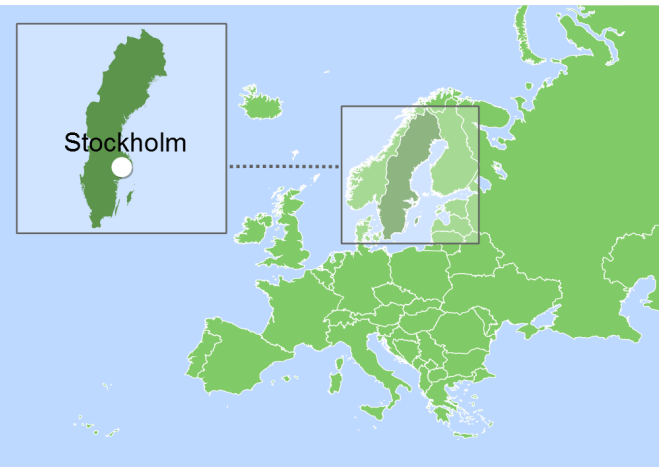
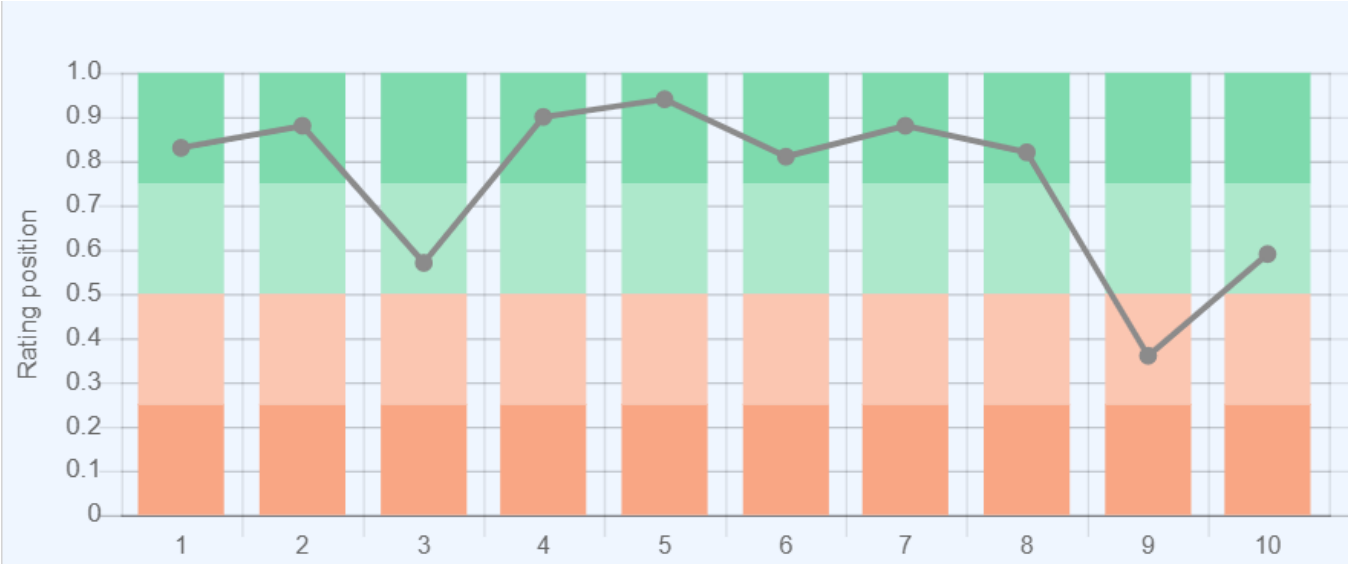


Energy Industry in **Sweden**

General State of the Economy

Sweden, officially the Kingdom of Sweden, is a European state on the Scandinavian Peninsula. The western border of the country separates it from Norway; the eastern border from Finland. The country also has access to the Baltic Sea. As of 2022 Sweden is home to around 10.4 million people, and is the fifth largest country in Europe. In terms of population density, the country is 202nd in the world [1,2,3]. The total length of the country's coastline is 3 218 km [3]. The capital city is Stockholm, Sweden is a parliamentary constitutional monarchy and the official language is Swedish. The administrative map of the country is divided into 21 counties [3].

Due to the successful combination of the free market and extensive social benefits, Sweden has one of the highest living standards in the world and this is reflected in the comparative diagram of various economic indices – Figure 1.



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* Total number of countries participating in ranking

Figure 1. Economic indices of Sweden

The export of technological equipment, iron ore and the timber industry form the base of the economy [3]. For almost all indices shown, Sweden is positioned in the top quarter of the diagram (i.e. among the top 25% of countries included in the rating). Since the early 1990s, the country has experienced a steady growth in GDP at purchasing power parity, both in general and per capita [4,5]. However, after several years of steady growth, GDP at purchasing power parity fell slightly to $524 billion in 2020 from $532 billion in 2018 (39th in the world) [3]. The country's GDP at purchasing power parity per capita is somewhat higher (27th place in the world in 2020), and it has also declined slightly after a long positive period; from $52 300 in 2018 to $50 700 in 2020 [3]. The inflation rate rose from 1.1% in 2016 to 1.7% in 2019. According to this indicator, the country is 97th in the world [3].
According to the Global Competitiveness Report 2019, Sweden placed 8th out of a total of 141 countries considered, behind Switzerland, Germany and the Netherlands; notably, the country has gained one position compared to the previous year's rating. This rating measures 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 innovation, etc.
In a list of countries that exported high-tech products in 2019, the country was 25th out of 134 countries, behind Austria and the Czech Republic. According to the Index of Economic Freedom, which is based on freedom of business, freedom from government intervention, property protection, and freedom from corruption, Sweden was 21st in 2021 out of the 178 countries considered; behind Finland. In terms of gold reserves and foreign exchange reserves, Sweden ranked 37th in the world in 2016. According to the indicator for the average GDP growth in percentage over the last 10 years (2011-2020), in 2020 the country was 132nd out of 206 countries. In terms of public debt, calculated as a percentage of the country's GDP, Sweden was ranked 124th out of 210 countries considered in 2017.

