PROTOTYPE TURBINE AT SWPTC WITH WOODEN TOWER FROM MODVION ON BJÖRKÖ (GOTHENBURG), NACELLE HEIGHT 30 M, ROTOR DIAMETER 16 M. (SOURCE: MODVION).

SWEDEN

In 2020, Sweden installed 1,403 MW of new wind energy capacity (1,588 MW were installed in 2019). At the end of the year, the country's total installed capacity was 10,084 MW from 4 333 wind turbines.

ANDREAS GUSTAFSSON and PIERRE-JEAN RIGOLE, Swedish Energy Agency, Sweden.

Through the EU burden-sharing agreement, Sweden has a goal of greenhouse gas emission reduction of 40% in 2030 in relation to 2005 levels. 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% 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

TABLE 1. KEY NATIONAL STATISTICS 2020: SWEDEN

Total (net) installed wind power capacity*	10.1 GW
Total offshore capacity	0.2 GW
New wind power capacity installed	1.4 GW
Decommissioned capacity (in 2020)	0 GW
Total electrical energy output from wind	27.5 TWh
Wind-generated electricity as percent of national electricity demand	20.2%
Average national capacity factor**	31.2%
Target	30 TWh
National wind energy R&D budget	5.86 MUSD

*Installed wind power capacity: Use nameplate power ratings of the installed wind turbines.

Average national capacity calculation. Only include turbines in operation the whole year: **(MWh production/8,760 hrs) / MW installed capacity MWh total electrical production from wind turbines operating 1 January through 31 December divided by 8,760 hrs divided by the total installed wind capacity (in MW) at the beginning of the year. [You can also use an estimate based on the average installed capacity during the year: (installed 1 Jan + installed 31 Dec)/2. But in that case, state that this is how the estimate is calculated.]

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 programmes. The overarching goal 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

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 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.

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

Since 2003, Sweden has 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 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. 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.

