Report 2021

Sweden

Prototype turbine at SWPTC with a wooden tower from Modvion on Björkö (Gothenburg), Nacelle height 30 m, rotor diameter 16 m. *(Source: Modvion).*

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In 2021, Sweden installed 2042 MW of new wind energy capacity (1403 MW were installed in 2020). At the end of the year, the country's total installed capacity was 12116 MW from 4679 wind turbines.

Through the EU burden-sharing agreement, Sweden has a goal of greenhouse gas emission reduction of 40% in 2030 in relation to the 2005 level. At the national level, Sweden is to have no net emissions of greenhouse gases into the atmosphere by 2045 and should thereafter achieve negative emissions. To achieve zero net emissions, emissions from activities in Swedish territory are to be at least 85 percent lower than emissions in 1990. Another national goal is to reach 100% renewable electricity production in 2040. The Swedish Energy Agency estimates that the country will need to install an additional 2.5 to 6 TWh of renewable power capacity per year between 2030 and 2040 to reach that goal and that wind power will provide a large part of it.

As Sweden's primary wind power R,D&D funding agency, the Swedish Energy Agency finances research conducted by universities and industries in several research programs. The overarching goals of wind power

Table 1. Key National Statistics 2021: Sweden [1]

Total (net) installed wind power capacity	12.1 GW
Total offshore capacity	0.19 GW
New wind power capacity installed	2.0 GW
Decommissioned capacity (in 2020)	- GW
Total electrical energy output from wind	26.6 TWh
Wind-generated electricity as percent of national electricity demand	21.5%
Average national capacity factor	27.8%
Target	30 TWh
National wind energy R&D budget	5.86 MUSD

tries in several research programs. The overarching goals of wind power R,D&D are to help Sweden reach its targets and national objectives for a renewable energy system, contribute to business development and increase jobs and exports.

Highlight(s)

- The installed wind power capacity in 2021 was a record high 2.0 GW despite significant delays due to the pandemic.
- Sweden surpassed 10 GW installed wind capacity and 20% share of wind in electricity consumption.
- Towards 2024 wind generation is expected to reach 47 TWh, nearly a doubling compared to 2019.

Market Development

Targets and Policy

In 2016, the government, the Moderate Party, the Centre Party, and the Christian Democrats reached an agreement on Sweden's long-term energy policy, although, in 2020, the Moderate party and Christian Democrats left the agreement. The goals were though ratified by the parliament, so they are still valid. They consist of a common roadmap for a controlled transition to an entirely renewable electric power system, with targets as follows:

- By 2030, Sweden's energy use should be 50% more efficient than in 2005. The target is expressed in terms of energy relatively to GDP.
- By 2040, Sweden should achieve 100% renewable electricity production. This target is not a deadline for banning nuclear power, nor does it mean closing nuclear power plants through political decisions.
- By 2045, Sweden is to have no net emissions of greenhouse gases into the atmosphere; thereafter, the country should achieve negative emissions.

These goals and good wind power potential in Sweden are driving the development of wind energy in Sweden.

Since 2003, Sweden has had a technology-neutral, market-based support system for renewable electricity production called the electricity certificate. In addition, the work done in assessing areas of national interest for wind power can be considered a "soft incentive."

In the electricity certificate scheme, the government awards electricity producers a certificate for each MWh produced from renewable resources. Only new power plants, or plants that have undergone recent significant changes, are entitled to certificates. Producers then sell the certificates on an open market to electricity consumers. The demand for electricity certificates is regulated by a quota, which is set in proportion to total electricity use; however, the energy-intensive industry is exempt from this requirement. The price is determined freely by the market and varies with demand and supply. Renewable energy sources include wind, solar, wave, and geothermal, as well as some hydropower, biofuels, and peat in combined heat and power (CHP) plants. The main contributors are biopower and wind power. Sweden and Norway have shared

