5 TWh (1 per cent) (Figure 2). Sweden was a net exporter for the year, exporting 33.9 TWh, the majority to Finland, and importing 8.3 TWh, the majority from Norway. Domestic electricity usage was 139.8 TWh and 11.5 TWh were considered losses.[5]

Figure 2. **Annual Electricity Generation by Source in Sweden in 2021 (TWh)**




Source: Swedenergy[5]

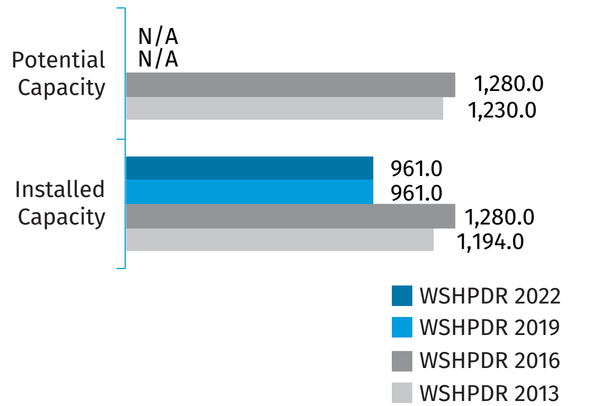
The electrification rate in Sweden is 100 per cent. The electricity sector has been liberalized since 1996, meaning that consumers can choose between several suppliers.[6] While there are many companies that supply electricity in Sweden, the largest companies that, combined, produced over 73 per cent of electricity in 2021 are Vattenfall, E.ON, Fortum, Sydkraft, Statkraft and Skelleftea.[5] Electricity distribution is also liberalized, with over 170 companies, but the same major producers are typically the major distributors. Transmission of electricity is fully state-owned with one company, Svenska kraftnät, responsible for the country's 564,000 kilometres of transmission lines. The transmission lines cross national borders at several locations so that there are interconnections with Norway, Finland, Denmark, Germany, Poland and Lithuania.[6]

The electricity market of Sweden is deregulated and electricity is traded on the Nord Pool market along with the neighbouring countries. The Swedish Energy Markets Inspectorate (SEMI) is the industry regulator responsible for supervising compliance with laws and regulations. The price of the traded electricity can differ depending on operational parameters and the mix of generating capacity. There are four bidding areas (north to south) that display slightly different prices since most of the generating capacity is found in northern Sweden, while much of the demand is found in the south.[6] The average Nord Pool system price for the year of 2020 was 10.95 EUR/MWh (11.76 USD/MWh).[7] Consumer prices of electricity in Sweden include the electricity base price, an energy tax and a value-added tax (VAT). Final prices vary with usage and in 2021 prices typically ranged between 0.17 EUR/kWh (0.18 USD/kWh) and 0.26 EUR/kWh (0.28 USD/kWh).[8]

## SMALL HYDROPOWER SECTOR OVERVIEW

The definition of small hydropower (SHP) in Sweden is up to 10 MW. The installed capacity of SHP is estimated to be 961 MW.[9] These most recent accurate data for installed capacity are from 2016, but as of 2022, the Swedish Hydropower Association (SVAF) confirmed that installed capacity remained close to 1,000 MW. Exact total SHP potential capacity is unknown. While SVAF estimates that total potential could possibly be up to double of current capacity, no comprehensive feasibility study has been carried out to confirm this.[10] Compared to the *World Small Hydropower Development Report (WSHPDR) 2019,* the installed capacity has remained the same due to lack of an updated exact amount and potential capacity has remained unknown (Figure 3).

Figure 3. **Small Hydropower Capacities in the WSHPDR 2013/2016/2019/2022 in Sweden (MW)**




Sources: Eurostat,[9] *WSHPDR 2019,*[11] *WSHPDR 2016,*[12] *WSHPDR 2013*[13]

The first hydropower plant in Sweden was built in the mid-1880s. Between the beginning of the 20th century and the early 1970s, the country saw a steady expansion of hydropower capacity, which provided a secure power supply for industry and also supported the electrification of the country. In 1975, the Government formulated a target of 66 TWh of annual contribution from hydropower to the energy balance by 1985, which was achieved in 1984.[11] Since then, total installed capacity of hydropower has generally levelled out with slight increases and the average generation of hydropower between the years 1984 and 2021 was 67.1 TWh.[5]

