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INTERNATIONAL CENTER
ON SMALL HYDROPOWER

World Small Hydropower Development Report 2022

Western Europe

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WSHPDR2022 team

Head	LIU Heng — Senior Technical Advisor, United Nations Industrial Development Organization (UNIDO)
Coordinators	Oxana Lopatina — International Center on Small Hydro Power (ICSHP)
	Eva Krēmere — United Nations Industrial Development Organization (UNIDO)
Team	UNIDO: Eva Krēmere, Sanja Komadina. Interns: LIU Fangjie, REN Wenxuan
	ICSHP: HU Xiaobo, Oxana Lopatina, Danila Podobed, Alicia Chen Luo, Veronika Spurna, Tamsyn Lonsdale-Smith, Bilal Amjad, Oluwatimilehin Paul Olawale-Johnson, Davy Rutajoga, Laura Stamm, YUAN Ruize, BAO Lina, ZHANG Yingnan, DING Yan

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Contributing Experts

Arturo Alarcon, Sameer Algburi, Alsamaoal Almoustafa, Gabrial Anandarajah, Vicky Ariyanti, Fredrick Arnesen, Engku Ahmad Azrulhisham, Ayurzana Badarch, BAO Lina, Mathieu Barnoud, Alexis Baúles, Sow Aissatou Billy, Alaeddin Bobat, Frank Charles Ramírez Bogovich, Ejaz Hussain Butt, Abou Kawass Camara, Jose Campos, Joan Cecilia C. Casila, Piseth Chea, Julian Chin, Salim Chitou, Gift Chiwayula, Brenda Musonda Chizinga, Nouri Chtourou, Romao Grisi Cleber, Ryan Cobb, Poullette Faraon Chaul Corona, John Cotton, Slobodan Cvetkovic, Manana Dadiani, Asger Dall, Bassam Al Darwich, Denise Delvalle, Tobias Dertmann, Gabriel Chol Dhieu, Jonas Dobias, Aurélie Dousset, Choten Duba, José Rogelio Fábrega Duque, Nadia Eshra, Cayetano Espejo Marín, Paola Estenssoro, Soukaina Fersi, Geraldo Lúcio Tiago Filho, Danilo Fras, Fujimoto Tokihiko, Patrick Furrer, Camila Galhardo, Ramón García Marín, Adnan Ghafoor, Gaëlle Gilboire, Zelalem Girma, Mohammad Hajilari, Geon Hanson, Richard Hendriks, Mabikana Voula Boniface Hervé, Yan Huang, Chinedum Ibegbulam, Michela Izzo, Jamal Jaber, Gordana Janevska, Sergio Armando Trelles Jasso, Rim Jemli, Marco Antonio Jimenez, Annabel Johnstone, Julien Jomaux, Wim Jonker Klunne, Abdoul Karim Kagone, John K. Kaldellis, Bryan Karney, Raul Pablo Karpowicz, Egidijus Kasiulis, Shorai Kavu, Eleonora Kazakova, Joseph Kenfack, Dong Hyun Kim, George Kimbowa, Dimitar Kisliakov, Maris Klavins, Ioannis Kougias, Rastislav Kragic, Arun Kumar, Sarah Kwach, Kristian Dahl Larsen, Seung Oh Lee, Jean-Marc Levy, Bryan Leyland, Laura Lizano, Galina Livingstone, Kimberly Lyon, Sarmad Nozad Mahmood, Ewa Malicka, Pedro Manso, Andrés Teodoro Wehrle Martínez, Anik Masfiqur, Mareledi Gina Maswabi, Hamid Mehinovic, Juan José García Méndez, Luiza Fortes Miranda, Guram Mirinashvili, Julio Montenegro, Bastian Morvan, Reynolds Mukuka, Béla Munkácsy, Patricio Muñoz, Wakati Ramadhani Mwaruka, Thet Myo, N'guessan Pacôme N'Cho, Sea Naichy, Niels Nielsen, Gilbert Nzobadila, Emna Omri, Karim Osseiran, Sok Oudam, Victor Odundo Owuor, Grant Pace, Aung Thet Paing, Hok Panha, Sotir Panovski, Ahmet Penjiev, Georgy Petrov, Alexandra Planas, Bogdan Popa, Cecilia Correa Poseiro, Sunil Poudel, Ravita D. Prasad, Kenneth Bengtson Tellesen Primdal, Leonardo Peña Pupo, Thoeung Puthearum, Emanuele Quaranta, Samira Rasolkhani, Atul Raturi, Thomas Buchsbaum Regner, António Carmona Rodrigues, Jorge Saavedra, Najib Rahman Sabory, Victor Sagastume, Esmina Sahic, Alberto Sanchez, Karine Sargsyan, Vahan Sargsyan, Goran Sekulić, Ozturk Selvitop, Shamsuddin Shahid, Stafford W. Sheehan, Manish Shrestha, Sangam Shrestha, Mundia Simainga, Gjergji Simaku, Martin Sinjala, Seming Skau, Nicolae Soloviov, Amine Boudghene Stambouli, Dmytro Stefanyshyn, Pavel Štípský, Jean Sumaili, Dinesh Surroop, Areli Sutherland, Alberto Tena, Pierre Kenol Thys, Anastasiya Timashenok, Panagiotis Triantafyllou, Alexander Urbanovich, Joelinet Vanomaro, Goran Vasilic, Ciza Willy, Ernesto Yoel Fariñas Wong, Gendensuren Yondongombo, Saida Yusupova

Western Europe

Countries: Austria, Belgium, France, Germany, Luxembourg, Netherlands, Switzerland

INTRODUCTION TO THE REGION

The electricity sectors of countries in Western Europe are highly integrated as a consequence of participation in the European Network of Transmission Systems (ENTSO-E). Additionally, all countries in the region with the exception of Switzerland are members of the European Union (EU). This, along with participation in a wide array of other pan-European and international agreements and frameworks on energy, trade and climate-related topics has meant that the legislative frameworks regulating the electricity sector and long-term energy development strategies of the countries in the region likewise adhere to a set of similar goals and standards.

Nevertheless, geographic, climatic, socio-economic and political factors have meant that countries in Western Europe have often adopted different strategies with regard to their national energy mix. While decarbonization of the electricity sector has been a common priority, several countries, including Germany, Belgium and the Netherlands, continue to rely on natural gas for a significant part of their electricity generation, as an alternative to coal- and oil-fired thermal power plants. Other countries in the region, such as Austria, Luxembourg and Switzerland, have prioritized hydropower or other renewable energy sources (RES) as the mainstay of electricity generation. The development and continued exploitation of nuclear power plants is another contentious issue in the region. The Government of Germany has been a regional proponent of denuclearization and the country has significantly scaled down its operational nuclear power capacity. On the other hand, France, Belgium and Switzerland continue to heavily exploit nuclear power for their energy needs. With regards to RES other than hydropower, the region has invested heavily in wind power and solar power capacity, with Germany possessing by far the largest share of the regional installed capacities in both technologies and aiming to source 80 per cent of its electricity generation from RES by 2050.

Hydropower is a major source of electricity generation for all countries in the region with the exception of Belgium and the Netherlands, where hydropower development is constrained by the flat topography. In Germany, hydropower is mainly concentrated in the mountainous parts of the country, with the states of Bavaria and Baden-Württemburg accounting for over 80 per cent of the country's annual hydropower generation. In France, hydropower is a key secondary energy source, while in Switzerland, Luxembourg and Austria, hydropower is the leading source of electricity generation.

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

Table 1. **Overview of Western 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)
Austria	9	100	100	26,153	72,866	14,640	45,380
Belgium	12	100	100	24,343	81,200	175	N/A
France	67	100	100	136,211	500,000	25,732	65,100
Germany	83	100	100	229,000	489,000	4,856	18,300
Luxembourg	1	100	100	522	2,230	35	1,094
Netherlands	17	100	100	39,132	117,940	38	90
Switzerland	8	100	100	22,063	70,900	15,544	40,700
Total	-	-	-	**477,424**	-	**61,020**	-

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) in most countries of Western Europe with the exception of Germany adheres to that established by the EU, which defines SHP as hydropower plants with an installed capacity of up to 10 MW. Germany has not adopted an official definition of SHP as the Government recognizes the lack of international consensus on the definition, but the up to 1 MW definition is used in the country on an unofficial basis.

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

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

Country	Local SHP definition	Installed capacity (local def.)	Potential capacity (local def.)	Installed capacity (≤10 MW)	Potential capacity (≤10 MW)
Austria	Up to 10 MW	1,521.6	1,780.0	1,521.6	1,780.0
Belgium	Up to 10 MW	76.0	103.4	76.0	103.4
France	Up to 10 MW	2,200.0	2,615.0	2,200.0	2,615.0
Germany	N/A	N/A	N/A	1,674.0	1,830.0
Luxembourg	Up to 10 MW	25.0	44.0	25.3	44.0
Netherlands	Up to 10 MW	13.0	N/A	13.0	13.0*
Switzerland	Up to 10 MW	1,000.0	1,500.0	1,000.0	1,500.0
Total	-	-	-	**6,509.9**	**7,885.4**

Source: *WSHPDR 2022*[1]

Note: *Based on installed capacity.

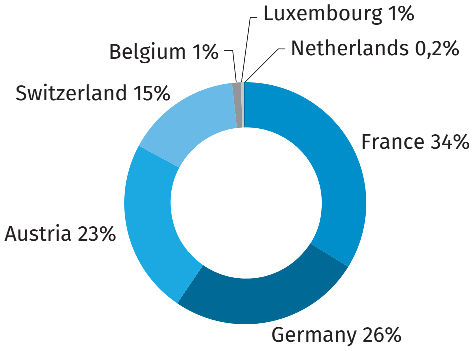
The total installed capacity of SHP of up to 10 MW in Western Europe is 6,509.9 MW, while estimated potential capacity is 7,885.4 MW. Relative to the *World Small Hydropower Development Report (WSHPDR) 2019*, the installed capacity has remained largely the same, decreasing by less than 1 per cent as a result of changes in reporting standards with regard to SHP data in Germany and Luxembourg. Meanwhile, potential capacity has increased slightly by approximately 3 per cent, due to a reassessment of the SHP potential of Switzerland.

Overall, the SHP sector in Western Europe is one of the most mature in the world. Nearly 83 per cent of the potential capacity for SHP of up to 10 MW in the region has already been developed. Consequently, little new SHP development is taking place, as the expansion of RES capacities in the region in recent years has focused on technologies other than SHP. Additionally, as has occurred elsewhere in the world and particularly in Europe, SHP has come under increasing scrutiny from environmental groups, which has resulted in a tightening of environmental regulations and requirements for SHP projects. A significant share of recent activity in the SHP sector has focused on refurbishing or rebuilding existing plants to meet new environmental regulations, including the installation of fish passes and modifications for ensuring reserved flow thresholds. Due to increasingly limited opportunities within the region, many SHP developers from the countries of Western Europe have been looking to expand their range of activity to projects in other parts of the world, particularly in South and Central America and Africa.

Nonetheless, some expansion of SHP capacities has taken place in recent years, particularly in Switzerland. It must also be noted that probable new construction in the SHP sector of the countries of Western Europe is likely higher than publicly available data indicates due to the specificities of data collection practices and legislation in the SHP sectors of several counties including Germany, France and Austria that make it difficult to acquire a comprehensive list of all ongoing and completed projects.

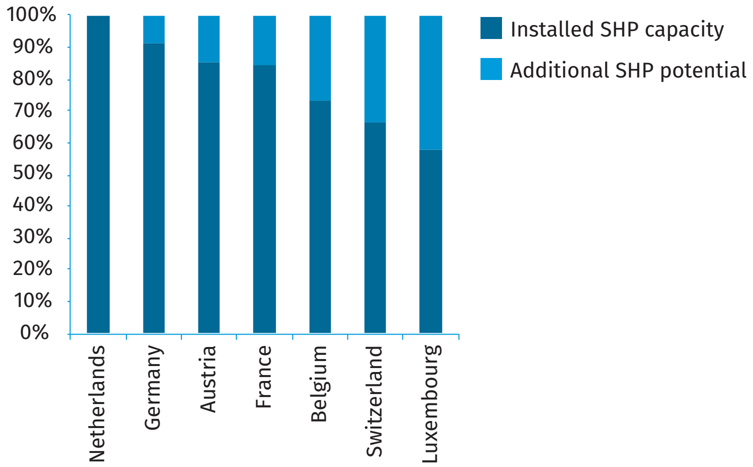
The national share of regional installed SHP capacity by country is displayed in Figure 1, while the share of total national SHP potential utilized by the countries in the region is displayed in Figure 2.

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



Source: *WSHPDR 2022*[1]

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



Source: *WSHPDR 2022*[1]

The installed capacity of **Austria** for SHP of up to 10 MW was estimated at 1,521.6 MW at the end of 2017, provided by 3,307 SHP plants. The potential capacity is estimated at 1,780 MW, indicating that 85 per cent has been developed. The most current data on SHP capacity in Austria are difficult to acquire due to the decentralized and fragmentary nature of reporting on the SHP sector in the country. However, the overall number of registered SHP plants has increased in recent years even as total installed capacity has decreased slightly, due to changes in reporting standards by the relevant national authorities. Over 100 SHP projects were in various stages of planning as of 2021, with many suspended ones due to various obstacles.
Belgium has an installed capacity of 76 MW for SHP of up to 10 MW, which accounts for 43 per cent of the country's total hydropower capacity. Potential SHP capacity is estimated at 103.4 MW, indicating that nearly 74 per cent has been developed. Information on existing SHP plants in the country is incomplete and recent increases in installed capacities most likely re-

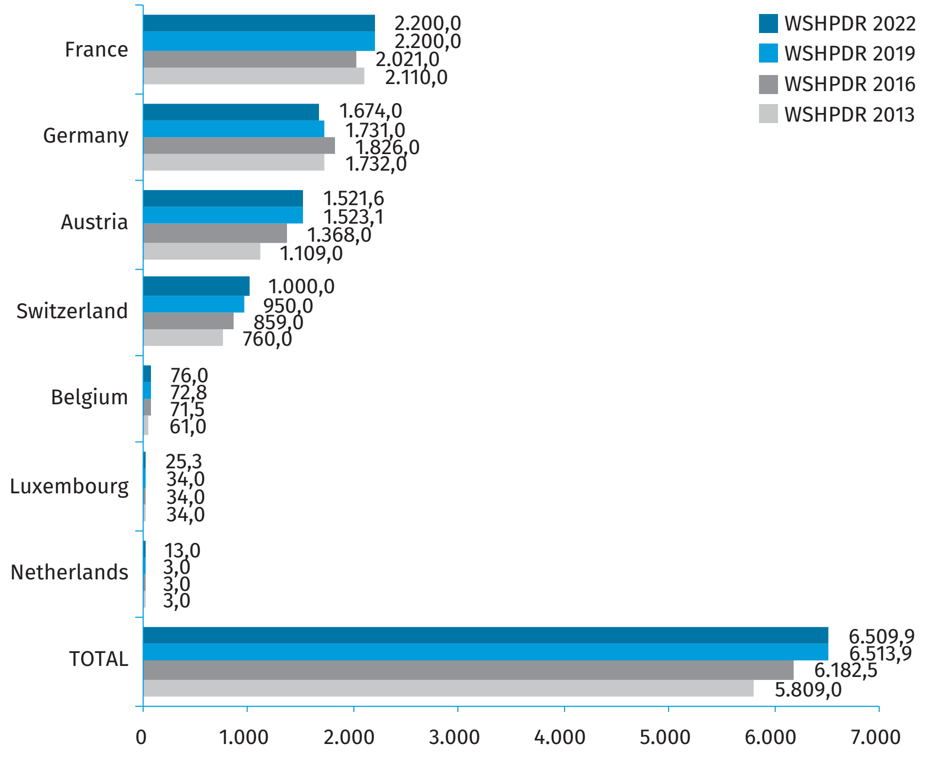
flect the inclusion of previously-unreported SHP capacities in official statistics rather than any new development. Confirmed activity in the sector includes one existing SHP plant undergoing rehabilitation as of 2022.

The total installed capacity of **France** for SHP of up to 10 MW is estimated at 2,200 MW, provided by approximately 2,270 SHP plants. However, comprehensive data on existing SHP plants are difficult to acquire due to legislation specifically limiting the public disclosure of SHP plants with an installed capacity under 0.035 MW. Potential capacity for SHP of up to 10 MW is estimated at 2,615 MW, indicating that 84 per cent has been developed. While the overall estimate of total installed capacity has not changed in the last few years, a large number of new SHP projects were commissioned between 2019 and 2020, with capacities ranging between 0.07 MW and 5.50 MW. Planned projects include the refurbishment of one 2.7 MW SHP plant.

The total reported installed capacity of SHP of up to 10 MW in **Germany** was 1,674 MW in 2020, representing a significant decrease from previous years. However, this figure is the result of changes in reporting standards and likely underrepresents the actual installed SHP capacity of the country. Potential SHP capacity is estimated at 1,830 MW. On the basis of the reported installed capacity data, this suggests that over 91 per cent of the potential has been developed, although data from previous years suggest a figure closer to 100 per cent. There has been no new SHP construction reported in the country in the last decade, as the country's SHP potential is considered to be almost fully developed.

Luxembourg has an installed capacity of 25.3 MW for SHP of up to 10 MW while potential capacity is estimated at 44 MW, indicating that nearly 57 per cent has been developed. The reported SHP capacity of the country decreased due to the exclusion of one previously-included plant with an installed capacity of 13 MW. One additional plant is still reported as part of the installed capacity total, but has functionally been out of operation since 2021 due to heavy flood damage. There has been no significant activity in the SHP sector of Luxembourg in recent years and no new projects are planned.

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



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

The installed capacity of SHP of up to 10 MW in the **Netherlands** is 13 MW, which is believed to account for the country's entire SHP potential, although a detailed assessment of SHP potential in the country is not available. Reported installed capacity has increased due to the inclusion of a 10 MW hydropower plant not previously recognized as an SHP plant, rather than any new development. In addition to traditional SHP, there is some potential in the Netherlands for tidal SHP applications and several such projects have been installed in 2008 and 2015.

Switzerland has approximately 1,400 SHP plants of up to 10 MW with an estimated total installed capacity of 1,000 MW. SHP potential in the country is estimated at 1,500 MW, suggesting that 66 per cent has been developed. Over the last few years, the country's SHP capacity has increased by approximately 50 MW, with many new plants commissioned between 2018 and 2020. Development is actively ongoing and several additional projects were under construction as of 2021.