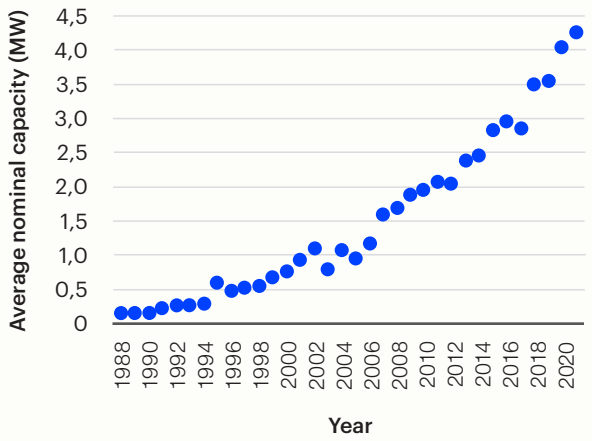

Figure 1. Rotor diameter trend

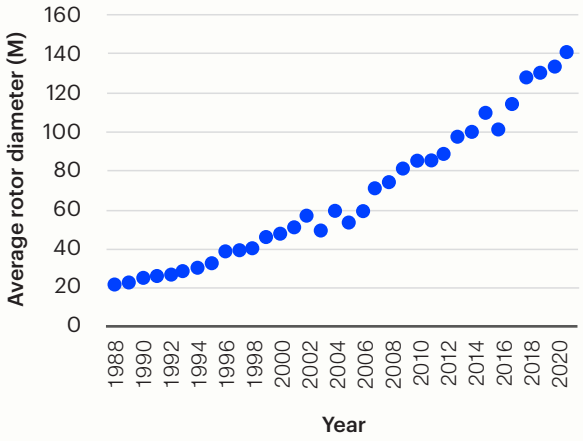

Figure 2. Nominal capacity trend

a common electricity certificates market since 2012, with certificates traded across borders. The objective of the common certificates market is to increase the production of renewable electricity by 26.4 TWh by 2020 (compared to 2012). This corresponds to approximately 10% of total electricity production in both countries, achieved principally through biopower and wind power. In the 2016 Swedish energy policy agreement, the electricity certificate support scheme was extended to 2030 with the goal of an additional 18 TWh. This goal was already achieved in March 2021. December 31, 2021, is the stop date for new facilities, which means that new facilities or plants that are put into operation after the stop date will not be eligible for electricity certificates.

Progress and Operational Details

In 2021, 428 turbines were commissioned with an average nominal capacity of 4.7 MW. All of them were onshore. During 2020, the phase 1 of Markbydgen in Piteå commune was completed. It consists of three different areas (Ersträk, Markbygden ETT, Skogberget) with a total of 283 turbines (2.3 MW, 3.6 MW and 4 MW) for a total of 956 MW. During 2021, 34 turbines (3.5MW and 4.2 MW) were installed. Fully installed in 2026, the project (3 phases) will have 1100 turbines with an annual electricity production of 8-12 TWh.

A clear trend is an increase in the size of turbines, as shown in the figures below. Based on available data from 492 turbines [2], the rotor diameter of installed turbines during 2021 was 141 m on average, with a nominal power of 4.3 MW.

Matters Affecting Growth and Work to Remove Barriers

- Permitting and initiative to make it more predictable. The permit process in Sweden is long (about 10 years), and the outcome has been described as unpredictable, especially due to the outcome of municipality approval, so-called "municipality veto." In October 2020, the Swedish Government appointed a special investigator with the task of examining the conditions for repealing the municipal approval of wind power plants or examining alternative proposals. The proposal from the investigator is that the municipalities still have a right to say no to wind power, but, unlike today, the municipality will give notice early in the process, and the scope of the municipality's decision will be limited to land and water use only. A clear difference is thus proposed between municipal assessments and the licensing authority's review. The municipality decides where in the municipality wind power is appropriate, and a positive response from the municipality is a prerequisite for being able to submit an application for a permit [3].

- Grid limitation – There is an urgent need for grid investment in Sweden not to limit the deployment of wind power. Specifically, increasing the transmission capacity from the north of Sweden, where large wind power farms are constructed, to the south, where consumption is.

- Overall, electricity prices have been historically low in Sweden, which on one hand, is stressing the electricity producers, but on the other hand, enables electrification of the industry though increasing the demand. However, during

S&L Access Systems, Salamander Quick Lift Crane prototype. *(Source: S&L Access Systems)*

the winter of 2021/22, electricity prices have been unusually high in Sweden and varied greatly throughout the day. Even in the north, where electricity normally costs between 5$ and 60$ per MWh, consumers have been hit by electricity prices up to 400$ per MWh. The increased electricity prices can be explained by two main reasons: Sweden's electricity network is closely connected with our neighbouring countries and other countries down on the continent. This means that prices in Sweden are affected by temporary high energy prices seen in the rest of Europe. The second reason is the unusual weather. After a mild autumn and temperatures above normal throughout Sweden in October, the winter suddenly hit at the end of November. It caused the ice to settle simultaneously in several of our large rivers. As a result, total production from hydropower temporarily decreased at the same time as demand was high, which also increased prices in northern Sweden. In November and December, it has also been unusually cold around Europe and less wind than usual.

