

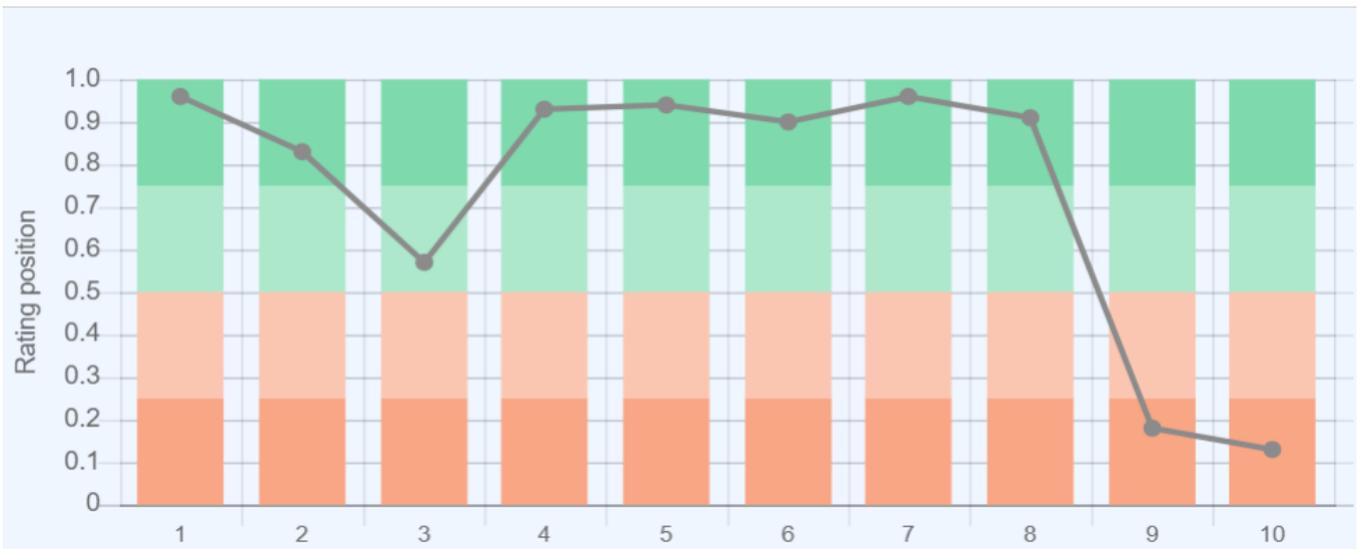
Energy Industry in the United Kingdom



General State of the Economy

Great Britain, officially the United Kingdom of Great Britain and Northern Ireland, is a country located on the British Isles to the northwest of continental Europe. Its capital city is London. The country consists of England, Scotland, Northern Ireland and Wales. The south-east coast of the country is connected by a tunnel running under the English Channel to continental Europe. The country has access to the North, Irish, Celtic and Hebrides seas.

According to 2022 statistics the UK, which in terms of the size of its territory is 85th in the world, is home to about 68 million people. In terms of population density the country is 52nd in the world out of 248 countries considered [1,2,3]. The total length of the country's coastline is 12,429 km [3]. The political form of government is parliamentary constitutional monarchy, and the official language is English [3]. The UK has a balanced and diversified market economy, the third largest in Europe, after Germany and France [3], which is reflected in the diagram presented in Figure 1.



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 the UK

In terms of selected economic indicators, the country is above the world average, in the top quarter of the graph (i.e. among 25% of the top performing countries in the world included in the rating).

From the early 1990s, 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 \$2.88 trillion in 2017 to \$3.101 in 2019 (10th in the world) [3]. The country's GDP at purchasing power parity per capita is substantially lower (40th in the world in 2020), which has been demonstrating negative dynamics: from \$46,000 in 2018 to \$41,600 in 2020 [3]. The level of inflation in the UK changed from 2.6% in 2017 to 1.7% in 2019. In terms of this indicator the country is 97th in the world [3].

According to The Global Competitiveness Report 2020, presented by the World Economic Forum, the United Kingdom was 9th (out of an estimated total of 141 countries), losing one ranking position over the last year and being behind Switzerland, the Netherlands, Germany and Sweden in Europe. In addition to a number of economic indicators this index also takes into account such variables as education, health and level of innovation. In the list of countries that exported high-tech products

in 2019-2020, the country was 13th, above the world average and behind Germany, France and the Netherlands in the Europe. According to the Index of Economic Freedom 2021, which is based on freedom of business, freedom from government action, property protection, and freedom from corruption, the country was 7th, out of the 178 countries considered. In terms of gold reserves and foreign exchange reserves, in 2017 United Kingdom was 18th, behind Germany, France and Italy.

According to the indicator for average GDP growth in % over the last 10 years (2011-2020), in 2020 the UK was 168th out of 206 countries. In terms of public debt, calculated as a percentage of the country's GDP, in 2017 the UK was ranked 29th out of 210 countries considered.

Several UK energy companies, including BP plc., Centrica and others, are among the top global companies in the world and simultaneously rate among the largest energy companies – S&P Global Platts 2021 Top 250 Company.

More information about the economy of the UK can be found in the attached link library by clicking [here](#).

Energy resources

The United Kingdom does not possess significant fossil energy resources (Table 1). In terms of proven reserves of oil and natural gas, the country is ranked 33rd and 46th in the world, respectively [3]. According to data for 2021, in terms of tons of oil equivalent, proved oil reserves were 65.3%, natural gas – 31.2%, coal – 3.5% (Fig.5). The matrix of unconventional fossil resources looks somewhat different – (EIA – Dec. 2021) shale gas reserves accounted for 50.4%, oil shale (kerogen) – 40%, shale (tight) oil

– 7.1%, associated gas – 1.7%, oil sands and extra heavy oil – 0.8%, coal mine methane utilisation potential – 0.1% (Fig.7).

According to [3,6], as of the beginning of 2021, oil reserves in the UK were estimated at about 2.5 billion barrels, according to [11] – 2.0 bboe (proven) and 3.1 (probable). The proven reserves of natural gas in the UK according to [3] were 180.6 bcm (2021), according to [6] – 200 bcm (at and 2020), according to [11] – 0.8 bboe (proven) and 1.3 (probable).

Table 1. Fossil energy resources of the UK

Resource/explanations	Crude oil	Natural gas	Coal	Shale Gas*	Tight Oil*	Coal mine methane	Oil Sands and Heavy Oil**	Oil Shale***	Associated Petroleum Gas****
Value	2.5	200	29	25.8	0.7	0.3-1.73	76	3.500	643
Unit	billion barrels	Bcm	million tonnes	Tcf	billion barrels	Bcm	million barrels	million barrels	Bcf
Year	2020	2020	2020	2015	2015	2018	2008	2008	2020
Source	[6]	[6]	[6]	[8]	[8]	[6,7]	[9]	[10]	[11]

* unproved technically recoverable

**reserves

***in-place resources

****1P

According to BP, natural gas reserves at the end of 2020 amounted to 6.6 Tcf, and total proven coal reserves to 26 million tons [6]. According to Advanced Energy Technologies calculations, the methane utilization potential, according to the methodology based on methane emissions from coal mining [7] and its reserves in 2018 from [6], was 0.3-1.73 Bcm. By regional standards, the United Kingdom has small shale gas reserves – 25.8 Tcf and shale oil reserves – 0.7 billion barrels, according to 2015 data [8]. In terms of shale gas reserves among European countries, the United Kingdom is substantially inferior to France (where its extraction is prohibited) and slightly

inferior to the Netherlands. Resources of extra heavy and bituminous oil, at the end of 2008, were estimated at 76 million barrels [9], and resources of kerogen oil were 3,500 million barrels [10]. The proved reserves (1P) of associated gas from oil fields as of 2020 were 643 Bcf [11].

