

Energy Industry in Germany



General State of the Economy

Germany, officially The Federal Republic of Germany, is a country in Central Europe. Its capital is Berlin. The country borders France, Luxembourg, Belgium and the Neth-

erlands (to the west), Denmark (to the north), Austria and Switzerland (to the south), and Poland and the Czech Republic (to the east). The country has access to the Baltic and North Seas.



Sources:

1. GDP (purchasing power parity), 2020 est. / The World Factbook/Library/Central Intelligence Agency *228
 2. GDP - per capita (PPP), 2020 / The World Factbook/Library/Central Intelligence Agency *229
 3. Inflation rate (consumer prices), 2019 est. / The World Factbook/Library/Central Intelligence Agency *228
 4. Charges for the use of intellectual property, receipts (BoP, current US\$), 2020 / International Monetary Fund, Balance of Payments Statistics Yearbook, and data files. / License: CC BY-4.0 *88
 5. The Global Competitiveness Index 2019 / Rankings / Reports / World Economic Forum *141
 6. High-technology exports (current US\$) 2019-2020 / United Nations, Comtrade database through the WITS platform / License: CCBY-4.0 / Data *134
 7. 2021 Index of Economic Freedom / International Economies / The Heritage Foundation *178
 8. Reserves of foreign exchange and gold, 2017 est. / The World Factbook / Library / Central Intelligence Agency *195
 9. Annual average GDP growth in %, for the last 10 years (2011-2020) / World Bank national accounts data, and OECD National Accounts data files / License: CC BY-4.0 *206
 10. Public debt (% of GDP), 2017 est. / The World Factbook / Library / Central Intelligence Agency (from smallest to largest) *210
- * Total number of countries participating in ranking

Figure 1. Economic indices of Germany

Germany is the 69th largest country in the world and, according to 2022 statistics, is home to around 84,3 million people. In terms of population density the country

ranks 61st in the world out of 248 countries considered [1,2,3]. The total length of the country's coastline is 2,389 km [3].

The political form of government is a federal parliamentary republic. The official language is German. The country is divided into 16 administrative states [3]. Germany is one of the main exporters of industrial goods and high-tech products in the European Union, which contributes to it having Europe's largest economy, and the fifth largest economy in the world, which is reflected in the diagram presented in Figure 1. By almost all economic indicators, excluding average GDP growth and public debt, the country ranks higher than the world average, in the top quarter of the graph (i.e. among the top 25% of countries in the world included in the rating). From the early 1990s, barring a slight decline in 2008, the country experienced sustained GDP growth in purchasing power parity, both in general and per capita [4,5]. GDP at purchasing power parity increased from \$4.199 trillion in 2017 to \$4.238 in 2020 (5th place in the world) [3]. The country's GDP at purchasing power parity per capita is lower (26th place in the world), demonstrating negative dynamics: from \$53,500 in 2018 to \$50,900 in 2020 [3].

The level of inflation in Germany changed from 1.5% in 2017 to 1.4% in 2019 [3].

According to The Global Competitiveness Report 2020, compiled by the World Economic Forum, Germany is 7th out of a total of 141 countries considered, behind Switzerland and the Netherlands in the EU. This rating reflects the effectiveness of the use of the country's own resources for sustainable development. In addition to a number of economic indicators this index also takes into account such variables as education, health, level of in-

novation, etc. In the list of countries that exported high-tech products in 2019-2020, the country was second only to China, out of 134 countries.

According to the Index of Economic Freedom, which is based on freedom of business, freedom from government intervention, property protection, and freedom from corruption, the country was 29th in 2021, out of 178 countries considered.

In terms of gold reserves and foreign exchange reserves Germany was 13th, behind Russia and Switzerland in the region.

In terms of average GDP growth in % over the last 10 year (2011-2020), the country was 154th out of 206 countries, behind Switzerland, but ahead of the Netherlands, in 2020. In terms of public debt, calculated as a percentage of the country's GDP, Germany was ranked 62nd out of 210 countries considered in 2017. A large number of German energy companies, including such large companies as RWE and E.ON, are included in S & P Global's Platts 2021 Top 250 Company ratings of the largest energy companies. A number of other German companies, which are well-known suppliers of energy products, were also included in the top global companies of the Global 500 in 2021, among them – Siemens Energy, E.ON, Siemens, BASF, Thyssen Krupp, and Robert Bosch.

For more information on the German economy, see the attached link library by clicking [here](#).

Energy resources

Germany has large coal reserves, and is among the top 25% of countries by this indicator (Fig. 4). The coal reserves in Germany are highly differentiated depending on its type. Thus, according to [6], in 2019 hard coal resources in Germany are estimated at 82,965 Mt, making up 0.5% of the world's total, however, anthracite and

bituminous coal reserves are estimated at only 12 Mt. The primary coal reserves in Germany are comprised of lignite, according to which the country is among the world leaders both in terms of resources (36,500 Mt – 0.8% of world resources and 11th in the world) and reserves (36,100 Mt – 11.4% from world reserves and 3rd in the world). The reserves of other fossil sources are not significant (Table 1).

Table 1. Fossil energy resources of Germany

Resource/ explanations	Crude oil	Natural gas	Coal	Shale Gas*	Tight Oil*	Coal mine methane	Oil Shale
Value	129.6	39.5	35 900	17	0.7	10.9-72.3	2
Unit	million barrels	Bcm	million tonnes	Tcf	billion barrels	Bcm	million barrels
Year	2018	2018	2020	2013	2013	2018	2008
Source	[3]	[3]	[7]	[10]	[10]	[7,9]	[11]

*unproved technically recoverable

According to proven reserves of oil and natural gas, the country ranks 65th and 64th in the world, respectively [3]. In terms of tons of oil equivalent, proven coal reserves were 99.8 %, oil reserves 0.1%, and natural gas was 0.1%, according to data from 2021 (Fig.5). The matrix of unconventional fossil resources as of 2014-2015 looks somewhat different – shale gas accounted for 48.8%, kerogen oil – 33.6%, tight oil – 10.4%, coal mine methane utilization potential – 7.2% (Fig.5).

According to [3] at the beginning of 2018, oil reserves in Germany were estimated at 129.6 million barrels, and according to [6] – crude oil reserves were 28 Mt in 2019. Proven natural gas reserves in Germany at the beginning of 2018, based on [3], amounted to 39.5 bcm, and according to [6] – to 25 bcm in 2019. It should be noted that the consumption of oil and gas in Germany significantly exceeds existing production levels.