*Detailed information about the economic development of Sweden is available **here**.*

Energy resources

Sweden does not have significant reserves of fossil resources (Table 1). Nevertheless, there are small coal reserves in the country – about 1 million tons; shale gas reserves amount to 9.8 Tcf, and kerogen oil resources to 6 144 million barrels [6,7,8].

Table 1. Fossil energy resources of Sweden

Resource/explanations	Crude oil	Natural gas	Coal	Shale Gas*	Tight Oil	Oil Shale
Value	No data	No data	1	9.8	No data	6114
Unit	-	-	million tonnes	Tcf	-	million bbl
Year	-	-	2016	2014	-	2008
Source	-	-	[6]	[7]	-	[8]

**unproved technically recoverable*

Sweden has a rich variety of renewable energy sources. A selection of basic indicators for this type of resource is presented in Table 2. The level of global horizontal solar radiation in most of the country is low < 2,7 kWh/m^2/day. The maximum level of solar radiation can be observed in the south of the country around Gotland island – around 2.8-3.0 kWh/m^2/day [9]. The distribution of wind resources is as follows: in most of the country the wind speed is < 6,5 m/s, but in the southern part of the country, at a height of 50 m, it can reach over 7.5 m/s [10].

Sweden's economically exploitable hydropotential in 2013 was 20 000 GWh/year [11], which allows for the intensive use of hydro resources for electricity generation.

Table 2. Renewable energy resources of Sweden

Resource/ explanations	Solar Potential (GHI)*	Wind Potential (50 м)*	Hydro energy Potential**	Bio Potential (agricultural area)	Bio Potential (forest area)	Municipal Solid Waste
Value	<2.7	<6.5	20 000	7.5	68.7	431
Unit	kWh/m^2/day	m/s	GWh/year	% of land area	% of land area	Kg per capita
Year	2018	2018	2013	2018	20168	2020
Source	[9]	[10]	[11]	[12]	[13]	[14]

**for most of the territory of the country*
*** economically exploitable potential*

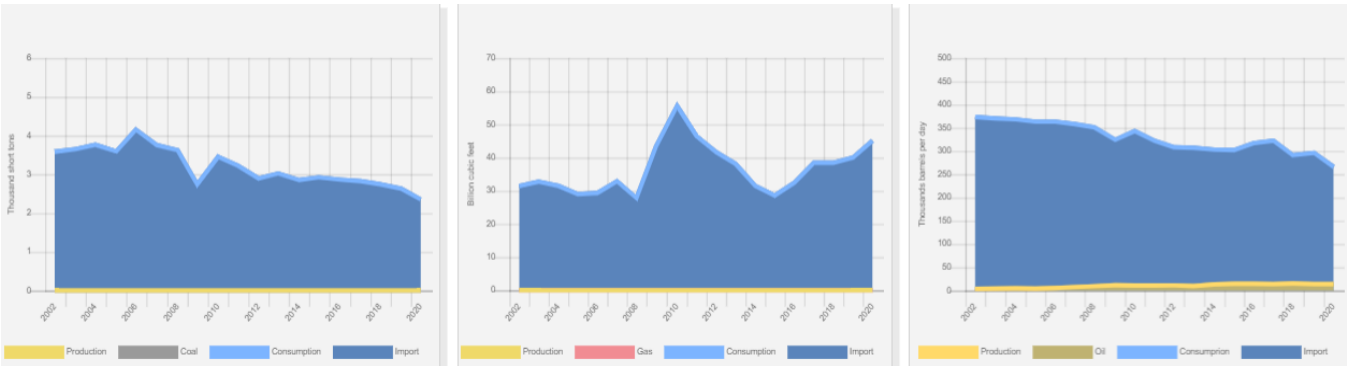
More than 68.7% of Sweden is forested and 7.5% is covered by agricultural land [12,13]. In 2020 the level of municipal waste generation in Sweden was 431 kg per capita, behind, for example, Norway (726 kg per capita). This resource is a valuable raw material for recycling or energy production, the technologies of which have reached a very high level of development in Sweden [14].

*Detailed information about the energy resources of Sweden is available **here.***

Energy Balance

According to the 2021 BP Statistical Review of World Energy, total primary energy consumption in Sweden in 2020 amounted to 2.20 Exajoules, around 25% of which was from oil, 1.8% from natural gas, 3.2% from coal, 21.8% from nuclear energy, 29.5% from hydropower, and 18.6% from renewable energy sources [15]. Using the data from [3,12], we calculated GDP per unit of energy use in Sweden in 2017 – 9.6 US dollars, taking into account the PPP in 2011 prices per unit of energy used (equivalent to the energy contained in one kilogram of oil), which roughly corresponds to the world average energy efficiency.

The volume of oil consumption in the country since 2002 has declined (Fig.2) and in 2020 totalled 226 thousand barrels/day [16]. According to BP, this figure was 290 thousand barrels/day in 2020 [15]. According to the Swedish Energy Agency, the total consumption of oil products in the country in 2017 was 87 TWh [17]. Oil imports in 2017 amounted to 400 200 barrels/day [3].