The United Kingdom, due partly to its geographic location, has a variety of renewable sources for energy production. A selection of basic indicators of this type of resource is presented in Table 2.

Table 2. Renewable energy resources of the UK

Resource/explanations	Solar Potential (GHI)*	Wind Potential (50 m)*	Hydro energy Potential**	Bio Potential Agricultural area	Bio Potential Forest Area	Municipal Solid Waste
Value	2.4-3.0	8.0-8.7	41	71	11.9	463
Unit	kWh/m ² /day	m/s	GWh/year	% of land area	% of land area	kg per capita
Year	2018	2018	2016	2018	2018	2020
Source	[12]	[13]	[14]	[16]	[17]	[18]

* for the majority of the territory of the country

** gross theoretical capability

The level global horizontal irradiation for the majority of the country is 2.4-3.0 kWh/m²/day [12]; a slightly higher level of solar radiation of between 3.0-3.3 kWh/m²/day can be registered in the south of the country and along the coast [12].

The main renewable resource in the UK is wind power. According to this indicator, the United Kingdom is one of the most promising countries in the world for the development of wind power. The distribution of wind resources on land is as follows: for the majority of the country the wind speed is 8.0-8.7 m/s [13], while in the north-west of Scotland in the offshore region wind speed can reach 9.75 m/s at a height of 50 metres. Gross theoretical hydropower capability of the UK is 4.1 GW/year [14]. The potential of wave energy along the western coast of the country can reach 25-60 kW/m per year [15].

(Fig.9). This is a major renewable energy resource of the country that is inaccessible to most other countries. About 71% of the UK is covered by agricultural land [16], the area of which has been steadily declining for the past half century. At the same time, forest area has slightly increased to 11.9%, compared with 11.5% in 1990 [17]. The level of generation of municipal waste was 463 kg per person in 2020 in the United Kingdom. This is lower than, for example, in Italy – (487 kg per person) and France – (538 kg per person). This resource is a valuable raw material for recycling or energy production, technologies that have reached a high level of development in the UK.

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

Energy Balance

According to the Statistical Review of World Energy 2022, primary energy consumption in the UK in 2021 amounted to 7.18 exajoules and was dominated by natural gas – 38.6%, followed by oil – 34.8%, renewable

energy – 17.3%, nuclear energy – 5.7%, coal – 2.9%, hydropower – 0.7% [6].

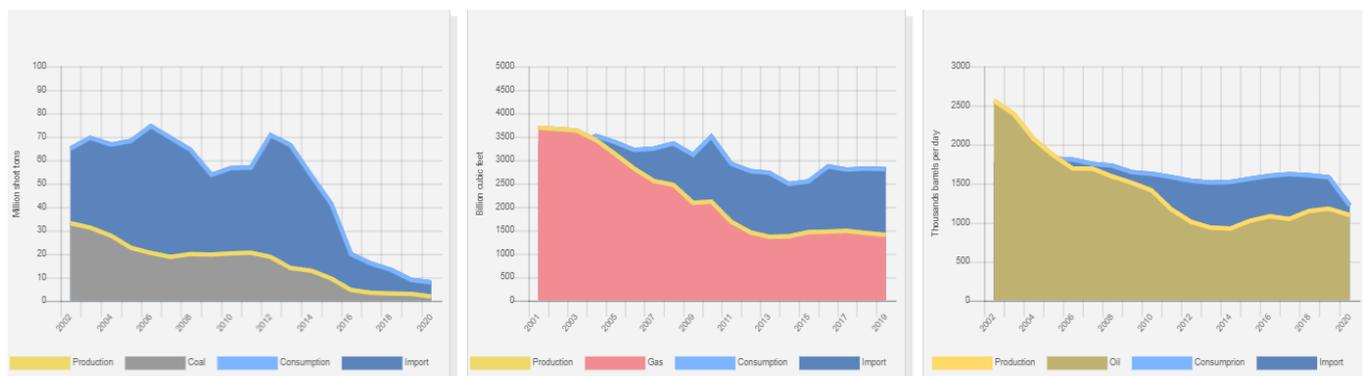
Using data from [3,6] we calculated an estimated value of the energy intensity of GDP in the UK in 2020 to be \$16.3, taking into account the PPP in 2011 prices per unit of energy expended (the equivalent of energy contained in one kg of oil), which is above the world average.

ge. Oil production in the UK between 2001 and 2014 has been steadily declining due to significant depletion of reserves in the North Sea, but in 2015 it stabilized and in 2020 it was 1,095 barrels/day. Oil consumption for the same period also decreased significantly less and in 2020 was 1,215 thousand barrels/day [19]. Over the past ten years, the United Kingdom has been consuming more oil than it produces with an increasing deficit. According to BP's report, oil production in the country in 2021 was 874 thousand barrels/day, with consumption at the level of 1.271 thousand barrels/day [6]. According to the Department for Business, Energy and Industrial Strategy, the primary oil production was 50.9 million tons of oil equivalent in 2017, and the final oil consumption in the UK amounted to 63.9 million tons of oil equivalent. In 2021 oil production in the UK fell to about 44 million tons [20].

Oil imports to the UK in 2018 were 891,700 barrels/day, with exports of 818,200 barrels/day [3]. According to [20], Norway remains is the main supplier of oil to the UK, accounting for 36% of total crude imports, the rest being supplied by OPEC countries. Oil products are sup-

plied to the country from the Netherlands. Despite the decline in oil production, the United Kingdom remains one of the largest producers and exporters of oil and condensate in Europe; the main export destinations are the EU countries, with the Netherlands and Germany receiving the largest share [21].

Gas consumption in the UK between 2001 and 2019 declined (with slight fluctuations) and in 2019 was 2.805 Bcf, against 3.338 Bcf in 2001. Natural gas production has fallen rapidly since 2004, and in 2019 was 1401 Bcf [19]. According to BP, consumption in the country in 2021 was 76.9 billion m³, and production was estimated at 32.7 billion m³ [6]. According to the UK Energy in Brief 2022 report, primary gas production in 2021 was 44.7 million tonnes of oil equivalent, with a total consumption of 44.6 million tonnes of oil equivalent [20]. The United Kingdom began importing gas in 2004, ¾ of imports goes to the country via pipelines; the rest is imported in the form of LNG. The main suppliers are Norway and Qatar [21]. In 2021, the volume of imports was 51 Bcm, with exports of 6,83 Bcm [3].