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

Climate Change and Small Hydropower

The changes in the runoff pattern from Alpine rivers due to increased snow and glacial melt induced by climate change in the next decades may be advantageous for SHP in the near term. However, natural hazards, such as floods, glacial lake outburst floods (GLOFs) and landslides, are likely to increase and hamper SHP plant operation and development. Additionally, precipitation in the region is expected to decrease. Without seasonal storage capacity, the downtimes due to extended droughts may halt electricity generation if adaptation measures are not taken. For example, France expects periods of extreme drought due to an increase in evaporation of between 30 and 50 per cent by the end of the century. On the contrary, SHP plants in Belgium and Germany might benefit from increased precipitation in winter and spring and more evenly spread precipitation in summer, respectively. Austria shows a tendency towards decreased annual production overall.

BARRIERS AND ENABLERS FOR SMALL HYDROPOWER DEVELOPMENT

Barriers to SHP development in **Austria** include increasingly strict environmental standards, limited subsidies, bureaucratic barriers and community resistance to SHP projects in direct proximity, despite a generally positive view of SHP. While several support schemes including feed-in tariffs (FITs) have been increasingly restricted to smaller SHP plants (below 2 MW), other forms of support available to SHP in the country include a market premium system, investment support and mixed technology tenders. The SHP sector in the country is well-established and promoted by several lobbying organizations, and RES strategic development plans issued by the Government include targets for the realization of the country's remaining undeveloped SHP potential.

In **Belgium**, SHP development is hampered by the lack of detailed data on potential sites and stringent environmental requirements, causing some local SHP developers to redirect their efforts to projects in other countries. Potential enablers of SHP development include the maturity of the SHP sector, incentives in the form of tradeable green certificates and possible benefits from future increases in runoff.

The main barriers to SHP development in **France** are the financial costs of increasingly restrictive environmental regulations, insufficient incentives to offset these costs, as well as blanket bans on SHP construction on certain watercourses. However, the Government of France has recognized the value of hydropower in general for the country's electricity sector in public pronouncements and detailed studies, particularly with regard to ensuring system flexibility. This is likely to ensure an ongoing active role for the country's SHP sector.

The key barrier to SHP development in **Germany** are the very strict licensing requirements related to environmental standards for both new and existing plants. At the same time, the SHP sector in the country benefits from several enabling factors including a high electricity price, guaranteed funding periods, as well as a carbon tax introduced in 2021, which is expected to make SHP significantly more attractive in the coming years.

The main barriers to the development of SHP in **Luxembourg** are the country's low remaining undeveloped SHP potential and the general lack of demand for additional generating capacities. Additionally, data on SHP sites are lacking and the country has prioritized solar power and wind power in meeting its RES targets. However, support for SHP is available in the form of FITs, market premiums and investment subsidies. One prospective direction for further SHP development in the country are projects on existing non-powered hydraulic infrastructure.

SHP development in the **Netherlands** is limited by the country's flat topography and faces resistance from local water communities as well as from competing water users such as fishermen. However, potential exists in the repurposing of old water mills for power generation, as well as in the development of tidal SHP.

There are some obstacles to the development of SHP in **Switzerland**, including conflicts over water use rights, difficulties with providing electricity transmission and access to greenfield sites, competition from other RES, tightening of requirements necessary for enrolment in support schemes and excessive documentation during the approval process. Overall, however, the prospects for future SHP development in the country are positive, as the SHP sector in the country is mature and abundant undeveloped potential remains available. Most importantly, SHP plays a key role in the country's energy strategy and benefits from multiple forms of support including FITs, investment grants and support for innovative research in the SHP sector. Despite some resistance to greenfield SHP development, SHP projects on existing infrastructure enjoy a high level of social support.

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Austria

Thomas Buchsbaum-Regner, Kleinwasserkraft Österreich

KEY FACTS

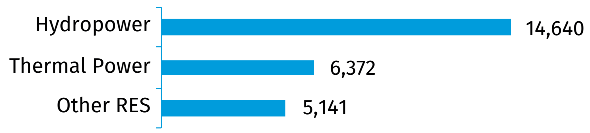
Population	8,926,290 (2020)[1]
Area	83,878 km^2 [2]
Topography	Austria is mountainous in the south and west (the Alps), while along the eastern and northern borders it is mostly flat or gently sloping. Alpine regions cover 67 per cent (appr. 56,200 km^2) of the total land area. The highest point is Grossglockner at 3,798 metres.[3]
Climate	Austria has a temperate continental climate. There are three climatic regions in the country. The eastern region is characterized by a Pannonian climate with continental influence, low precipitation, hot summers and moderately cold winters. The Alpine region has an Alpine climate with high precipitation (with the exception of the inner Alpine valley regions such as the upper Inntal), short summers and long winters. The remainder of the country has a transient climate influenced by the Atlantic in the west and a continental influence in the south-east. Winters in Austria, between December and January, are cloudy and cold with frequent rain and some snow in the lowlands and snow in the mountains. Winter temperatures average between -7 °C and -1 °C. Summers, between June and August, are moderate with occasional showers. Temperatures in July average between 18 °C and 24 °C.[3,4]
Climate Change	Average temperatures in Austria are expected to continue to rise throughout the 21st century. Hot, drier summers will increase in frequency, while the number of days per year with a temperature of over 30 °C will double. Winters are expected to become less cold, with a decrease in the number of days with snow cover. Observed climate change trends in the Alpine region, including increasing intensity and frequency of precipitation, hail and thunderstorms, but also more periods of drought, stronger flood events and glacier retreat, are expected to continue.[5]
Rain Pattern	Rainfall ranges from more than 1,020 mm annually in the western mountains to less than 660 mm in the driest region, near Vienna.[3]
Hydrology	Austria is situated in three transboundary river basins: the Danube, Rhine and Elbe basins. Approximately 96 per cent of the territory of the country belongs to the Danube River basin, which has an average flow of 1,955 m^3/s at the border with Slovakia. Approximately 3 per cent of the territory is part of the Rhine River basin and 1.1 per cent belongs to the Elbe River basin. There are 7,339 rivers and 62 lakes in the country.[3]

ELECTRICITY SECTOR OVERVIEW

The total installed electricity capacity in Austria was 26,153 MW as of 2020. Hydropower, including pumped-storage facilities, provided 14,640 MW (56 per cent) of this total, thermal power provided 6,372 MW (24 per cent). Other renewable energy sources (RES), including wind power, solar power and geothermal power, provided 5,141 MW (20 per cent) (Figure 1). The thermal power capacity in the country has been on a continuous decline since 2015 due to the phase-out of coal power plants, while the capacity of non-hydropower RES has increased dramatically over the last two decades.[6]

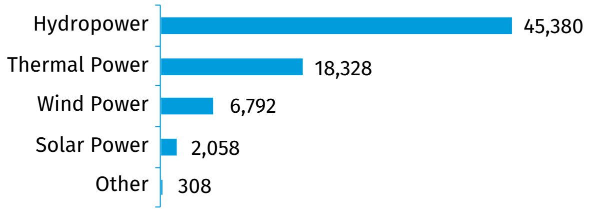
Total electricity generation in Austria reached 72,866 GWh in 2020, with hydropower contributing 45,380 GWh (approximately 62 per cent) of this total, thermal power including both fossil fuels and biofuels contributing 18,328 GWh (25 per cent), wind power contributing 6,792 GWh (9 per cent), solar power contributing 2,058 GWh (3 per cent) and other sources contributing 308 GWh (less than 1 per cent) (Figure 2). The total share of RES (including hydropower and excluding biofuels) in electricity generation was approximately 74 per cent in 2020. Imports of electricity in 2020 amounted to 24,523 GWh while exports amounted to 22,327 GWh.[6]

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



Source: E-Control[6]

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



Source: E-Control[6]

The electrification rate in Austria is 100 per cent, with 100 per cent of all electricity consumers being connected to the national grid with the exception of some remote mountain lodges.[7]

Following the Austrian Electricity Industry Organisation Act (EIWOG) adopted in 2000, the Austrian electricity market became fully liberalized by adopting an unbundled market structure with E-Control operating as the state-owned independent regulatory authority. Verbund is the largest electricity provider, covering approximately 40 per cent of the country's electricity demand, with almost 90 per cent of its generation coming from hydropower plants.[8,9] The company also has purchase rights for electricity generated from 20 hydropower plants owned by several other companies. Verbund is listed on the Vienna Stock Exchange as well as the Austrian Traded Index (ATX) with the Government of Austria as the majority shareholder with 51 per cent of the shares.[9] Other significant hydropower producers include Energie AG Oberösterreich, Energie Steiermark, EVN Group, KELAG, Salzburg AG, TIWAG-Tiroler Wasserkraft AG, Vorarlberger Kraftwerke AG and others.

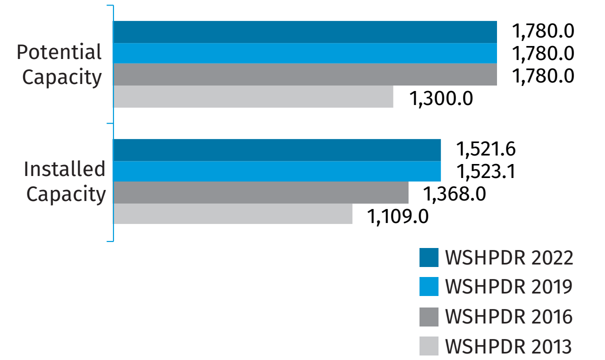
Electricity is traded without intermediaries on the Over-the-Counter (OTC) market or on an energy exchange such as the European Energy Exchange (EEX) or the Energy Exchange Austria (EXAA). The EXAA is a public limited company owned by the Vienna Stock Exchange as well as a number of different companies from the Austrian energy sector that operates a day-ahead electricity spot market. The Austrian Power Grid (APG), a 100 per cent subsidiary of Verbund AG, operates the transmission grid, which is part of the trans-European transmission grid.[7]

The price of electricity for consumers in Austria is based on three components: the amount charged by the supplier, which is set by individual suppliers; a network charge paid to the system operator, which is set by E-Control and based on the grid connection of individual consumers; and taxes and surcharges levied by the Government, including value-added tax (VAT). In 2020, the average gross electricity price, including energy taxes and VAT, was 0.208 EUR/kWh (0.230 USD/kWh) for households and 0.104 EUR/kWh (0.110 USD/kWh) for industrial users.[10]

SMALL HYDROPOWER SECTOR OVERVIEW

Regulated by ÖNORM (Austrian Standards), small hydropower (SHP) is defined in Austria as hydropower plants with a maximum capacity of 10 MW.[11] As of December 2017, Austria had an estimated total installed SHP capacity of 1,521.6 MW from 3,307 plants.[12] Potential SHP capacity has been estimated at 1,780 MW, and included in capacity targets established by the Government. Relative to the *World Small Hydropower Development Report (WSHPDR) 2019*, installed capacity of SHP in Austria has decreased by a small fraction (less than 1 per cent) even as the number of registered SHP plants has increased, likely due to changes in reporting standards by E-Control. Potential capacity has remained the same due to lack of new estimates (Figure 3).[7,13]

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



Source: *WSHPDR 2019*,[7] E-Control,[12] *WSHPDR 2013*,[14] *WSHPDR 2016*[15]

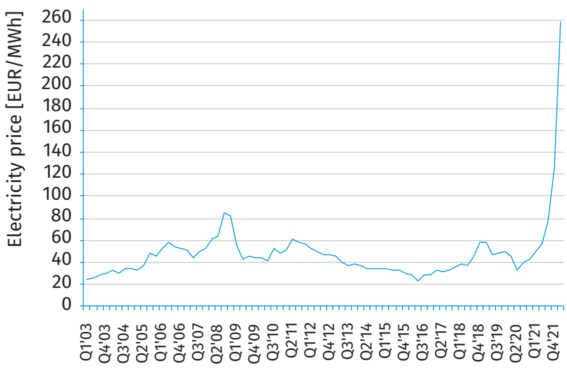
The 3,307 SHP plants identified above were those certified as Green Power Plants by the authorities of Austria at the time, although this number did not include all existing SHP plants in the country.[12] The statistical evaluation of certified Green Power Plants was discontinued in 2018, due to a change in national regulations. The new method of reporting installed capacity and generated electricity established by E-Control is now based on reporting plants issued Guarantee of Origin Certificates (GoO).[16] As of 2020, there were 2,895 SHP plants in the GoO database, with a total installed capacity of 1,374 MW declining from the 1,413 MW reported in 2019.[17] Electricity generated by hydropower plants up to 10 MW, including both run-of-river and pumped-storage plants, amounted to 6,564 GWh in 2020.[6]

The actual total number and installed capacity of SHP plants in Austria is higher than the totals included in the GoO database. Additionally, generation totals for SHP do not reflect self-consumption by the plant operators, which in many cases include industrial facilities such as sawmills. Self-consumption is estimated at approximately 10 per cent of a plant's gross electricity production. However, even accounting for the under-reporting of SHP installed capacity and generation, SHP targets established in 2013 by the Austrian Energy Strategy 2020 of 1,780 MW of installed capacity and an annual generation of 8,000 GWh have likely remained unmet as of the beginning of 2022.[7,18]

New SHP targets have been set by the Renewable Expansion Law of 2021, which envisions an additional 5 TWh of annual electricity generation by 2030 with approximately 2–3 TWh to be accounted for by SHP.[19] Recent studies in three of the nine federal states of Austria have demonstrated that there is still untapped SHP potential in the country, while another 2018 study estimated unused hydropower potential at 11,000 GWh/year.[20,21,22,23]

Approximately 85 per cent of the total electricity produced by SHP plants in Austria receives a market price. In most cases, the plant operator sells directly to a trader in the private sector. In very few cases, the electricity is traded at the Energy Exchange Austria (EXAA) or the European Energy Exchange (EEX) platform in Leipzig, Germany. Since the separation of the Austrian and German electricity markets on 1 October 2018, the obtained price has been strongly linked to the Phelix-AT Baseload Quarter Future derivatives, which are traded at the EXAA. A market-based purchase price, formerly determined on the EEX Phelix Base Quarter Future, is now based on Phelix-AT and settled according to the Austrian Green Electricity Act (ÖSG), last amended in 2017. This price is determined quarterly by E-Control (Figure 4).[7,24]

Figure 4. **Quarterly Electricity Market Prices in Austria 2003-2022 (EUR/MWh)**



Source: E-Control[25]

Before 2003, the federal states of Austria had individual tariff regulations. With the passage of the Green Electricity Act in 2002, a new countrywide tariff system was introduced, with the new tariffs being dependent on the amount of electricity fed into the public grid.[26] SHP plants eligible for incentives under the new system now included two different categories of plants: new SHP plants or SHP plants undergoing refurbishment to increase the mean annual production or capacity by more than 50 per cent, and SHP plants undergoing refurbishment to increase the mean annual production or capacity by more than 15 per cent. New plants and those which were refurbished between 2003 and 2005 with a more than 50 per cent increase in annual production or installed capacity received feed-in tariffs (FITs) for 15 years. Conversely, plants that were refurbished during those years with a more than 15 per cent increase, as well as all plants refurbished thereafter, received FITs for 13 years.[26] After the Green Electricity Act was amended in 2012, new SHP plants (or those undergoing refurbishment that increased the mean annual production or capacity by more than 15 per cent) with a capacity below 2 MW could choose between FITs or an investment support incentive scheme, while SHP plants above 2 MW were only eligible for the investment support option.[27] FITs for SHP plants current as of 2021 are displayed in Table 1.

Table 1. **Small Hydropower Feed-in Tariffs in Austria in 2019**

Delivered electricity	*Feed-in tariffs in EUR/kWh (USD/kWh)*	
	Refurbishment > 15%	*New SHP or refurbishment > 50%*
< 500 MWh	0.0851 (0.1053)	0.1020 (0.1262)
Next 500 MWh	0.0676 (0.0837)	0.0836 (0.1035)
Next 1,500 MWh	0.0577 (0.0714)	0.0725 (0.0897)
Next 2,500 MWh	0.0355 (0.0439)	0.0442 (0.0547)
Next 2,500 MWh	0.0328 (0.0406)	0.0405 (0.0501)
7,500 MWh	0.0251 (0.0311)	0.0320 (0.0396)
For power buoys < 500 MWh		0.1287 (0.1593)
For power buoys > 500 MWh		0.1190 (0.1473)

Source: Source: BMWFW[28]

The Renewable Expansion Law (EAG) adopted in 2021 replaced FITs with market premiums for newly commissioned plants, retained the investment support system and added a third incentive option in the form of mixed-technology tenders. An updated investment support scheme was in the process of being adopted by the Government of Austria as of 2022.

