Sweden

Table 1. Key Statistics 2017, Sweden	
Total (net) installed wind power capacity	6.691 GW
Total offshore capacity	0.190 GW
New wind power capacity installed	0.199 GW
Decommissioned capacity (in 2017)	0.034 GW
Total electrical energy output from wind	17.6 TWh
Wind-generated electricity as percent of national electricity demand	12.5%
Average national capacity factor	30%
National wind energy R&D budget	60 mil SEK

OVERVIEW

In 2017, Sweden installed 199 MW of new wind energy capacity (605 MW were installed in 2016). At the end of the year, the country's total installed capacity was 6,691 MW from 3,437 wind turbines.

Through the EU burden-sharing agreement. Sweden has a renewable energy goal of at least 50% of total energy use by 2020. New ambitious targets were announced in 2016 for 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 R,D&D is to help Sweden reach its targets and national objectives for a renewable energy system, contribute to business development, and increase jobs and exports.

MARKET DEVELOPMENT

National Targets & Policies Supporting Development

According to the EU burden-sharing agreement, Sweden is required to achieve a renewable energy share of 49% by 2020. However, Sweden increased this goal to a renewable energy share of at least 50% of the total energy use.

In 2016, the government, the Moderate Party, the Centre Party, and the Christian Democrats reached an agreement on Sweden's long-term energy policy. This agreement consists of a common roadmap for a controlled transition to an entirely renewable electricity 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.

Sweden has a technology-neutral, market-based support system for renewable electricity production called the electricity certificate. The electricity certificate scheme came into force in 2003 with the intention to increase renewable electricity production and decrease production costs. 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 which 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.

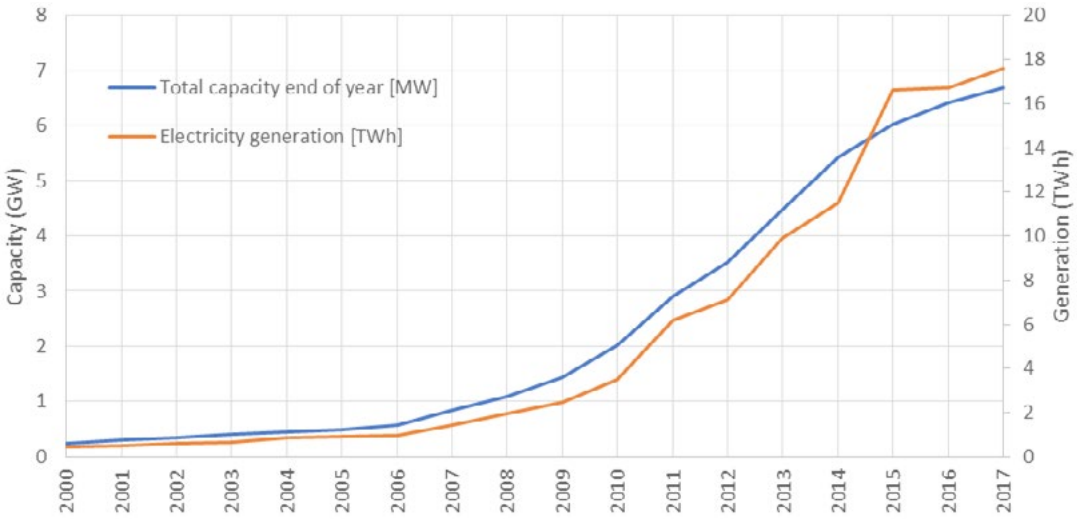

Figure 1. Installed wind power capacity in Sweden, 2000-2017

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 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.

Progress & Operational Details

Wind energy installations in 2017 resulted in 199 MW of new capacity—significantly lower than the 605 MW installed in 2016. At the end of 2017, Sweden's total installed capacity was 6,691 MW from 3,369 wind turbines. The total electrical energy output from wind was 17.6 TWh.

Interest is gaining around Northern Sweden, as the region exhibits many areas with high potential for wind power. Turbines in these cold climate areas face several challenges not found in areas with warmer climates.

One such challenge is turbine blade icing, which leads to substantial production losses and risk for falling ice. Wind turbines in such areas must be equipped with special cold climate packages, which include tower and nacelle structures with special steel qualities and special types of oil and grease. There are also often equipped with de-icing or anti-icing equipment. However, since many challenges remain, the Swedish Energy Agency considers wind power in cold climates an R,D&D priority.