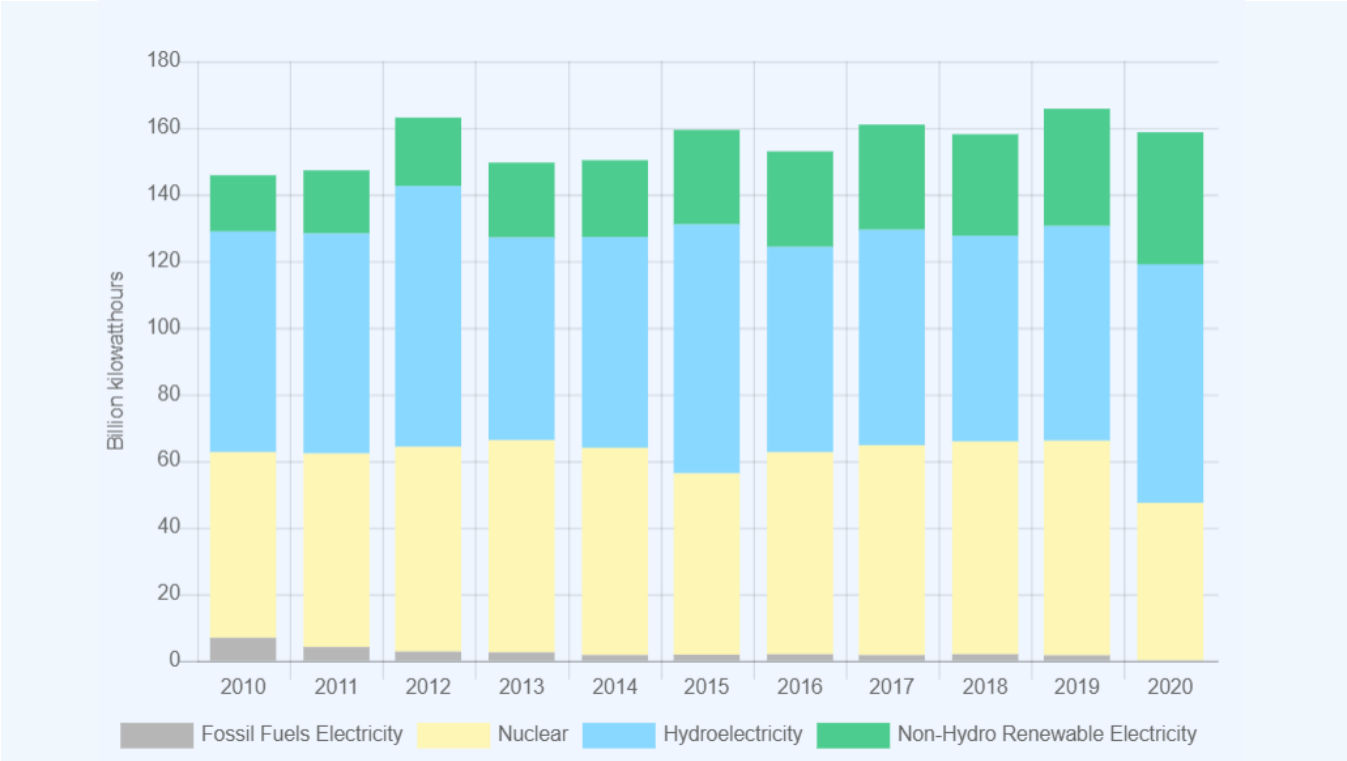
Source: U.S. Energy Information Administration (Dec 2021) / https://www.eia.gov/

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

Natural gas consumption in Sweden showed steady growth between 2008 and 2010, but then declined rapidly (Fig. 2); in 2017 consumption reached the level of 27 Bcf, compared to 56 Bcf in 2010 [16]. After 2017, natural gas consumption went up again, reaching about 45 Bcf in 2020. According to the BP Statistical Review of World Energy in June 2021 [15] it was estimated at 1.81 billion m^3 in 2020. According to the Swedish Energy Agency, gas consumption in 2017 totalled 6 TWh [17]. 764.5 million m^3 of gas was imported in 2017 [3].

Coal consumption in the country gradually decreased - albeit with annual fluctuations - between 2001 and 2020, and totalled 2.35 million short tons in 2020 [16]; in 2020, according to BP, it amounted to 0.07 Exajoules [15].

Historically, Sweden has had a high share of nuclear and hydro energy in electricity production (Fig. 3).



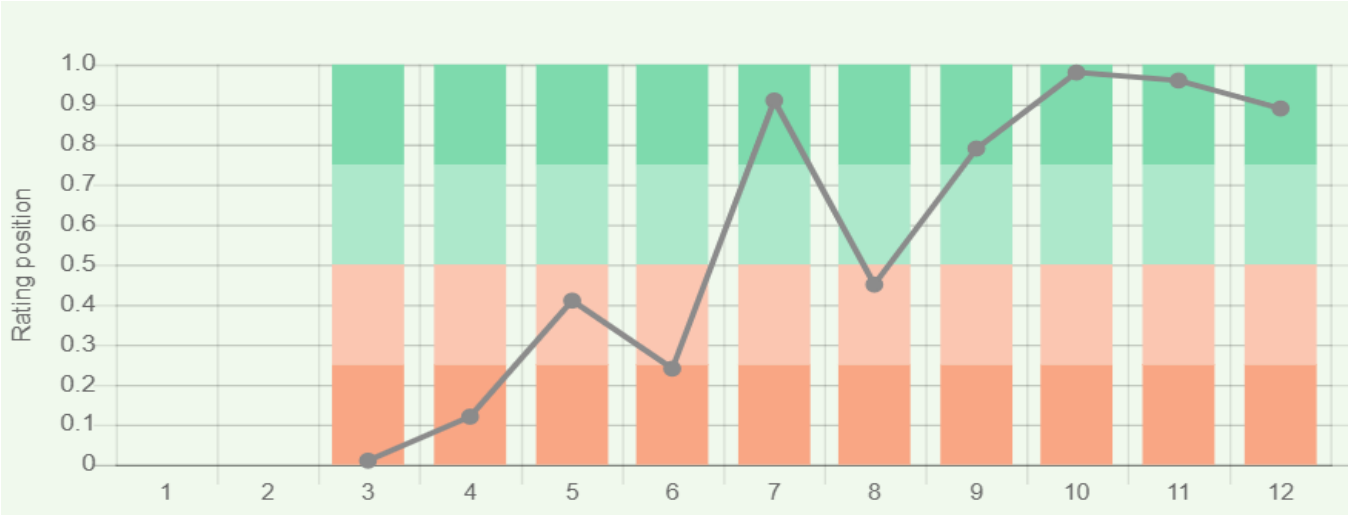
Sources:
U.S. Energy Information Administration (Dec 2021) / https://www.eia.gov/