RENEWABLE ENERGY POLICY

The key policy document outlining the renewable energy targets of Austria is the Austrian Climate and Energy Strategy (#mission2030), adopted in 2018. Targets include reducing the country's greenhouse gas emissions by 36 per cent by 2030 relative to the 2005 levels, to be achieved by increasing the share of RES in total energy demand to 45–50 per cent. By 2030, 100 per cent of electricity produced in Austria should come from renewable sources, while the transport sector and heating sectors should also be fully RES-based by 2050. SHP plants play an important role in the #mission2030 strategy, which aims to decentralize electricity generation in order to ease the strain on the electric grid and to gain more grid stability.[29]

The Regulation (EU) 2018/1999 binds Austria to achieving CO2-neutrality by 2050. In 2020, the new Government of Austria set a significantly more ambitious goal, aiming for climate neutrality by 2040.[30]

SMALL HYDROPOWER LEGISLATION AND REGULATIONS

The key piece of legislation adopted in pursuit of renewable energy targets is the Austrian Renewable Expansion Law 2021 (EAG). The law entered into force on 7 July 2021, with amendments passed on 20 January 2022. Under this law, subsidies for SHP plants constructed on protected stretches of rivers were mostly eliminated and are now applicable only under certain conditions. Furthermore, refurbished or repowered plants of up to 1 MW in installed capacity must now demonstrate a 5 per cent increase in performance or regular working capacity rather than 15 per cent as indicated by the tariff system established in 2003. For plants above 1 MW, this threshold is further reduced to 3 per cent. In addition, performance losses due to environmental protection measures are considered and excluded from the performance increase threshold necessary to receive incentives. The bottleneck performance or regular working capacity must not be lower than the values achieved before the refurbishment.[31]

Types of subsidies available for SHP plants include:

- Investment subsidies, amounting to a maximum of 30 per cent of the investment amount, are to be granted in the course of funding calls, ending the efficient first come-first serve principle. The investment subsidy is an option for the construction and revitalization of an SHP plant up to 2 MW.
- The market premium system, newly established by the EAG, involves a flexible premium to be paid on top of the mean market price of each month. The premium will be calculated as the difference between the average production cost for each renewable technology and the electricity market price of each month.
- Mixed-technology tenders were introduced in the EAG amendments from 20 January 2022, establishing a bidding process for contracting an additional 20 MW of RES capacity per year (wind power and SHP).[31]

In addition to the EAG, earlier legislation plays a major role in regulating SHP in Austria. The Water Rights Act 1959 (WRG) regulates all forms of water use, defining whether a certain water use must be licensed and the conditions and legal requirements for issuing a water use licence. The European Union (EU) Water Framework Directive was implemented in the Water Rights Act in 2003. The Act sets clear targets concerning the protection of surface water bodies and of groundwater.[32]

The National Water Management Plan (NGP), based on the WRG, aims to fulfil the requirements of the EU Water Framework Directive and specifies the means of achieving the established targets for water resources.[33]

Finally, the Environmental Impact Assessment Act (UVP-G 2000) establishes rules and regulations for carrying out environmental impact assessments (EIAs), in line with integrated environmental management principles. The EIA procedure is applied to SHP plants above 2 MW in power plant chains, defined as a series of two or more hydropower plants with an installed capacity of at least 2 MW each and without a sufficient minimum distance between the weir systems in the fish habitat.[34,35]

EFFECTS OF CLIMATE CRISIS ON SMALL HYDROPOWER DEVELOPMENT

As a result of climate change, hydropower generation in Austria is expected to decrease in the summer and increase in the winter. Long-term forecasts show an overall tendency towards decreasing annual production, estimated at between ±5 per cent and -15 per cent by the end of the 21st century.[5]

BARRIERS AND ENABLERS FOR SMALL HYDROPOWER DEVELOPMENT

Barriers for SHP development in Austria have been increasing in recent years, particularly for plants with capacity below 100 kW. Major barriers include the following:

- Limited subsidies leading to sustained stop-and-go cycles in construction activities. As of 2021, more than 100 SHP projects were stuck in the planning process. Dozens more were waiting for the needed decrees determining the detailed regulations for subsidies in order to start construction works;
- Increasing costs of construction;
- Administrative bureaucracy, with excessive requirements for surveys to be completed during the planning process that are of limited relevance to the project itself and raise costs considerably;
- Increasing environmental requirements issued by the Government, including fish passes and reserved flow thresholds;
- Resistance to development works by local communities due to a “not-in-my-backyard” mentality, despite an overall positive perception of SHP.

Factors enabling SHP development in Austria include the following:

- Considerable local technical and economic capacity for SHP development, with dozens of local hydropower companies involved in SHP innovation and development. The SHP sector in Austria has a strong focus on export markets and implementation of environmentally-friendly solutions;
- SHP development is promoted by lobbying groups, including Renewable Energy Austria and Small Hydropower Austria;
- Untapped SHP potential identified by several studies and accounted for in government strategic development plans for RES;
- Several support schemes available for SHP plants, including FITs and investment subsidies.

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Belgium

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

KEY FACTS

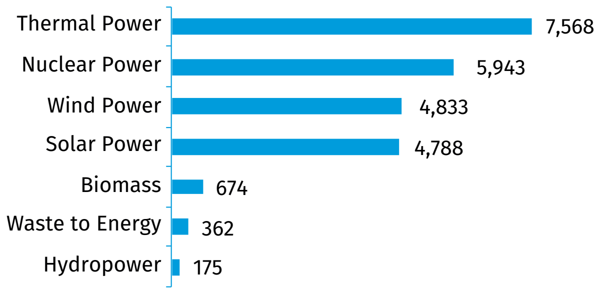
Population	11,521,238 (2021)[1]
Area	30,688 km²[2]
Topography	The country is made up of three main geographic zones. The lower region of Belgium is situated around the coast, generally below 15 metres in altitude. Middle Belgium, with altitudes between 60 metres and 180 metres, is a central plain with scattered rivers and streams. The Ardennes, with altitudes ranging from approximately 200 metres to over 500 metres, are home to the highest peak in Belgium — the Signal de Botrange at 694 metres above sea level, which is located in the Hautes Fagnes region near the border with Germany.[2,3]
Climate	The climate in Belgium is temperate oceanic, with mild temperatures and strong winds in the western regions. The mean annual temperature is 10.7 °C, with average maximum temperatures ranging from 5.9 °C in January to 23.9 °C in June (1991-2020). Average minimum temperatures range from 0.4 °C in February to 13.5 °C in July.[4]
Climate Change	Climate change has already been observed in the country, with an average increase of 0.4 °C per decade. Rainfall accumulation has increased by 15 per cent during spring and winter months since 1833, while annual rainfall has increased on average by 7 per cent. Under the RCP 8.5 worst-case emissions scenario, temperatures are expected to rise by 12.7-16.3 °C by the end of the century. In contrast, under the RCP 2.6 scenario, temperatures are predicted to increase by 10.4-12.2 °C.[4]
Rain Pattern	Mean annual precipitation in the country is 885.5 mm (1991–2020). The least rainy month is April, with an average of 50.6 mm, while the month with the heaviest rainfall is December, averaging 92.6 mm (1991–2020). The Wallonia region has a higher monthly precipitation, averaging 84.0 mm, with rain scattered throughout the year. Meanwhile, the highly elevated Ardennes region can accumulate up to 1,400 mm of precipitation per year.[3,4]
Hydrology	There are two major river systems in the country originating from France and continuing eastwards towards the Netherlands: the Schelde (Escaut) and the Meuse (Maas). The highest points of the Ardennes contain peat bogs, offering poor drainage.[5]

ELECTRICITY SECTOR OVERVIEW

In 2021, installed capacity in Belgium reached 24,343 MW, excluding pumped-storage hydropower and approximately 19 MW of unclassified other generation.[6] Thermal power plants made up 31 per cent of total capacity at 7,568 MW, while renewable sources accounted for 44 per cent. Nuclear power accounted for 24 per cent at 5,943 MW. Hydropower made up the least amount of capacity with 175 MW (1 per cent), while wind power and solar power made up 4,833 MW and 4,788 MW respectively (20 per cent each) (Figure 1).

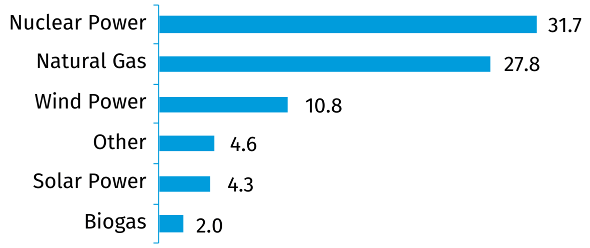
Electricity generation in the country was 81.2 TWh in 2020. This was met primarily by natural gas at 27.8 TWh (34 per cent) and nuclear power at 31.7 TWh (39 per cent).[7] Wind power made up 10.8 TWh of the total generation (Figure 2). Belgium has gone from being a net exporter in 2018 to a net importer of electricity in 2019 and in 2020.[7] Electrification in urban and rural areas is at 100 per cent.

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



Source: ENTSO-E[6]

Figure 2. **Annual Electricity Generation by Source in Belgium in 2020 (TWh)**



Source: Elia Group[7]

Note: Hydropower is included in "other" generation under official energy statistics in Belgium.

Belgium is constituted of three main regions: The French-speaking Wallonia region, the Dutch-speaking Flemish region and the capital of Brussels. This segregation has influenced the structure of the electricity system, which is largely governed by the regions separately from the Federal Government. Belgium has a fully liberalized electricity sector, allowing for market competition in both the generation and supply subsectors. The national regulator, the Commission for Electricity and Gas Regulation (CREG), is tasked with regulating access to the networks and approving electricity tariffs. Each region also has its own regulator, including the Flemish Regulator of the Electricity and Gas Market (VREG), Walloon Energy Commission (CWaPE) and Brussels Gas Electricity (BRUGEL). The role of the national regulator includes advising on energy issues to Government authorities, monitoring the energy market, ensuring compliance with legislation, monitoring anticompetitive behaviour, settling disputes and imposing sanctions.[9] The regional regulators are tasked with granting supply licences and green certificates and advising regional authorities on energy-related issues.
The transmission network handles voltages of 30–400 kV with over 8,896 kilometres of lines and underground cables.[8] The network is owned and operated under monopoly by Elia Group, a company that is interconnected on a European level. The Third Energy Package of Belgium enforces the unbundling of the transmission system operator (TSO) from generation and supply activities. However, the Act of 8 January 2012, which was intended to transpose this requirement into national law, has been significantly watered down following a challenge in the Constitutional Court, reducing the expected ambition towards unbundling of these activities.[9] Distribution networks are operated by the regional distribution system operators (DSOs) at below 70 kV voltage levels.[9] In Flanders, the umbrella DSO organization is called Eandis and is composed of 11 smaller DSOs. The overarching DSO in Wallonia is called ORES.

Across all regions, electricity prices have fallen from January 2020 to January 2021 (Table 1) despite an increase in average electricity bills by 66 per cent during the period from 2007 to 2019.[10] Electricity tariffs in Belgium are partially driven by the market and partially regulated. In June 2021, the annual average Wallonian household electricity bill amounted to EUR 994.12 (USD 1,153.08), of which 38 per cent was due to market competition reflected through the unregulated part of the electricity price.[11] Distribution grid charges represented 33 per cent of the price (Table 2).

Table 1. **Electricity Prices in January 2020 and January 2021 by Region in Belgium**

Region	*Electricity price in 2020 (EUR (USD))*	*Electricity price in 2021 (EUR (USD))*	*Decrease (%)*
Flanders	0.275 (0.31)	0.262 (0.30)	4.73
Wallonia	0.277 (0.31)	0.264 (0.30)	4.66
Brussels	0.233 (0.26)	0.220 (0.25)	5.25

Source: Energy Price Belgium[10]

Table 2. **Composition of Annual Average Electricity Tariffs in Wallonia in 2021**

Total electricity price (EUR (USD))	*Federal and regional surcharges (EUR (USD))*	*Green energy tariff (EUR (USD))*	*Transport (EUR (USD))*	*Distribution (EUR (USD))*	*Energy production (EUR (USD))*
994.12 (1,153.08)	23.08 (26.77)	117.92 (136.76)	153.14 (177.61)	326.10 (378.21)	373.89 (433.64)

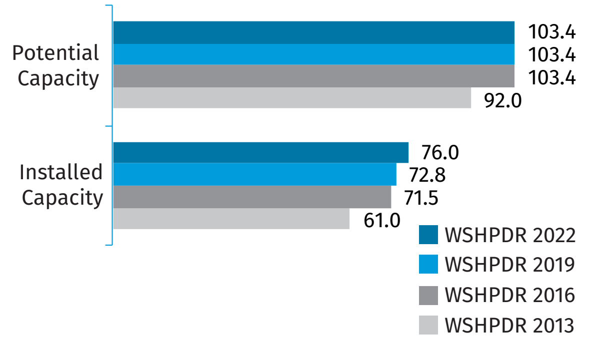
Source: CWaPE[11]

SMALL HYDROPOWER SECTOR OVERVIEW

The definition for small hydropower (SHP) in Belgium is plants up to 10 MW in capacity. The total installed capacity of SHP as of 2019 was 76 MW, with the vast majority of this capacity being situated in the Wallonia region, whereas Flanders was home to approximately 5.6 MW of SHP capacity from 13 power plants.[12,14,15] Information on installed SHP capacity is only known for transmission-connected plants and those that appear in the green certificates database.

The increase in the combined capacity of operational SHP plants since the *World Small Hydropower Development Report (WSHPDR) 2019* (Figure 3) is due to the inclusion into the SHP capacity calculation of two new databases on the allocation of green certificates, which provide lists of hydropower capacities benefiting from this scheme in each region.[14,15] The increase is thus likely due to the inclusion of micro- and pico-hydropower pants in the official statistics, rather than actual growth in the sector. Meanwhile, the economically-feasible potential of SHP in Belgium has stayed the same as in the previous two editions of the *WSHPDR* due to the lack of more recent data. The European Small Hydropower Association has carried out a potential assessment, having identified 83 potential SHP sites in Belgium.[13] Economically feasible annual production from these sites was estimated at 293 GWh. Unfortunately, this source is no longer publicly available and the total capacity of these sites is unknown.

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



Source: Energie Commune,[12] VREG,[14] CWaPE,[15] *WSHPDR 2013*,[16] *WSHPDR 2016*,[17] *WSHPDR 2019*[18]

Note: Only data for SHP plants that received green certificates or are TSO-connected are available.

Apart from two large pumped-storage plants, there are two hydropower plants, both located in Wallonia, that surpass 10 MW of installed capacity at a combined installed capacity of approximately 38 MW.[19,20] By deducting the capacity of these two power plants from the regional hydropower installed capacity estimates provided by Energie Commune, it can be determined that approximately 73 MW of SHP capacity is located in the Wallonia region, while the remaining are from plants in Flanders.[12]

Hydropower in Belgium faces constraints originating from competing water uses, in particular from the industrial and large consumer sectors, such as the nuclear sector, which represents a significant demand for water as a cooling agent.[5]

Comprehensive data on hydropower plants are not publicly available and data are only published on solar and wind power plants under a voluntary initiative from the Belgian Federation of Electricity and Gas Enterprises (FEBEG).[21] Table 2 displays a non-comprehensive list of SHP plants in Belgium.

Table 2. **List of Selected Operational Small Hydropower Plants in Belgium**

Name	*Location*	*Capacity (MW)*	*Operator*	*Launch year*
Hu Ivoz-Ramet	Liege	10.00	EDF Luminus	1954
Ampsin-neuville	Amay	9.90	EDF Luminus	1965
Hu Andenne	Andenne	9.00	Luminus	1980
Hu Grand-Malades	Namur	5.00	Luminus	1988
Heid-de-goreux 2	Aywaille	5.00	Electrabel	1931
Heid-de-goreux 1	Aywaille	4.00	Electrabel	1931
Wtr-0025 Ham	Sluisstraat 24 A, 3945 Ham	2.40	Inter-Energa	2015
Wtr-0026=Olen	Sluizenweg zn, 2250 Olen	2.40	Iveka	2014
La Vierre	Chiny	1.90	Electrabel	n/a
Butgenbach	Butgenbach	1.80	Electrabel	1932
Hu Floriffoux	Namur	0.80	EDF Luminus	1993
Wtr-0001 Wijnegem Waterkracht (gsc rest)	Stokerijstraat zn, 2110 Wijnegem	0.33	Iveka	2009
Wtr-0023 Hydrocatala	Grote Baan 302, 1620 Drogenbos	0.11	Iverlek	2013
Wtr-0007 Lozen Hydro (nai)	Kempenstraat, 3950 Bocholt	0.10	Inter-Energa	2007
Wtr-0006 Bocholt Hydro (nai)	Snellewindstraat, 3950 Bocholt	0.06	Inter-Energa	2007
Wtr-0021 Johnny Thijs	Klein Overlaar 75, 3320 Hoegaarden	0.02	Iverlek	2011
Wtr-0022 Molen van Schoonhoven	Diestsesteenweg 12, 3200 Aarschot	0.01	Iverlek	2012
Wtr-0020 Provinciebestuur Oost-vlaanderen	Rekegemstraat 29, 9630 Zwalm	0.01	Gaselwest	2010
Wtr-0018 Willy Bauwens Waterkracht	Kloosterstraat 92, 9340 Lede	0.01	Imewo	2007
Wtr-0019 Vrienden van de Molen	Molenhoek 14, 9620 Zottegem	0.004	Intergem	2009

Source: Elia Group[22]

Information on potential sites or projects in planning are not publicly available either, nor are they published in a centralized database. However, environmental data on stream flow and height could be a starting point for future studies on SHP potential in Belgium.[23] Table 3 provides details on one SHP project currently undergoing rehabilitation.

Table 3. **Planned Small Hydropower Project in Belgium**

Name	*Location*	*Capacity (MW)*	*Plant type*	*Developer*	*Planned launch year*	*Stage of development*
Bevercé	Robertville Dam, Malmédy	10.0	Reservoir	Tractebel	2022	Rehabilitation

Source: Hydro Review[24]

RENEWABLE ENERGY POLICY

The Act of 29 April 1999 on the organization of the energy market is the primary federal act containing information on generation rules as well as the role of the transmission grid and federal regulator. Each region has its own main piece of legislation detailing electricity sector rules, including available support mechanisms for renewable energy generation. These are the Decree of 8 May 2009 for Flanders, the Decree of 12 April 2001 for the Wallonia region and the Ordinance of 19 July 2001 for the Brussels-Capital region.[9]

Recent policies include the European Union–mandated Integrated National Energy and Climate Plan 2021–2030, which set a target of 17 per cent of gross final energy consumption to be met by renewable sources by 2030.[25] The plan defines several regional scenarios, with the most ambitious scenario for the Wallonia region, indicating that hydropower is to meet 440 GWh of generation by 2030, up from 314 GWh in 2015. No increased hydropower generation is envisioned under the Flemish regional projections. The new long-term strategy document to 2050 has no mention of hydropower, suggesting that renewable energy policy is not favourable towards hydropower development in the medium-to-long term.[26]

SMALL HYDROPOWER LEGISLATION AND REGULATIONS

Supply licences are offered by the regional regulators: CWaPE, VREG and BRUGEL. Obtaining a production permit as part of the licensing process is not mandatory for any plants under 25 MW.[9]

COST OF SMALL HYDROPOWER DEVELOPMENT

The cost of SHP projects varies greatly depending on the size of the plant, the model, the developer and other factors. According to a study by the International Renewable Energy Association (IRENA), the installation costs can vary from 1,300 USD/kWh to 8,000 USD/kWh within the European Union.[28] The estimate for Belgium is 20,000 EUR/kW (22,668 USD/kW) in installed capacity for plants of under 1 MW and 3,000 EUR/kW (3,400 USD/kW) for plants above 1 MW.[27] Operational costs are approximately 1–4 per cent of installation costs. The levelized cost of electricity (LCOE) for SHP in Belgium is between 0.15 USD/kWh and 0.18 USD/kWh. This is higher than the EU average LCOE for SHP.[28]

FINANCIAL MECHANISMS FOR SMALL HYDROPOWER PROJECTS

In Belgium, each region is responsible for the promotion of renewable energy sources within its own territory. A Tradeable Green Certificate (TGC) Mechanism is in place across the regions and in collaboration with the Federal Government. For Brussels and Wallonia, certificates are issued to producers who save a predetermined quantity of CO_2 emissions compared to the average generation facility. Currently, hydropower plants receive, depending on their generation and consumption, between 2.5 and 0.71 green certificates per MWh produced for 20 years.[27] TGCs are allocated by the regulation authorities of each region, each having its own set quota for green certificates that suppliers must abide by. Failure of suppliers to comply could lead to penalties. Installation premiums are also available for renewable energy generators or installers.[9]

EFFECTS OF CLIMATE CRISIS ON SMALL HYDROPOWER DEVELOPMENT

Climate change is already taking effect in the country, with precipitation having increased by 7 per cent on average compared to 1833. This could have a positive effect on SHP capacity factors, especially during the spring and winter months when precipitation increases are most prominent. However, without proper design, SHP plants could be at risk of overflow and flooding, especially in the case of small catchment areas.[29]

BARRIERS AND ENABLERS FOR SMALL HYDROPOWER DEVELOPMENT

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

- Limited access to data on potential sites for development;
- Environmental limitations imposed on developers, including EU-level environmental restrictions from legislation such as the European Water Framework Directive, and unclear rules regarding environmental constraints;
- Ageing sector with key developers focused on bringing designs to other countries.