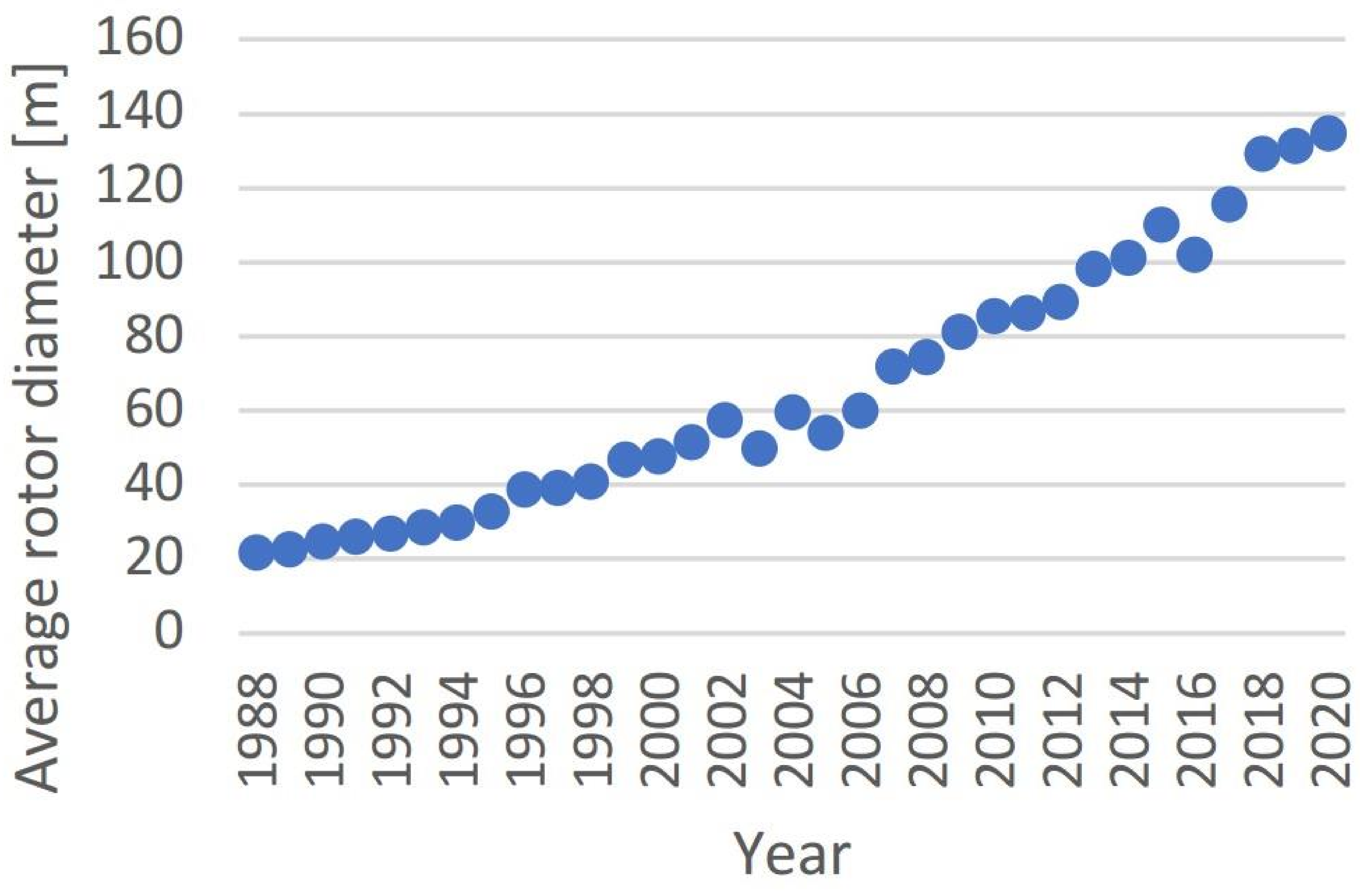


FIGURE 1. ROTOR DIAMETER TREND

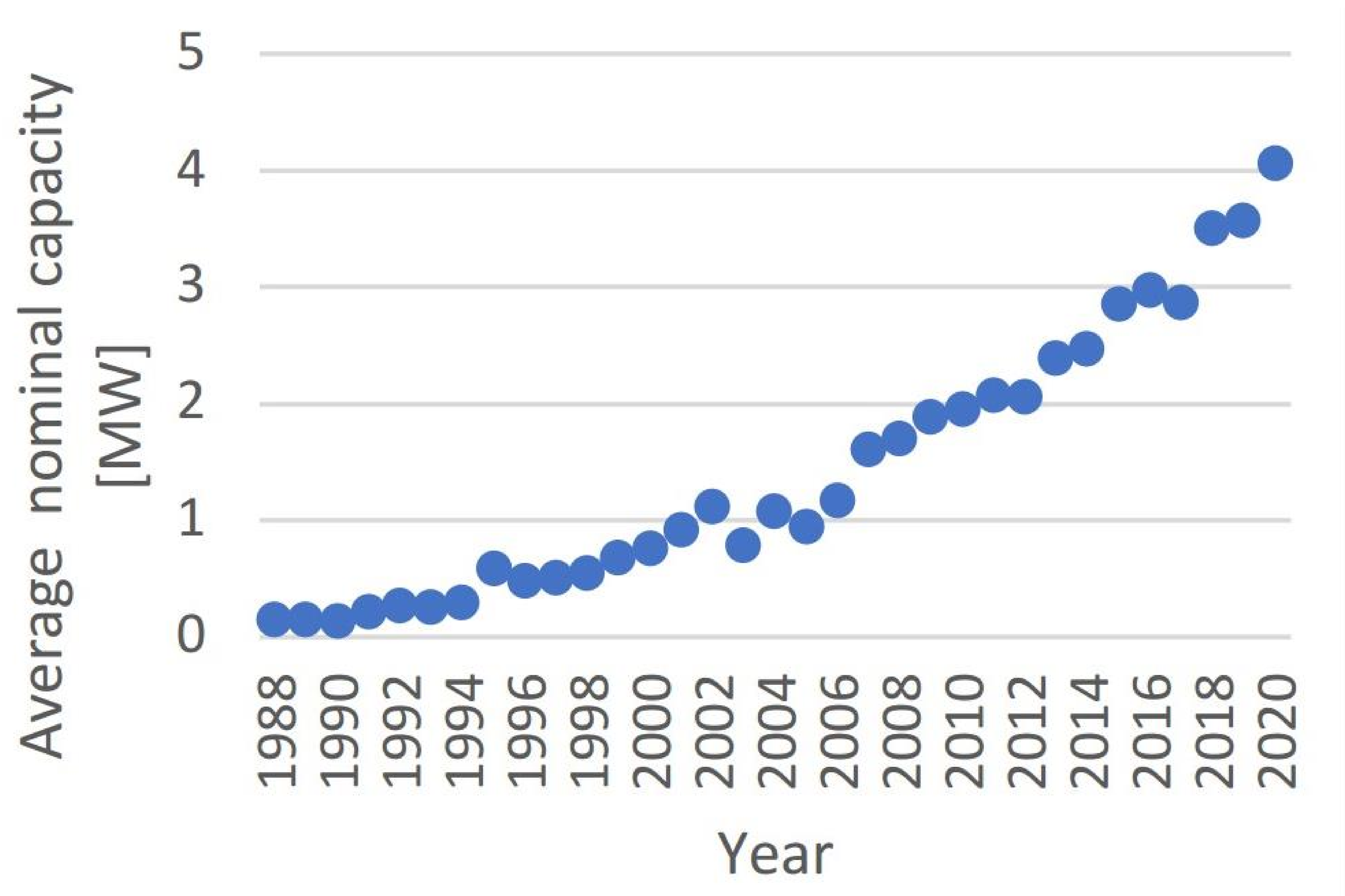


FIGURE 2. NOMINAL CAPACITY TREND

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 and operational details

In 2020, 357 turbines were commissioned with an average nominal capacity of 3.9 MW. All of them were onshore. During the year, the phase 1 of the Markbydgen Wind Farm in Piteå Municipality was completed. It consists of three different areas with a total of 283 turbines (2.3 MW, 3.6 MW and 4 MW) for a total of 956 MW. 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 of the size of turbines as shown in the figures below. Based