Matters Affecting Growth & Work to Remove Barriers

The expansion of wind power in Sweden is mainly driven by incentives within the electricity certificate system. Because of price erosion for both electricity and certificates in recent years, only the most profitable—and nearly exclusively land-based—sites are considered for new wind farms today.

The government has commissioned Swedish Energy Agency to investigate potential ways to eliminate grid-connection costs for offshore wind power. The Agency has chosen to examine two different models.

The first model moves the grid connection point to the offshore wind farm. This would make the Swedish national grid operator (Svenska Kraftnät) responsible for the planning, construction, and operation of the undersea connection cable, as well as all the connection costs. This measure could be funded by an increase in grid tariff.

However, the Agency believes this model would create unequal conditions for land-based wind power, as land-based wind power and other electricity production facilities would continue to pay connection costs. The Agency's also assessed that wind power producers would have no incentive to select locations that lead to cost-efficient connections if they are not obligated to pay any portion of the connection costs.

The second model provides wind power producers with subsidies to cover a portion of the connection costs. The Agency proposes that this support only cover the undersea cable and transformers, as this would create conditions more comparable to land-based wind power. In the Agency's estimation, this model would limit the total cost of removing connection costs, while still incentivizing wind power producers to choose cost-effective connection locations. The subsidies under this model would be financed by a special surcharge, which all electricity consumers would pay.

Given the framework of this assignment, the Swedish Energy Agency has not been able to conduct a more detailed analysis of the constitutional aspects of the models for removing grid-connection costs. Due to EU regulations on State aid, such an analysis would be required in order to assess each model's feasibility.

In 2016, the Swedish Energy Agency adopted a wind energy strategy with three prioritized areas: wind in Swedish conditions, sustainability, and integration in the energy system. Wind in Swedish conditions refers to the installation and operation of wind turbines in cold climates, forested areas, and the Baltic Sea.

The overarching aim of wind power R,D&D is to make contributions that help Sweden reach its national targets and objectives for a renewable energy system. Moreover, it should also contribute to business development in Sweden by creating jobs and increasing Swedish exports.

National R,D&D Priorities & Budget

Four research programs carried out publicly-funded wind energy research in 2017: Vindforsk, Vindval, the Swedish Wind Power Technology Centre (SWPTC), and VindEL [5]. All four programs were under the supervision of the Swedish Energy Agency [2-5].

The present period of Vindforsk runs from 2013-2017 with a total budget of 60 million SEK (6.2 million EUR; 6.6 million USD). The program is financed by the Swedish Energy Agency (50%) and industry (50%). Vindforsk is organized in three research topics:

- Wind resource assessment and installation
- Operation and maintenance
- Grid integration

Vindval is a knowledge 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 program will run through 2018 with a budget of 27 million SEK (2.8 million EUR; 3.0 million USD). Vindval researches wind power's impact on reindeer, golden eagles, and marine life, as well as noise annoyance from wind turbines.

The SWPTC runs from 2010-2018. The program is financed by industry, some universities, and the Swedish Energy Agency, with a total budget of 96 million SEK (10.0 million EUR; 10.6 million USD).

The center focuses on optimizing wind turbine design, which takes into account the interaction between all components. The SWPTC is organized into six theme groups:

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

The program VindEL 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:

- Wind in Swedish conditions
- Sustainability
- Integration in the energy system

National Research Initiatives & Results

Below are some of Sweden's 2017 wind energy projects:

"**Wind turbine performance decline in Sweden**" showed that wind power production is nearly constant during the first years of operation, but subsequently it begins to decline. Wind turbines constructed before 2007 lose around 0.15 capacity factor percentage points per year in absolute terms, corresponding to a lifetime energy loss of 6%. A gradual increase of downtime accounts for about one-third of the decline, while worsened efficiency accounts for the rest. This project gave recommendations for wind energy calculations for current and future projects. The recommended estimate is a decline of 0.10-0.20 pp/yr, including increased downtime and worsened efficiency. This rate of energy loss is higher than normally assumed in the wind sector today; however, compared to results from the UK, the decline is considerably smaller.

Deicing of wind turbines—continuous autonomy system for deicing of wind turbine blades aimed to develop a new and innovative method for deicing and anti-icing wind turbine blades. The project researched methods for detecting ice, as well as controlling temperature of the blade surface. The goal within the project was to develop a prototype and evaluate it on an existing wind turbine.