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

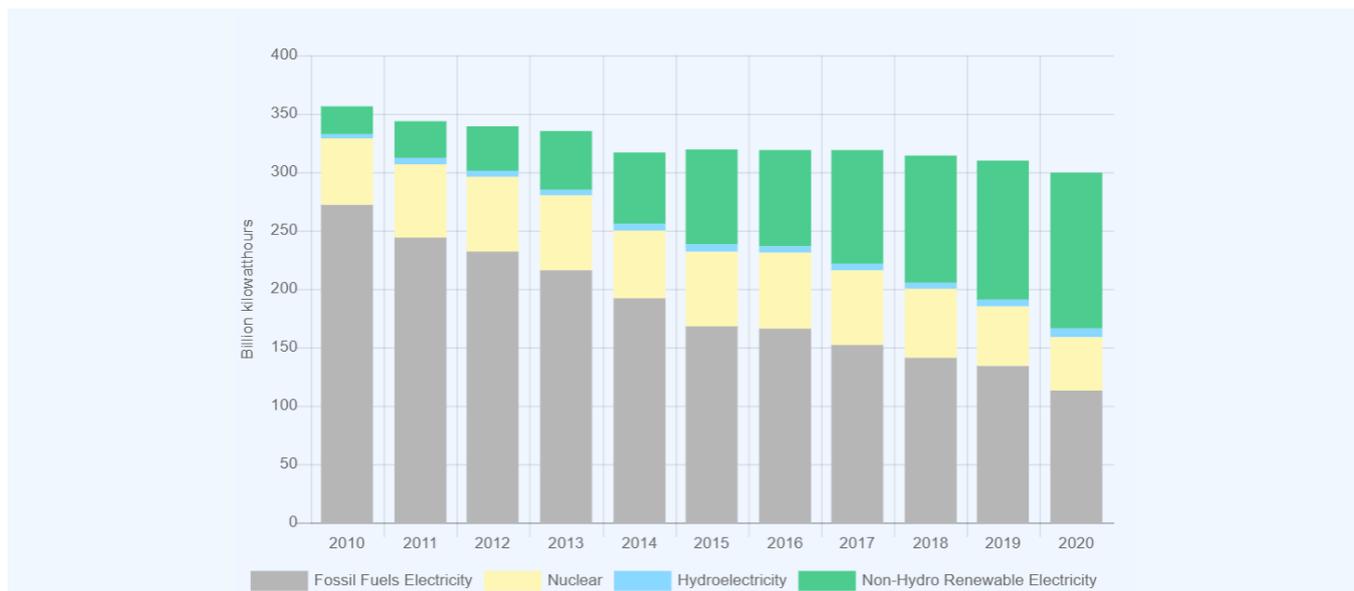
Figure 2. The production and consumption of fossil fuels in the UK (coal – left, gas – in the center, oil – right)

Coal production in the country has also been steadily declining since 2001 and amounted to 1.8 million short tons in 2020. Coal consumption has shown multidirectional dynamics, however, and by 2020 it decreased to 7.8 million short tons [19]. When compared with data from other sources we can note a sharp decline in coal production and consumption. As such, according to BP's report in 2021, coal consumption amounted to 0.21 Exajoules, against 0.97 Exajoules in 2015. Production levels also fell more than twofold and amounted to 0.03 Exajoules in 2021 [6]. According to UK Energy in Brief in 2021, total coal production fell to its record low of 1.1 million tons, 37% lower than in 2020 and consumption to 7.4 tons [20].

Renewable energy sources have been actively used in recent years for the production of electricity in the UK,

and the share of fossil fuels is declining (Fig. 3.) against a background of a general decline in electricity production. In 2020, according to the U.S. Energy Information Administration, electricity production in the country was 299.53 TWh and was dominated by renewable energy – 44.5%, followed by fossil fuels – 37.8%, nuclear power – 15.3%, and hydropower, including pumped storage stations – 2.4% (Fig.8).

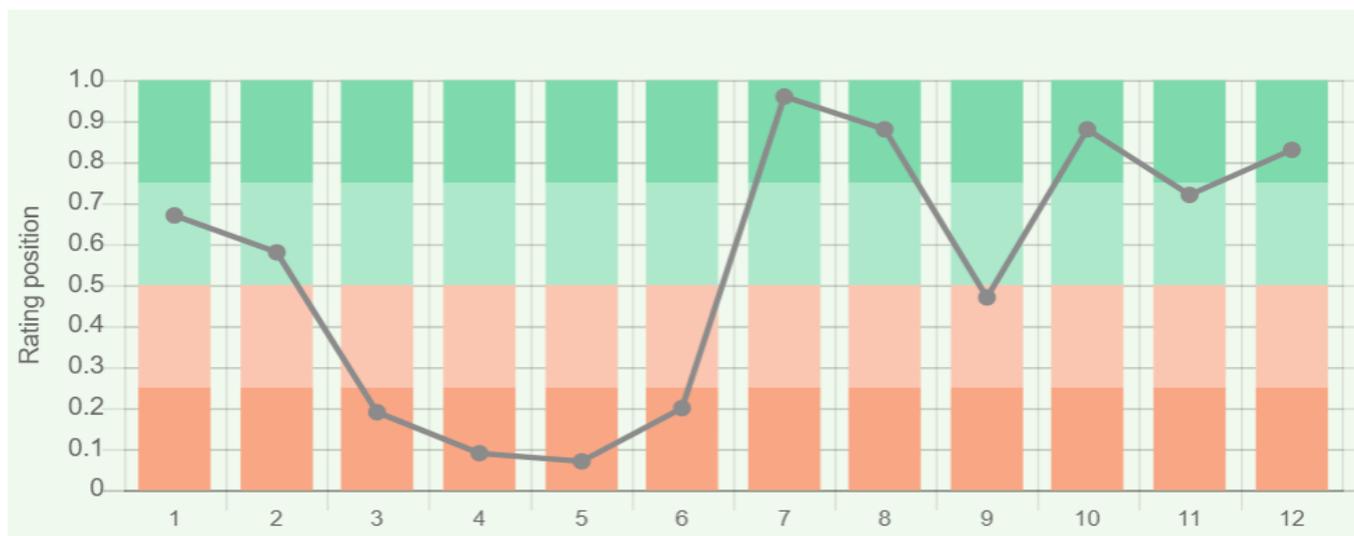
According to the Department for Business, Energy and Industrial Strategy, in 2021 electricity production was 308.1 TWh, where fossil fuels and nuclear power accounted for about 60%, for renewable sources, incl. hydropower this figure was 40% [20].



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

Figure 3. Electricity generation in the UK

The UK's position in the comparative diagram of energy indices is shown in Figure 4. The United Kingdom is at the bottom of the list of countries in terms of production/consumption ratio of fossil fuels, ranging from high-



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
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 4. Combination production-consumption for Crude oil 2018 / International Energy Statistic / Geography / U.S. Energy Information Administration (Nov 2021) *129
 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
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 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 the UK

to lower values, and for all major resource components - oil, gas and coal. At the same time, in terms of oil and gas reserves, the country is positioned above the world average.

In terms of the share of electricity production from renewable energy sources (excluding hydropower), the United Kingdom was 6th in 2017, second to Germany and Denmark in the region, out of 170 countries considered. The United Kingdom is ranked 15th in the EAPI of 2017 (Energy Architecture Performance Index), which is based on the level of economic growth, environmental safety, and energy independence, including access to energy. In terms of GDP per unit of energy use, the United Kingdom ranked ahead of the world average in 2017 - 8th,

out of 66 countries considered; while in terms of energy consumption per capita the country was 35th in the world.

In terms of electricity consumption per capita, the country was 60th in the world. The UK ranked 36th out of 216 countries considered according to the combination of electricity production-consumption indicator, behind of a number of EU countries.

More information about the energy balance of UK see the documents in our link library [here](#).

Energy Infrastructure

A territorial map showing the distribution of the largest infrastructure projects of the fossil-fuel sector in the UK is displayed in Figure 5.

As previously mentioned, proven oil reserves account for 65.3% of fossil fuel resources in the country (Fig.5). The country's oil fields are mainly offshore. One of the largest oil fields is Buzzard, which produces on average 85,500 bbl/day, as of 2020 [67].