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

- Increased precipitation due to climate change with a positive effect on plant capacity factors;
- Incentive to develop green energy through the TGC mechanism and exoneration from distribution costs;
- Strong baseline of existing operational SHP plants, indicating a mature sector with learned expertise.

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France

Aurélie Dousset and Jean-Marc Levy, France Hydro Électricité; and Tamsyn Lonsdale-Smith, ICSHP

KEY FACTS

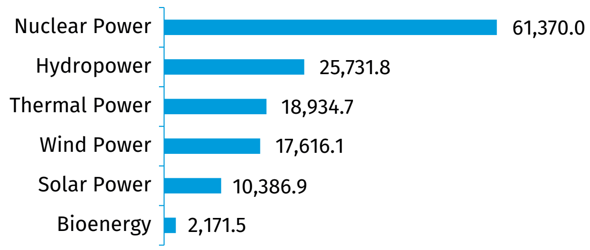
Population	67,063,703 (2020)[1]
Area	549,000 km[2] [2]
Topography	The topography of France includes mostly flat plains or gently rolling hills in north and west. The remainder is mountainous, particularly the Pyrenees in the south and the Alps in the east. The country's highest point is Mont Blanc at 4,807 metres.[2]
Climate	Three types of climate are found in France: oceanic (west), continental (central, east) and Mediterranean (south). Average temperatures in oceanic Brittany are 6 °C in winter and 16 °C in summer. Paris, which lies in the continental climate, averages a yearly temperature of 11 °C. The southern coastal city of Nice experiences an annual average of 15 °C.[2]
Climate Change	By 2040, France is expected to experience longer periods of drought and low rainfall. At the same time, episodes of intense rainfall will be more frequent in the south of the country. Heat waves will also become more intense by the end of the century. Under an unabated emissions scenario (RCP 8.5), average temperatures would increase by 3.9 °C between 2070 and 2100 compared to the average pre-2005 temperatures. Summer temperatures under the same scenario would increase by 6 °C.[3]
Rain Pattern	Annual precipitation ranges from 680 mm in the central and southern regions to 1,000 mm around Paris and Bordeaux. In the northern coastal and mountainous areas precipitation can reach up to 1,120 mm or more.[2]
Hydrology	Five major rivers create the drainage system of France. The Seine (780 kilometres) flows through the Paris basin and has three tributaries: the Yonne, Marne and Oise Rivers. The Seine drains into the English Channel. The Loire (1,020 kilometres) is the longest river in France and flows through the central region. The Garonne is the shortest of the major rivers in France. It rises in the Pyrenees, across the border with Spain, and empties into the Bay of Biscay at Bordeaux. The Rhone is the largest and most complex of French rivers. Rising in Switzerland, it flows southwards through France for 521 kilometres, emptying into the Mediterranean. Lastly, the Rhine flows along the eastern border for approximately 190 kilometres, fed by Alpine streams.[2]

ELECTRICITY SECTOR OVERVIEW

In 2020, installed capacity in France amounted to a total of 136,211 MW, of which nuclear power made up 61,370 MW, or 45 per cent (Figure 1). The most capacity additions since 2019 were seen in solar and wind power, which is in line with policy objectives for new renewable capacity additions. The only power source to see reductions since 2019 was nuclear, which declined by 2.8 per cent.[3] Renewable energy sources (including large hydropower) made up 55,906 MW in total, or 41 per cent of total installed capacity. Discounting large hydropower, renewable energy made up 32,374.5 MW, or almost 24 per cent.

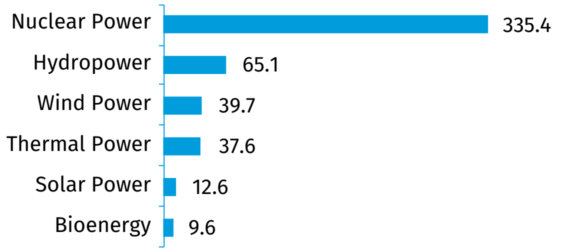
Electricity generation in France is mainly made up by nuclear power. In 2020, it accounted for 335.4 TWh or 67 per cent of the total electricity generation of 500.0 TWh. Other sources of generation include hydropower at 65.1 TWh, wind power at 39.7 TWh, thermal power at 37.6 TWh, while the remaining 22.3 TWh was made up of solar power and bioenergy (Figure 2).[3] Most of the thermal power production was from natural gas, constituting 34.5 TWh or 91.8 per cent in 2020, which indicates a 10 per cent decrease from the 2019 levels of natural gas production. In 2020, electricity production in France declined by 7 per cent compared to 2019 due to the Covid-19 crisis, in response to a reduction in consumption.[4] During 2020, energy consumption in France decreased to 460 TWh from 477 TWh in 2019, which translates into an almost 4 per cent decrease.[3]

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



Source: RTE[4]

Figure 2. **Annual Electricity Generation by Source in France in 2020 (TWh)**



Source: RTE[3]

The Ministry of the Ecological Transition is in charge of regulating the energy sector. The electricity grid is owned and operated by the Electricity Transmission Network (Réseau de Transport de l'Électricité, RTE) and ENEDIS. RTE operates the public high-voltage electricity transmission network from production centres to distribution networks, whereas ENEDIS operates the medium- and low-voltage electricity distribution network in 95 per cent of France. The electricity network consists of 106,047 kilometres of power lines. In 2020, more than 250 kilometres of underground power lines were added.[3] The French electricity market is open. However, it remains largely dominated by the formerly state-owned Électricité de France (EDF). The electrification rate of the country is 100 per cent.[5]

According to Article L410-2 of the Commerce Code and Article L337-1 of the Energy Code, electricity tariffs are generally subject to competition, buy may be regulated against the high and low competitive prices, in crisis situations, or under exceptional circumstances.[6,7] Electricity tariffs in France are regulated by the Ministry of Ecological Transition and the Ministry of Economy, Finances and Recovery by means of decree, twice a year in July and January, after consultation with the National Consumer Council. Consumers have the choice between a regulated tariff with their electricity producer or a market-based rate. The prices as of 1 August 2021 during peak and off-peak hours are displayed in Table 1.

Table 1. **Electricity Tariffs in France as of 1 August 2021**

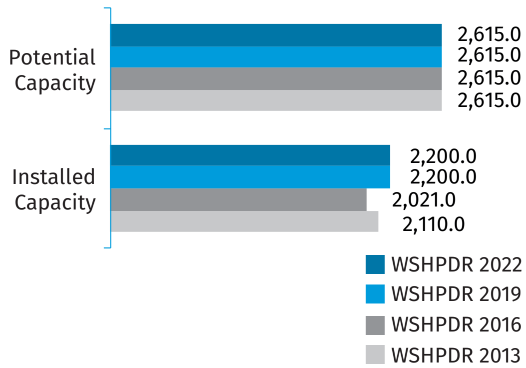
	Residential Rates		*Business Rates*	
Meter Power rating	*Peak EUR/kWh (USD/kWh)*	*Off-peak EUR/kWh (USD/kWh)*	*Head (m)*	*Type of site (new/refurbishment)*
3 kVA	0.1558 (0.18)	0.1558 (0.18)	n/a	n/a
6 kVA	0.1821 (0.21)	0.1360 (0.16)	0.1125 (0.13)	0.785 (0.90)
9 kVA	0.1821 (0.21)	0.1360 (0.16)	0.1125 (0.13)	0.785 (0.90)
12 kVA	0.1821 (0.21)	0.1360 (0.16)	0.1125 (0.13)	0.785 (0.90)
15 kVA	0.1821 (0.21)	0.1360 (0.16)	0.1125 (0.13)	0.785 (0.90)

Source: Kelwatt[8]

SMALL HYDROPOWER OVERVIEW

In France, small hydropower (SHP) is defined as plants having an installed capacity up to 10 MW. The SHP installed capacity is approximately 2,200 MW from approximately 2,270 plants (Table 1).[15] Compared to the *World Small Hydropower Development Report (WSHPDR) 2019*, the installed capacity has remained unchanged (Figure 3). No new feasibility studies have been conducted and the potential capacity also remains at 2,615 MW. The total annual generation from SHP is 6 TWh on average, which is roughly 10 per cent of the total hydropower generation in France.[9,10,11] It should be noted that in France there is no systematic tracing of SHP plants and thus the installed capacity figures presented are indicative rather than exact. Overall, information on SHP is not fully transparent in France. This is exemplified by the fact that any plant of under 36 kW cannot be publicly disclosed under the Public Order of 7 July 2016.

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



Source: *WSHPDR 2013*,[12] *WSHPDR 2016*,[13] *WSHPDR 2019*,[14] France Hydro Electricité[15]

Renewable energy plays an increasingly important role in meeting energy needs in France and hydropower remains the leading source of renewable electricity in the country. The Multi-Year Energy Plan (Programmation Pluriannuelle de l'Energie, or PPE) published in October 2016 sets the goal of increasing hydropower installed capacity from 500 MW to 750 MW by 2023.[16]

The Ministry of Ecological and Solidarity Transition launched the first call for projects for the development of SHP in April 2016 to promote the construction of new green fields and upgrade the equipment of existing dams. The 19 winners of this first call for projects, representing a capacity of 27 MW, were announced in April 2017. To continue this dynamic initiative, the Ministry announced in April 2017 a new call for tenders for 105 MW of new SHP capacity, divided into three application periods of 35 MW. This multi-year call for tenders, which ended in 2021, enabled the addition of 93.6 MW of new capacity over three periods. The PPE published in October 2019 set the goal of increasing hydropower installed capacity to 26.4-26.7 GW by 2028. As a result, the previous call for tenders for 35 MW in Q1 of each year has been renewed until 2024.[8]

A national register of electrical installations, hosted by Open Data Energy Networks réseaux énergies is the most comprehensive database that collates information from many electricity producers on SHP plants in France, both operational (Table 2) and in planning (Table 3).[14]

Table 2. **List of Selected Operational Small Hydropower Plants in France**

Name	*Location*	*Capacity (MW)*	*Head (m)*	*Plant type*	*Operator*	*Launch year*
Centrale de consolation-maisonnettes	Consolation-Maisonnettes, Doubs	0.54	63	Run-of-river	ENEDIS	2020
Moulin de ratayrens	Le Riols, Tarn	0.42	2	Run-of-river	ENEDIS	2019
Centrale de crevoux	Crévoux, Hautes-Alpes	3.06	283	Run-of-river	ENEDIS	2019
Sh aqua bella	Val-d'Arc, Savoie	2.20	0	Run-of-river	ENEDIS	2019
Sacom - moulin de cartels	Le Bosc, Hérault	0.12	6	Run-of-river	ENEDIS	2019
Confidential	Villard-Bonnot; Isère	5.50		Run-of-river	GAZ ELECTRICITE DE GRENOBLE	2019
Confidential	Velaux; Bouche-du-Rhône	0.23	6	Run-of-river	ENEDIS	2019
Micro-centrale du roc de la peche	Pralognan-la-Vanoise, Savoie	0.16	140	Run-of-river	ENEDIS	2019
Centrale de turbinage du debit reserve	Condat, Cantal	0.16	19	Run-of-river	ENEDIS	2019
Confidential	Saint-Girons, Ariège	0.24	2	Run-of-river	ENEDIS	2019
Moulin de bezon	PloÃ«rmel, Morbihan	0.07	0	Run-of-river	ENEDIS	2019
Centrale d eyguieres	EyguiÃ¨res, Bouches-du-Rhône	1.60	12	Run-of-river	ENEDIS	2019
Barrage de mervent - siaep	Mervent, Vendée	1.74	0	Run-of-river	ENEDIS	2019
Hydro antoigne	Sainte-Jamme-sur-Sarthe, Sarthe	0.43	0	Run-of-river	ENEDIS	2019
Confidential	La Roche-Chalais, Dordogne	0.42	3	Run-of-river	ENEDIS	2019
Microcentrale - commune de jougne	Jougne, Doubs	0.09	9	Run-of-river	ENEDIS	2019
Moulin d arignac	Arignac, Ariège	0.50	30	Run-of-river	ENEDIS	2019
Confidential	Schirmeck	0.48		Run-of-river	SA ELECTRICITE DE STRASBOURG	2019
Spl eau du bassin rennais	Plouasne	2.60	0	Run-of-river	ENEDIS	2019
Le moulin de cezi	Arbois	0.75	2	Run-of-river	ENEDIS	2019

Source: Open Data Réseaux Énergie[17]

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

Name	*Location*	*Capacity (MW)*	*Head (m)*	*Plant type*	*Developer*	*Stage of development*
P.ROLH-CENTRALE HYDRAULIQUE DE PONT-ROLLAND-3	Hillion, Brittany	2.7	22	reservoir	RTE	refurbishment

Source: Open Data Réseaux Énergie[14]

The French water administration drafted an inventory of obstacles on rivers and aims to assess the degree to which these obstacles block the movement of species and sediment. A database was created in May 2012, including more than 60,000 obstacles such as dams, locks, weirs and mills no longer in operation.[18] A protocol called the Information on Ecological Continuity (Informations sur la continuité ecologique, or ICE) has been also created to measure the capacity of obstruction of these obstacles. This project identifies the installations causing the greatest problems and makes it possible to set priorities for corrective action.[19]

RENEWABLE ENERGY POLICY

A regional plan for climate, air and energy (Schema regional du climat de l'air et de l'energie, SRCAE) was jointly developed by the national Government and regional authorities. For 2020 and based on geographical area, this plan defines qualitative and quantitative regional targets for the valorization of renewable energy potential. In practice, this means identifying all sources to produce renewable energy and of energy savings according to socio-economic and environmental criteria and defining, in association with the local stakeholders (regional authorities, companies and citizens), the level of regional contribution in achieving the set national targets. This plan represents a strategic planning tool to guide the activities of local and regional authorities in relation to renewable energy development.[5] For hydropower potential, SRCAE is based on producers' data and compatibility with lists of no-go rivers and restoration of river continuity priorities.

In 2012, the share of energy produced from renewable sources in France amounted to less than 14 per cent and the target for 2020 was set at 23 per cent. Since renewable energy capacity stood at almost 24 per cent in 2020, France has reached the target. In August 2015, the Energy Transition Law was promulgated. This law set the framework for the energy transition towards a greener and cleaner energy, with a new objective of 32 per cent of energy consumption met by renewable resources, and 40 per cent of production, by 2030.

SMALL HYDROPOWER LEGISLATION AND REGULATIONS

One of the major difficulties in the preservation and development of SHP in France lies in the implementation of ecological continuity, directly resulting from the implementation of the European Framework Directive on Water. Given the many blockages in the implementation of the restoration of ecological continuity, a working group has been set up by the National Water Committee (Comité National de l'Eau, CNE). The CNE, created in 1964, is made up of representatives of users, associations, local authorities, representatives of the state, presidents of basin committees and persons competent in the water sector. The working group is consulted on the major orientations of water policy, national water development, distribution projects, major regional developments as well as on draft laws and regulations.

In 2018, the CNE published an action plan for a "policy of restoring the ecological continuity of rivers".[20] A technical note, published on 30 April 2019, detailed the implementation of this plan. In particular, the plan provides for a homogeneous prioritization of actions to restore ecological continuity for the benefit of the good condition of the watercourses and the restoration of biodiversity. This prioritization process has not been fully successful in improving the situation on the ground, and should be reflected in the new Master Plan for Water Development and Management (SDAGES) in preparation as of 2021.[21]

The maximum duration of permits is 75 years for big concessions. For relicensing, the duration is 20 years if there is no particular investment and approximately 30–40 years if there is a significant investment. France has a lot of perpetual old permits for former mills subjected to new environmental restrictions. The Government's priority is to simplify the legislation and some measures, such as a proposed law on Unique Authorization, are under review as of 16 October 2019.[22] The idea is to merge the different authorizations into one category to accelerate the process and relieve the administrative burden for rehabilitation of old SHP plants in particular.

Residual flow regulation exists: 10 per cent of interannual average flow and for modules over 80 m^3/s 5 per cent is allowed.[10] While the minimum (10 or 5 per cent) is set by the law, the adapted minimum ecological flow is set on a case-by-case basis through environmental assessments. The most used method is the micro-habitat method (using EVHA software), but there are also other possible methods adopted when EVHA does not suit the type of river. After 1984, the reserved flow was approximately 10 per cent of the average annual flow. Since 2006, 10 per cent is the minimum and local administrators often ask for more (12–17 per cent), without any justification on improvement or maintenance of the ecological status. In periods of extreme low water levels, the heads of departments (French administrative subdivision) can decide to temporarily lower the residual flow.

A Commitments Agreement for the Development of a Sustainable Hydropower was signed by the minister, representatives of local elected authorities, representatives of power producers, several NGOs and the national committee for professional fresh water fishing in June 2010 to promote hydropower if deemed suitable considering the environmental specifications.[23] This was done in compliance with European aquatic environment restoration requirements. A part of the agreement directly concerns the equipment of existing weirs. The methodology and the suitable conditions for building a power plant onto existing weirs need to be made more detailed. A guidebook Towards the Hydroelectric Plant of the 21st Century for the development of SHP plants with regards to the natural environment is available.[11] It defines standards for the construction of an environmentally sustainable plant. This guide is recognized and disseminated by European national administrations.

FINANCIAL MECHANISMS FOR SMALL HYDROPOWER PROJECTS

Finally, under the impetus of the European Commission, France enacted a law on energy transition (2015) in compliance with European State Aid Guidelines. A new tariff order was published in December 2016, the H16 contract, which sets out conditions for plants under 1 MW to access a support mechanism. Plants under 500 kW can benefit from feed-in tariffs (FIT) (tariff H16) and plants between 500 kW and 1 MW can benefit from premium FITs (additional remuneration). This new support mechanism is a bonus paid monthly in addition to the sale of electricity on the market. Purchase prices are between 0.11 EUR/kW and 0.13 EUR/kW (0.13–0.16 USD/kW). Finally, a tendering system is implemented for plants above 1 MW. The draft Renewable Purchase Obligations (RPO) contract for power plants between 1 MW and 4.5 MW, HR21, which has been in the pre-distribution phase since 2019, was to be submitted to the European Commission at the end of the 1st quarter of 2021.