Total proven coal reserves in 2020 were estimated at 35 900 million tons according to BP [7], and at 39 917 million short tons in 2015 according to the U.S. Energy Information Administration [8], which corresponds to data from BGR 2017. According to calculations made by Advanced Energy Technologies, the methane utilization potential, according to the methodology based on methane emissions from [9] and coal reserves from [7], amounted to around 10.9-72.3 Bcm.

Germany also has substantial reserves of unconventional hydrocarbons: shale gas – 17 Tcf, tight oil – 0.7 billion barrels and kerogen oil – 2 billion barrels [10,11]. Germany has a variety of renewable resources for energy production. A selection of basic indicators is presented in Table 2.

Table 2. Renewable energy resources of Germany

Resource/explanations	Solar Potential (GHI)*	Wind Potential (50 m)*	Hydro energy Potential**	Bio Potential Agricultural area	Bio Potential Forest Area	Geo thermal Potential	Municipal Solid Waste
Value	2.8-3.0	6.0-7.0	20	48	31.78	164	628
Unit	kWh/m ² /day	m/s	GWh/year	% of land area	% of land area	MWe	Kg per person
Year	2018	2018	2008	2018	2018	2008	2020
Source	[12]	[13]	[15]	[16]	[17]	[15]	[18]

*for most of the territory of the country

**gross theoretical capability

The level of global horizontal radiation in most of the country is 2.8-3.0 kWh/m²/day [12]. In the southern part of the country, Bavaria, Baden-Württemberg and Hesse states, this figure can increase to 3.2 kWh/m²/day [12]. The distribution of wind resources is as follows: in most of the country the wind speed is 6.0-7.0 m/s [13]; along the coast of the North Sea, as well as in the north-west of the country, and the Baltic Sea region of the northeast, the wind speed exceeds 7.0 m/s at a height of 50 meters. The North Sea Region, including the section adjacent to Germany, is one of the richest regions in the world in terms of wind resources. At many locations in this region, according to long-term meteorological data, the average annual wind speed, even at an altitude of 10 m, exceeds 7 m/s, and the total time when the wind speed is within the operational range of the wind turbine (3-25 m/s) reaches 90%.

Economically exploitable hydropower capability in the

country is 20 TWh/year [14].

The geothermal potential of the country is low and in 2008 was estimated at 164 MW [15]. Nevertheless, Germany is active in developing geothermal energy. Taking into account the relatively low temperature of geothermal layers, binary systems with the Organic Rankine Cycle (ORC) are used, which make it possible to effectively use the resources available.

According to data for 2018, 48% of the territory of Germany is occupied by agricultural land, the area of which has been steadily decreasing during the last half-century [16]. There has been a slight increase in forest area to 31.8% of the country's territory in 2018, compared to 32.4% in 1990 [17].

The level of municipal waste generation in Germany (628 kg per person) corresponds to the level of highly developed European countries (e.g. Switzerland – 706 kg per person) [18].

On one hand, municipal waste is a valuable raw material for recycling or energy production, which is actively used in Germany, but on the other hand, long-term decomposing substances can significantly pollute the environment.

A detailed list of sites and special reports on German energy resources can be found [here](#).

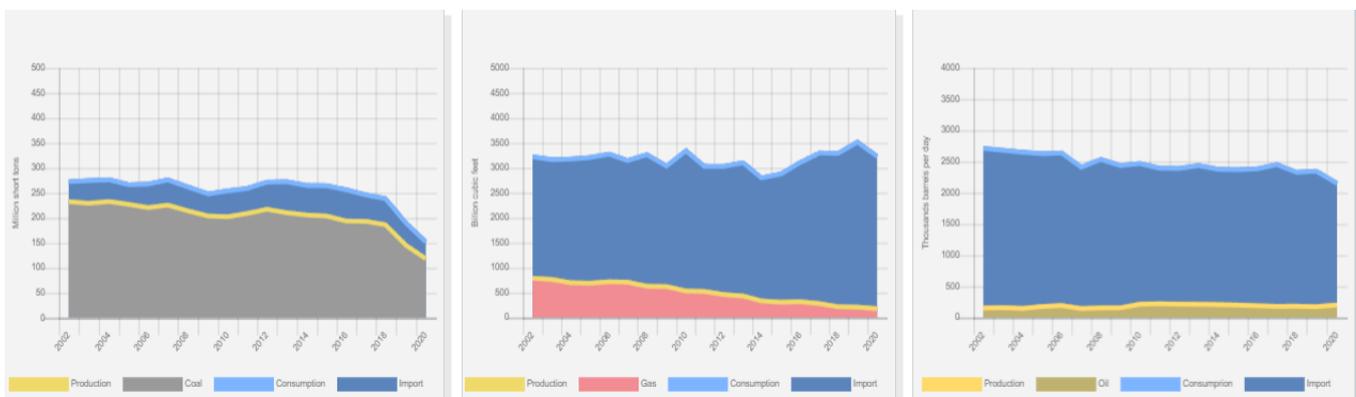
Energy Balance

According to the BP Statistical Review of World Energy 2022, total primary energy consumption in Germany in 2021 was 12.64 Exajoules, about 33% of which was oil, 23.4% – natural gas, 16.8% – coal, 18% – renewable energy, 4.9% – nuclear energy, 1.4% – hydropower [7]. Oil production between 2020 remained practically unchanged, not exceeding the level of 222 thousand barrels/day; in 2020 it was 201 thousand barrels/day [19]. The volume of oil consumption in the country since 2007 has shown a decline (Fig.2), despite demonstrating a small growth in 2017, reaching the level of 2,450 thousand barrels/day, and declining to 2,149 in 2020 [19]. Crude oil imports in 2020 were 1.663 million bbl/day [3].

The production of natural gas in Germany has been gradually decreasing since 2001 and reached the level of 308 Bcf in 2015, half the levels of 2001, and 179 Bcf in 2020 [19].

The consumption of natural gas in Germany between 2001 and 2014 also decreased, with small fluctuations, not exceeding the level of 3,338 Bcf. From 2016 gas consumption has begun to rise again, reaching 3,380 Bcf in 2019 and 3,091 Bcf in 2020 [19].