on available data from 203 turbines [2], the average rotor diameter of installed turbines during 2020 was of 135 m with a nominal power of 4.1 MW.

Matters affecting growth and work to remove barriers

- Permitting and initiative to make it more predictable. The permit process is Sweden is long (about ten years) and the outcome has been described as unpredictable. The Swedish Government has launched an investigation to increase the predictability of the permitting process for wind power [3].

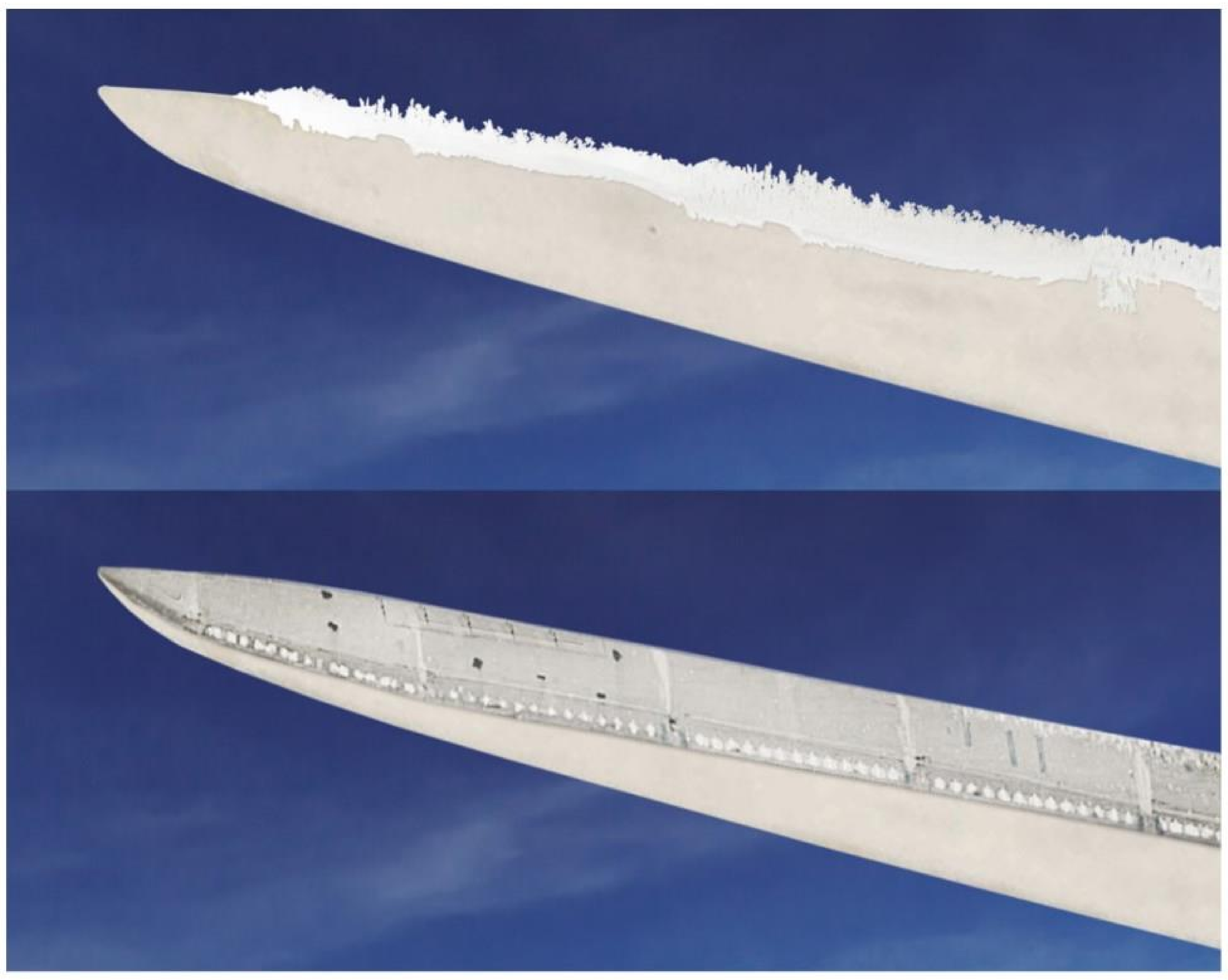
> The installed wind power capacity growth during 2020 has been 1.4 GW despite significant delays due to the pandemic.