France uses RPO mandates to support the development of renewable energy, including SHP. In 2018, 1,940 MW worth of SHP received support in this form.[8]

COST OF SMALL HYDROPOWER

According to a recent report by the CRE, the cost of SHP development in France is between 2,100 and 5,600 EUR/kW (2,547–6,791 USD/kW) for 70 per cent of the new projects, while operational expenditures are between 50 and 180 EUR/kW (61–218 USD/kW).[24] This does not include costs pertaining to replacement of materials.

EFFECTS OF CLIMATE CRISIS ON SMALL HYDROPOWER DEVELOPMENT

According to a recent report by Météo France, under several climate change scenarios, periods of extreme evaporation during summer draughts are expected to increase, which will have implications for all hydraulic resources. The extent of this phenomenon varies depending on the scenario. Under both the RCP 4.5 and RCP 8.5, periods of extreme evaporation will increase by between 30 and 50 per cent by the end of the century. However, under a minimum warming scenario, the effect is less strong, with the possibility of a decrease in duration of these summer droughts.[3]

BARRIERS AND ENABLERS FOR SMALL HYDROPOWER DEVELOPMENT

There are multiple barriers to SHP development in France. Some of the main barriers are outlined below:

- The classification of rivers carried out by the Government in 2012 states that no more new works (no hydropower plants among other) can be created on the rivers ranked in List 1, which impacts more than 71 per cent of the hydropower potential. This classification also implies for the owners of hydropower plants located on rivers ranked in List 2 to carry out heavy and expensive installations to ensure the transport of the sediment and fish migration.
- Costs related to the environmental development are becoming increasingly burdensome for producers, representing investments in the range of several times the turnover of a plant.
- There are numerous financial obstacles to SHP development. French producers who cannot or do not wish to invest to benefit from new FIT contracts have to sell their electricity directly on the market. The market price does not take into account specificities of SHP production (i.e., the green value and the decentralized production). The market price level of SHP electricity generation (approximately 40 EUR/MWh (49 USD/MWh) in 2017) does not allow any investment and may push some small units into bankruptcy. The industry has also alerted the authorities about the inflation of the local taxation, which can reach to 10 EUR/MWh (12 USD/MWh), i.e., a quarter of the purchase price of electricity on the market.[25]

The following points summarize the main enablers to SHP development in the country that have been identified:

- In his speech presenting the Multiannual Energy Programme, President E. Macron specifically praised the role and qualities of hydropower as "*a strength of our territories and a strength of our low electricity production, cost and low emission*". The objectives set for hydropower by 2028 are a clear message from the Government who wants to preserve production capacities by strengthening them wherever possible.[26]
- France Hydro Electricité published in December 2020 a study about hydropower and flexibility. Based on the 2020 operation, this study confirms the role played by hydropower in the flexibility of the electrical system according to its three components: the structural variation of the residual demand, coverage of forecast errors of the residual demand between D-1, real time and dynamic (less than half an hour). It then shows the extent of the flexibility needs that will be necessary in the medium and long term, whatever the electricity mix scenario envisaged, and the evolution of the role that hydropower could play.

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Germany

Tobias Dertmann, Hydropower Consultant

KEY FACTS

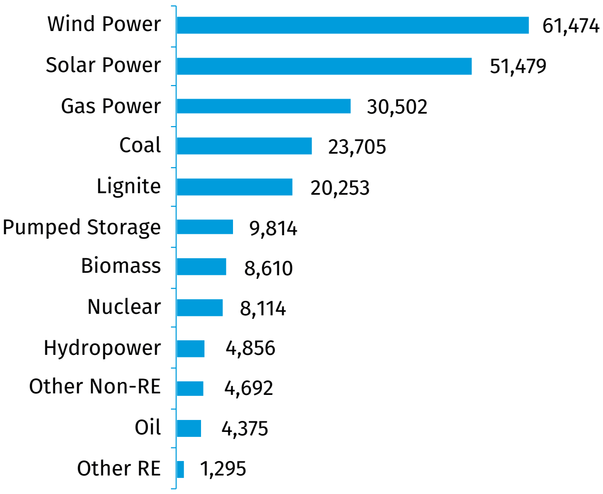
Population	83,157,201 (2020)[1]
Area	357,580 km²[2]
Topography	The northern areas of Germany are characterized by coasts and lowlands, while the centre is mainly covered by forested uplands. Low mountains in the south-west merge with the Bavarian Alps in the south-east, which form the border with Austria and Switzerland, with the highest altitude at the Zugspitze (2,963 metres). The country's lowest point is 3.5 metres below sea level.[3]
Climate	The north-western and coastal areas of Germany are characterized by a maritime-influenced climate with warm summers and mild winters. The climate transitions to a continental one to the south-east, with greater seasonal variations in winter and summer. The Alpine regions exhibit lower temperatures and higher precipitation. Historically, the mean temperature in winter (December-February) has been 0.9 °C and in summer (June-August) 16.3 °C. Extreme temperatures can reach from -10 °C to +35 °C. Occasionally there is warm mountain wind.[3]
Climate Change	The German weather service predicts an increase of up to 30 per cent in winter precipitation, while summers are predicted to be up to 40 per cent warmer due to climate change. Higher amounts of heavy precipitation are to be expected in the entire country.[3]
Rain Pattern	Average annual precipitation is 789 mm. The amount of rainfall decreases across the country from west to east, with markedly higher precipitation in the southern mountainous regions.[4]
Hydrology	Germany is rich in water resources, with 2 per cent of its surface area covered by water, of which 40 per cent are natural lakes. The country is traversed by major European rivers such as the Rhine, Elbe, Saale, Neckar, Weser, Oder and Danube. The main flow direction of rivers is from the southern Alpine region and central mean range mountains to the north (Rhine, Elbe, Weser) and to the east (Danube). The country's largest lake is Lake Constance (Bodensee), which is shared with Austria and Switzerland.[5]

ELECTRICITY SECTOR OVERVIEW

The German power system is the largest in Europe. In 2020, the country's installed electricity generating capacity totalled 229 GW, with renewable energy sources making up approximately 56 per cent (128 GW) (Figure 1).[6] The generating capacity participating in the electricity market totalled 114 GW.[6] The net power production in Germany in 2020 was 489 TWh, of which renewable sources contributed approximately 51 per cent (247 TWh) (Figure 2).[7]

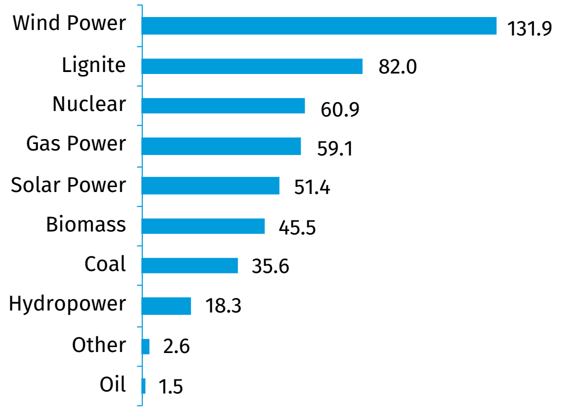
Power generation in the German electricity market is currently dominated by four incumbent power generators that share the market with a small number of regional utilities and hundreds of municipal utilities. With the liberalization of the electricity market in 1998 and dedicated policies focused on ushering in the energy transition (*Energiewende*), several independent power producers have entered the market, especially operating small-scale wind power and solar photovoltaic (PV) plants, reflecting a trend towards increasing decentralized power generation. Following the European Commission legislation mandating a legal unbundling of network businesses in 1996, the four incumbent transmission companies became legally independent from their parent generator companies. Distribution networks are owned and operated by more than 800 regional and local operators. The rate of electrification in Germany is 100 per cent.

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



Source: Federal Network Agency[6]

Figure 2. **Annual Electricity Generation by Source in Germany in 2020 (TWh)**



Source: Fraunhofer ISE[7]

The energy policy of Germany is predominately driven by the *Energiewende*, seeking the gradual phase-out of nuclear and coal power, while concurrently reducing greenhouse gas emissions through increased renewable energy production and energy efficiency improvements. Long-term goals plan for 80 per cent of electricity demand to be met by renewable generation by 2050, compared to the current average rate of 45 per cent.

As a result of dedicated policies and investment, Germany has experienced a remarkably rapid increase of renewable energy over two decades. However, the continued growth of renewable sources and stability of the power grid hinges on the expansion and improvement of the power grid. This includes both large-scale north-south transmission lines, but also upgraded low and medium distribution grids that can incorporate increased decentralized generators, energy storage and new smart technology and electric vehicles.

German power prices are among the highest in the European region. Despite wholesale electricity prices declining on average over the past decade, additional politically determined surcharges and taxes as well as grid fees (Table 1) have, in general, increased electricity bills for households. In 2020, the average consumer price in Germany for electricity was 0.3147 EUR/kWh (0.38 USD/kWh).[8]

Table 1. **Composition of Electricity Prices in Germany in 2020**

Breakdown	*Electricity price (USD/kWh)*
Generation cost	0.086
Grid cost	0.096
Electricity tax	0.025
VAT	0.061
Renewable energy cost	0.082
Offshore cost	0.012
Concessions	0.020

Source: STROM-REPORT[8]

SMALL HYDROPOWER SECTOR OVERVIEW

There is no official definition of size of small hydropower (SHP) plants in Germany. The German Ministry for Economic Affairs and Energy recognizes that no international consensus on the definition of SHP currently exists. Despite accepting that definitions across the European Union place the limit at 10 MW, in Germany the limit is arbitrarily drawn at the plant size of 1 MW. The current Report uses the definition up to 10 MW.

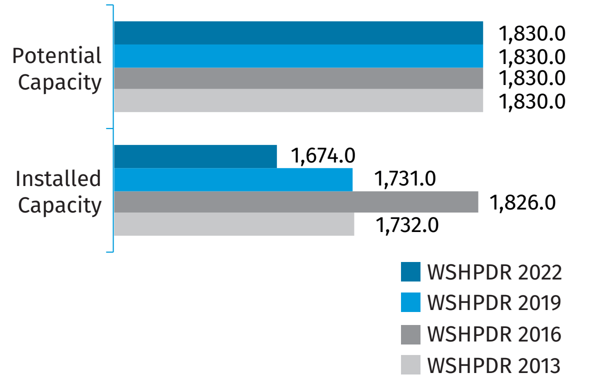
Germany has been a one of the global leaders in developing, installing and operating hydropower plants for over 100 years. The power plant stock of the country is characterized by a large number of SHP plants. Although SHP dominates the plant stock, the few large plants generate well over 80 per cent of the electricity of the entire hydropower sector.

No central register is kept specifically for hydropower plants in Germany, which means that the exact number of plants is unknown. This is due to the difficulty in keeping records of SHP plants, as many micro- and pico-hydropower projects used for self-consumption are difficult to identify. Therefore, the available data on the number of SHP plants in the country are based, to a certain extent, on estimates. In 2011, the existing data on hydropower plants were compiled by a survey of the German states and other institutions as part of a research project of the Federal Environment Agency. According to this survey, the total number of all hydropower plants in Germany is approximately 7,600.[9]

However, according to the Federal Association of German Hydropower Plants, in 2018 there were an estimated 7,300 hydropower plants in Germany with a total capacity of 5,600 MW. Approximately 6,900 of these plants had an installed capacity of less than 1 MW and nearly 80 per cent had less than 100 kW of installed capacity. According to the association data, the share of SHP plants under 1 MW in annual electricity generation is approximately 14 per cent.[10] Furthermore, based on the annual reports submitted by the transmission system operators to the Federal Network Agency, 6,249 SHP plants received compensation under the Renewable Energy Sources Act (EEG) in 2008, of which 80 per cent had less than 100 kW of installed capacity.[11] The locations of 406 plants with a capacity of more than 1 MW are known. The hydropower plants operated in Germany also include 31 pumped-storage plants, 11 of which have a natural inflow and therefore also produce renewable energy.[12]

According to the Bundesnetzagentur (the Federal Network Agency for Electricity, Gas, Telecommunications, Post and Railway), installed SHP capacity in Germany amounted to 1,674 MW in 2020 (Figure 3).[6] The decrease in installed capacity since the *World Small Hydropower Development Report (WSHPDR) 2019* is due to different definitions and measurements. In some calculations, private SHP plants are not included. Furthermore, the definition of 10 MW is not always followed, and many government websites include plants of up to 1 MW capacity, which make up the vast majority of SHP in Germany. According to the current information, however, the installed capacity of SHP plants has been almost constant over the last decade. There are no known plans for SHP development at the time of writing and the most recent known commissioning was in 2012 (Table 2). The available SHP potential is almost fully developed in Germany. The potential estimate of 1,830 MW is based on targets for exploitation of full economic potential by 2020, as outlined in the European Small Hydropower Roadmap, as no new feasibility studies are available.[13]

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



Source: Federal Network Agency,[6] ESHA,[13] *WSHPDR 2013*,[14] *WSHPDR 2016*,[15] *WSHPDR 2019*[16]

Note: Data for SHP up to 10 MW.

Table 2. **List of Selected Operational Small Hydropower Plants in Germany**

Name	*Location*	*Capacity (MW)*	*Head (m)*	*Plant type*	*Operator*	*Launch year*
Wasserkraftwerk Hausach	Hausach, Baden-Württemberg	0.4	4	Kaplan, run-of-river	E-Werk Mittelbaden	2012
Weserkraftwerk Bremen	Bremen	10.0	2–6	2x Kaplan, run-of-river	Weserkraftwerk Bremen GmbH & Co. KG	2012
Wasserkraftwerk Rebdorf	Rebdorf, Bavaria	0.1	2	–	Bistum Eichstätt	2011
Weserkraftwerk Bremen	Bremen	10.0	–	Run-of-river	Weserkraftwerk Bremen GmbH & Co. KG	2011
Praterkraft-werk	Munich, Bavaria	2.5	6	Kaplan, run-of-river	Stadtwerke München	2010
Wasserkraft-werk Johanniswehr	Hildesheim	0.3	4	Kaplan, run-of-river	EVI Energieversorgung Hildesheim	2009
Kraftwerk Oberföhring	Munich, Bavaria	1.0	5	Kaplan, run-of-river	E.ON	2008
Fuhlsbütteler Schleuse[	Hamburg	0.1	3	Kaplan, run-of-river	UWW Windstrom Wedel	2000
Kraftwerk Bad Abbach	Bad Abdach	3.5	5	Run-of-river	Uniper Kraftwerke GmbH	2000
Unterwasserkraftwerk Karlstor	Heidelberg	2.6	3	Underground, Kaplan	EnBW	2000
Wasserkraftwerk Dietfurt	Dietfurt	0.5	4	Run-of-river	Uniper Kraftwerke	1991
Kraftwerk Krün	Krün	0.2	5	Run-of-river	Uniper Kraftwerke	1990
Wasserkraftanlage Alte Schleuse	Hameln	1.3	5	Run-of-river	Stadtwerke Hameln	1988
Kraftwerk Dausenau	Dausenau	1.2	4	Kaplan, run-of-river	Süwag Energie	1986
Wasserkraftanlage Pfortmühle	Hameln	0.7	3	Kaplan-R, run-of-river	Stadtwerke Hameln	1986
Flusskraftwerk Auerbrücke	Pforzheim	1.0	4	2 x Kaplan, run-of-river	Stadtwerke Pforzheim	1985
Kraftwerk Nassau	Nassau	1.2		Kaplan, run-of-river	Süwag Energie	1985
Höchstädt	Bremen	9.9	–	Run-of-river	LEW Wasserkraft GmbH	1982
Kraftwerk Regensburg	Regensburg	7.2	5	3 x Kaplan, run-of-river	E.ON	1977
Speicherkraftwerk Lister	Attendorn	2.6	20	Kaplan, storage	LLK GmbH	1965
Kraftwerk Deizisau	Deizisau	2.0	5	Run-of-river		1963
Kraftwerk Offingen	Offingen	7.4	5	2 x Kaplan, run-of-river	Bayerische Elektrizitätswerke GmbH	1963
Werkskraftwerk Sappi Alfeld	Mühlenmarsch 1, Niedersachsen	0.1	--	Run-of-river	Sappi Alfeld GmbH	1912

Source: Federal Network Agency,[6] Wikipedia[17]

The majority of SHP plants are located in the mountainous southern provinces, with 50 per cent of all plants located in Bavaria and 20 per cent in Baden-Württemburg. These two states typically account for over 80 per cent of annual hydropower production in Germany. Electricity generation from hydropower can fluctuate year-on-year by 10–15 per cent depending on precipitation and river flows.[18]

RENEWABLE ENERGY POLICY

Feed-in tariffs (FITs) were introduced in Germany as part of the Renewable Energy Act (EEG) in 2000 as a measure to incentivize renewable energy deployment and production. FITs apply also to hydropower.[18] The FIT system has been amended several times. In 2014, it was amended to be applicable only to small-scale power plants. Most recently, with the revision of the EEG in 2021 (still in process at the time of writing), auctions became the standard process for the determination of tariffs which were previously fixed by State Governments. However, hydropower remains excluded from the auctioning system.[19] The duration of a FIT is 20 years, while the tariffs are revised every four years. The FIT under the current 2017 revision as well as the new 2021 revision under the EEG are displayed in Table 3. The revised EEG maintains the additional regulations on annual decreases (0.5 per cent) and on the fulfilment of the environmental protection standards.

Table 3. **FIT Rates in Germany under the 2017 and 2021 Revisions**

FIT – 2017 revision		*FIT – 2021 Renewable Energy Act*	
Capacity category	*Rate (USD/kWh)*	*Capacity category*	*Rate (USD/kWh)*
≤ 500 kW	0.15	≤ 500 kW	0.15
≤ 2 MW	0.10	≤ 2 MW	0.10
≤ 5 MW	0.08	≤ 5 MW	0.07
≤ 10 MW	0.07	≤ 10 MW	0.07
		≤ 20 MW	0.06
		≤ 50 MW	0.05
		> 50 MW	0.04

Source: Federal Ministry of Justice and Consumer Protection[20]

SMALL HYDROPOWER LEGISLATION AND REGULATIONS

SHP development in Germany is regulated by European, Federal and State legislation. Federal legislation concerning environmental impacts, biodiversity, greenhouse gas emissions and renewable energy have all been formed or recently amended to adhere to the European Directives such as the Water Framework Directive, Habitats Directive and the Environmental Impact Assessment Directive.