According to BP [7], gas production in the country in 2021 amounted to 4.5 billion m³, with consumption at 90.5 billion m³; BGR publishes similar figures for 2020. Germany is the largest consumer of gas in Europe; and according to [6], the country imported 139 bcm of natural gas in 2019 [3]; exports amounted to 72.4 billion m³ in 2019.



Source: U.S. Energy Information Administration (Jan 2020) / <https://www.eia.gov/>

Figure 2. The production and consumption of fossil fuels in Germany (left—coal, cen)

Coal production in the country declined since 2001, with slight fluctuations, not exceeding 233 million short tons; in 2020 it was 193 million short tons. Coal consumption did not exceed 276 million short tons, and in 2020 it was 151 million short tons [19].

According to BP's report in 2020, coal production amounted to 0.98 Exajoules, while consumption was estimated at 1.84 Exajoules [7]. According to the Bundesanstalt für Geowissenschaften und Rohstoffe (BGR), in 2020 the country imported about 32 million tons of coal, mainly from Russia, the US and Australia [20]. In recent years Germany has been actively using renewable energy sources for the production of electricity (Figure 3.).

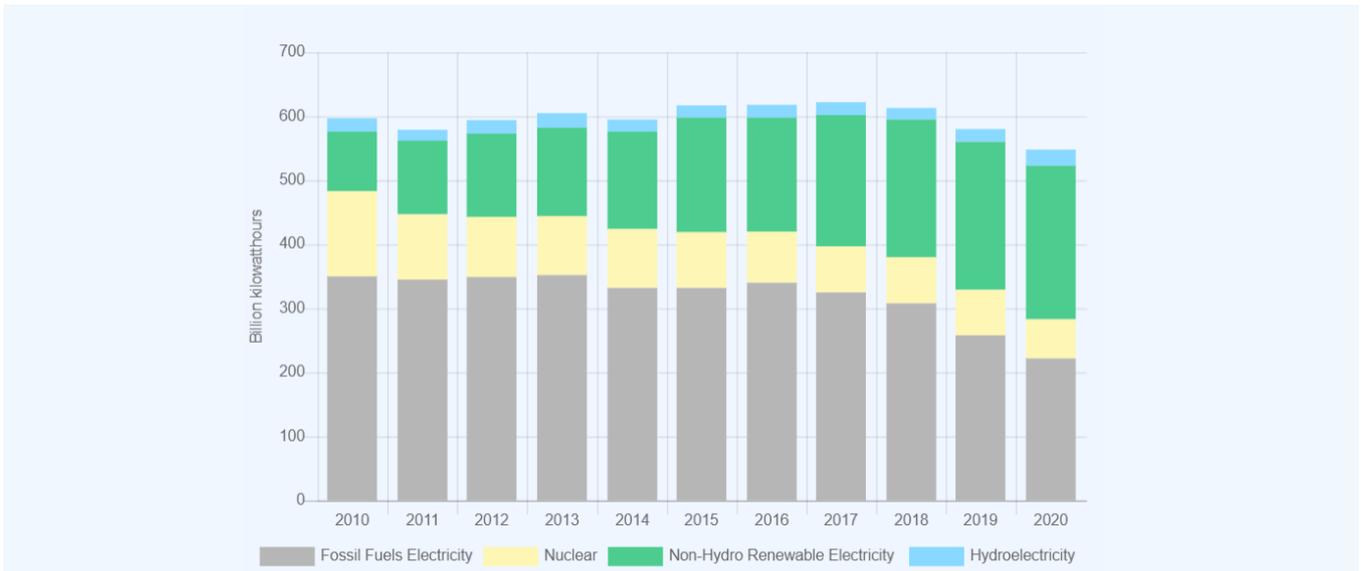
In 2020, according to the U.S. Energy Information Administration, electricity production in the country

was 545.20 TWh, where fossil fuels accounted for 40.7%, renewables – 44%, nuclear energy – 11.2%, and hydropower – 4.1% (Fig.6).

According to the German statistical agency, in 2021 electricity production was about 518 billion kWh, where fossil fuels (including nuclear energy) accounted for 57.6%; and renewable sources, including hydropower accounted for 42.4% [21].

On January 1st 2018, an important historical event occurred in Germany – 95% of electricity consumed was generated from renewable sources, primarily from wind and solar energy.

It was expected that in 2018 the supply of grid electricity through renewable sources in Germany would outperform coal for the first time. In 2021, the share of renewable energy in electricity generation decreased, and

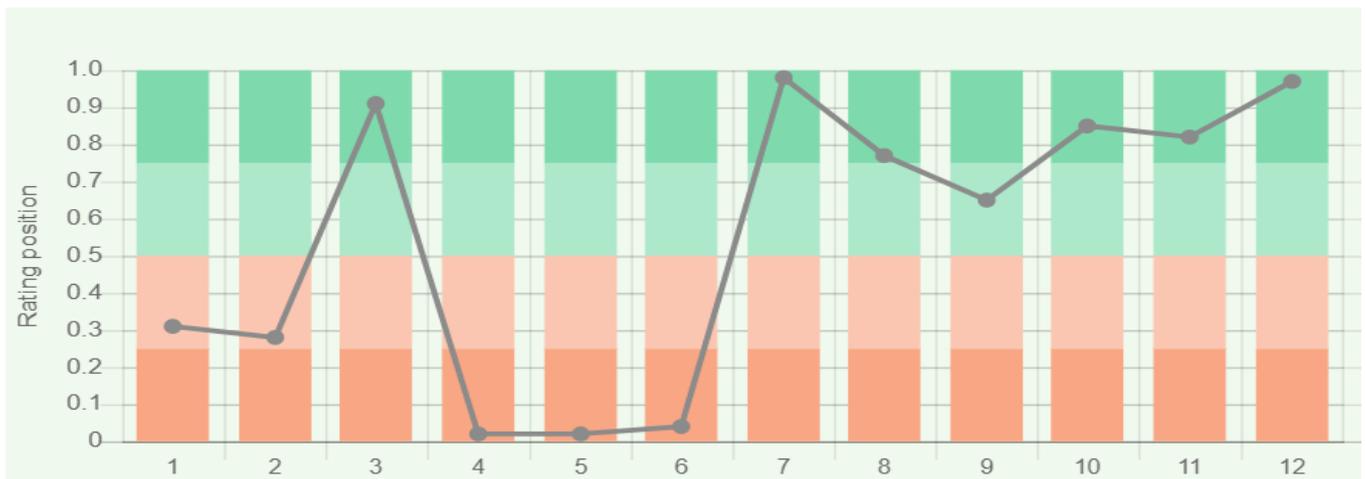


Sources:
U.S. Energy Information Administration (Dec 2021) / <https://www.eia.gov/>

Figure 3. Electricity production in Germany

coal became the most important energy source for electricity generation in Germany in 2021, showing a high growth of 24.9% compared to 2020. In 2021, coal power accounted for 30.2% of total electricity supplied

to the grid (24.8% in 2020), according to the German statistical agency. Germany's position in the comparative diagram of energy indices is shown in Figure 4.