- Grid limitation—there is an urgent need for grid investment in Sweden to avoid limiting 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.

- Sweden experienced for the first time negative prices, Minus 0,2 EUR per MWh, for electricity on the Nordpool electricity market. This happened for a short time during the night of 20 February and is a consequence of overproduction of renewable energy. Overall, electricity prices are low in Sweden which puts pressure on the electricity producers.

- The green certificate price in Sweden has varied, but has shown a clear trend of erosion due to supply exceeding demand. In practice, new installations of wind power are without subsidies. This is a good deal for the consumers in terms of their electricity bills, but has of course a large economic impact for 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 actions. There will be no new allocations after 2021 and the support scheme will end before planned in 2035 [4].

- The government commissioned the Swedish Energy Agency to investigate potential ways to eliminate



ANTI-ICING SYSTEM MANUFACTURED BY LINNOVATION AB. THE EQUIPPED TURBINE BLADES ARE TOTALLY ICE FREE AND PRODUCTION IS NORMAL. ON THE NON-EQUIPPED TURBINE, THE ICE BUILD-UP STOPS PRODUCTION. (SOURCE: LINNOVATION AB)

grid connection costs for offshore wind power during 2017. The government has invited different organization for referral of the report during 2018, but there has not yet been any decision regarding the two different models that were suggested by the Swedish Energy Agency.

- In 2018, the Swedish Environmental Protection Agency and Swedish Energy Agency have taken the initiative to prepare a common strategy for a sustainable wind power expansion in Sweden. The goal is to produce a roadmap for wind power expansion that facilitates municipal planning and local and regional permit processes, and that 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 greatly to the deployment of wind power in Sweden as the target is 100 TWh wind power.
- In December 2019, the Swedish Agency for Marine and Water Management released a report on a proposal of sea use in Sweden [6]. The proposal provides a map of the utilization of the sea around Sweden for various uses: fishing, shipping, defence, energy production, culture, sand mining, 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.

R,D&D activities

In 2018, the Swedish Energy Agency adopted a wind

> Sweden surpassed 10 GW installed wind capacity and 20% share of wind in electricity consumption

energy strategy with three prioritized areas: Resource-efficient wind in Swedish conditions, wind power in society and environment, 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 and budget

Three research programmes carried out publicly funded wind energy research in 2020: Vindval, Swedish Wind Power Technology Centre (SWPTC), and VindEL. All three programmes were under the supervision of the Swedish Energy Agency.

Vindval [7] is a research programme focused on studying the environmental effects of wind power. The programme 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 for the implementation of the new phase of Vindval which focuses on wind power and spatial planning. The programme extends through December 2021.