The most important legislation for SHP in Germany is the Federal Water Resources Law (*Wasserhaushaltsgesetz*, WHG). Particularly relevant are the regulations that govern the damming, abstraction or diversion of river flows, which are only permitted if minimal environmental flows can be ensured. Any new dam infrastructure or change to operations must maintain or improve the quality of the water. For hydropower specifically, greenfield projects are only permitted when appropriate steps to preserve fish populations are implemented.[19] In Germany, the regulation and approval of hydropower projects is the responsibility of the State authorities to interpret and apply Federal legislation. Thus, SHP potential is limited in Germany, especially for new greenfield projects. However, potential exists in modernizing, upgrading or restarting existing plants.[21]

A 2010 report on hydropower potential in Germany commissioned by the German Government identified 450 potential new SHP sites for development with an average output of 200 kW, with a total capacity of 90 MW.[22]

COST OF SMALL HYDROPOWER DEVELOPMENT

The costs for the development of SHP plants in Germany are in the average range. On the one hand, the good infrastructure and the easy access to equipment manufacturers can lead to prices in line with the market. On the other hand, the costs for planning and development are in the upper range due to the high labour cost structure. Furthermore, high concession and market prices for rights and land can increase the overall development costs. High standards are also cost drivers.

FINANCIAL MECHANISMS FOR SMALL HYDROPOREW DEVELOPMENT

Under the FIT scheme there is a fixed remuneration for the electricity produced by hydropower plants available for a period of 20 years. It enables plant operators to plan and finance with certainty. For many SHP plant operators, direct self-consumption can be even more financially attractive if the share of self-consumed electricity is high.

EFFECTS OF CLIMATE CRISIS ON SMALL HYDROPOWER DEVELOPMENT

The German weather service predicts higher winter precipitation and drier summers in the country due to climate change. The total amount of precipitation may be higher or lower than today, depending on the region. Higher amounts of heavy precipitation are also to be expected.[11]

Since in Germany the currently highest precipitation amounts fall in summer, the spread will become more conspicuous due to climate change. A uniform water supply would not have any disadvantageous consequences for most hydropower plants. The total amount of rainfall will develop differently depending on the region. This means higher annual rainfall for some plants and lower annual rainfall for others. A clear trend across the country is not yet discernible. Heavy rainfall events can lead to hydropower plants having to adapt to increased maximum water volume.[12,23]

BARRIERS AND ENABLERS FOR SMALL HYDROPOWER DEVELOPMENT

The development of SHP in Germany faces barriers of different types, related to complex licensing procedures:

- Existing plants: licensing is based on the assessment of the possible impact on stream ecology. This is valid for the optimization or the reactivation of already existing plants.
- New plants: new sites are licensed only after an approval procedure, which requires thorough assessments of environmental concerns with respect of European, Federal and State legislation. Few entirely new projects on suitable sites are realized. Expensive assessments are required to avoid any undesired impact on stream ecological systems. Furthermore, the required hydraulic structures and operation modes are usually of high quality and expensive. [24]

The enabling factors for SHP development include:

- The Renewable Energies Act of 2000 is the most important support instrument for SHP plants, allowing for a funding period of 20 years and, hence, enabling secure financing;
- The CO_2 tax introduced in 2021 will also make hydropower generation significantly more attractive in the coming years;
- The infrastructural conditions are excellent throughout Germany;
- Germany has one of the highest electricity prices worldwide with an average of 0.36 USD/kWh. Further increases in electricity prices will also be supportive for SHP plants.

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Luxembourg

International Center on Small Hydro Power (ICSHP)

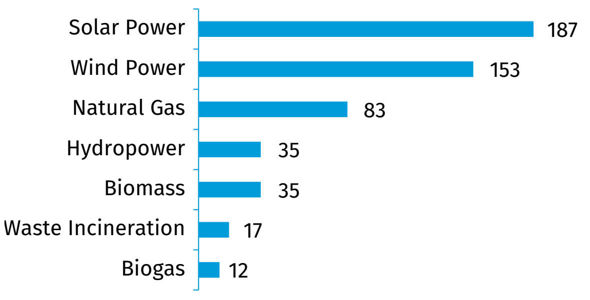
KEY FACTS

Population	638,639 (2021)[1]
Area	2,586 km^2[2]
Topography	Luxembourg is a landlocked country, characterized by low mountains and rolling hills covered in green, dense forests. The highest point of the country is the peak Burgplatz, which reaches 559 metres above sea level. The southern region of Gotland has fertile lands and rivers. In contrast, the northern region of the country is a rigid plateau with an arid soil.[2]
Climate	The climate is mild with no dry seasons, typical for marine countries in the western part of Europe. The annual average temperature is 8.5 °C. In the winter, temperatures reach on average 3.3 °C during the day and -1.8 °C at night. Average high temperatures in the summer reach 21 °C, with lows of roughly 11.3 °C. The summers are thus generally cool and winters mild.[3]
Climate Change	Average air temperatures in Luxembourg have gradually increased over the years, particularly in the winter season. Mean annual temperatures are projected to rise to 11.6°C between 2071 and 2100. Temperature extremes also impact water quality in summer when the river flow is at its lowest.[4,5]
Rain Pattern	Rain falls throughout the year in Luxembourg. The month receiving the most rain is November, with an average rainfall of 83 mm.[5] The month with the least rain is April, with an average rainfall of 58 mm. The average annual rainfall is 850 mm.[6] The country also recorded its second wettest summer with an average of 336 mm of rain in 2021.[7]
Hydrology	The Moselle River is the lowest point in Luxembourg, at only 133 metres above sea level, and one of the most important rivers of the country. The Sûre and the Our are other major rivers and form the border with Germany. In the southern region, the Alzette River flows northwards, until it reaches the Sûre River.[8]

ELECTRICITY SECTOR OVERVIEW

In 2020, total electricity generation in Luxembourg amounted to 2,230 GWh (Figure 1). Hydropower, including the Vianden pumped-storage plant, accounted for roughly 49 per cent of the total produced electricity. In total, over 70 per cent of the electricity was generated from renewable energy sources. In 2020, Luxembourg imported 23,557 GWh of electricity and exported 3,883 GWh. Population gross demand for electricity was estimated at 7,540 GWh.[9]

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

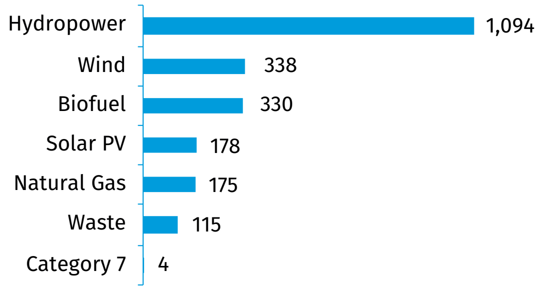


Source: IEA[9]

Luxembourg has a 100 per cent electrification rate and one of the lowest electricity consumption rates among the European Union (EU) member states. However, over 80 per cent of its electricity is imported. This makes the country highly dependent on electricity imports and therefore its energy sector policies are affected by the markets in the neighbour countries.[10,11,12]

The total installed capacity of power plants in Luxembourg between 2019 and 2020 increased from 488 MW to 522 MW, with the share of renewable energy increasing from 377 MW to 422 MW (Figure 2; these totals exclude the Vianden pumped-storage hydropower plant). This increase is mainly due to the commissioning of new wind power plants and new solar photovoltaic (PV) power plants. Since 2019, the solar PV capacity has steadily risen, with a 41 MW increase recorded in the first half of 2021.[10]

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



Source: ILR[10]

Note: The installed capacity does not take into account the Vianden pumped-storage plant.

The largest share of electricity generated in Luxembourg comes from the Vianden pumped-storage hydropower plant, which accounted for 1,010 GWh in 2020. The hydropower plant Moselle–Sûre generated 92.9 GWh in 2019 and small private hydropower plants produced an estimated 4.8 GWh in the same year.[13]

There are multiple electricity suppliers in Luxembourg: Eida, Electris, Enovos, Leo, Nordenergie, Steinergy, Sudgaz and Sudstroum. The main provider of electricity is Enovos, however, certain municipalities might use specific private electricity suppliers. Creos is the subsidiary of Enovos that is in charge of the electricity grid in the country.[14] LEO, an important player in the country's energy market, is another subsidiary of Enovos and has the second largest market share, with 13 per cent in the residential sector and 28 per cent in the commercial sector. The main shareholder in Enovos is the Grand-Ducal State, therefore, most of the shares are owned by the Government of Luxembourg.[14]

La Société Électrique de l'Our (SEO) is one of the main renewable energy companies in the region and operates seven run-of-river hydropower plants on the Moselle River, including four in France. In collaboration with ENOVOS and through the company SOLER, it operates the Esch-sur-Sûre, Rosport and Ettelbrück hydropower plants owned by the Government of Luxembourg.[15]

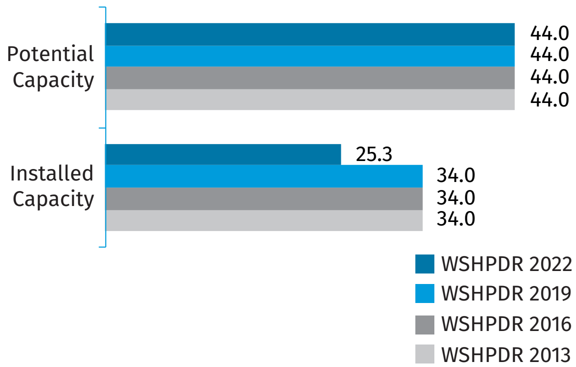
The average price of electricity is 0.210 EUR/kWh (0.237 USD/kWh) for households and 0.128 EUR/kWh (0.129 USD/kWh) for businesses, which is inclusive of the cost of power, distribution and taxes.[16] Distributors such as Enovos and LEO also offer a real green electricity plan. The scheme offers better tariffs for electricity produced from renewable energy sources, encouraging the adoption of renewable energy in the country. The Luxembourg Regulatory Institute also launched an online price comparison tool that allows users to compare prices offered by various suppliers and tariffs based on their location and energy consumption.[17]

SMALL HYDROPOWER SECTOR OVERVIEW

The definition of small hydropower (SHP) in Luxembourg refers to plants up to 10 MW. In 2020, the installed SHP capacity of the country was 25.3 MW, including micro-hydropower plants (Table 2).[18] Compared to the *World Small Hydropower Development Report (WSHPDR) 2019*, the installed capacity decreased due to the exclusion of the Esch-sur-Sûre plant, which has a capacity of 13 MW.[18] The SHP potential estimate has remained unchanged (Figure 3). The potential for hydropower development in Luxembourg is limited by the country's physical size and the lack of access to major water resources.[19]

In 2013, the European Small Hydropower Association (ESHA) reported that the Government of Luxembourg had planned to increase the installed capacity of SHP in the country to 44 MW.[20] However, there is no new information on the progress of this plan from the Government or private stakeholders. One study on the hydropower potential of existing water mills and weirs estimated that in Luxembourg there are 44 micro-hydropower sites per 1,000 km^2.[21]

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



Source: The Statistics Portal,[18] ESHA,[20] *WSHPDR 2013*,[22] *WSHPDR 2016*,[23] *WSHPDR 2019*[24]

According to Soler's latest updates, the company under the joint leadership of SEO and Enovos, the Rosport SHP plant must reach a good ecological status to fulfill the requirements of the European Water Framework Directive. To achieve the aforementioned status, the minimum flow must be considerably increased. The Government of Luxembourg will install a wastewater turbine near the existing dam to enhance minimum flow. The 7 MW Rosport SHP plant is located on the dam of the Sûre, in Rosport Ralingen. The plant is equipped with two vertical Kaplan turbines. The Rosport plant produces roughly 24 GWh per year.[25] In July 2021, the Rosport plant was heavily damaged by record high floods and has been out of service with no update on its reopening.[26] The Ettelbruck SHP plant is located on the Alzette River and generates 0.8 GWh per year. The installed capacity of the power plant is 200 kW. Ettelbruck was completely renovated in 1998 and operates today without any personnel, monitored remotely from Esch-sur-Sûre.[25] In addition to the mentioned SHP plants, there are also a number of smaller scale-plants, some of which are listed in Table 2.[27]

Table 2. **List of Selected Installed Small Hydropower Plants in Luxembourg**

Name	*River*	*Installed capacity (MW)*
Grevenmacher	–	7.80
Rosport	Sûre	7.00
Schengen	–	4.50
Nospelt	–	0.40
Ettelbruck	Alzette	0.20
Clouterie/Bissen	Attert	0.14
Moestroff	Sûre	0.14
Birtrange	Alzette	0.11
Cruchten	Alzette	0.11
Essingen	Alzette	0.09
Erpeldange	Sûre	0.09
Bounsmuhle	Syr	0.06
Bettendorf	Sûre	0.05
Bigonville	Sûre	0.05
Steckenmuhle	Syr	0.05
Bissermuhle	Attert	0.05
Felsmuhle	Syr	0.05
Stolzemburg	Our	0.05
Useldingen	Attert	0.05
Bannmuhle	Attert	0.04

Source: Industrie Luxembourg,[27] Lalieu[28]

RENEWABLE ENERGY POLICY

In 2018, the Ministry of Energy and Spatial Planning of Luxembourg published the National Energy and Climate Plan for Luxembourg (NECP LU). This plan highlights specific goals for greenhouse gas emissions reduction and raising the renewable energy share in the country's energy mix. It also aims to improve the energy efficiency of the country. Luxembourg aims to align national policies with the Paris Agreement, the European climate and energy framework 2030 and the European Green Deal Roadmap and to contribute at best to the common European goals. The Government has adopted a 2030 target to:

- Reduce the greenhouse gas emissions of the non-ETS (Emissions Trading System) sectors by 55 per cent compared to 2005, which exceeds the 40 per cent reduction required by the EU and aims below the 2/1.5 °C global temperature target;
- Increase the share of renewable energy in gross final consumption to 25 per cent, from 11 per cent in 2020;
- Reduce the end energy demand by 40–44 per cent compared to the EU-Primes Baseline projection (2007).

Taken together, these goals will require considerable investment in electricity infrastructure. However, it is unclear if existing policies and support schemes adequately address the problems presented by rapid population growth and a growing economy. Low energy prices for consumers are also a threat to investments needed in energy efficiency and renewable energy promotion.[12]

The initial regulation on renewable energy was amended in 2005, with feed-in tariffs (FITs) for electricity produced from renewable energy being established.[29] The tariffs are guaranteed for 15 years from the date of the first feed-in of electricity into the network.[30] FITs are available for SHP plants up to 6 MW (Table 3). Investment subsidies have been available since January 2010. Market premiums are also available but only apply to installations with a production capacity equal to or higher than 500 kW. In addition, under the general provisions of the Law on the Organization of the Electricity Market, power generation plants can use the electricity grid for applicable charges. However, renewable energy plant operators are exempt from grid usage fees and electricity from renewable sources is a preferred choice when compensating for power losses.[29]

Table 3. **Feed-in Tariffs for Small Hydropower in Luxembourg in 2019**

Plant size	*FIT (EUR (USD) per kWh)*
≤ 300 kW	0.179 (0.20)
> 300 kW and ≤ 1 MW	0.149 (0.17)
> 1 MW and ≤ 6 MW	0.124 (0.14)

Source: RES Legal[29]

BARRIERS AND ENABLERS FOR SMALL HYDROPOWER DEVELOPMENT

There are multiple barriers to SHP development in Luxembourg. Some of the most relevant are outlined below:

- The country's energy needs are mostly met through imports at present, therefore, there is no motivation to implement or approve the construction of new SHP projects;
- There is no well-defined energy strategy specific to SHP;
- The SHP potential in Luxembourg is very limited;
- Lack of feasibility studies in the sector makes it difficult to determine the true SHP potential;
- The licensing procedure for SHP projects is time-consuming and bureaucratic as numerous permits are necessary;
- The country's research and development policies focus on clean energy technologies, but not specifically on SHP, with higher interest in solar and wind power technology development.

The key enabling factors for SHP development include:

- Availability of support in the form of FITs, market pre-

miums and investment subsidies;
- Identified potential for developing micro-hydropower plants on existing water mills and weirs.