- The price of green certificates in Sweden has varied but has shown a clear trend of price erosion due to supply exceeding demand. In practice, new installations of wind power are without subsidies. This is a good deal for the consumers who pay the cost of their electricity bill, but has of course a large economic impact on wind power companies, which represent 70% of allocated green certificates. The wind power industry has therefore repeatedly requested to stop new allocations to limit supply. This year, the government has taken action. There will be no new allocations after 2021 and the support scheme will be end before planned in 2035 [4].

- The government has taken the decision to reduce connection costs for offshore wind power, It has assigned the Swedish National Grid (Svenska Kraftnät) to expand the transmission network to areas within Sweden's maritime territory where there are conditions to connect more offshore wind.

- In 2018, the Swedish Environmental Protection Agency and Swedish Energy Agency took the initiative to prepare a common strategy for Sweden's sustainable wind power expansion. The goal is to produce a roadmap for wind power expansion that facilitates municipal planning and local and regional permit processes and contributes to increased predictability for all stakeholders involved. The final report was presented in January 2021 [5]. The outcome is tools for planning and guidance, regional targets for wind power deployment, proposals

for legal and regulatory measures to improve the permit process, and an implementation strategy. If this is successful, it will contribute significantly to deployment of wind power in Sweden, as the target is 100 TWh wind power.

- In February 2022, the government decided on a proposal for sea use in Sweden [6]. The offshore plan provides a map of the utilisation of the sea around Sweden for various uses: fishing, shipping, defence, energy production, culture, sand mining, and power cable, which are assessed against environmental values. For the energy production, which is exclusively wind power, the conclusion is a potential for an annual production of 23 to 31 TWh. In connection with the decision on offshore plans, the government has commissioned the Swedish Energy Agency, Swedish Agency for Marine and Water Management, and several other central authorities to jointly produce planning documents for additional areas for offshore wind power.

R,D&D Activities

In 2021, the Swedish Energy Agency adopted a strategy for research and innovation for the future electric power system. As a result, a new research program was launched in 2022, gathering previous R&D programs within wind power, hydropower, smart grid, solar power, and ocean energy. The new program will support the transition to a sustainable energy system by facilitating the electrification of other sectors and, at the same time, work for an electric power system characterised by the security of supply, competitiveness and ecological and social sustainability.

National R,D&D Priorities and Budget

Three research programs were publicly funded wind energy research during 2021: Vindval, Swedish Wind Power Technology Centre (SWPTC), and VindEL. All three programs were under the supervision of the Swedish Energy Agency.

Vindval [7] is a research program focused on studying the environmental effects of wind power. The program is financed by the Swedish Energy Agency and administrated by the Swedish Environmental Protection Agency. The agency has allocated a total of 20 million SEK (EUR/USD?) for the implementation of the new phase of Vindval, which focuses on wind power and spatial planning. The program extends through December 2021.

The Swedish Wind Power Technology Centre (SWPTC) [8] is a research center that focuses on optimising wind turbine design by taking into account the interaction between all components. The center is commonly financed by industry, universities, and the Swedish Energy Agency, with a total budget of 48 million SEK (4.5 million EUR; 5.1 million USD) and runs from 2019-2022.

The SWPTC is organised into six theme groups:

- Power and control systems
- Turbine and wind load
- Mechanical power transmission and system optimisation
- Offshore
- Maintenance and reliability
- Cold climates

The program VindEL [9] runs from 2017-2021. It is financed by the Swedish Energy Agency and has a total budget of 133 million SEK (13 million EUR, 16 million USD). The program focuses on finding technical solutions within the three priority areas defined in Sweden's strategy for wind power:

- Conflicts of interest and competition for land use both on land and at sea
- Resource-efficient wind power in Swedish conditions with minimised environmental impact
- Robust electricity grid with high security of supply requires new solutions and incentives

National Research Initiatives and Results

Frequency services from wind power in the Swe dish power system [10] – A project from SWPTC
This project is run at the Swedish Wind Power Technology Centre. The project will develop, simulate and test frequency control with wind turbines. The standard built-in frequency control will be tested in commercial wind farms and participate in the bidding of ancillary services on the frequency regulation market for the first time

"The technical function and demand for wind turbines to control the frequency in the electricity grid will be verified and evaluated."

in Sweden. Furthermore, existing frequency regulating services will be tested and developed at Chalmers wind turbine. The technical function and demand for wind turbines to control the frequency in the electricity grid will be verified and evaluated. This also includes an analysis of wear and how the lifetime of the pitch system and gearbox is affected. The results will also show the economic potential of wind power operators to participate in the frequency regulation market.