Sources:
 1. Crude oil proved reserves, 2021 / International Energy Statistic/Geography / U.S. Energy Information Administration (Nov 2021)*98
 2. Natural gas proved reserves 2021 / International Energy Statistic / Geography / U.S. Energy Information Administration (Nov 2021) *99
 3. Total recoverable coal reserves 2019 / International Energy Statistic / Geography / U.S. Energy Information Administration (Nov 2021) *81
 4. Combination production-consumption for Crude oil 2018 / International Energy Statistic / Geography / U.S. Energy Information Administration (Nov 2021) *219
 5. Combination production-consumption for Natural gas 2019 / International Energy Statistic / Geography / U.S. Energy Information Administration (Nov 2021) *123
 6. Combination production-consumption for Coal 2019 / International Energy Statistic / Geography / U.S. Energy Information Administration (Nov 2021) *128
 7. Electricity – from other renewable sources (% of total installed capacity), 2017 est. / The World Factbook / Library / Central Intelligence Agency *170
 8. GDP per unit of energy use (PPP per unit of oil equivalent), 2020 *66
 9. Primary energy consumption - BP Statistical Review of World Energy 2021/BP/GDP (purchasing power parity) - The World Factbook/Library/Central Intelligence Agency
 10. Energy use (primary energy use of oil equivalent per capita) 2020 *127
 11. Primary energy consumption – BP Statistical Review of World Energy 2021; Population - United Nations, Department of Economic and Social Affairs, Population Division (2019). World Population Prospects 2019, custom data acquired via website. Retrieved 15 November 2021*66
 12. The Global Energy Architecture Performance Index Report (EAPI) 2017 / Rankings / Reports / World Economic Forum
 11. Electric power consumption (kWh per capita), 2016 *217
 Electricity Consumption - The World Factbook / Library / Central Intelligence Agency; Population - United Nations, Department of Economic and Social Affairs, Population Division (2019). World Population Prospects 2019, custom data acquired via website. Retrieved 15 November 2021
 12. Combination of electricity production-consumption (kWh)/The World Factbook/Library/Central Intelligence Agency *216
 * Total number of countries participating in ranking

Figure 4. Energy indices of Germany

Germany is at the bottom of the list of countries in terms of the production/consumption ratio of fossil fuels, ranked from high to low, and for all major resource components – oil, gas and coal. At the same time, in terms of coal reserves, the country's positioning looks strong – among the top 25% of world leaders. In the list of countries showing levels of electricity production from renewable sources (excluding hydropower), in 2017 Germany was 3rd, second only to Denmark, out of 213 countries selected for consideration. In the Energy Architecture Performance Index 2017, which is based on the level of economic growth, environmental safety, access to energy, and energy independence of the country, Germany was 19th. It should be not-

ed that during the last 8 years the country has gained 4 ranking positions.

Germany is in the top quarter for such indicators as GDP per unit of energy expended in 2020 – 15th; similarly, for such indicators as energy use per capita the country is 23rd.

In terms of electricity consumption per capita, the country is 39th in the world. Germany ranked 7th out of 216 countries considered according to the combination of electricity production-consumption indicator.

More information about the energy balance of Germany can be found in the documents from our reference library [here](#).

Energy Infrastructure

A territorial map showing distribution of the largest infrastructure projects of the fossil fuel sector in Germany is displayed in Figure 5. As previously mentioned, coal

reserves account for 99.8% of conventional proved reserves (Fig.5).



Figure 5. Basic infrastructure facilities of the fossil fuel sector in Germany

The last active German coalmine, Ruhr Prosper-Haniel, is was located in the west of the country and produced about 2.5 million tonnes [22]. The closure of the mine in December 2018 marked the end of coal mining in Germany [74].

The largest oil field is the Mittelplate, which in 2017 produced about 2,700 tons of oil per day [23]. The installed capacity of oil refineries in Germany is one of

the largest in Europe and in 2016 amounted to 2,188,000 barrels/day [24]. The largest refinery, owned by Shell Deutschland Rheinland Godorf & Wesseling is situated in Cologne and has an installed capacity of 340,000 barrels/day [25].

One of the main oil terminals of Germany is HES Wilhelmshaven with a 1.3 million m³ tank farm. Rostock is the largest petroleum products storage, with a capacity

of 700,000 m³ [26,27]. Transportation of crude oil and petroleum products is carried out via pipelines with a length of 2,826 km and 4,479 km, respectively (Fig.5). The largest gas deposits are located in the central part of the country, and there are natural gas hydrates occurrences in the north of the country (Fig. 5). The German gas system consists of more than 40 gas storages and more than 30 gas compressor stations [28,29]. Gas is transported within the country via a network of pipelines with a total length of 26,985 km (Fig. 5).

At the beginning of the 20th century Germany was prominent in the development and production of various fuels from coal. Despite the fact that this direction is not prevalent today, Germany still has several synthetic fuel enterprises, in particular the Karlsruhe Dimethyl Ether (DME) plant, which can annually produce about 608 tons of biomass from waste, and the Wesseling Methanol-to-Gasoline (MTG) [30,31].

A territorial map showing the distribution of the largest infrastructure facilities for electricity generation in Germany is shown in Figure 6.