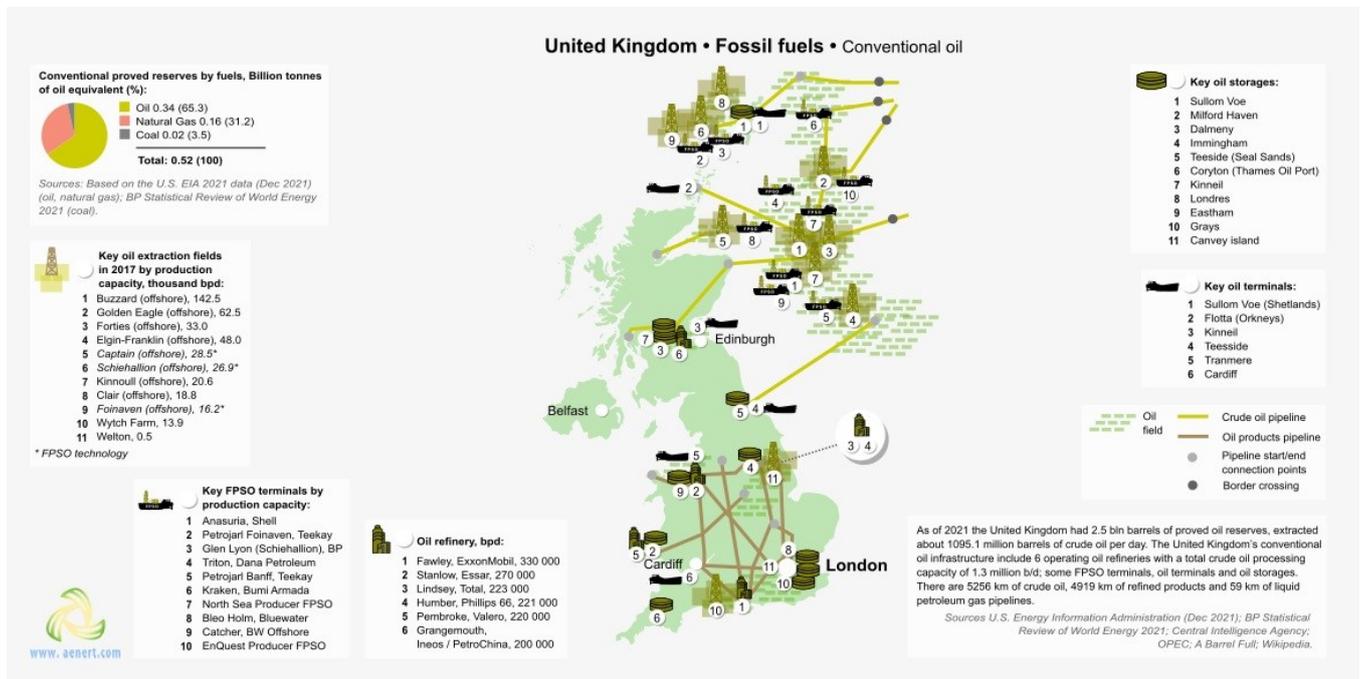


Figure 5. Basic infrastructure facilities of conventional oil in the UK

As mentioned above, in recent years oil production has fallen significantly due to the depletion of the nation's oil fields, leading to the closure of many wells. In 2016, UK refineries had a total installed capacity of 1.3 million barrels/day [23]. The largest is Fawley, owned by ExxonMobil, with an installed capacity of 330,000 bbl/day [24] (Fig.5). Oil and petroleum products are imported via

6 large oil terminals; Sullom, BP Oil Storage Terminal (1,600,000 m³) is the largest of these [25]. Transportation of crude oil, petroleum products and LNG is carried out via a network of pipelines with a length of 5.256 km, 1.574 km and 59 km respectively (Fig.6). On the country's continental shelf, oil extraction is also carried out by means of FPSO, the largest of which is Anasuria FPSO,

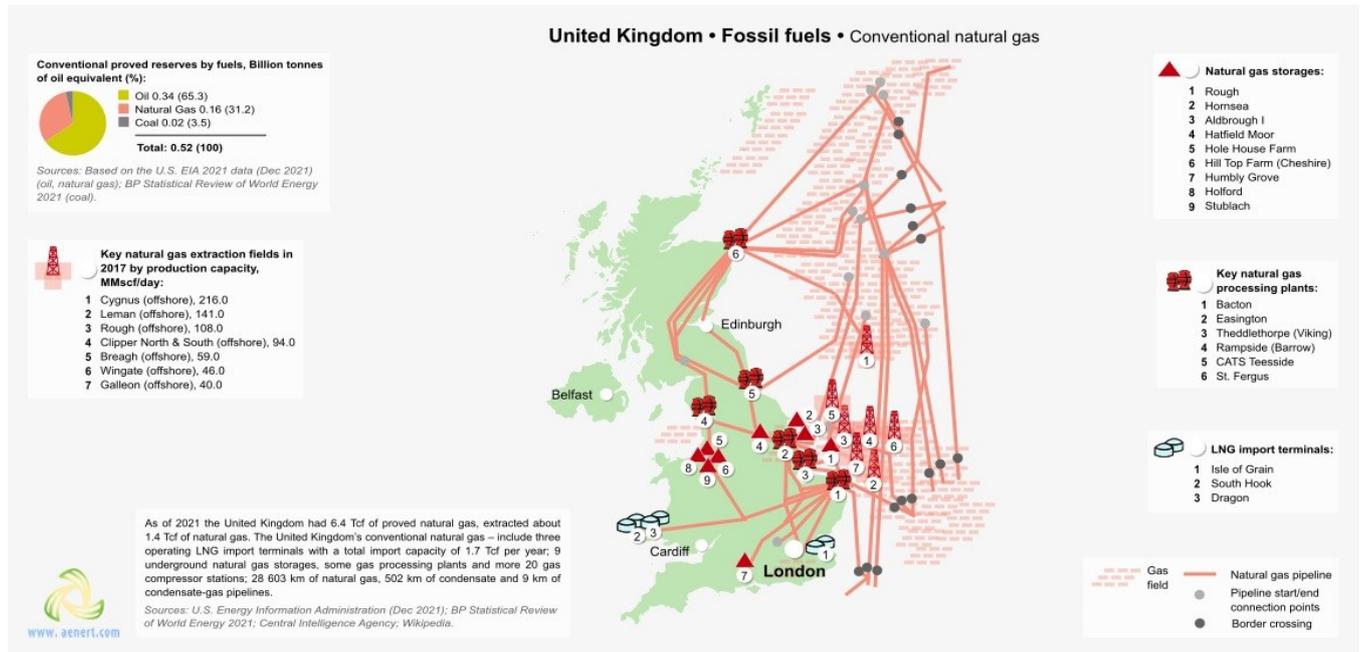


Figure 6. Basic infrastructure facilities of the fossil fuels sector in the UK: conventional natural gas

owned by Shell, with a storage capacity of 850,000 barrels [26]. Gas extraction fields in the UK are also predominantly offshore. The largest of them is Cygnus, produces an average of 216 Mmscf/day, according to data for 2017 [22]. The UK gas system consists of 20 gas compressor stations and 9 gas storage facilities. Gas transportation inside the country is carried out via a network of pipelines with a total length of 28,603 km, gas condensate is transported via a network of pipelines with

a length of 502 km (Fig.6). The import of gas is carried out through three receiving LNG terminals, the largest of these is on the Isle of Grain with a throughput of 19.5 bcm per year [27]. In the balance of fossil fuel resources, the share of coal in 2018 2021 was 3.5% 4.4%, with a substantial annual decline. The main coal mine fields are shared between Scotland, Wales and England, with notable reserves located in the Cardiff area (Fig.7).