As of 2022, there were 1,959 SHP plants in Sweden (Table 1). The combined generation was just under 5 TWh, indicating that approximately 7 per cent of electricity generated from hydropower in 2021 was using SHP. While many of the large hydropower plants are located towards the northern region, most of the SHP plants are located closer to consumption in the southern region. Most of the production occurs between November and April.[10]

Table 1. **Number of Small Hydropower Plants in Sweden by Capacity**

| *Capacity (MW)* | *Number of plants* |
|---|---|
| 0 – 0.125 | 1,030 |
| 0.125 - 1.50 | 680 |
| 1.50 - 10 | 249 |
| **Total** | **1,959** |

Source: SVAF[10]

While there are currently no government targets or policies explicitly aimed at increasing the capacity of SHP in the country, there are also no specified limitations for development as long as new projects comply with environmental standards, construction regulations and dam safety requirements. There has been little expansion of the number of SHP plants in recent years and it does not seem likely that there will be a drastic increase of plants in the near future. Instead, installed capacity will most likely be increased through the modernization and improved efficiency of existing plants, as recognized by SVAF and the Swedish Energy Agency.

For a country with a long history of hydropower, the current focus is how to align existing hydropower plants with new legislation concerning environmental adherences. Large hydropower supplies a significantly higher percentage of electricity to the grid and serves as a balancing capacity for the power system.[14] Conversely, SHP has a very limited balancing capacity, but is, nonetheless, planned to remain as a contributor to the grid. This is because it helps maintain energy security while having a less substantial impact on the natural watercourses.[10] Another motivation for preserving the country's SHP is that many of the plants are considered important to Swedish cultural heritage.[15]

In order to comply with contemporary environmental standards, a number of fauna passages or bio-channels have been installed around SHP plants. These have the potential to reduce the fragmentation in the river caused by dam construction. However, as a result of many SHP plants being constructed many years ago, it is common that new ecosystems have since been established around them. This has caused owners of plants and related stakeholders to raise concerns of the true net benefits of these installations.

Despite the acknowledgement of the contribution to the energy system that SHP provides, due to, among other things, the old permits linked to many of the existing plants, many organizations are not actively promoting the development of SHP as a better alternative to large hydropower. Environmental organizations, such as the Swedish Society for Nature Conservation, are actively supporting environmental improvements such as bio-channels to existing plants as well as the eco-labelling scheme, Bra Miljöval (Good Environmental Choice) and the environmental funds generated from the purchase of eco-labelled products.[11,15]

## RENEWABLE ENERGY POLICY

Sweden has long been committed to increasing the share of renewable energy in the energy sector. Out of all International Energy Agency (IEA) member states, Sweden has the second largest renewable energy share, with only Norway having a share slightly higher. Sweden was the first country to adopt a carbon tax in 1991 and has provided incentives for renewable energy production beginning in 2003 with the electricity certificate system. This is a market-based support system of certificates that supports investments in renewable energy aimed to help reach the goal of 50 per cent of electricity consumption to be with renewable energy by 2020, a goal that was reached. Norway joined the electricity certificate system in 2012 so that certificates can be easily traded in either country. Originally, the certificate system was to be in effect until 2020, but it was extended to 2030 in 2016 and then further extended to 2045 in 2017.[6]

In the 2016 Energy Agreement, targets were set regarding renewable energy. These targets included 100 per cent renewable energy in electricity generation by 2040 and to have a net-zero carbon economy by 2045. It also aimed for another 18 TWh of renewable electricity production to be added through the electricity certificate system between 2020 and 2030. The 2017 Climate Policy provided further framework for achieving these targets, and the Integrated National Energy and Climate Plan of 2020 further elaborated on the country's goals, specifying the roles which different stakeholders would play in achieving these targets.[6,16]

## SMALL HYDROPOWER LEGISLATION AND REGULATIONS

There are three overarching goals set by the Government in relation to hydropower in Sweden. The first relates to the concession rights — water operators in Sweden should have concessions that are in line with the Swedish environmental legislation and European Union (EU) regulations. The second goal relates to the production with the aim to maintain both production and balancing capacity for hydropower in Sweden. The third goal is to ensure the efficient operation of hydropower.[11]