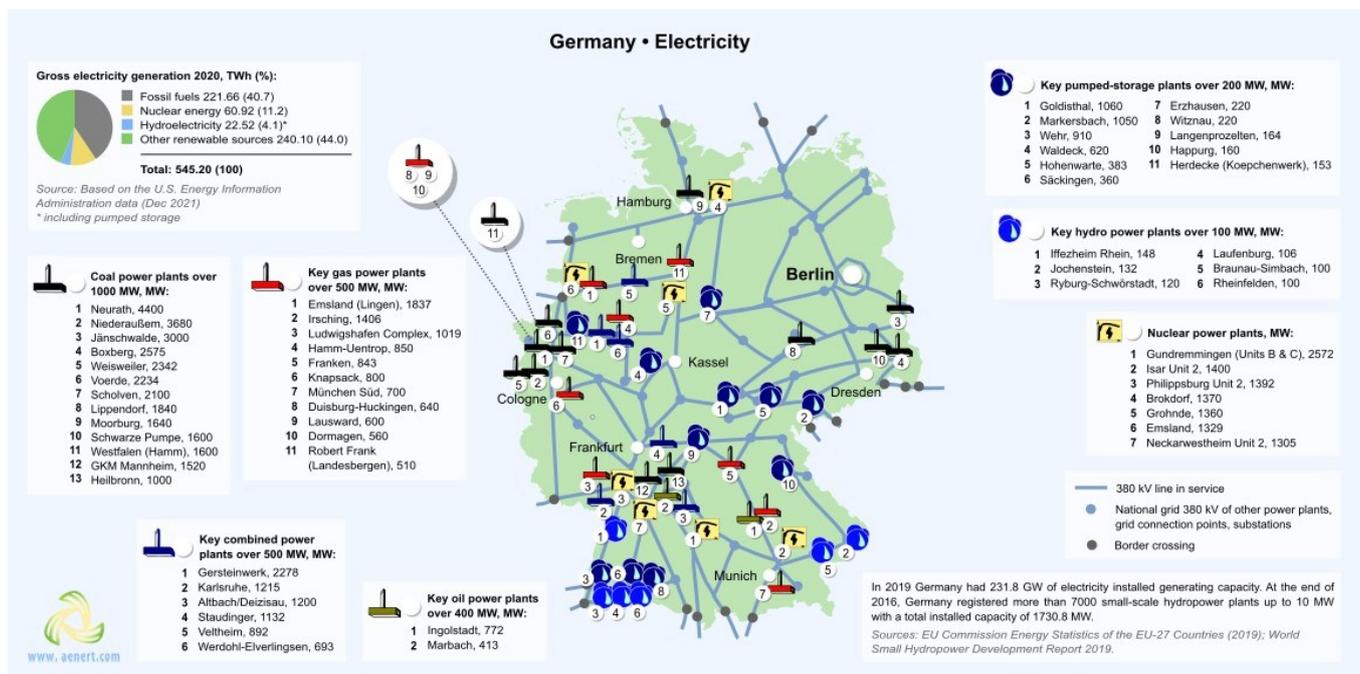


Figure 6. Electricity production in Germany

The share of fossil fuels in electricity generation in Germany, according to the EU Commission Energy Statistics of the EU-28 countries was about 40.27% in 2020 (Fig. 6). The country has a significant number of stations for the production of electricity from hydrocarbons, including two oil, eleven gas, thirteen coal, seven nuclear and six combined power stations with a capacity of more than 400 MW (Fig.6).

The largest German power plants are: Emsland (Lingen) gas power plant with a capacity of 1,837 MW, Ingolstadt oil power plant, with a capacity of 772 MW [32,33], Neurath coal power plant with a capacity of 4,400 MW, Gersteinwerk combined power plant with a capacity of 2,278 MW and Gundremmingen (Units B and C) nuclear power plant with a capacity of 2,572 MW [34,35,36,37]. Hydro-power in Germany accounts for 4.1% of electricity generation, and is represented by both pumped storage plants and large and small hydropower plants (Fig. 6).

The largest pumping station is Goldisthal with an installed capacity of 1060 MW. The main hydroelectric power plant is Iffezheim Rhein with an installed capacity of 148 MW [38,39]. In Germany in 2016, there were more than 7,000 small hydropower stations, with a total installed capacity of 1730.8 MW [40].

Figure 7 shows the main infrastructure facilities in Germany for the production of renewable energy. As noted above, renewable energy in Germany accounts for 44% of electricity generation. Thus, the total production of electricity from renewable sources excluding hydropower in 2020 was 240,10 TWh (Fig. 7). In zones of high wind activity, there are more than 2 dozen offshore and on-shore wind parks, each with a capacity of more than 100 megawatts. In 2021 in Germany, the total installed capacity of wind power was about 57,5 GW [41].