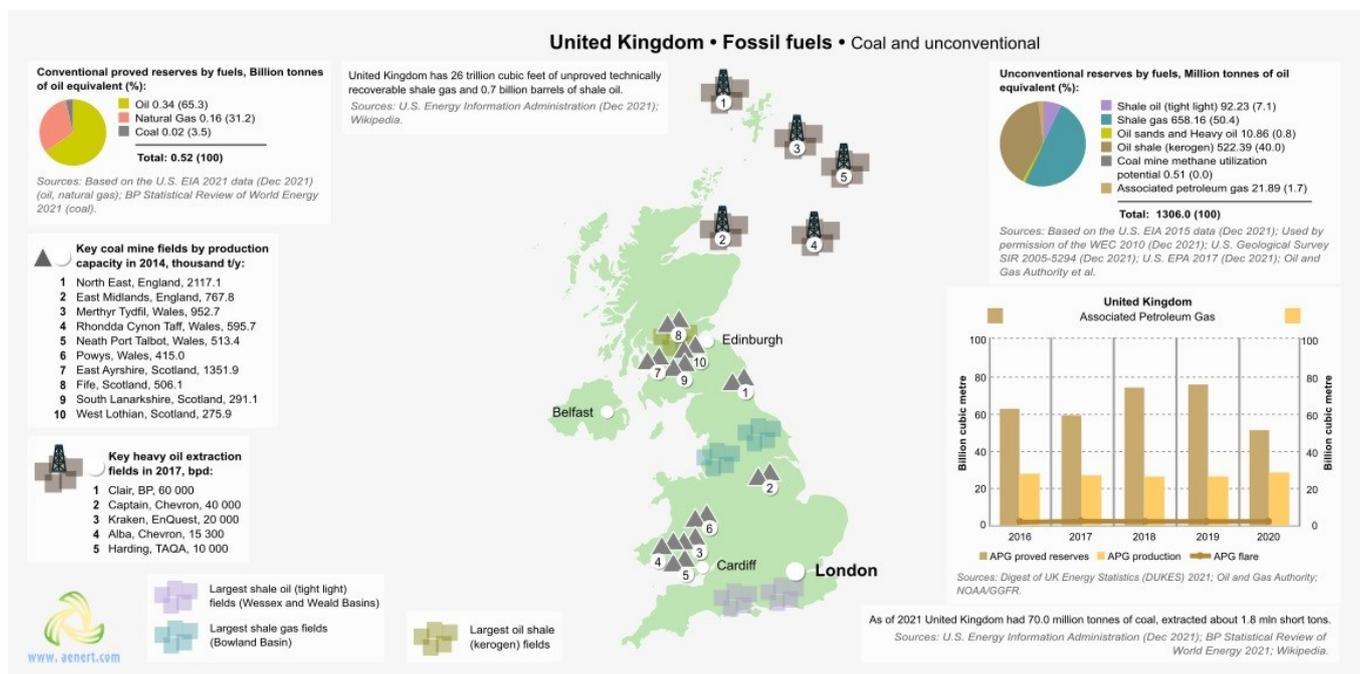


Figure 7. Basic infrastructure facilities of the fossil fuels sector in the UK: coal and unconventional resources

The most productive field is in the North East, which produced 2,117,114 tons of coal in 2014 [28]. One of the leading extraction fields of extra-heavy oil is Clair [29]. The largest reserves of shale oil are located in the south of the country; shale gas in the central part of the country; and kerogen oil reserves were discovered in Scotland (Fig.7). Since the removal of the ban on oil and gas production using hydraulic fracturing (hydrofracking) in 2012, discussions about its feasibility continues. As such, in 2016 the Scottish parliament voted to introduce a moratorium on the use of fracking technologies, given the large-scale protests of local residents. Negative atti-

tudes towards fracking factor into the decision making of companies with development licenses, for example, Third Energy [30], which operates in Yorkshire, or Cuadrilla Resources Ltd [31] – West Sussex, Lancashire, and Yorkshire, who are extremely cautious in drilling and operating wells.

The map of the territorial distribution of the UK's largest infrastructure facilities for electricity generation is presented in Figure 8.

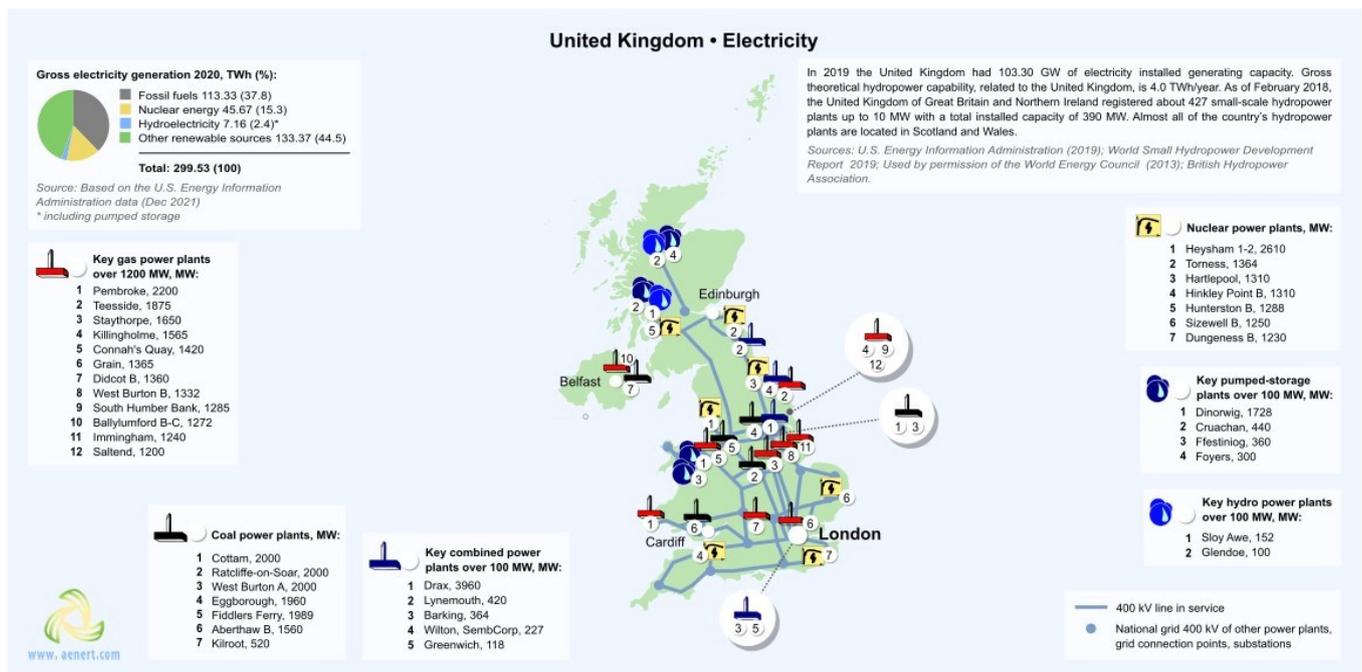


Figure 8. Electricity production in the UK

According to U.S. Energy Information Administration, the share of fossil fuels in energy production in the UK in 2020 was 37.8% (Fig.8), the share of nuclear power was 15.3%.