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The Netherlands

International Center on Small Hydropower (ICSHP)

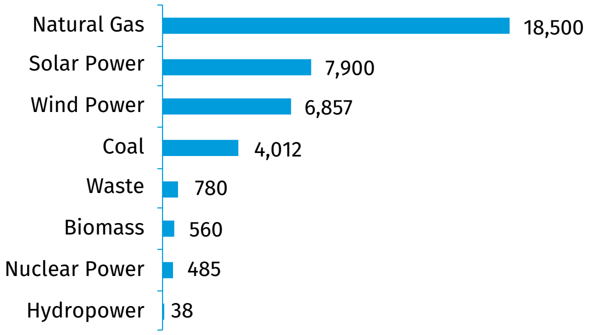
KEY FACTS

Population	17,441,500 (2020)[1]
Area	41,543 km^2 [2]
Topography	The Netherlands has a predominately low-lying, flat terrain. Approximately half of the territory lies no more than one metre above sea level and much of the coastal land is reclaimed land from the sea, or polders, lying below sea level. There is a region of hills in the south-west with elevations reaching 100 metres. The highest point in the country is Vaalserberg at 323 metres, located in the extreme south-west on the border junction with Belgium and Germany.[2]
Climate	The Netherlands has a maritime temperate climate. Summers are mild and cool with an average temperature of 17 °C in July. The Gulf Stream creates relatively mild winters with an average temperature of 2 °C in January. Cloudy skies and high humidity are very typical throughout the year.[2]
Climate Change	Effects of climate change have already been experienced in the Netherlands and are expected to continue. Average temperatures have risen approximately 1.7 °C in the past century and average precipitation has increased by 20 per cent. In the following decades, weather is expected to become more extreme with an increase of extended wet periods as well as an increase of extended dry periods. A sea level rise of between 35 cm and 85 cm is possible by the end of the century, which will put strain on the manmade water management structures the country has in place to maintain the coastal lands.[3]
Rain Pattern	Precipitation is distributed relatively evenly throughout the year (50–90 mm/month) with a slight increase during late summer and a slight decrease during spring. Average annual precipitation is 790–850 mm.[2]
Hydrology	The largest river is the Rhine, which begins in Central Europe and enters the Netherlands from Germany, flowing north-west to empty into the North Sea. Other major rivers are the Meuse and the Schelde, which begin in France, and the Eems, which begins in Germany. These rivers and their arms form the delta with its many islands. Together with numerous canals, the rivers give ships access to the interior of Europe.[4]

ELECTRICITY SECTOR OVERVIEW

In 2021, the Netherlands had approximately 39,132 MW of installed capacity, of which 39 per cent was with renewable energy sources. Natural gas accounted for 18,500 MW (47 per cent), solar power for 7,900 MW (20 per cent), wind power for 6,857 MW (18 per cent), coal for 4,012 MW (10 per cent), waste for 780 MW (2 per cent), biomass for 560 MW (1 per cent), nuclear power for 485 MW (1 per cent) and hydropower for 38 MW (less than 1 per cent) (Figure 1).[5] In recent years, wind power and solar power have been increasingly more important and have seen the largest increases in installed capacity, while installed capacity of coal has been steadily decreasing. As there are some solar photovoltaic (PV) units that are not part of the centralized grid, actual installed capacity of solar power is higher.[6]

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

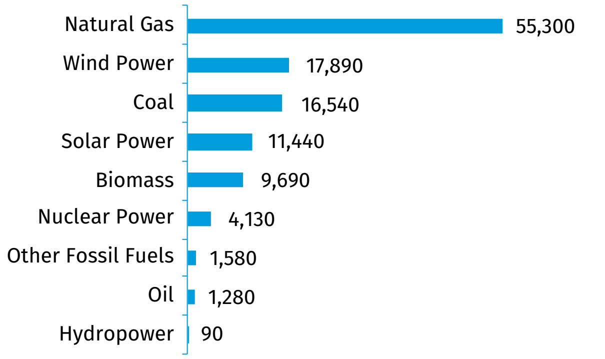


Source: ENTSO-E[5]

In 2021, total electricity generated in the Netherlands was approximately 117,940 GWh, of which 33 per cent was generated using renewable energy. Natural gas generated approximately 55,300 GWh (47 per cent), wind power 17,890 GWh (15 per cent), coal 16,540 GWh (14 per cent), solar power 11,440

GWh (10 per cent), biomass 9,690 GWh (8 per cent), nuclear power 4,130 GWh (4 per cent), other fossil fuels 1,580 GWh (1 per cent), oil 1,280 GWh (1 per cent) and hydropower 90 GWh (Figure 2). In the same year, 20,890 GWh of electricity was imported, much of which was nuclear power from Belgium, and 20,630 GWh was exported.[7]

Figure 2. **Annual Electricity Generation by Source in the Netherlands in 2021 (GWh)**



Source: CBS[7]

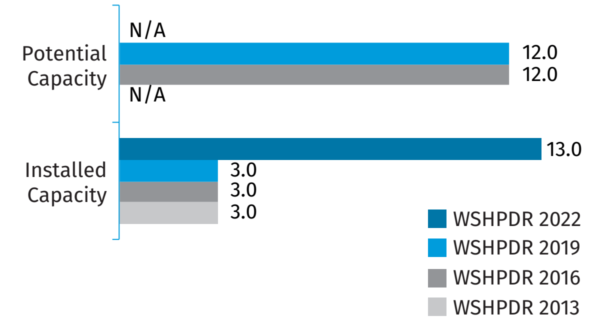
The electrification rate in the Netherlands is 100 per cent. The electricity sector is liberalized, a process that began with the Electricity Act of 1998 and was completed in 2004. While there are approximately 50 electricity supply companies in the country, the major six are Delta, EON, Eneco, Engie, Essent and Nuon.[8] The distribution and transmission systems are both publicly owned. The distribution system is split up into seven regional companies: Coteq, Enduris, Enexis, Liander, Rendo, Stedin and Westland Infra. The transmission system is fully operated by one company, TenneT. The transmission system crosses national borders in several locations and has interconnections with Belgium, Denmark, Germany, Norway and the United Kingdom, facilitating imports and exports of electricity.[9]

The Netherlands is a part of the wholesale electricity market in Europe that comprises over 20 countries to buy, sell and trade electricity. There are two nominated electricity market operators (NEMOs), Epex Spot and Nord Pool, which are responsible for the future and spot markets for the country. The prices of electricity are heavily influenced by the rest of Europe.[9] Consumer prices of electricity include the variable electricity price, an energy tax and an environmental tax. In 2021, the average final price for consumers was 0.26 EUR/kWh (0.28 USD/kWh), which included an average variable price of 0.11 EUR/kWh (0.12 USD/kWh), energy tax of 0.11 EUR/kWh (0.12 USD/kWh) and environmental tax of 0.04 EUR/kWh (0.04 US/kWh).[10] Due to the global increase of gas prices, average electricity prices for the year of 2022 were expected to be considerably higher.[11]

SMALL HYDROPOWER SECTOR OVERVIEW

The definition of small hydropower (SHP) in the Netherlands is up to 10 MW. The installed capacity of SHP is 13 MW while the total potential is unknown.[12] Compared to the *World Small Hydropower Development Report (WSHPDR) 2019,* the installed capacity has increased due to categorizing the Maurik hydropower plant with a capacity of 10 MW as SHP, which it previously was not considered to be. Since previous potential has been exceeded and no updated estimates are available, an accurate value for current potential has been updated as unknown (Figure 3). New potential capacity could be found by more accurate feasibility studies, in particular, at old watermill sites throughout the country.[13]

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



Source: Microhydropower,[12] *WSHPDR 2019,*[14] *WSHPDR 2016,*[15] *WSHPDR 2013*[16]

The installed capacity being equal to the potential capacity indicates that all SHP opportunities that have already been identified and considered feasible have been developed. As the Netherlands is a very flat country, hydropower is not considered an important potential source of electricity generation.[17] Currently, hydropower accounts for less than 1 per cent of all electricity generation in the country, having generated 90 GWh in 2021 with its installed capacity of 38 MW. SHP represents approximately 34 per cent of all hydropower, while the other 66 per cent of large hydropower is concentrated in two locations, the Alphen aan de Maas plant with 14 MW and the Linne plant with 11 MW. The two SHP plants that have a capacity over 1 MW are the Maurik with 10 MW and the Hagestein with 1.8 MW (Table 1).[12] The remaining 1.2 MW of SHP in the country is distributed among 16 other plants, some of which are modernized centuries-old watermills.

Table 1. **List of Selected Small Hydropower Plants in the Netherlands**

Name	*Installed capacity (MW)*
Maurik	10.000
Hagestein	1.800
Roermond	0.200
Haandrik	0.100
Meerssen	0.035
Nederweert	0.035
Mechelen	0.020
Hackfort	0.005

Source: Microhydropower[12]

In addition to the hydropower plants, the country has potential for tidal SHP to be installed on the coastal structures regulating water outflow and on the sea-flood protection structures. The turbines on barriers at Afsluitsijk (IJsselmeer) were installed in 2008 and are used for tidal turbine development and feed the Dutch grid. Since autumn 2015, the tidal turbines installed on the storm-surge barrier in Oosterschelde operated with a total capacity of up to 1.2 MW.[18]

RENEWABLE ENERGY POLICY

Under the European Union Renewable Energy Directive (Directive 2009/28/EC), the Government of the Netherlands created the National Renewable Energy Action Plan of 2010. This plan committed to a target of 14 per cent of the country's final energy consumption to be from renewable energy sources by 2020, including at least 10 per cent of renewable energy in transport.[19] Although the share of renewable energy sources in the country's energy mix has strongly increased in the last years, the actual renewable energy share of final energy consumption in 2020 fell short of the target, with just over 11 per cent, and biofuels in transport accounted for less than 2 per cent.[20]

More recent renewable energy targets for 2030 and 2050 were stated in the Climate Agreement of 2019. This plan called for a reduction in carbon emissions by 49 per cent by 2030 and for renewable energy to generate at least 84 TWh.[21] In 2021, renewable energy generated just under 40 TWh, indicating that in order to reach the goal, renewable energy generation will have to more than double in the following nine years.[7] The Climate Agreement also includes the proposal to ban coal production from 2030 onwards and for 100 per cent renewable energy production by 2050.[21] The Climate Act passed in 2019 substantiates this target of carbon neutrality for 2050 and mandates that the Climate Action Plan must be reviewed every five years.[22]

Current instruments that promote the production of renewable energy include:

- Sustainable Energy Production and Climate Transition Scheme (SDE++);
- Obligation to use biofuels in the transport sector;
- Co-firing with biomass in coal-fired power stations;
- Import of renewable energy.[7,21]

The growth should mainly be sourced from wind power, biomass and solar PV. Hydropower is expected to account for less than 1 per cent of the total.

In most of Western Europe, energy producers are separated from the high-voltage grid. In the Netherlands, the grid operator does not distinguish between different electricity producers and is obligated by law to connect all parties to the grid and transmit electricity across the high-voltage grid. Under the Electricity Supply Act of 1998, transmission operators are required to connect all new installations to the grid, without discrimination.[19]

Financial incentives for renewable energy development are mainly supported by the operating grant of the Stimulation of Sustainable Energy Production and Climate Transition (SDE++) scheme and the Energy Investment Allowance tax deduction. The SDE++ is available for the production of renewable electricity, renewable gas, renewable heat and the renewable combination of heat and electricity. The SDE++ offers 12- or 15-year financial security by subsidizing unprofitable project components. The subsidy is the difference between a basic amount (cost price of the renewable energy) and the energy market price. The Government of the Netherlands determines a maximum SDE++ budget for each year and the budget for 2021 was EUR 5 billion (USD 5.4 billion).[23]

For hydropower plants, the subsidy term is for 15 years. Different amounts are offered for hydropower plants with a drop of less than 50 cm, more than 50 cm and for hydropower renovations with a new turbine and the subsidy is given in four different phases with each phase having a different value. Based on the type of hydropower and the phase, the scheme provides between 0.0579 EUR/kWh (0.062 USD/kWh) and 0.1097 EUR/kWh (0.12 USD/kWh) for between 2,600 and 5,700 working hours.[23]

The Energy Investment Allowance grants the ability to offset a certain percentage of investments in renewable energy production against income taxes, both personal and corporate. The exact percentage changes every year and for the year of 2021 it was 45.5 per cent.[24].

BARRIERS AND ENABLERS FOR SMALL HYDROPOWER DEVELOPMENT

The main limitations for SHP development in the Netherlands include:

- Hydropower potential is low due to the flat relief;
- Local water communities ("Waterschappen") are reluctant to issue permits;
- The development of SHP is hindered due to the lobby of fishermen (recreational and professional).[14]

The main enablers for SHP development in the Netherlands include:

- Old watermill sites could be modernized to install SHP plants;
- Further comprehensive feasibility studies could uncover additional SHP potential.[13,17]

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Switzerland

Pedro Manso & Mathieu Barnoud, MHYD Water & Energy Solutions Sàrl

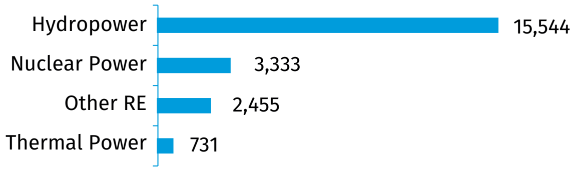
KEY FACTS

Population	8,419,550 (2019)[1]
Area	41,277 km²[2]
Topography	Switzerland mostly consists of mountains, with the Alps in the south and the Jura Mountains in the west and north-west, and a central plateau with large lakes. The highest summit is the Pointe Dufour/Dufourspitze at 4,634 metres above sea level.[3]
Climate	Switzerland has a temperate climate, which varies with elevation and with location relative to the main Alpine ridge. Winters are cold and cloudy, with rain and snow, whereas summers are humid, cool to warm and occasionally hot, with frequent thunderstorms along the main Alpine ridge.[2] Selected average temperatures vary from -10 to +9 °C (low) to -4 to +17 °C (high) across the country. [3]
Climate Change	The Alps, and therefore Switzerland, are affected by global warming, the main consequences being the retreat of melting glaciers and the increase of the snowfall altitude limit. Extreme weather events, such as heat waves or bad weather and floods, are also expected to become more frequent. Climate change is likely to influence the frequency, intensity and seasonality of landslide activations, rockfalls, debris flows, wet snow avalanches and floods. Changes in runoff availability are expected to increase competition for water uses.[3]
Rain Pattern	Switzerland experiences frontal and orographic rainfall, with 2,000 mm/year of average precipitation in the northern foothills of the Alps, in the Alps and in southern Switzerland; 1,000-1,500 mm/year in the lowlands north of the Alps; and between 500 and 700 mm/year in Valais and Grisons regions. The amount of precipitation during the summer semester (April–September) is nearly double that of the winter semester, except in the Canton of Valais. From an elevation of 1,200-1,500 metres above sea level, precipitation during winter usually occurs as snowfall.[2] Due to climate change, average precipitation on a large scale is expected to change on a seasonal but not annual level. According to current climate models considering a temperature increase of approximately 2 °C, winter precipitation will increase by up to 24 per cent and summer precipitation will decrease by up to 39 per cent by the end of the century.[3]
Hydrology	The share of precipitation available for runoff depends on evapotranspiration and temporal storage (as snow, ice or underground). In Switzerland, the potential evapotranspiration decreases with elevation going from the central plateau to the alpine areas, due to decreasing temperatures and less intensive land use. Rivers exhibit a variety of runoff regimes, which mainly differ depending on the role played by snow and ice storage in the contributing catchment. Mountain rivers exhibit monthly peak flow during spring and summer due to snow and ice melt. Lowland rivers have low flow months in summer due to evapotranspiration and extended dry spells.[4] Higher temperatures will not necessarily lead to a nationwide increase in evaporation but could cause significant water loss locally (up to 6 mm per day). Swiss glaciers are predicted to lose between 76 and 98 per cent of their current ice volume by 2100, hence, glacier melt contribution to runoff will become virtually non-existent by the end of the century. Higher temperatures in the Alps will change the precipitation type from solid (snow) to liquid, which in turn will lead to more runoff in winter. Overall, the timing of melting peak will occur earlier in spring and the melt volume will be smaller as a result of reduced snow storage. In Alpine areas, glacier retreat, shrinking permafrost and shorter snow cover will lead to greater sediment availability, which is expected to increase sediment yield above 1,400 metres above sea level.[3]

ELECTRICITY SECTOR OVERVIEW

The main sources of electricity in Switzerland are hydropower and nuclear power, accounting for 57.4 per cent and 33.6 per cent, respectively, of total production, which amounted to 70.9 TWh in 2020 (including 4.5 TWh from pumped-storage plants).[4] Production from thermal power plants (non-renewable and renewable) accounted for 6.4 TWh, or 9 per cent of the total electricity production (Figure 1). The total consumption summed up to 59.6 TWh in 2020 (including 4.2 TWh of transmission and distribution losses). Electricity consumption has remained stable in recent years, with efficiency gains offsetting positively the demographic growth and the increase in electrical household heating. However, the winter electricity supply depends on imports (between 500 and 10,000 GWh per winter semester in the past 11 years). Over the last consolidated year of statistics (2020), hydropower produced 15.4 TWh in winter (Q1 & Q4) and 22.3 TWh in the summer semester (Q2 & Q3).[4]

Figure 1. **Annual Electricity Generation by Source in Switzerland in 2020 (TWh)**



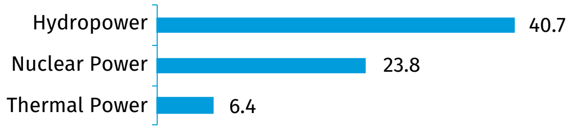
Source: Swiss Federal Office for Energy[4]

Note: The thermal power category includes both renewable and non-renewable sources.

In 2011, Switzerland decided to gradually withdraw from the production of nuclear energy. Consequently, a long-term energy policy, termed Energy Strategy 2050, was outlined to guarantee a safe electricity supply.[5,6] In September 2016, the Parliament formally accepted a first set of measures of this strategy, approved by a universal referendum in May 2017. The strategy focuses on improving energy efficiency, expanding renewable energy production, adopting an active foreign energy policy and, where necessary, ensuring electricity imports and/or local production from fossil fuels. Renovation and expansion of the grid infrastructure is also among the objectives of the strategy; aggregation of parallel lines from different operators is ongoing to improve efficiency, reduce transmission bottlenecks within the country and at international connections. Renewal of transmission lines more than forty years old is also underway in view of handling larger numbers of decentralized producers feeding electricity into the grid.

Currently, 674 hydropower plants with a capacity of at least 300 kW operate in Switzerland.[4,7,8] A 49 per cent share of the total hydropower production comes from run-of-river plants, 47 per cent from storage plants and 4 per cent from pumped-storage plants. According to the official energy statistics, in 2019 Switzerland had 15,544 MW of effective installed hydropower capacity (vs. 15,575 MW forecasted), 3,333 MW of nuclear capacity, 2,455 MW from other renewable energy sources and 731 MW of thermal capacity, resulting in a total of 22,063 MW of installed capacity from all sources (Figure 2).[4]

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



Source: Swiss Federal Office for Energy[4]

Note: Data for 2019.

The Energy Strategy 2050 foresees an increase of hydropower efficiency and generation: annual hydropower generation should reach at least 37.4 TWh by 2035 and at least 38.6 TWh by 2050. New pumped-storage plants should help increase energy storage and support the integration of solar and wind power plants. Winter supply and operation flexibility remain the main challenges.

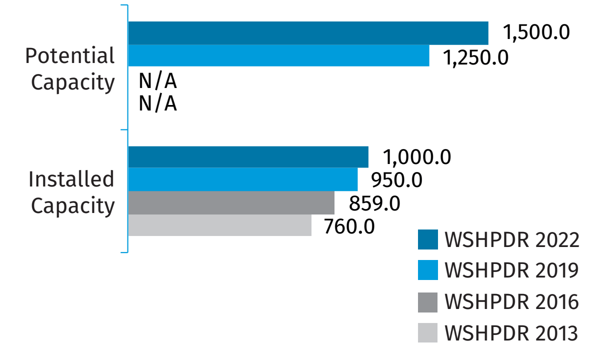
In the short to medium term, imports of electricity and the deployment of gas power plants are the available solutions for guaranteeing the electricity supply in winter. The importance of renewable sources other than large hydropower in the Swiss energy mix is slowly increasing, following progressive steps towards a nuclear phase-out. Incentives to the deployment of renewable sources such as small hydropower (SHP), solar power, wind power and biomass exist in multiple forms. These incentives are regularly revised to account for increased technology maturity and reduced deployment costs. However, wind power and SHP face significant opposition from local stakeholders and non-governmental organizations. Geothermal power plants face not only public opposition due to fears of induced seismicity, but also still struggle to develop cost-effective technical solutions allowing for a viable business plan. The supply of electricity must be fully identified by source, which has recently led utilities to replace grey supplies with mostly domestic nuclear production.