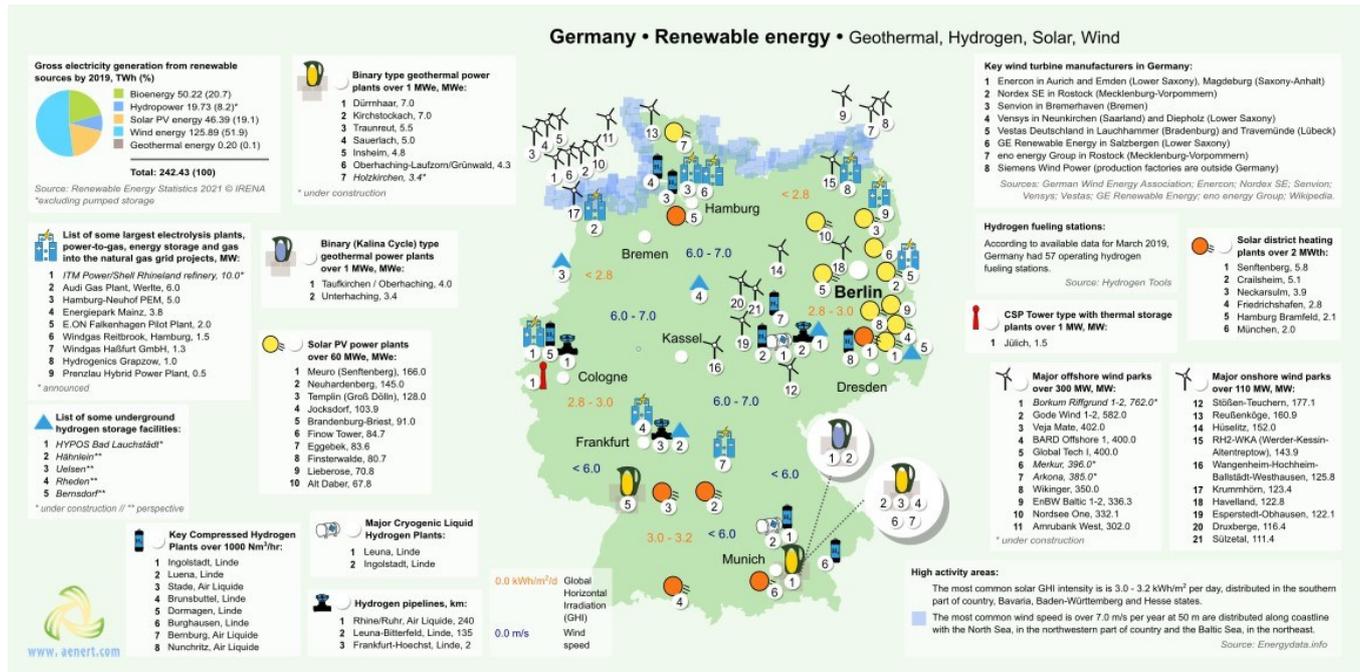


Figure 7. Renewable energy in Germany: solar, wind, geothermal and hydrogen

The largest onshore wind park is Stöben-Teuchern with an installed capacity of 177.1 MW [42], and the largest offshore park is Borkum Riffgrund 1-2 with a total installed capacity of 762 MW [43,44]. The majority of the largest wind farms are located in the north of Germany in off-shore zones. In terms of the total installed capacity, Germany was third in the world at the end of 2021 (64,542 MW), second only to China and the USA [45]. Germany has the largest wind turbine manufacturing companies, including Enercon, Nordex SE, Senvion, Vensys, Vestas, GE Renewable Energy, Eno Energy Group, and Siemens Wind Power (Figure 7). As mentioned earlier, the level of global horizontal solar radiation in some areas of the country can reach 3.2 kWh/m², which is sufficiently high for electricity production by means of photovoltaics and for the production of thermal energy [12]. As a consequence, there are a large number of solar energy facilities, both photovoltaic and solar district heating plants. A number of research organizations in Germany are actively exploring various options for concentrating solar energy. There is also an experimental CSP tower type - Jülich (1.5 MW) [46]. About 20% of electricity from renewable sources in Germany is produced by photovoltaic stations. The largest station of this type is Meuro with a capacity of 166 MW [47]. Solar energy is also used for district heating, for example the Senftenberg Solar Heating Plant, which provides about 5.8 MW of solar energy [48]. At the end of 2021 Germany installed more than 59.2 GW of photovoltaic facilities (5th in the world after China, the

USA, and Japan and India). In 2021 5.3 GW of new capacities were added [49]. In Germany, particularly in the south of the country, there are natural resources for the development of geothermal technologies. Despite the low indicators of geothermal resources, the development of geothermal energy is developing dynamically. For these purposes, binary technologies, including Calina cycle, are being used. In Bavaria there are 9 geothermal stations, with another being under construction. One of the largest stations is Dürrenhaar, with a capacity of 7 MW [50]. In 2010, only 6.6 MW of geothermal capacity was installed in Germany, but this had increased to 27 MW by 2015, and to 350 MW in 2020. The country has a state program for the development of geothermal energy, including financial support for projects, as well as preferential tariffs [51,75]. Germany is active in developing hydrogen as an energy source for vehicles. As of March 2019, there were about 57 hydrogen filling stations in operation in the country (Figure 7). There are also several plants producing hydrogen, including the largest one in Ingolstadt, managed by Linde, with an installed capacity of 97,917 Nm³/hr [52]. There are also several electrolysis, power-to-gas and other plants in the country, the largest of which is ITM Power PLC/Shell Rheinland Refinery with installed capacity of 10 MW [53]. Several underground hydrogen storage facilities are under construction. Hydrogen is transported via a network of three pipelines with a total length of 377 km (Fig. 7).

Figure 8 shows the main German bioenergy facilities for energy production. Bioenergy is a rapidly developing field in Germany and in 2017 about 50.93 GWe (23.5%) of electricity was generated from biomass (Fig.7).

The country has biomass and municipal waste processing plants; biogas, biodiesel, bioethanol, pellet and landfill gas production (Fig.8).



Figure 8. Renewable energy in Germany : Bioenergy

In Germany, plants for the production of energy from biomass, as well as biofuel production, are becoming widespread. Zellstoff Stendal is the operator of the largest Arneburg biomass power plant, with an installed capacity of 135 MW [54]. Germany's main enterprise in the field of production of biomass fuels: Frankfurt am Main, Cargill, has the ability to produce 300,000 tons of biodiesel annually [55]. Germany is one of the world's leading producers of biogas, second only to China, and at the end of 2015 had a 62% share of total biogas capacity in Europe. By the end of 2015, there were more than 8,000 biogas plants in the agricultural sector, about 1,400 sewage treatment plants and 400 landfill gas processing plants distributed throughout the country [56,57]. In Bavaria there are about 2,360 biogas plants; one of the largest is the plant in Vettin with an installed capacity of 8.5 MW [58]. The total installed capacity of biogas plants in Germany in 2016 was about 5,104 MW or about 32% of the world's total installed capacity [59]. Germany is actively engaged in bioethanol production, and Zeitz, managed by Crop Energies, is one of the largest in Europe, and produces 400,000 m³ of biofuel annually [60]. Second-generation bioethanol from cellulose is produced at the largest facility in the country - the Sunliquid Project (Straubing) bioethanol power plant, which has an

installed capacity of 1000 t/year [61]. Others notable facilities include: Rüdersdorf Zement biomass gasification from biowaste power plant, with an installed capacity of 100 MW [62]; Wismar, producing about 256,000 tons of pellets per year [63]; and the largest fast pyrolysis plant, Lüneburg, with an installed capacity of 150 kg/h [64]. The leader in the generation of electricity from municipal waste is an enterprise in Cologne, capable of processing about 760,000 tons of waste annually [65]. In Germany, landfill gas is also used for electricity generation; the North-Rhine Westphalia region is leading in terms of installed capacity of such stations - 55.3 MW (Fig. 8). The pilot Btl-FT plant in Oberhausen is able to process around 3 tons of biofuel and 2 tons of liquid hydrocarbons (diesel-type hydrocarbons) annually [66]. According to a number of European agreements, Germany is obliged to reduce CO₂ emissions by 40%. The German Energiewende (energy program) 2017-2022 is primarily aimed at reducing the share of nuclear energy and fossil energy sources in electricity generation [67]. To achieve this nuclear power plants will be decommissioned. In late 2017, Block B of the Gundremmingen nuclear power plant stopped operating and at the end of 2019 the nuclear power plant Philippsburg 2 was also