Modvion [11] – Supported by the research program VindEL
Modvion is a company developing a modular tower in laminated wood. They erected a 30 m tower in April 2020. Their wood tower offers a lower cost; it simplifies and improves construction logistics due to its modular structure, reduces emissions by 90% compared to steel, and provides a carbon sink. This solution contributes clearly to making wind power more sustainable. In 2020, Modvion Awarded Multimillion-Euro EU from the EU EIC Accelerator program. The money will be used to build the first commercial wooden turbine tower

Inside view of the 30 m wooden tower from Modvion on Björkö (Gothenburg) *(Source: Modvion).*

of 100 m. In June 2021, the corporate venture capital arm of Vestas, Vestas Ventures, have made a new investment in Modvion through a recent directed share issue to strengthen its engagement and support to Modvion. In May 2022, Modvion inaugurated the world's first factory for wooden wind turbines in Gothenburg.

S&L Access systems with STENA AB as a majority shareholder - Supported by the research program VindEL
The size of wind turbines is gradually increasing and has reached a critical size where both construction and service require very large resources in the form of cranes and peripherals. S&L Access Systems has developed the Salamander Quick Lift Crane Technology featuring a new top crane technology enabling heavy lifts on hub heights well beyond 200 meters. The moveable platforms enable better safety and are less wind sensitive when conducting up-tower works. The crane also requires a smaller crane pad. The new crane will significantly reduce both time and cost for new construction and service. The project included the further development and testing of a prototype.

Research program Vindval – Environmental and Social Impact
In the spring of 2021, the Swedish Energy Agency granted funding for three projects within Vindval's call "Follow-up of wind power establishments." The purpose of the call is to produce a knowledge base about experiences from recent years' wind power expansion in Sweden.

- Wind power and experience values in nature areas.
- Wind power and unforeseen impact on species and their habitats.
- Wind power and bats - evaluation of operational regulation, and wind power in forest environments - mortality of birds and bats.

Test Facilities and Demonstration Projects

RISE Research Institutes of Sweden and Skellefteå Kraft establish a test center in Uljabuouda, in Arjeplog, during 2019. The test site will provide an opportunity to build wind turbines or other types of energy-generating equipment up to a height of 330 meters for testing [12]. There, the global wind industry will be able to test its wind turbines and other equipment in cold and icy conditions. There were no large demonstrations initiated in 2021.

Collaborative Research

In 2021, Sweden participated in several IEA Wind TCP Tasks:

- Task 11 Base Technology Information Exchange

- Task 19 Wind Energy in Cold Climates
- Task 25 Design and Operation of Power Systems with Large Amounts of Wind Power
- Task 28 Social Acceptance of Wind Energy Projects
- Task 31 WAKEBENCH: Benchmarking Wind Farm Flow Models
- Task 34 Working Together to Resolve Environmental Effects of Wind Energy (WREN)
- Task 39 Quiet Wind Turbine Technology
- Task 42 Wind Turbine Lifetime Extension
- Task 43 Wind Energy Digitalization
- Task 45 Recycling of Wind Turbine Blades
- Task 47 TURBulent INflow Innovative Aerodynamics (TURBINIA)

Impact of Wind Energy

The Swedish energy policy aims for the social, economic, and ecological long-term sustainability of the energy system while maintaining the security of supply. This can be achieved with an active energy policy, incentives, and research funding. Currently, CO2 emissions from electricity production are relatively low because hydropower, nuclear, bioenergy, and wind energy are the main contributors to the energy system.

Environmental Impact

Sweden has the goal to be carbon neutral by 2045. In all the scenarios, electrification of the industry and transport sector is expected to be the main path. In order to reach that goal, wind power is expected to become the backbone of electricity production as Sweden is a large country with excellent wind conditions.

Economic Benefits and Industry Development

According to the Swedish Wind Energy Association [13], investments in wind power in Sweden (both committed and notified projects) between 2017-2023 sum up to 100 billion SEK (10 billion €). The investments create a total of 7832 annual jobs for construction and 12 397 for operation and maintenance. Another economic impact is the result of a lower electricity price (minus 0,088 SEK/kWh), which creates a total value for the users of 12.3 billion SEK.

Next Term

Based on current planned and in-construction projects, Sweden will reach 47 TWh in total electrical energy output from wind by 2024, which will be 30% of the electricity production in Sweden. The installed power will go above 16 GW, nearly a doubling compared to 2019.

Looking at the coming years, much of the focus on wind power in Sweden is expected to turn to off-shore and joint-production with hydrogen. Much of the deployment will be then in the Baltic Sea. With good wind conditions, short distance to shore, limited wave height, low salinity, and icing during winter, the Baltic Sea has unique conditions that both are a challenge, but also an opportunity to develop Baltic Sea technique that brings further down the cost of offshore. All the research programs: Framtidens elsystem, Vindval, VindEl, and the SWPTC, are addressing these challenges and opportunities.

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