Swiss electricity tariffs operate under an open market and prices are determined by supply and demand. Tariffs are regulated by the Electricity Commission (ElCom), which monitors fees for network use and is responsible for prohibiting unjustified or excessively high rates. The tariff for using the transmission grid is defined by Swissgrid, while tariffs for the use of the distribution grid are determined by the network operators. Tariffs may vary depending on market procurement rates and costs of production on site.

SMALL HYDROPOWER SECTOR OVERVIEW

In Switzerland, SHP refers to plants with a mean gross hydraulic power of up to 10 MW.[8] As of 2019 and following a detailed inventory, approximately 1,400 SHP plants were in operation in the country (of which 487 plants were between 300 kW and 10 MW), with an overall installed capacity of approximately 1,000 MW (of which 939 MW were from plants between 300 kW and 10 MW) and an annual production of approximately 4,100 GWh (of which 3,808 GWh were from plants between 300 kW and 10 MW).[9] Compared to the *World Small Hydropower Development Report (WSHPDR) 2019*, the installed capacity increased by 5 per cent, whereas the potential grew by 20 per cent (Figure 3). SHP represents roughly 5.8 per cent of the national electricity production and 10.1 per cent of the total hydropower production. Tables 1 and 2 present a non-exhaustive list of recently commissioned SHP plants and planned SHP plants, respectively.

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



Source: Swiss Federal Office of Energy,[6] Swill Small Hydro,[9] *WSHPDR 2013*,[11] *WSHPDR 2016*,[12] *WSHPDR 2019*[13]

Note: Installed SHP capacity reported in *WSHPDR 2016* did not include data for plants up to 300 kW.

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

Name	*Location*	*Capacity (MW)*	*Head (m)*	*Plant type*	*Operator*	*Launch year*
Mitlödi (Föhnen/Sool)	Mitlödi	4.00	35	Run-of-river	Mitlödi (Föhnen/Sool)	2020
Schächen, Schattdorf	Schattdorf	4.90	85	Run-of-river	Schächen, Schattdorf	2020
Oberwald	Oberwald	6.25	236	Run-of-river	Gere Kraftwerk	2020
Churwalden	Churwalden, Bärgliwäg	0.35	233	Run-of-river	Churwalden	2019
Grida, Churwalden	Churwalden, Grida	0.36	340	Run-of-river	Grida, Churwalden	2019
La Moille, Finhaut	Finhaut	0.42	159	Run-of-river	Turbinage des Torrents Finhaut	2019
Le Bruet, St - Triphon, Ollon	St - Triphon Com. Ollon, Bruet	0.62	585	Run-of-river	MCE Le Bruet	2019
Chapfensee	Mels, Plons	0.65	46	Run-of-river	KW Chapfensee	2019
Dietikon-Dotierzentrale	Dietikon	0.77	3	Run-of-river	Dietikon-Dotierzentrale	2019
Crans-Montana	Crans-Montana, R. Bourgeoisie	1.05	183	Run-of-river	Centrale du Lac d'Igogne	2019
Breithorn, Blatten	Blatten	1.70	214	Run-of-river	KW Breithorn-Fafleralp AG	2019
Vionnaz - l'Avançon	Vionnaz	2.20	804	Run-of-river	Vionnaz - l'Avançon	2019
Gadastätt, St. Antönien	St. Antönien	2.22	126	Run-of-river	Kraftwerk Schaniela	2019
Eggli, Walenstadt	Walenstadt	3.14	356	Run-of-river	Kraftwerk Berschnerbach AG	2019
Grafenau, St. Gallen	St. Gallen, Grafenau	0.31	3	Run-of-river	Kraftwerk Grafenau	2018
Mühlebach II, Engi	Engi, Unter Engi	0.53	38	Run-of-river	Kraftwerk Mühlebach AG	2018
Weissenstein, Mels	Mels, Plons	0.64	558	Run-of-river	KW Weissenstein	2018
Mädems-Parmort	Mels	1.76	399	Run-of-river	Kraftwerk Mädems-Parmort	2018
Fellitobel, Gurtnellen	Gurtnellen	2.30	347	Run-of-river	KW Gurtnellen	2018
Eaux du torrent du Fossau	Vouvry	2.30	521	Run-of-river	Eaux du torrent du Fossau	2018

Source: Swiss Federal Office of Energy[14]

Table 2. **List of Selected Ongoing/Planned Small Hydropower Projects in Switzerland**

Name	*Location*	*Capacity (MW)*	*Head (m)*	*Plant type*	*Developer*	*Planned launch year*	*Stage of development*
Ovella Dotierzentr. Nauders	Nauders. A	0.3	2	Run-of-river	Gemeinschaftskraftwerk Inn	2021	Construction
Madonna degli Angeli	Giubiasco	0.3	702	Run-of-river	Madonna degli Angeli	2021	Construction
Uister Chiipelfurä, Kippel	Kippel	5.2	49	Run-of-river	Kraftwerk Wiler Kippel AG	2021	Construction

Covatanne	Vuiteboeuf	0.6	151	Run-of-river	Arnon Energie SA	2022	Construction
Au Bévieux	Bex	4.2	77	Run-of-river	Saline de Bex SA	2022	Construction
Glarey	Bex	1.7	39	Run-of-river	ERA SA	2023	Detailed design

Source: Swiss Federal Office of Energy[14]

Among these SHP plants, an estimated 900 have installed capacity below 300 kW and account for only 1 per cent of hydropower production. This group represents the remaining ones of a high number of the small-scale plants (approximately 7,000) that were operating in Switzerland at the beginning of the 20th century. These plants could be refurbished and contribute to the growth of SHP production. However, the best sites in the country are already in use. In fact, as of October 2020, 651 plants with a total installed capacity of 500 MW benefited from feed-in-tariffs (FITs), producing on average 1,776 GWh/year.[10] Exploiting the remaining potential is under debate, both from the economic and the ecological perspectives.

New technologies are under development to harvest hydraulic energy on existing infrastructure (e.g., drinking water and wastewater networks, tailrace channels). Social acceptance of such plants is high. The federal authorities are sponsoring the required engineering developments (e.g., of new turbines), under the Hydropower Research Programme managed by the Federal Office of Energy.

The Energy Strategy 2050 indicates an available SHP potential of up to 110 GWh/year in present conditions, which may even increase to 550 GWh/year if design and implementation practices are improved and social acceptance is increased.[6] In 2020, the total potential capacity of SHP plants was estimated at approximately 1,500 MW. This value is obtained by taking into account the average design and operating conditions of SHP plants in Switzerland.[9] Therefore, the 20 per cent increase in potential capacity compared to the *WSHPDR 2019* is due to access to more detailed and technical information.

In Switzerland, SHP projects with 1–10 MW of capacity can apply for financial support with the implementing agency Pronovo AG instituted by the Swiss administration. As of October 2020, there were 234 applications from SHP projects awaiting a decision, representing a total capacity of 245 MW and an estimated production of 821 GWh/year.[10] However, there are no funds left to finance them before the FIT will expire in 2023. Also, several SHP plants are part of the list of national priority projects of hydropower plants producing more than 10 GWh/year.[15,16]

SMALL HYDROPOWER PROJECTS AVAILABLE FOR DEVELOPMENT

Table 3 shows a list of SHP projects available for investment.

Table 3. **List of Small Hydropower Projects Available for Investment in Switzerland**

Name	*Location*	*Potential capacity (MW)*	*Type of site (new/ refurbishment)*
Val Curciusa	Grison	~10	New
EES+	Valais	~10	New
Wynau 2e étape	Bern	~10	New
Jaberg-Kiesen / Aare Thun-Bern	Bern	~10	New
Litzirüti-Pradapunt	Grison	~10	New

Source: Swiss Federal Office of Energy[15]

RENEWABLE ENERGY POLICY

The Swiss energy policy is defined by the energy and water articles of the Federal Constitution and is detailed in the Acts on Energy, on CO_2, on Nuclear Energy, on Electricity Supply, on the Protection of Waters, on Hydropower and on Spatial Planning.[5] In particular, the Energy Act defines the regulatory framework for renewable energy, while the Waters Protection and Hydropower Acts regulate the field of hydropower planning and operation. Other relevant regulations are the Fishery Act, the Environmental and Forestry Protection Acts and the Nature and Cultural Heritage Act.

The Energy Strategy 2050 is a key milestone of the Swiss energy policy.[6] As mentioned, this strategy focuses on the exploitation of energy potential from increased energy efficiency, hydropower and new renewable energy sources. The Swiss Energy Programme is the instrument specifically developed to implement the energy and climate objectives of the Federal Government and of the cantons. In particular, cantons determine strategies for the building sector, sustainable energy supply, energy planning and energy efficient mobility and by means of financial incentives promote the efficient use of energy and of waste heat. The Renewable Energy Action Plan sets targets for advancing renewable energy production.

The Federal Government promotes electricity production from renewable energy sources through two main economic instruments: cost-covering FITs and one-off investment grants.[17] The cost-covering FIT bridges the gap between the market price and the cost borne by producers of electricity from renewable sources. This tariff is available for hydropower plants (up to an annual-average capacity of 10 MW), solar photovoltaics (PV) (starting from an installed capacity of 10 kW), wind and geothermal power, biomass and biological waste and is applicable for 15 years (10 years for biomass power plants). For existing facilities being object of reconversion, previous investments in water conveyance (e.g., intake works, waterways and penstocks) are eligible for a tariff bonus if carried out in the past 20 years, promoting good asset management. Tariff rates are regularly reviewed to take into account technological progress and increasing maturity of new technologies. The reviewed tariffs only apply to new production facilities. One-off investment grants are available for SHP plants above 300 kW of capacity that are being renewed and/or expanded. In addition to the described mechanisms of financial support, non-financial measures have been set in the Energy Act, such as priority dispatch (i.e., supply companies must purchase electricity from independent producers).

Economic, social and environmental barriers for the development of SHP are effectively addressed in Switzerland, for example, through the cost-based FIT and the involvement of communities in renaturing rivers that are or will be affected by plant operation. A water platform promoting dialogue among stakeholders is currently being organized. The focus of the last roundtable discussion was to develop a common basic understanding of the challenges facing hydropower against the background of the Energy Strategy 2050, the net-zero emissions target and the objectives pertaining to the security of supply and the preservation of biodiversity.[18] Research efforts aiming to address the arising questions receive support from the federal authorities. Additional barriers result from the complex regulatory context, which for SHP involves complying with legislation on water and energy, environment and development planning, at the federal, cantonal and municipal levels. The Energy Strategy 2050 attempts to address these issues by simplifying and harmonizing administrative procedures throughout the country. Examples of needed interventions include (i) the establishment of a single contact point for SHP plants (only available for wind power so far) as there are numerous topics to be addressed and the concerned municipalities do not have the required experience, and (ii) a checklist for project promoters, the possibility to bundle applications for several installations along the same river and the expansion of the Hydropower Research Programme of the Swiss Federal Office for Energy.[19]

SMALL HYDROPOWER LEGISLATION AND REGULATIONS

SHP plants are regulated by the same legislation as larger hydropower projects. The main legislation and regulation documents in Switzerland concerning hydropower projects are:

- The Energy Act (2018);
- The Water Power Act (1916) ref. 721.80;
- The new Electricity Supply Act (2007) ref. 734.7.

In addition to these federal documents, each canton has specific legislation following the main principles defined at the federal level.

COST OF SMALL HYDROPOWER DEVELOPMENT

The construction costs of SHP plants are very site-specific. The main investment cost indicators in Switzerland are the installed capacity and the head: the higher the head the lower the investment cost; the same applies to the plant size. However, the costs also depend on the power plant operation, energy output and lifetime, which are paramount to assess the unit cost of a kWh produced (or levelized cost of electricity, LCOE). The Swiss Small Hydro association regularly provides an overview of the sector and costs (Table 4).[9] The cost-covering remuneration tariffs linked to the subsidies do not tell the whole story as the concession period and the lifetime of an SHP plant significantly exceed the subsidized period, with the residual value of net present value assessment being an important matter of discussion.

Table 4. **Mean Costs of Small Hydropower Construction in Switzerland**

Installed capacity (kW)	*Construction unit cost (CHF/ kWh (USD/kWh))*
0–50	0.13 (0.13)
50–300	0.10–0.17 (0.10–0.17)
300–1,000	0.08–0.12 (0.08–0.12)
1,000–10,000	0.04–0.10 (0.04–0.10)

Source: Swiss Small Hydro[9]

FINANCIAL MECHANISMS FOR SMALL HYDROPOWER PROJECTS

Subsidies for promoting renewable energy (including SHP) are financed through a levy on every kWh consumed in Switzerland. With the introduction of the Energy Act (LEne) that came into force on 1 January 2018, the subsidized FITs are now governed via a system of direct marketing.[16] This new system is available for SHP plants from 1 MW to 10 MW of capacity; and SHP owners can request this subvention until the end of 2022. Furthermore, investment contributions are available for renovations and expansions until 2030. The aim of direct marketing is to make the FIT system market-oriented. Under the new system, the producers themselves are responsible for selling the electricity they produce. To this end, they conclude individual purchase agreements with utility companies or energy service providers, which creates an incentive to design and operate plants according to the demand. In addition to the proceeds from the sale of electricity, the plant operators receive a technology-specific feed-in premium, which is designed to cushion long-term market price fluctuations and, thus, provides producers with extensive investment security. To compensate for the costs of direct electricity marketing, producers also receive a technology-specific management fee.

It is also possible to have electricity production from SHP certified as “naturemade”, i.e., as being of hydraulic and ecological origin. Anyone who orders electrical products from "naturemade" star-certified hydropower plants contributes to an ecological improvement fund: one CHF cent per kWh of electricity sold. This money is used to carry out regular ecological improvement projects in the catchment area of the plants.

EFFECTS OF CLIMATE CRISIS ON SMALL HYDROPOWER DEVELOPMENT

Precipitation variability is expected to increase in Switzerland as a consequence of climate warming. As SHP plants in the country are mostly without seasonal storage possibilities, the down-times of the plants increase due to extended dry spells as well as during floods, when floating debris and sediment-laden flows hamper plant operation. Furthermore, natural hazards are likely to increase with climate change and therefore floods, rock falls and landslides will negatively affect SHP plants.

On the other hand, changes in the runoff pattern may result in more electricity generation from SHP plants in the short term. Indeed, changes in the snow melt and glacial melt, as well as in snow cover extension, will affect runoff generation mainly during late spring and in summer at altitudes above 1,400 metres above sea level and increase runoff in the winter semester, which may provide additional opportunities for SHP development.

BARRIERS AND ENABLERS TO SMALL HYDROPOWER DEVELOPMENT

In general, SHP provides a sound contribution to Swiss society. The development of new SHP projects is hampered mainly by:

- Conflicts with other water uses/rights in densely populated (lowland) areas, including with new restoration projects of impaired river reaches as required by the Waters Protection Act.
- Difficulties to come up with appropriate and cost-effective solutions for access and electricity transmission lines for greenfield projects in natural creeks. The social perception that individual SHP plants have (too) small a contribution to large societal needs (e.g., energy transition targets) raises public concern regarding the local and cumulated ecologic impact on small pristine river valleys in remote areas.
- Poorly engineered projects, with reduced teams and limited skills, often lead to production overestimation and costs underestimation.[19] Improvement of engineering design of SHP projects (often overlooked due to the associated high cost per kWh) and introduction of environmentally friendly solutions at new and existing facilities are required in order to enhance public acceptance. Improved engineering design should focus on properly sized facilities based on available water resources and site conditions, as well as on innovative management and environmental flow rules. The ecologic, technical and economic feasibility must be assessed in the early phases of the project, which implies mobilizing skilled engineering teams, to reduce uncertainty regarding water availability and potential energy production, as well as investment costs, too often poorly addressed in early stages. When hiring a skilled engineering team may prove too costly for a single small or micro-hydropower project, one alterative option is bundling several studies together.
- Raising of the incentive thresholds, following the approval of the new energy transition law and the entry into force of the new ordinance (in January 2018), to a minimum power of 1 MW in fluvial projects or 300 kW for rehabilitation projects, except for any synergetic projects combined with other industrial water uses that have no direct impact on the natural or high-ecological interest river reaches.
- Excessive production of legal and regulatory documents: despite the stable legal framework (updates carried out in general every 20 years), the operational directives and financial incentive mechanisms tend to change in shorter timeframes. This reflects the interplay between the different competing renewable energy technologies and their marginal interest but hampers developers from engaging in projects. Synergetic projects where hydropower is one among other purposes (e.g., solar power, water supply, drought-support, ecological restoration) tend to find better support with the authorities, the public and funding partners than stand-alone SHP projects.
- Competition with other renewable energy sources, in particular solar PV plants with appurtenant electrochemical storage. There is fierce competition in the public space for media attention to obtain public acceptance and financial support from the public authorities at cantonal and federal level.
- Public concerns about the reduction of biodiversity in Swiss river corridors based on monitoring and assessment over recent decades, which have led to increased pressure on SHP promoters, operators and authorities to mitigate negative impacts on biodiversity as well as on requests for further investment (for projects which can otherwise be eligible for public funding).

Enablers for SHP development in Switzerland include:

- Large availability of water across the country, increased by the glaciers melting due to climate change. Besides, mountains cover a major part of the territory, which enables SHP plant implementation with high water head.
- Due to more than 150 years of large hydropower development across Switzerland, methodologies of hydropower project implementation, including SHP plants, are well-known to responsible institutions. This ensures a relatively quick and systematic reaction from the federal offices and enables acceptation of this kind of projects by the population.
- The hydropower sector development, including SHP projects, is actively encouraged in Switzerland. In-

deed, the Energy Strategy 2050 presents an objective of hydropower production increase of 1.2 TWh/year in 2050. To encourage hydropower development, including SHP, the Swiss Confederation provides subsidies to investors (for projects with an installed capacity above 1 MW).

- Due to a large number of existing hydropower infrastructure in the country, there is significant experience in construction and operation of hydropower plants, as well as qualified workforce for design, construction, operation and maintenance.

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Contributing organizations

UNITED NATIONS
INDUSTRIAL DEVELOPMENT ORGANIZATION

Vienna International Centre
P.O. Box 300 · 1400 Vienna · Austria
Tel.: (+43-1) 26026-o
E-mail: renewables@unido.org
www.unido.org

INTERNATIONAL CENTER
ON SMALL HYDROPOWER

136 Nanshan Road
Hangzhou · 310002 · P.R.China
Tel.: (+86-571) 87132780
E-mail: report@icshp.org
www.icshp.org