shut down. At the end of 2021 the nuclear power plants Grohnde, Gundremmingen C and Borkdorf were shut down. It was planned to shut down three small Isar 2, Emsland and Neckarwestheim 2 facilities by the end of 2022, but the war in Ukraine have triggered a debate in Germany about extending the operation of the remaining nuclear power plants. It is worth noting that in 2020 nuclear power provided about 13% of electricity [67,68,76]. The government of Angela Merkel introduced a new electricity law, which included special price signals when demand is low, and also supports the construction of underground power lines [68]. In the long term, the country is aiming to reduce green-house gas emissions by 55% compared to 1990 levels and increase the share of renewable energy sources in electricity production to 50% by 2030 [68]. Germany moved eight lignite coal stations with a total capacity of 2.7 GW to the "cold capacity reserve" regime, which could be re-activated in the event of an electricity shortage [68]. In 2017, in the North-Rhine Westphalia region, which generates about a third of the country's electricity, it was decided to transform the Prosper-Haniel coal mine into a 200 MW pumped

storage station that would power 400,000 households. Similar activities may occur in the future with other coal stations [69]. In 2016, 205 new biogas plants with a total capacity of 45 MW were put into operation in the country. In 2017 it was planned to put into operation 143 new stations. Another 239 MW will be added due to the modernization of old stations. It should also be added that biogas plants reduce the total amount of CO₂ emissions by 20 million tons [70]. In 2020, Germany, along with France and Sweden, was among the top 3 EU countries for bio-heat use [49,70].

In January 2017, Siemens and its partners announced the construction of the world's largest hydrogen electrolysis facility. Hydrogen that will be generated at The Mainz facility can be used for fuel-cell powered vehicles, for industrial purposes, or as an energy storage medium [71].

For current information on the development of energy in the country see [here](#). More information about German energy infrastructure is also available [here](#).

Education and Innovation

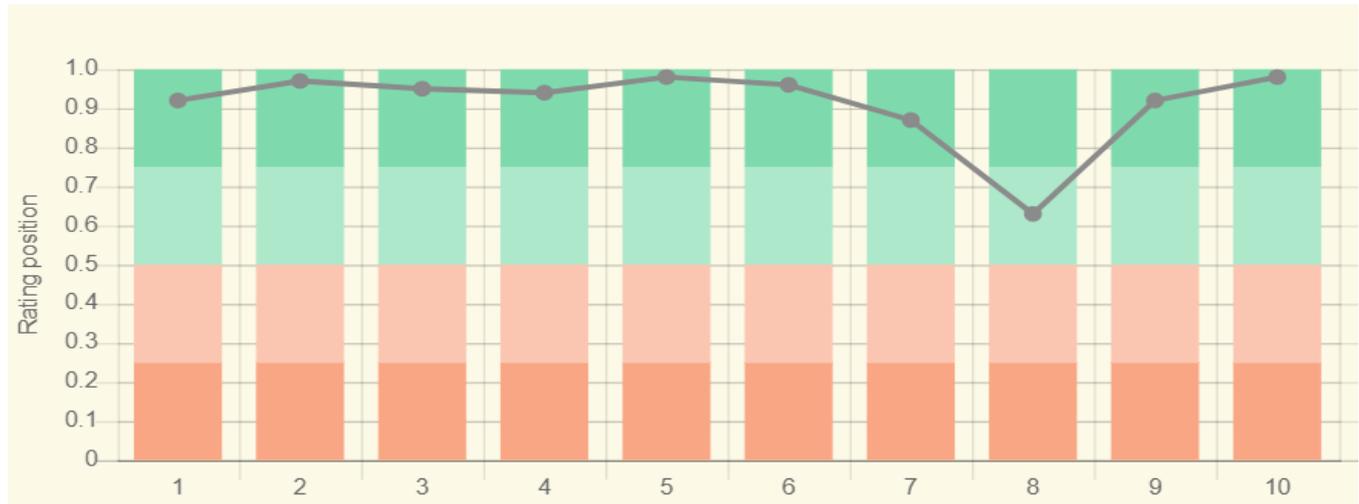
The set of indices reflecting the position of Germany relative to other countries in the field of education and innovation can be seen in Figure 9. According to the number of patents granted to German residents, both inside the country and abroad, the country ranks 5th in the world, and 1st in Europe. Similarly, by the number of patents in force, the country ranks 5th in the world, indicating the country's favorable conditions for innovation.

Germany places 10th out of 132 countries considered in the Global Innovation Index 2021 (see diagram). In terms of government expenditure on education as a percentage of the country's GDP, the country demonstrates a result close to the world average – 66th out of 177 countries considered. Nevertheless, 46 German universities are included in the QS University Rating of the world's leading universities. It should also be noted that the country's GDP is high, therefore, in absolute terms the government's spending on education is significant. In terms of public expenditure on research and development as a percentage of GDP, Germany is 9th, behind Sweden, Finland, Denmark and Switzerland. Germany is very well positioned in terms of the number of publications of specialist scientific and technological journals and patent activities. Germany is 4th out of 240 participating countries in the Scimago ranking, and in Scientific and Technical Journal activities is ranked

4th out of 197 countries. The country is also among the leaders in the region in terms of the number of Internet users.

German Universities, such as the Free University of Berlin, the University of Bayreuth, the Karlsruhe Institute of Technology, the University of Tübingen, the Technical University of Munich, and the Humboldt University of Berlin train specialists in various fields of energy, including Environmental Earth Studies, Geological Sciences, and Environmental Hydrology, Environmental Systems and Sustainability – Monitoring, Modelling and Management, etc.

German companies eminent in the field of synthetic fuel production patenting include Uhde GmbH, Lurqi GmbH, Linde AG, Thyssenkrupp Uhde GmbH, BASF, SE. Research and development in this field is carried out by the Karlsruhe Institute of Technology (KIT), Technische Universität Bergakademie Freiberg, Deutsches GeoForschungsZentrum GFZ. In the field of unconventional oil, Siemens AG, Wintershall Holding GmbH, BASF, SE, Thyssenkrupp Fördertechnik GmbH rank prominently in terms of patent activity. RWTH Aachen University, Deutsches GeoForschungsZentrum GFZ are actively engaged in research in this field.