Figure 3. Electricity production in Sweden

In 2020 Sweden produced around 158.68 TWh of electricity and the share of renewable resources in the total production volume has consistently increased, particularly with regard to biomass and wind energy (Fig. 6).

Sweden's position in the comparative diagram of energy index is shown in Figure 4. As previously mentioned, Sweden does not have significant reserves of fossil resources so the first six indices are either not represented in the diagram or are extremely low. The volume of production of fossil energy resources is much lower than the level of their consumption in Sweden. On the one hand , this requires sustainable import support, however it also encourages the development of energy-saving technologies and renewable energy. Other indices are more convincing. In a rating from 2017 listing countries by their level of production of electricity from renewable sources (excluding hydropower) Sweden was 15th out of 170 countries selected for consideration.

In the Energy Architecture Performance Index 2017, which is based primarily on the level of economic growth, environmental safety, and energy independence of the country, including access to energy, Sweden is 3rd, only behind Norway and Switzerland.



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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 Sweden

The country has consistently placed highly by these indicators. In terms of GDP per unit of energy used, Sweden is slightly below the world average. However, the index of energy use per capita is much higher – 14th among 66 countries considered.. In terms of electricity consumption per capita, the country is 8th in the world. For the indicator of combination of electricity production-consumption, Sweden is 23rd in the ranked list of 216 countries.

*Detailed information about the energy balance of Sweden is available **here.***

Energy Infrastructure

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

As previously mentioned, kerogen oil reserves account for 78.5% and shale gas reserves account for 21.5% of the energy potential of unconventional fossil resources. Swedish refineries, which are mainly concentrated in the south, have a total installed capacity of 515 000 barrels/day (Fig. 5). The country's largest refinery is Preemraff Lysekil Oil Refinery, managed by Preem, with an installed capacity of 220 000 barrels/day [18]. The main oil terminal is Göteborg (4 million m^3), and the biggest oil storage is Brofjorden (Lysekil) Oil Storage Terminal (580 000 m^3) [19,20].

There is one large gas storage facility in the country – Skallen, which has a capacity of 10 million m^3 [21]. There are two LNG import terminals, the largest of which is Linde Brunnsviksholme LNG Import Terminal near Stockholm, with a storage capacity of 20 000 m^3 [22]. Domestic gas is transported through a 1 626 km long pipeline network (Fig. 5).