The water concessions that are linked to the hydropower power in operation today are in most cases based on older legislation. For example, according to a government report from 2014, more than 90 per cent of all hydropower concessions were granted prior to 1983 and, thus, the concession rights are based on the Water Law of 1918 or an even older legislation.[17] Many older SHP plants in Sweden have now been phased out of the Swedish green certificate support scheme. To be entitled to operate for the next 15 years, the plants are required to undergo a total refurbishment of all essential parts. In March 2018, a broad political agreement was reached between the Government of Sweden and several of the parties in the opposition with the aim of addressing the uncertain situation whereby SHP plants were facing the need to re-apply for concessions linked to potentially high legal and consultancy costs. The political agreement means that a more pragmatic approach has been chosen, according to which all hydropower in Sweden should operate based on modern permits, but existing power plants with old permits will have an opportunity to revise their permits instead of re-applying.[18] This opportunity will reduce the need for supporting documentation such as environmental impact assessments (EIA) and reduce administration requirements. This could potentially mean that new SHP initiatives could be taken.

To address the environmental impact of hydropower plants, legislations were passed in 2014 and 2019. In 2014, the National Energy Agency along with the Swedish Agency for Marine and Water Management raised the need for environmental standards to be put on hydropower plants, leading to legislation to be passed requiring it. This meant that existing plants would have to be modernized to adhere to these standards, including installing bio-channels and other mechanisms to maintain the ecological balance of the waters, many of which could be expensive. Consequently, in 2019 a new national plan was agreed upon. The Hydroelectric Environment Fund was created, which can grant plant operators up to 85 per cent of the costs of implementing the required updates as well as for licence revision.[19]

## BARRIERS AND ENABLERS FOR SMALL HYDROPOWER DEVELOPMENT

The major barriers to SHP development in Sweden include:

- There are costs involved in providing and generating the supporting documentation for new concession rights, and documentation requirements have been independent of the size of SHP plants;
- There are new strict environmental standards on hydropower plants and mechanisms to adhere to them could be costly.

The major enablers for SHP development in Sweden include:

- The green certificate scheme has been extended until 2045 and provides market-based incentives for hydropower development;
- It is recognized that modernizations of existing plants could considerably increase installed capacity and the Government is committed to ensure the further operation and modernization of these existing plants;
- Hydropower is considered a very important energy source and Sweden acknowledges the long tradition of SHP.

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# United Kingdom of Great Britain and Northern Ireland

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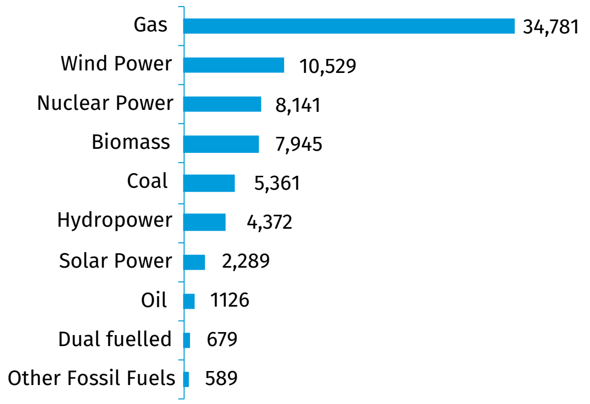
## KEY FACTS