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* Total number of countries participating in ranking

Figure 9. The indices of education and innovation in Germany

In the field of gas hydrates Deutsches GeoForschungsZentrum GFZ, Karlsruhe Institute of Technology (KIT) have produced significant patents; Universität Bremen, Helmholtz Centre for Ocean Research Kiel (GEOMAR), Deutsches GeoForschungsZentrum GFZ, and the Leibniz Institute of Marine Sciences (IMF-GEOMAR) are conducting notable research in this area. Another area in which German companies patent their inventions is coalbed methane, and here the leaders are Siemens AG and Linde AG; research in this field is being carried out by RWTH Aachen University, the Clausthal University of Technology. In the field of associated gas BASF, SE, Thyssenkrupp Uhde GmbH, Linde AG should be mentioned. Leading research organizations in this field include RWTH Aachen University and the Technische Universität Bergakademie Freiberg.

In the field of hydrocarbon production from reservoirs with low permeability – BASF, SE, Ashland-Sudchemie-Kemfest GmbH, Wintershall Holding GmbH and the following research agencies are actively engaged in research: Deutsches GeoForschungsZentrum GFZ, RWTH Aachen University, Clausthal University of Technology. The leading patent holders in the field of bioenergy are Energy Technologies GmbH & Co.KG, DGE GmbH, Linde AG, BASF, SE, Unde GmbH. Karlsruhe Institute of Technol-

ogy (KIT), RWTH Aachen University are conducting research in this area.

A large number of German companies patent technical solutions in the field of energy production from renewable sources. In the field of solar energy: Siemens AG, Deutsches Zentrum für Luft- und Raumfahrt (DLR), Fraunhofer-Gesellschaft zur Förderung der Angewandten Forschung e.V., Schott AG. Leading research organizations in this field are German Aerospace Center (DLR), Fraunhofer Institute for solar energy systems (ISE), German Aerospace Center (DLR) Institute of Technical Thermodynamics, Deutsches Zentrum für Luft- und Raumfahrt (DLR).

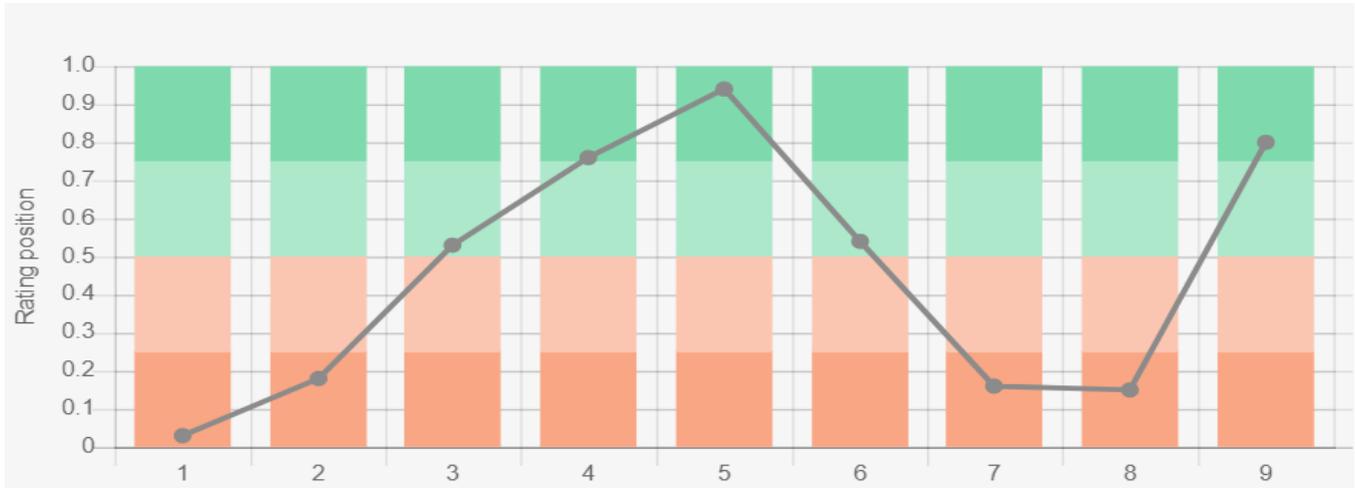
Siemens AG, Wobben Properties GmbH, Repower Systems AG, Senvion S.A. NORDEX ENERGY GMBH have the largest number of patents in the field of wind power; research in this field is being conducted by Carl von Ossietzky Universität Oldenburg, Fraunhofer Institute for Wind Energy and Energy Systems Technology, Technische Universität München, and the University of Stuttgart.

Additional information about education in the country can be obtained [here](#), and the list of research institutes [here](#).

Ecology and Environmental Protection

The diagram of environmental indices presented in Figure 10, alludes to the ambiguous environmental situation in Germany.

First of all, the country demonstrates a relatively high level of CO₂ emissions in general, and per capita. In 2020, the level of CO₂ emissions resulting from coal mining and processing was 199 mt, which is higher than, for example, in Poland – 161 mt [73].



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* Total number of countries participating in ranking

Figure 10. Germany's environmental indices

On average, the cost of mitigating the consequences of this kind of emission costs Germany more than 4,096 million euros (health costs, pollution costs). For comparison, in Poland, this figure was 4,519 million euros [72]. It is also necessary to note a relatively high level of methane emissions in Germany. Germany is 10th of the 61 countries responsible for more than 90% of global CO₂ emissions related to energy in the Climate Change Performance Index (CCPI) 2022. Its emissions are categorized as "medium".

The compilers of the rating emphasize that the country is the largest consumer of lignite in the world, and the GHG emissions are high.

In terms of forest area as a percentage of the country, Germany was 111th in the world in 2020; however, between 2010-2020 there was a trend towards reforestation, and according to this indicator the country is 57th in the world.

The situation is brightened by a very high valuation of Germany in the Environmental Performance Index rankings (EPI) 2020, which focuses primarily on assessing the environmental performance of national governments. Here, the country is 10th out of 180 countries, behind Denmark, the UK, Norway and France.

However, according to the Environmental Vulnerability Index, which is based on long term observations and 50 indicators that include, for example, changing climatic characteristics or the quality of water resources, waste volumes, oil spills and other hazardous substances, etc. Germany is 190th out of 234 countries, and is characterized as "highly vulnerable". The overall negative picture is aggravated by the Ecological Footprint Atlas rating, according to which Germany is among a number of ecological debtors.

For more information on the energy situation in Germany, see the attached link library by clicking [here](#).

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