The country has a significant number of stations that produce electricity from hydrocarbons, including power plants with a capacity of more than 100 MW, including twelve gas, five combined-type, seven coal, and seven nuclear power plants (Fig.8). The UK's largest electricity generating facilities are: the Pembroke gas power plant, with a capacity of 2,200 MW [32]; Drax combined type plant with an installed capacity of 3,960 MW; Cottam coal-power plant with an installed capacity of 2,000 MW; and Heysham 1-2 nuclear power plant, with an installed capacity of 2,610 MW [33,34,35].

Hydropower in the UK does not play a prominent role, contributing to 2.4% of the total power generation, and

is represented by several hydro power plants, pumped storage plants and small hydro stations (Figure 8).

The largest pumped storage power plant is Dinorwig, with an installed capacity of 1,728 MW. The largest pumped storage power plant is Dinorwig, with an installed capacity of 1,728 MW. The largest hydroelectric power plant is Sloy Awe, with a capacity of 152.5 MW [36,37]. In total, in the United Kingdom 427 small hydropower stations were registered, the installed capacity of which, according to British Hydropower Association, was 390 megawatts in 2018. In Figure 9, you can see the main facilities of the UK for the production of energy from renewable sources.

As already noted, renewable energy in the UK provides about 45% of electricity generation. The total production of electricity from renewable sources excluding hydropower was more than 115 TWh in 2019 (Fig.9).

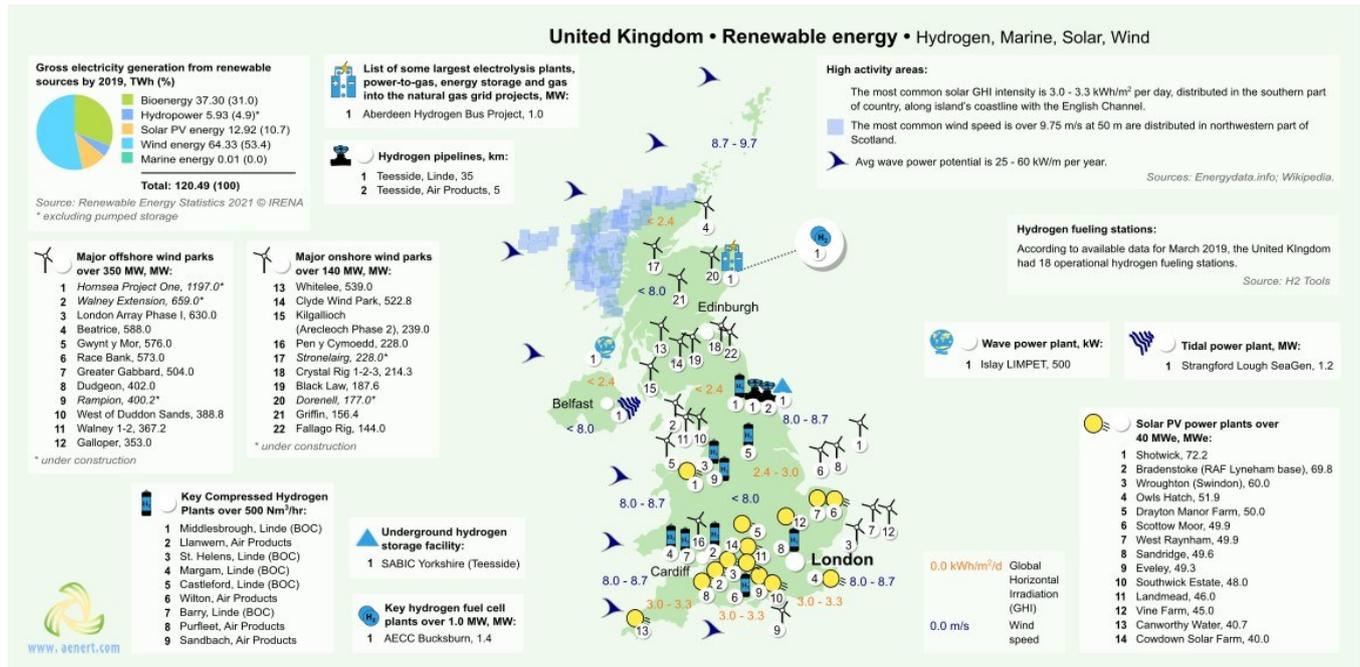


Figure 9. Renewable energy in the UK: hydrogen, marine, solar, wind

In zones of high wind activity, there are 22 large offshore and onshore wind farms, each with a capacity of more than 140 MW. In 2016 in the UK there were 1,034 wind parks registered, with a total capacity of 18,872 MW [39]. The largest of these will soon be Hornsea Project One, which is currently under construction, and will have a capacity of 1,197 MW [40]. As previously mentioned, the level of horizontal irradiation in some areas of the country can reach 3.3 kWh/m², which is sufficiently high for energy production. As of 2020, there are currently approximately 500 solar power plants operating in the U.K. Over five years, the capacity of solar installations in the U.K. has increased from 5,488.6 MW in 2014 to 13,258 MW in mid-2019 [68]. The largest photovoltaic station is Cleve Hill solar farm with an installed capacity of 350 MW [41].

The United Kingdom is one of the leading countries in the development of ocean energy technologies. The main focus of development is on tidal technologies and technologies using the energy of waves.

In the Belfast area, there are significant natural resources for such technologies. In 2008, SeaGen launched one of the first tidal stations - Strangford Lough, with a capacity of 1.2 MW [42]. Islay LIMPET with a capacity of 500 kW is one of the first commercial stations in the world to convert the energy of waves into electricity [43]. According to [44], Royal Haskoning DHV, is planning to build a large tidal station with a capacity of 30 MW near the Isle of Wight. One of the largest projects in the world, the Pentland Firth tidal power plant with 269 turbines with a total capacity of 398 MW [45,46].

The United Kingdom is active in developing hydrogen energy, including as a source of energy for vehicles. As of March 2019, about 18 hydrogen filling stations were in operation in the country. Transportation of hydrogen is also carried out via two pipelines, with a total length of 40 km (Fig. 9). In Northern Scotland, the city of Aberdeen operates the largest projects in Europe: a fuel cell installation with a total electrical capacity of 1.4 MW and a Hydrogen bus project, of 1 MW.

Figure 10 shows the main bioenergy production facilities. In 2020, bioenergy had about 7.24 GWe of installed capacity in the UK (Fig.10).

The country, has biogas plants, as well as biomass and municipal waste processing plants, biodiesel, bioethanol, pellet, landfill gas and other industries (Fig.10).

Drax Power Ltd manages the largest Drax Biomass power plant, with an installed capacity of 1,980 MW [47]. The UK's largest enterprises for the production of biodiesel and bioethanol are: Seal Sands with a capacity of 284 million litres per year and Immingham (Hull), producing 420 million litres per year [48]. The largest biogas plant in the country is Girvan Distillery, with an installed capacity of 7,200 kW [49].

Among other notable enterprises are: Birmingham Biomass Gasification Plant with a capacity of 10.3 MW [50]; Oldbury waste gasification plant, with a processing capacity of 350,000 tonnes of waste every year [51]; and Invergordon, that produces 100,000 tons of pellets annually [52].