| | |
|---|---|
| **Population** | 67,215,293 (2020)[1] |
| **Area** | 248,531.52 km[2 2] |
| **Topography** | The United Kingdom of Great Britain and Northern Ireland (UK) is divided into the hilly regions of the north, west and south-west and low plains of the east and south-east. Scotland in the north is almost entirely rugged, characterized by the northern Scottish Highlands and the Southern Uplands that are separated with a narrow Midland Valley region. Northern Ireland is a western continuation of the topography of Scotland but elevations tend to be lower. Wales also has a predominately rugged terrain due to the northern and central Cambrian Mountains. England is lower and flatter in comparison with the exception of the Pennines Mountains towards the north. The southern and south-eastern regions are mostly low-lying plains. Of the top 10 highest peaks, all are located in either Wales or Scotland. The highest point is Ben Nevis reaching 1,343 metres located in the Scottish Highlands.[2] |
| **Climate** | The UK has a temperate climate, with both polar and tropical maritime influenced weather. The polar winds in the winter cause cold, sometimes below 0 °C temperatures in Scotland, while southern England experiences slightly more moderate winters. Tropical maritime and continental winds in the summer cause temperatures to often reach 32 °C, especially in the south.[2] |
| **Climate Change** | The UK has already experienced increasing temperatures with an average increase of 0.8 °C since the 1960s and all 10 of the hottest recorded years have been since 1990. In the upcoming decades heat waves are expected to become more prevalent and intense, the rise in sea level caused by melting artic ice will cause increased coastal erosion and rainfall patterns are expected to become more dramatic with a drier dry season and a wetter wet season with concerns of flooding.[3] |
| **Rain Pattern** | The mountains of Wales, Scotland, the Pennines in northern England and the moors of south-western England are the wettest parts of the country. Some of these places receive over 5,000 mm of rainfall annually making them some of the wettest locations in Europe. Other parts of the country can be very dry with the southern and south-eastern regions receiving an annual average of less than 800 mm. The wettest months tend to be October and December while the driest months are May and June, but rainfall can be evenly distributed throughout the year in some areas. In winter months, especially in the northern regions, precipitation often comes as snow.[2] |
| **Hydrology** | The longest river is the Severn (354 km) flowing through both Wales and England and the second longest is the Thames (346 km).[5] Other major rivers in England and Wales include the Humber, Tees, Tyne, Great Ouse, Mersey and Trent Rivers. The river system of Scotland is largely separate from that of England characterized by many shorter, faster flowing rivers. The two major rivers of the Midland Valley of Scotland are the River Clyde and the River Forth. The longest river in Scotland is the River Tay (188 km).[2] As a result of its industrial history, the UK has an extensive system of canals, mostly built in the early years of the Industrial Revolution. |

## ELECTRICITY SECTOR OVERVIEW

Electricity infrastructure in the United Kingdom of Great Britain and Northern Ireland (UK) is well developed with a 100 per cent electrification rate.[4] In 2020, total installed capacity was 75,810 MW, of which approximately 30 per cent was with renewable energy and 70 per cent with non-renewable energy. Gas-fired plants accounted for 34,781 MW (46 per cent), wind power accounted for 10,529 MW (14 per cent), nuclear power for 8,141 MW (11 per cent), biomass for 7,945 MW (11 per cent), coal for 5,361 MW (7 per cent), hydropower for 4,372 MW (6 per cent), solar power for 2,289 MW (3 per cent), oil for 1,126 MW (1 per cent) and the remaining 1 per cent was split between 679 MW of dual fuelled plants and 589 MW of other fossil fuels (Figure 1). Total installed capacity has been decreasing since its peak of 90,393 MW in 2010, almost entirely due to the closing of several coal plants amounting to over 18,000 MW and oil plants amounting to over 4,000 MW. Capacity of renewable energy sources has been increasing during the same time, although at a lower rate, with the largest increases in wind (more than 8,000 MW) and solar power (more than 2,000 MW).[5]

Figure 1. **Installed Electricity Capacity by Source in the United Kingdom in 2020 (MW)**

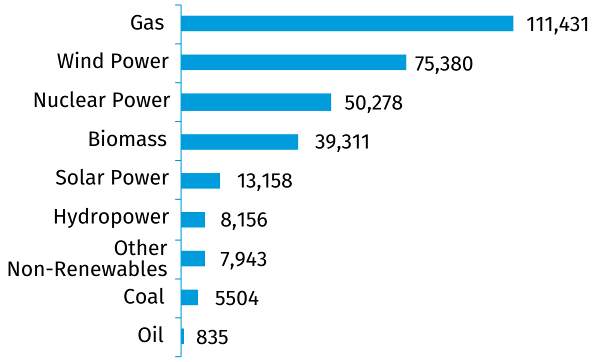



Source: DUKES[5]

In 2020, total electricity generation was 311,997 GWh, of which renewable energy (including renewable thermal energy) accounted for 43 per cent. Gas-powered plants generated 111,431 GWh (36 per cent), wind power generated 75,380 GWh (24 per cent), nuclear power 50,278 GWh (16 per cent), biomass 39,311 GWh (13 per cent), solar power 13,158 GWh (4 per cent), hydropower 8,156 GWh (3 per cent), other non-renewable sources 7,943 GWh (2 per cent), coal 5,504 GWh (over 1 per cent) and oil 835 (less than 1 per cent) (Figure 2). To satisfy a total demand of approximately 329,900 GWh in 2020, the UK imported 17,900 GWh worth of electricity from other parts of Europe. Of the electricity generated, the residential sector consumed 33 per cent, industry consumed 25 per cent, the commercial sector 20 per cent, the energy industry 15 per cent (which includes electricity used for generation and 8 per cent in losses), and the remaining 7 per cent was consumed by public administration, transport and agriculture (Figure 3).[5]