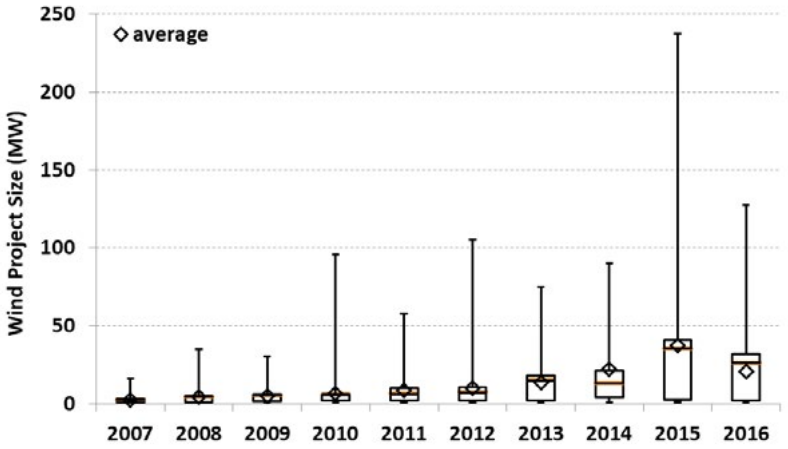

Figure 2. Installed wind power capacity in Sweden by commercial online date, 2000-2017

LoadMonitor—measuring and modeling vibrations and loads on wind turbines worked to maximize energy availability while keeping loads below reasonable limits. The project analyzed the relationship between upstream wind characteristics and nacelle vibrations, based on concurrent 3D-measurements of the upstream wind and high-resolution vibration measurements. LoadMonitor provided a combined measurement and analysis system, which measures nacelle vibrations with high resolution to detect underperformance and identify non-standard wind conditions and component failure. The knowledge and tools developed within this project will be of high relevance for turbine performance control.

Wind power in forest: fatigue and longevity used large eddy calculations (i.e. numerical accurate solutions of Navier-Stokes equations) of an atmospheric boundary layer above and in forest to measure instantaneous turbulent flow rates and calculate fatigue loads on a wind turbine. A wind turbine located in a forest area is expected to tolerate increased turbulence and windshield layers compared to wind turbines standing in an open landscape. Wind turbines and fatigue loads on the wind power plants become almost three times larger in a forest area than in an open landscape. The calculations from the project confirm this hypothesis and quantify this effect.

Test Facilities & Demonstration Projects

RISE Research Institutes of Sweden and Skellefteå Kraft are about to establish a test center in Uljabuouda, in Arjeplog. There, the global wind industry will be able to test their wind turbines and other equipment in cold and icy conditions. There were no large demonstrations initiated in 2017.

Collaborative Research

In 2017, Swedish researchers participated in EU programs (ERA-NET PLUS New European Wind Atlas), the Nordic Energy Research programs, and 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 29 Mexnext: Analysis of Wind Tunnel Measurements and Improvement of Aerodynamic Models
- Task 31 WAKEBENCH: Benchmarking Wind Farm Flow Models
- Task 34 Working Together to Resolve Environmental Effects of Wind Energy (WREN)
- Task 36 Chapter 16 Forecasting for Wind Energy

IMPACT OF WIND ENERGY

The Swedish energy policy aims for social, economic, and ecological long-term sustainability of the energy system while maintaining security of supply. This can be achieved with an active energy policy, incentives, and research funding. Currently, CO_2 emissions from electricity production are relatively low, because hydro, nuclear, bio, and wind energy are the main contributors to the energy system.

NEXT TERM

In the coming years, much of Sweden's new wind power capacity will be in forested areas and in northern Sweden; high wind potential, as estimated by Swedish wind mapping, has sparked interest in these regions. However, there is significant uncertainty surrounding the energy capture and loads of turbines in forested areas. Upcoming research projects hope to increase the knowledge of wind shear and turbulence in these areas. The research programs Vindval, VindEL, and the SWPTC will continue during 2018.

References

Opening photo: Wind turbine supplying electricity to Sweden (Credit: Per Westergard)

[1] www.energimyndigheten.se/en/ (English)

[2] www.energiforsk.se/program/vindforsk/ (Swedish)

[3] www.naturvardsverket.se/vindval (Swedish)

[4] www.chalmers.se/en/centres/SWPTC/Pages/default.aspx (English)

[5] http://www.energimyndigheten.se/forskning-och-innovation/forskning/fornybar-el/vindkraft/program/vindel-programmet/

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