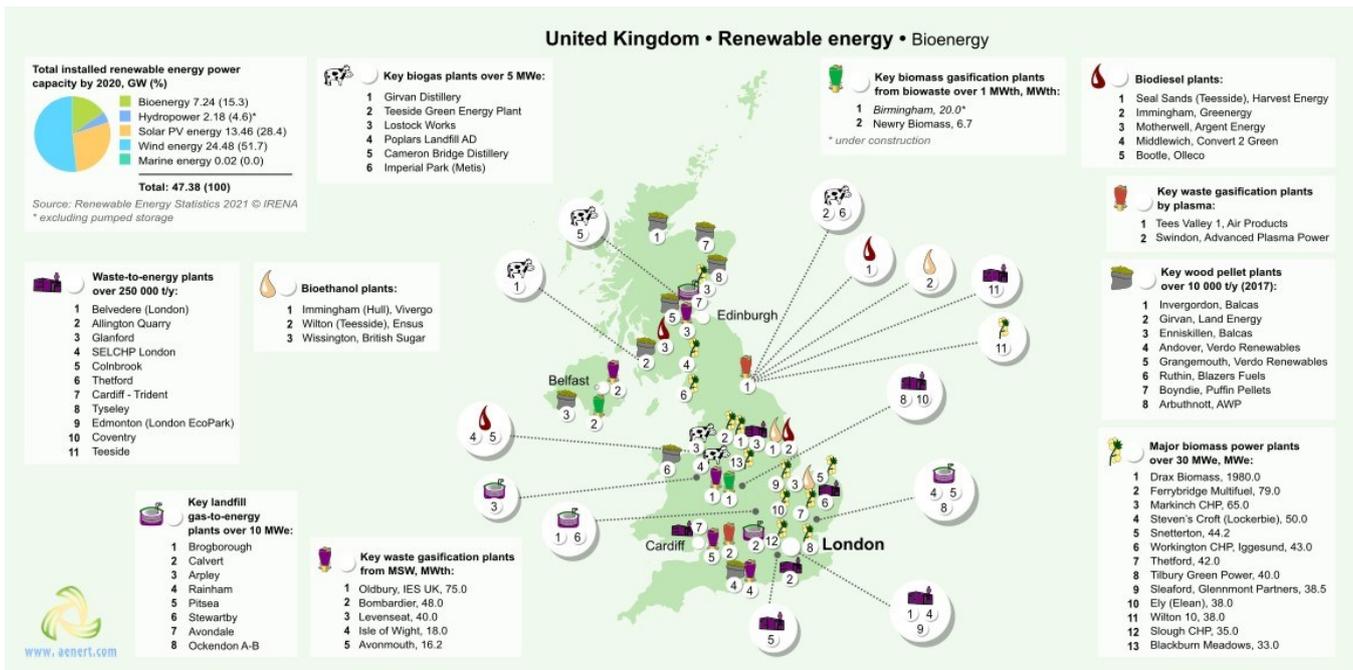


Figure 10. Renewable energy in the UK: bioenergy

The United Kingdom is among the pioneers in the development of technologies of waste gasification by plasma. One of the largest complexes of this type, with a capacity of 50 MW, is being built by Air Products in Teesside, North East England [53]. After the completion of the pilot tests, Advanced Plasma Power plans to build a commercial facility for municipal waste and biomass processing and for the production of Bio-substitute natural gas, for a total cost of £25 million [54].

The largest waste to energy plant – Belvedere, can process 585,000 tons annually [55]. Brogborough generates about 38.3 MWe of electricity from landfill gas [56]. The UK energy policy is aimed, among other things, at increasing energy efficiency, reducing overall energy consumption (and the consumption of fossil fuels in particular), reducing harmful emissions, processing and reusing of all kinds of waste [57, 58].

As part of the Northern Powerhouse strategy in Yorkshire, a pellet production plant is planned, with an invest-

ment of £10 million [59]. In November 2017, Snowdonia Pumped Hydro received approval for the construction of a 99.9 MW pumped storage station Glyn Rhonwy, one of the largest projects for the industry in the last 30 years [60]. The Aberdeen Exhibition and Conference Centre (AECC) has one of the largest fuel cell installations in the country and in Europe, with a capacity of 1.4 megawatts [61]. Within the framework of the Climate Change Act, Ofgem has invested £9 million in the H21 project to switch from a gas-based energy system to a hydrogen one, which can reduce carbon emissions by 80% by 2050 [62]. According to the study described in [63], the volume of the world market of fuel cells will reach £6 billion by 2024.

For current information on the development of energy in the country, click [here](#). More information on the UK energy infrastructure is also available [here](#).

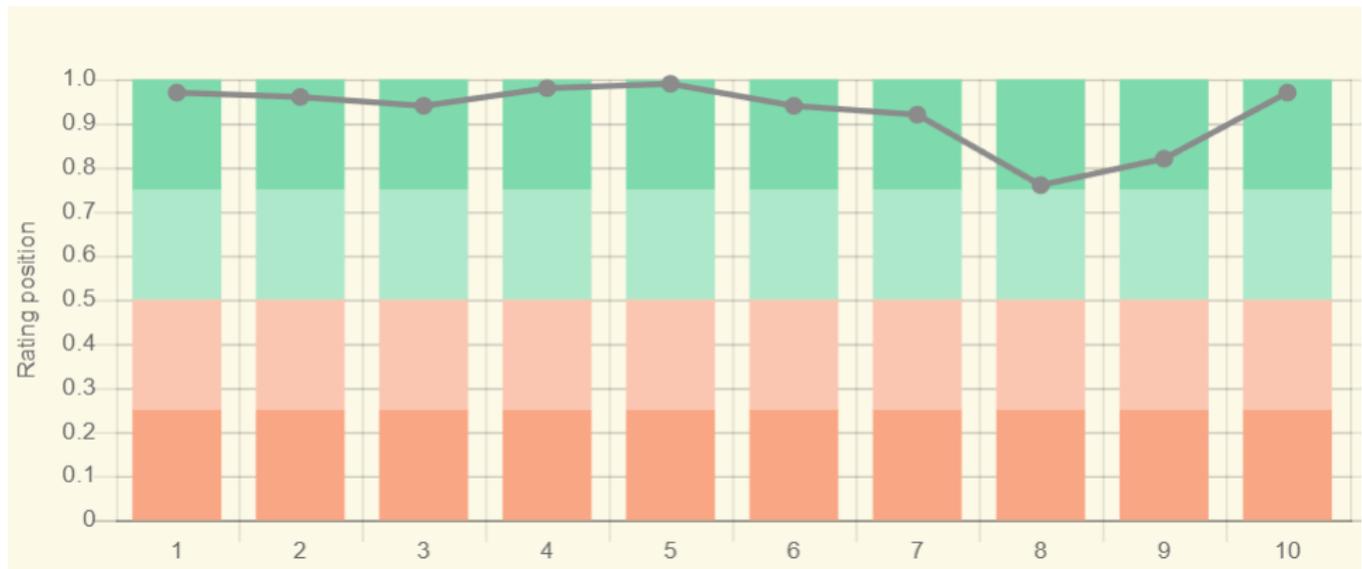
Education and Innovation

The set of indices reflecting the position of the UK relative to other countries in the field of education and innovation can be seen in Figure 11. This diagram shows that the United Kingdom has a very high level of intellectual culture indicators.

According to the Global Innovation Index, the United Kingdom is ranked 4th out of 132 countries in 2021 (see diagram for links). According to the number of patents

granted to UK residents, both inside the country and abroad, the country ranks 8th in the world, behind Germany and France, but higher than the world average. Similarly, by number of patents in force, the country is 6th in the world, indicating the country's favorable conditions for innovation.

In terms of government expenditure on education as a percentage of the country's GDP, the country demonstrates a result close the world average: 43rd place out of 177 countries considered.