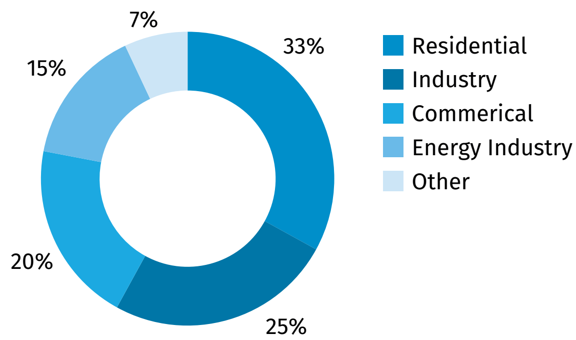
The electricity sector in the UK is fully liberalized, a process that began with the Electricity Act of 1989 and completed in the following years. Electricity suppliers buy electricity from the wholesale market or directly from generators and arrange for it to be delivered to the end customers, who can choose any supplier to provide them with electricity. The market is regulated by the Gas and Electricity Markets Authority, which operates through the Office of Gas and Electricity Markets (Ofgem).[6] Ofgem issues companies with licences to carry out activities in the electricity and gas sectors, sets the levels of return which the monopoly networks companies can make and decides on changes to market rules.

Figure 2. **Annual Electricity Generation by Source in the United Kingdom in 2020 (GWh)**




Source: DUKES[5]

Figure 3. **Electricity Consumption by Sector in the United Kingdom in 2020 (%)**




Source: DUKES[5]

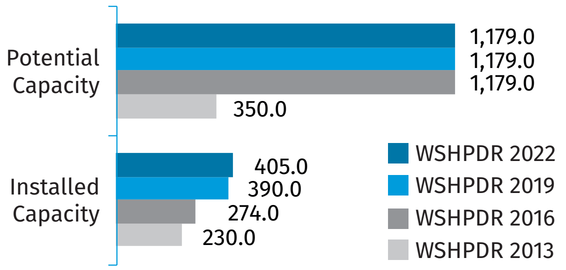
Currently, there are approximately 40 companies in the UK supplying electricity. For several years, there were six major companies that dominated the industry collectively known as the Big Six: EDF, Centrica (British Gas), E.ON, RWE nPower, Scottish Power and SSE plc. However, in 2019 E.ON acquired nPower and the Ovo Group acquired SSE and thus some refer to them now as the Big Five, but an official name is ungiven.[7] National Grid plc is responsible for the transmission network in England and Wales. In Scotland, the grid is split between two separate entities: SP Energy Network (a subsidiary of Scottish Power) is responsible for southern and central Scotland and SSE plc is responsible for northern Scotland. National Grid plc, however, remains the system operator for the whole UK grid. Nine Distribution Network Operators (DNO), operating in 12 separate regions, distribute electricity from the transmission network.[8]

Electricity costs vary across suppliers and regions. In 2021, the national average electricity tariff was 0.164 GBP/kWh (0.20 USD/kWh), similar to the years prior.[9] However, due to the global gas price increase in 2022, average electricity tariffs have increased accordingly. For example, the average tariff for British Gas in April 2022 was 0.28 GBP/kWh (0.35 USD/kWh) and the average tariff for E.ON Energy was 0.27 GBP/kWh (0.33 USD/kWh).[10,11]

## SMALL HYDROPOWER SECTOR OVERVIEW

In the UK, small hydropower (SHP) is generally defined as up to 10 MW. In 2020, installed capacity of SHP was 405 MW.[12] Total potential capacity is at least 1,179 MW, indicating that approximately 34 per cent has been developed. It is worth noting, however, that the estimated potential figure is based upon studies with minimum installed capacity limits meaning that sites with capacities below these limits were not included and the total potential should be higher. Compared to the *World Small Hydropower Development Report (WSHPDR) 2019,* installed capacity has increased by 15 MW and potential capacity has remained the same (Figure 4).