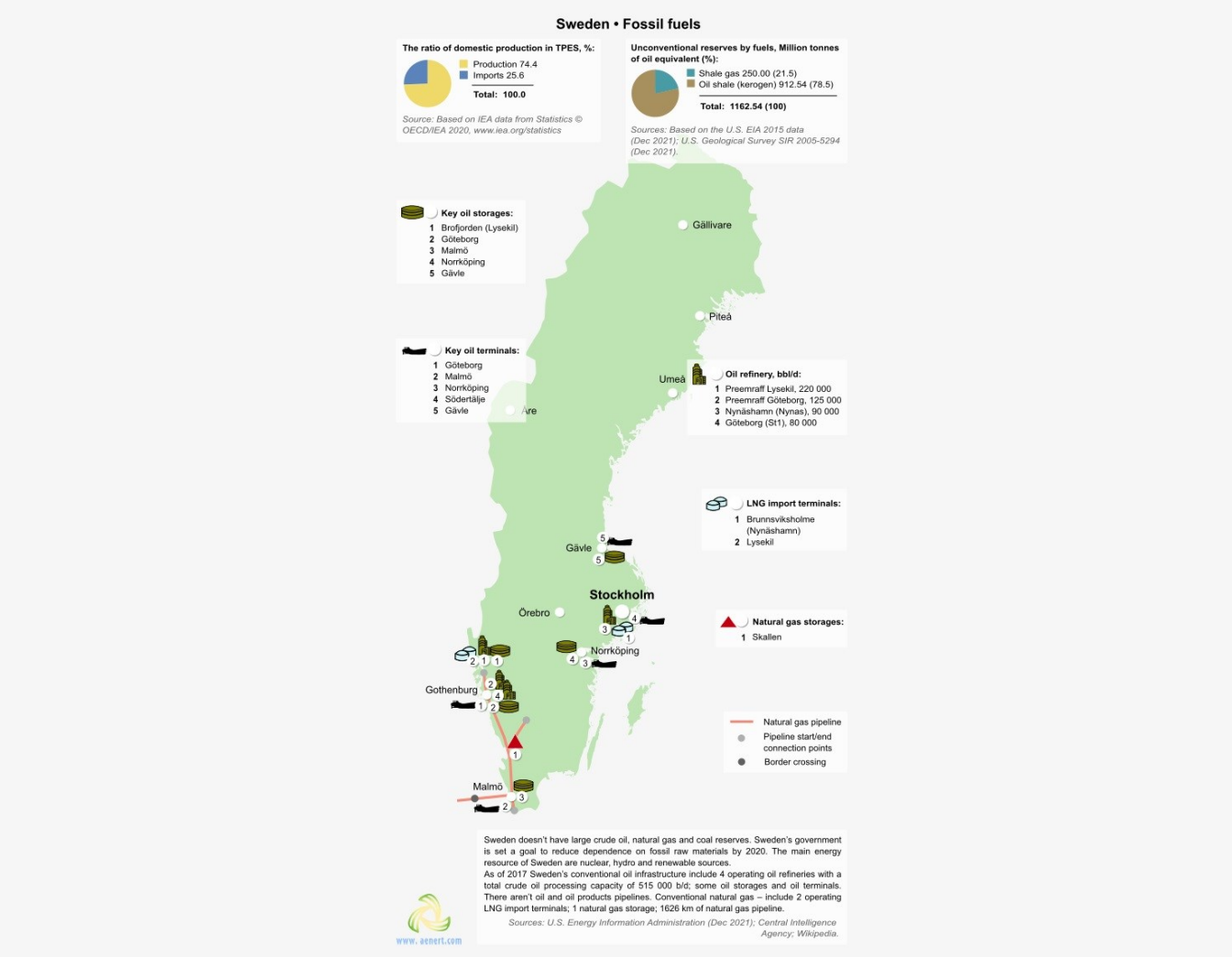


Figure 5. Basic infrastructural facilities of the fossil fuel sector in Sweden

According to EU Commission Energy Statistics of the EU-28 Countries, the share of fossil fuels in electricity production in Sweden in 2020 was only 0.1% (Fig. 6). The Central Intelligence Agency's estimates for 2016 are significantly higher – 5% [3]. For this indicator Sweden is behind only Switzerland, Iceland and Norway in Europe [3].

The country has several stations for the production of electricity from fossil fuels, including power plants with a capacity of more than 100 MW, such as two oil power plants, two gas power plants and three combined cycle power plants, as well as a large number of power plants with less output (Fig. 6).

The largest power plants in Sweden are: gas – Öresundsverket, with total capacity of 440 MW [23], oil; Karlshamn (Stärnö) Oil-fired power plant, with installed capacity of 1 005 MW, combined cycle; and Aroskraft (Vasteras) Combined Power Plant with installed capacity of 650 MW [24,25]. In the southern part of the country, on the coast of the Baltic Sea, there are three nuclear power plants; the most powerful of these is Ringhals Nuclear Power Plant (3 932 MW) [26].

As noted above, hydropower in Sweden has a significant share in electricity generation, and in 2020 it was represented by several hydro and pumped storage power plants that produced 71.58 TWh (Fig. 6). The most powerful hydroelectric power plant is the Harsprånget Hydro Power Plant with an installed capacity of 871 MW [27]. Among pumped storage power plants, the Juktan Hydro Pumped Storage Station has an installed capacity of 335 megawatts [28].