Sources:

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10. Scientific and technical journal articles, 2018 / National Science Foundation, Science and Engineering Indicators. License: CCBY-4.0 / Data *197

* Total number of countries participating in ranking

Figure 11. The indices of education and innovation in the UK

90 British universities are included in the QS University Rating. It should also be noted that the country's GDP is high, therefore, in absolute terms the costs of education and research are significant. In terms of the amount of government expenditure on research and development as a percentage of GDP, the country is 22nd, behind a number of European countries, including Germany, France and Norway. The UK is 3rd out of 240 participating countries in the Scimago ranking, and in Scientific and Technical Journal Activities it is ranked 6th out of 197 countries.

British universities such as the University of Cambridge, the University of Oxford, Imperial College London, and University College London train specialists in various fields of energy, including Energy and Resources Management, Electronic and Electrical Engineering, Energy Engineering, Chemical Engineering, Energy Technologies, etc.

In the field of synthetic fuel Johnson Matthey Plc, Davy Process Technology Limited, BP Exploration, CompactGTL, and BP Chemicals Limited are patenting their inventions and research is carried out by CompactGTL, Imperial College London, the University of Liverpool, and the University of Manchester.

OHM Ltd, the Natural Environment Research Council, are actively patenting their inventions, and the Heriot-Watt University, the University of Southampton, Geotek, Ltd. publish scientific works in the field of gas hydrates.

In the field of hydrocarbon production from low-permeability reservoirs, patent leaders are Qinetiq Ltd., Schlumberger Holdings Limited, Petrowell Limited, and studies are also carried out by Imperial College London, the Heriot-Watt University, the University of Durham, and the University of Cardiff.

In the field of unconventional oil, the largest number of patents were filed by Oilflow Solutions Holding Limited, Proflux Systems LLP, Imperial Chemical Industries PLC, the University of Nottingham, Prad Research and Development Ltd., Heriot-Watt University, Imperial College London, and the University of Birmingham are engaged in research in this field.

In the field of associated petroleum gas, CompactGTL, Johnson Matthey Plc, Gas2 Limited, Accentus Plc. are leading in the number of patents granted. CompactGTL, Caltec Ltd., the University of Lancaster, and Oxford Catalyst actively publish scientific works in this field.

Another important area of patenting is coalbed methane. Johnson Matthey Plc, BP PLC, Gas2 Limited, Swelltec

Ltd., Imperial College London, Heriot-Watt University, and the Imperial College of Science, Technology and Medicine are prominent in this area.

Patents in bioenergy technologies are owned by Johnson Matthey Plc, BP Biofuels UK Ltd, Aston University, Seab Energy Holdings Ltd. Scientific research in the same area is conducted by the University of Cambridge, Imperial College London, the University of Manchester and many other scientific divisions.

A large number of companies patent inventions and conduct research in the field of renewable energy technologies. In the field of solar energy, Naked Energy, Ltd., Microsharp Corporation, Limited, ISIS Innovation, Ltd., Sili-

con CVP, Plc are leaders by number of patents granted. The University of Nottingham, the University of Exeter, and Heriot-Watt University have largest number of publications.

Among companies and organizations involved in innovations in the field of wind power, Blade Dynamics Limited, Ricaro UK Ltd, Qinetiq Ltd., Marine Current Turbines Limited and the University of Strathclyde, Cranfield University, and Sheffield Hallam University can be mentioned.

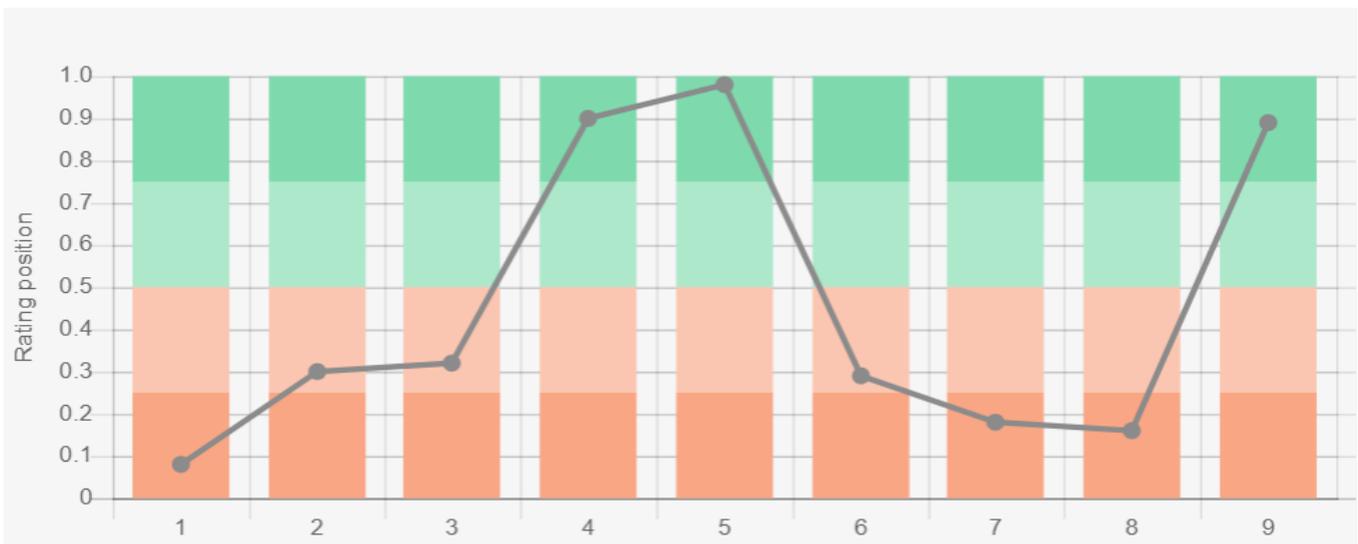
Additional information about education in the country can be obtained [here](#), and the list of research institutes in the country [here](#).

Ecology and Environmental Protection

The environmental indices shown in Figure 12 represent, to some extent, the ecological situation in the country, which is somewhat negative.

First of all, the country demonstrates a relatively high level of CO₂ emissions in general, but per capita this indicator is somewhat lower.

In 2020, the level of CO₂ emissions from coal mining and processing was 22.6 mt, which is lower than in Poland, – 161 mt, and Germany – 199 mt [66]. On average, the cost of mitigating the consequences of this kind of emission costs the UK more than 3.424 million euros (health costs, pollution costs). For comparison, in the Czech Republic this figure is 1,452 million euros [64]. It should also be noted that there is a relatively high level of methane emissions in the UK.



Sources:

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- * Total number of countries participating in ranking

Figure 12. The UK environmental indices

At the same time, the situation is aggravated by the fact that United Kingdom ranks 4th of the 61 countries that are responsible for more than 90% of global CO₂ emissions related to energy in the Climate Change Performance Index (CCPI) 2022.

In terms of forest area as a percentage of the country, the United Kingdom placed 159th in the world in 2020. However, between 2010-2020 there was a trend towards reforestation, and according to this indicator the country is 24th in the world.

The situation is brightened by a very high valuation of the UK in the Environmental Performance Index ranking (EPI) 2020, which focuses primarily on assessing the environmental performance of national governments. Here,

the country is 4th out of 180 countries, behind Denmark, Luxembourg and Switzerland.

However, according to the Environmental Vulnerability Index, which is based 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., the country is 207th out of 234 countries, and is characterized as "extremely vulnerable". The overall negative picture is aggravated by the Ecological Footprint Atlas rating, according to which the UK is among a number of ecological debtors.

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

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The sources of charts and curves are specified under the images.