Figure 4. **Small Hydropower Capacities in the WSHPDR 2013/2016/2019/2022 in the United Kingdom (MW)**




Sources: DUKES,[12] *WSHPDR 2019,*[13] *WSHPDR 2016,*[14] *WSHPDR 2013*[15]

SHP capacity represents just under 10 per cent of total hydropower capacity in the UK. Due to its wet climate, mountainous terrain and plentiful rivers, the large majority of hydropower plants, including SHP plants, are located in Scotland, followed by Wales.[16,17] SHP development in the UK saw expedited growth in the decade since 2010 due to a feed-in tariff (FIT) implemented by the Government that was ended in October of 2019. These FITs, called the Microgeneration Certificate Scheme, were offered to SHP plants under 5 MW. Between 2010 and October of 2019, 1,216 SHP plants with a combined capacity of more than 224 MW were commissioned through this scheme.[18] A list of selected SHP plants is shown in Table 1.

Due to the costs and concerns about its environmental impact, further large-scale hydropower development potential is limited, however, there is scope for exploiting the country's remaining SHP resources in a sustainable way. The good-quality most-financially-viable sites have already been utilized or lie in protected regions of the Scottish Highlands and Snowdonia, Wales. The 2010 England and Wales Hydropower Resource Assessment Report has identified approximately 1,692 potential sites in England and Wales with a combined capacity of between 146 MW and 248 MW.[19] A separate study of Scottish SHP potential carried out in 2008 modelled 36,252 separate sites that were deemed practically and technically feasible. Of these, 1,019 sites with a potential of 657 MW were deemed financially viable. More than half of these sites were estimated to have a capacity of between 100 kW and 500 kW (Table 2).[20] Both studies, however, had lower limits in terms of the potential capacity of sites that were included. For the England and Wales study, a lower limit of 25 kW was set for remote sites and for the Scotland study there were limits of 100 kW for sites in the north of Scotland and 25 kW in the south. This means that a number of pico-hydropower sites were not included, in particular old water mills that could be modernized to generate electricity. With some estimates suggesting there could be 20,000 old water mill sites in England alone, there remains significant potential unaccounted for.[13]

Table 1. **List of Selected Small Hydropower Plants in Operation in the United Kingdom**

| *Name* | *Location* | *Capacity (MW)* | *Operator* | *Launch year* |
|---|---|---|---|---|
| Glen Noe | Scotland | 2.0 | RWE Npower | 2021 |
| Grudie | Scotland | 2.0 | RWE Npower | 2017 |
| Cia Aig | Scotland | 3.0 | RWE Npower | 2016 |
| Derrydarroch | Scotland | 2.0 | Temporis Capital | 2015 |
| Upper Falloch | Scotland | 0.9 | Temporis Capital | 2015 |
| Maldie | Scotland | 4.0 | RWE Npower | 2013 |
| Black Rock | Scotland | 3.5 | RWE Npower | 2012 |
| Allt Fionn | Scotland | 2.1 | Osspower Ltd | 2012 |
| Osspower | Scotland | 2.0 | Temporis Capital | 2012 |
| Selset | North England | 0.8 | RWE Npower | 2010 |
| Inverlael | Scotland | 2.5 | RWE Npower | 2009 |
| Carnoch | Scotland | 1.4 | RWE Npower | 2009 |
| River E | Scotland | 3.0 | RWE Npower | 2008 |
| Douglas Water | Scotland | 3.0 | RWE Npower | 2008 |
| Fasnakyle | Scotland | 7.7 | SSE Group | 2006 |
| Kiedler | North England | 6.0 | RWE Npower | 2006 |
| Inverbain | Scotland | 1.0 | RWE Npower | 2006 |
| Kingairloch | Scotland | 3.5 | SSE Group | 2005 |
| Garrogie | Scotland | 2.4 | RWE Npower | 2005 |
| Braevallich | Scotland | 2.3 | RWE Npower | 2005 |

Sources: DUKES[16]

Table 2. **Potential Small Hydropower Plants by Capacity in Scotland (MW)**

| | *<100 kW* | *100 kW–500 kW* | *500 kW–1 MW* | *1 MW–5 MW* | *5 MW–10 MW* |
|---|---|---|---|---|---|
| Number of sites | 6 | 537 | 300 | 170 | 6 |
| Potential capacity (MW) | 0.45 | 150.4 | 193.2 | 276.6 | 36.2 |