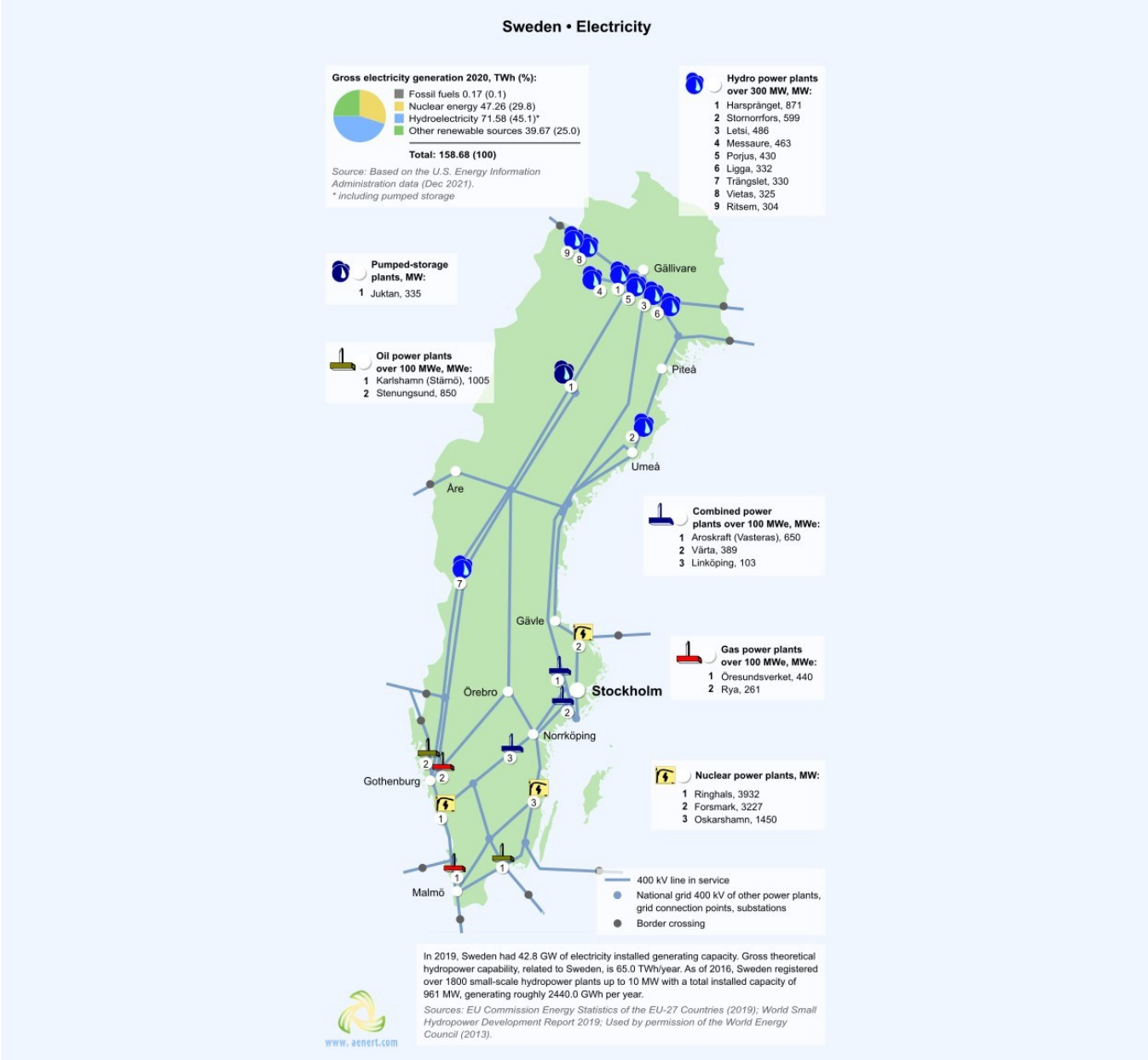


Figure 6. Electricity production in Sweden

As mentioned previously, the level of solar radiation in the most densely populated areas of the country can reach 2.7 kWh/m^2, which is a sufficient resource for the production of energy through photovoltaics [9]. There is one large photovoltaic station, Onsmyran Solar PV Plant, with installed capacity of 1 MW [29].

In areas with high wind activity there are 11 large wind parks, each with a capacity of more than 90 MW. The largest is Björkhöjden Wind Farm with an installed capacity of 270 MW [30].

The level of municipal waste is 431 kg per person per year [14]. There is large number of waste-processing plants of various capacities, including 10 power plants with a capacity of more than 200 000 tpy. The largest is Stockholm-Högdalen Waste-to-Energy Plant with an installed capacity of 600 000 tpy [31]. The ScanDust Landskrona Plasma Gasification Plant has an installed capacity of 200 TPD [32].

Bioenergy has a significant share in energy production in Sweden, and in 2019 biomass generated around 13.04 TWh (Fig.7). The country has biomass processing plants, biogas production plants, biodiesel plants, bioethanol plants, pellets and landfill gas plants, etc. E.On owns the largest biomass processing plant, the Åby Biomass power plant with an installed capacity of more than 130MW [33]. Termochemical GoBiGas Phase 1BTL-FT, managed by Göteborg Energi AB, has an installed capacity of 20 MW [34].

Lantmännen Energi produces around 235 000 m^3 of bioethanol annually at the largest plant in the country: Norrköping [34]. The largest biodiesel plant in the country is Piteå, SunPine Biodiesel Plant, which produces about 100 000 m^3 annually [35]. There are a number of biomass gasification plants in the country, the largest of which is the Södra Cell Värö Pulp Mill Biomass Gasification Plant, with an installed capacity of 35 MWh [36]. The largest pellet production company is located in Härnösand, the SCA Energy Wood Pellet Plant, which produces 160 000 tons annually [37]. In 2016, Sweden produced more than 1.9 TWh of biogas at 282 plants, and this resource is used as fuel for vehicles. In terms of biogas production, Skåne is the leader in electricity generation, with 47 plants generating 417.5 GW [38]. The largest torrefication plant is the ETPC Torrefaction Plant at Umeå, with an installed capacity of 30 000 tons/year [39].
The country has an 18 km long hydrogen pipeline at Stenungsund, and four hydrogen gas stations (Fig. 7).