Source: SISTech et al.[20]

## RENEWABLE ENERGY POLICY

National Renewable Energy Action Plan of 2009 set a target for 30 per cent of electricity to be sourced with renewable energy by 2020, which was met on time.[21] Having achieved its own target of 31 per cent by 2013, Scotland set the ambitious renewable electricity target of 100 per cent by 2020. This target was almost met, with over 97 per cent of electricity consumption from renewable sources in Scotland in 2020.[22] The Energy White Paper of 2020 states that the UK plans to have 100 per cent renewable energy penetration and a fully decarbonized economy by 2050. However, a year later in October of 2021, the Government announced that the plan to be decarbonized should be achieved by 2035 instead.[23]

Major polices that have been passed in the past decade relating to renewable electricity generation include: the Renewable Obligation (RO), the main support mechanism for large-scale renewable projects; FITs for smaller-scale renewable projects; and Contracts for Difference (CfD). FITs for renewable energy were announced as part of the Energy Act 2008, came into effect in April 2010 and were ended in October 2019. The tariffs applied to electricity generated from plants of no more than 5 MW utilizing hydropower, solar photovoltaics (PV), wind power or anaerobic digestion with an eligibility period of 20 years. Micro combined heat and power (CHP) installations of 2 kW or less were also eligible. After their introduction, the FITs were slowly reduced at regular intervals until they were ended at the end of the decade.[13,18]

For plants greater than 5 MW, the RO was introduced in England and Wales in 2002 and in Northern Ireland in 2005. In Scotland a different but similar policy, Renewable Obligation (Scotland), was also introduced in 2002. The RO requires electricity suppliers to source an increasing proportion of electricity from renewable sources. In order to demonstrate they have met their obligation, suppliers must obtain Renewable Obligation Certificates (ROCs), which are issued to operators of accredited renewable energy plants. Where suppliers do not present a sufficient number of ROCs to meet their obligation, they must pay an equivalent amount into a buy-out fund. In March of 2017, the Government closed down ROCs for new generating capacities in favour of the new CfD scheme, but they are still in place for those using it prior to closure.[24]
The CfD scheme was introduced in 2013 and constitutes a contract between a low-carbon electricity generator and the state-owned Low Carbon Contracts Company (LCCC). According to the scheme, generators are paid the difference between the price for electricity given the cost of investing in a particular low-carbon technology and the country's average market price for electricity. According to the Government, the aim of the new scheme is to give generating companies more exposure to market forces in order to encourage greater efficiency, to reduce uncertainty of revenues and to protect consumers from paying higher costs.[25]

## SMALL HYDROPOWER LEGISLATION AND REGULATIONS

All hydropower projects must obtain three permissions prior to construction and operation: an environmental licence granted by the relevant regional environmental agency, planning permission granted by the local council or National Park Authorities and accreditation to generate and export electricity provided by Ofgem. To build a new hydropower plant, the developer has to apply to the Environment Agency for:

- an abstraction licence — if water is diverted or taken from a river or watercourse;
- an impoundment licence — if it is planned to build a dam or weir to hold back the flow of an inland water, or if it is planned to change an existing weir or structure as part of the scheme;
- a fish pass approval — if it is planned to install or modify fish passes as part of the scheme;
- an environmental permit for a flood risk activity — when the developer builds in, over or next to main rivers (for rivers and watercourses that are not main rivers the developer must apply to the lead local flood authority for consent).[26]

## BARRIERS AND ENABLERS FOR SMALL HYDROPOWER DEVELOPMENT

Barriers to SHP development in the UK include:

- Investment in new SHP plants is limited despite the renewable energy policies;
- The ending of the FIT scheme in 2019 without replacing it with other incentives for small-scale electricity generation;
- Various administrative deliverables needed including the initial financial outlays for the build and for the economic and environmental feasibility studies amongst others.[13]

Enablers for SHP development in the UK include:

- A liberalized sector allows for any company to begin generating electricity, no matter how small;
- There is still undeveloped potential in the country including the old water mills that can be modernized and incorporated into the grid;
- With the newly announced ambition to have a decarbonized energy sector in less than 15 years, SHP can be a key tool towards this goal as it has lower start-up costs and faster construction times than large projects.

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