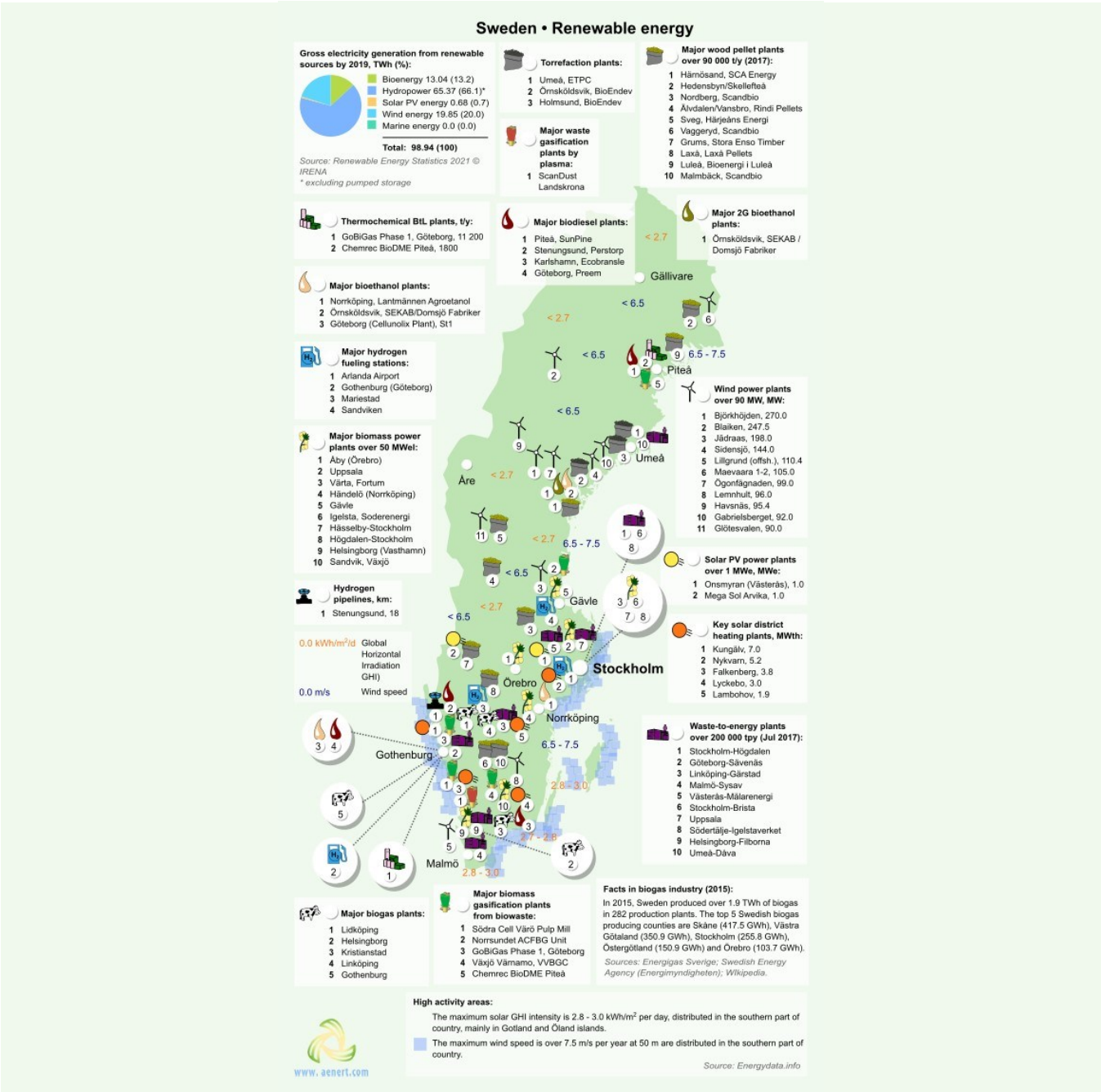


Figure 7. Renewable energy in Sweden

The primary direction of Sweden's energy policy is to increase the capacity of renewable energy, to meet the growing demand for electricity. As of June 2017, 246 wind turbines with a total capacity of 751 MW are under construction [40]. Svartnäs wind farm, which includes 32 turbines and will have a capacity of 115 MW, is planned to be constructed in 2018 [41].

The largest producer of fuel in Sweden, Preem, plans to produce about 3 million m^3 of biofuel by 2030. The company has announced a partnership with Vattenfall, which will supply hydrogen gas for this project, using wind and hydroelectric power [42].

*Detailed information about the energy infrastructure of Sweden can be found **here.***

Education and Innovation

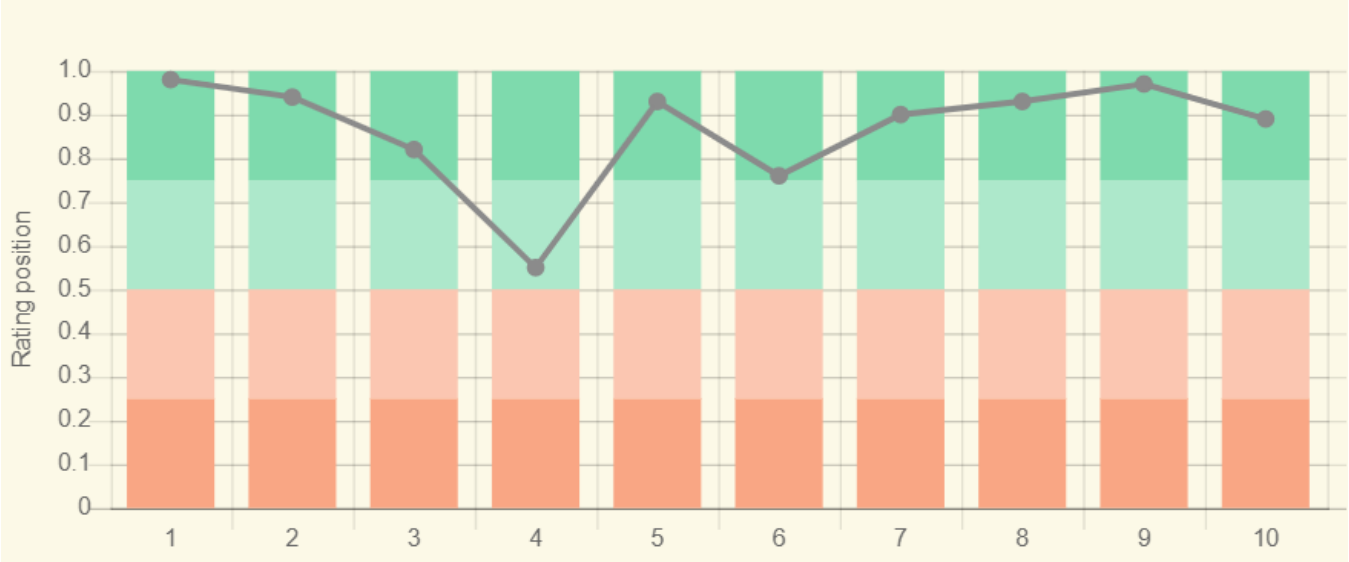
The set of indices reflecting the position of Sweden among other countries in the field of education and innovation can be seen in Figure below. As can be seen from the diagrams presented, Sweden is one of the world leaders in this segment of indicators, which contributes to technological development in the field of energy.

In the ranking of countries of the Global Innovation Index 2021, Sweden is second after Switzerland from the 132 countries considered (see diagram). According to the number of patents granted to Swedish nationals, both domestically and abroad, the country ranks 12th in the world. Similarly, by the number of valid patents, the country is 20th in the world, indicating the country's favourable conditions for innovation.

The level of government expenditure on education is very high. Eight Swedish universities are included in the QS University Rating. In addition, Sweden's GDP is very high, so the expenditure on education in absolute terms is also substantial.

In the ranking of countries, in terms of government expenditure on research and development as a percentage of GDP, the country is third behind to Israel and Republic of Korea. Sweden is well positioned when considering the number of publications of specialists in scientific and technological journals; in the Scimago, rating Sweden ranks 18th out of 240 countries, and in the Scientific and Technical Journal Activities places 22тв out of 197 countries.

Swedish universities, including KTH Royal Institute of Technology, Uppsala University, the University of Go-



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* Total number of countries participating in ranking

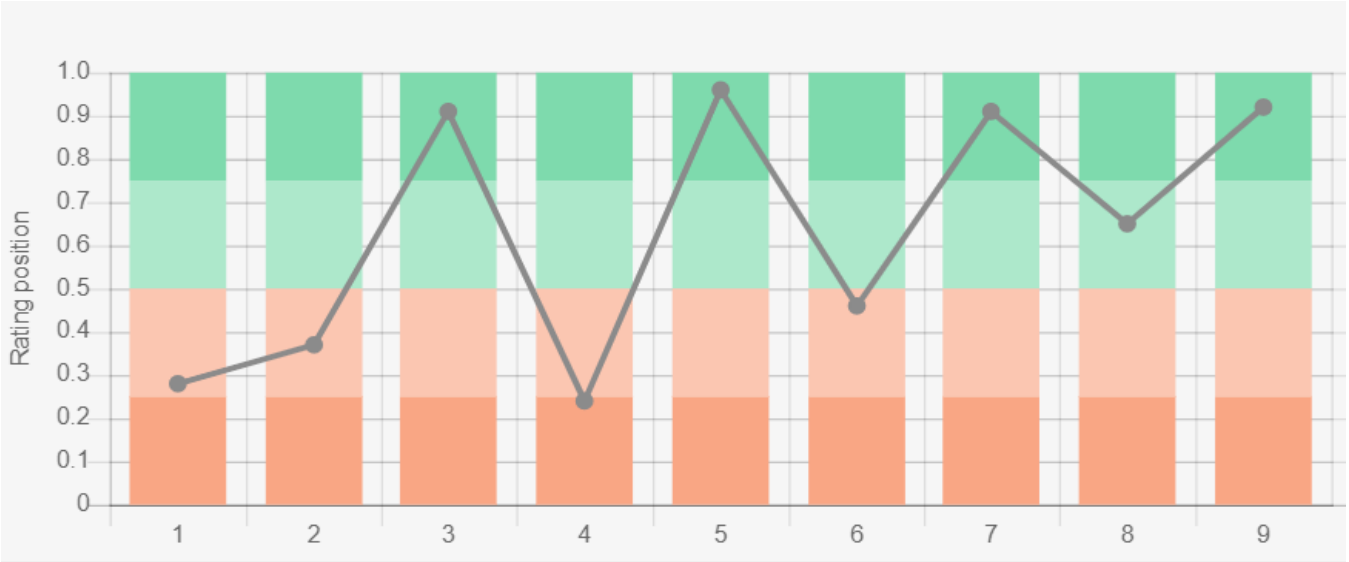
Figure 8. The indices of education and innovation in Sweden

thenburg and Karlstad University, train specialists in various fields of energy, including Renewable Electricity Production, Wind Power Project Management, Science in Environmental and Energy Engineering, Electrical Engineering, etc.
Cortus AB and Siemens AG are among the leaders in patenting among Swedish companies in the field of synthetic fuel production. Studies in this field have been conducted by KTH Royal Institute of Technology, Chalmers University of Technology, and Luleå University of Technology.
In the field of unconventional oil processing, the following companies are prominent – Siemens AG, and Alfa Laval Corporate AB. Uppsala University and Linköping University have the highest number of publications in this area.
A large number of Swedish companies patent technical solutions in the field of energy production from renewable sources. In the field of bioenergy, patenting leaders among Swedish companies are Bioendev AB, Cortus AB, Tekniska Verken Linkoeping AB, Bioprocess Control Sweden AB, and Scandinavian Biogas Fuels AB. Studies in this field have been conducted by KTH Royal Institute of Technology, Chalmers University of Technology, and the Swedish University of Agricultural Sciences. Notable enterprises in the field of solar energy include Siemens AG and Climatwell AB. KTH Royal Institute of Technology, Lund University and Uppsala University have the highest number of publications in this area.
Leaders in the field of wind power are Siemens AG and Senvion SE. Studies in this field have been conducted by KTH Royal Institute of Technology, Luleå University of Technology and Uppsala University.

*Additional information about education in the country can be obtained **here** , and the list of research institutes **here.***

Ecology and Environment Protection

A diagram of environmental indices is shown in Figure 9. This figure shows the indices that have an indirect effect on the energy sector, but in many respects shape its future.
Due to the country's extensive use of clean energy



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* Total number of countries participating in ranking

Figure 9. Environmental indices of Sweden

sources, Sweden demonstrates a relatively high level of CO_2 emissions, both in general and per capita .

Sweden is also included in the Climate Change Performance Index (CCPI), which shows the 61 countries responsible for more than 90% of the world's energy-related CO_2 emissions. The authors of the report note a reduction in emissions of harmful substances per capita. However, there are fluctuations in emissions from the agricultural sector, and the country's renewable energy target is still not sufficient.

In relation to forest area as a percentage of total land area, Sweden is 21st in the world. However, there is a negative trend in forest area change, and here the country is only 179th.

Nevertheless, the country has a relatively high Environmental Performance Index (EPI) 2020 rating, which focuses primarily on assessing the environmental performance of national governments. In this rating Sweden is 8th out of 180 member countries, behind France, Switzerland and Denmark.

At the end of the review it is also worth noting that, according to the Ecological Footprint Atlas, Sweden is among the environmental creditors.

*Detailed information about the energy industry in Sweden is available **here.***

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