The Swedish Wind Power Technology Centre (SWPTC) [8] is a research centre that focuses on optimizing wind turbine design taking into account the interaction between all components. The centre 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 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 programme 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 programme focuses on finding technical solutions within the three priority areas defined in Sweden's strategy for wind power:

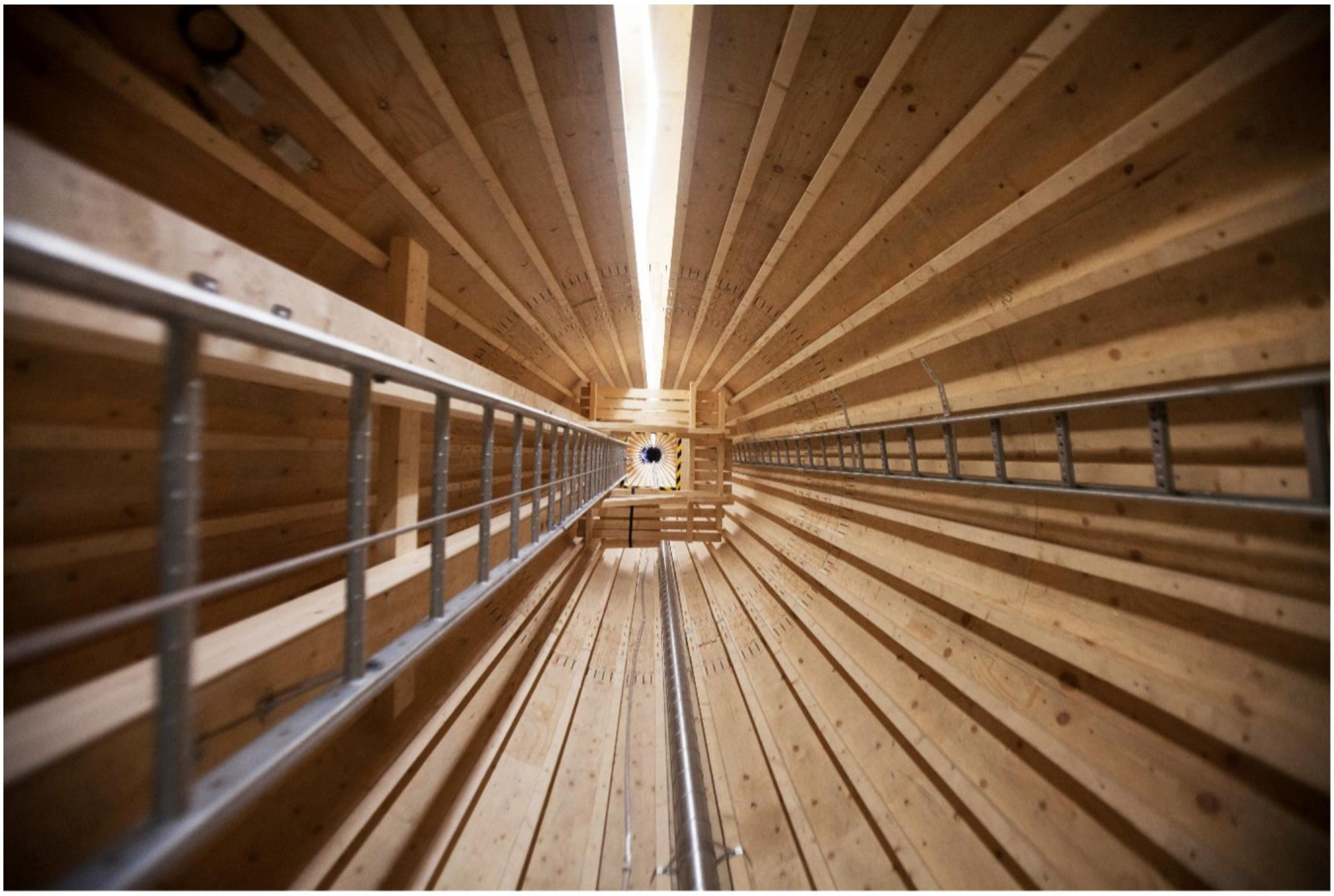
- Conflicts of interest and competition for land use both on land and at sea
- Resource-efficient wind power in Swedish conditions with minimized environmental impact
- Robust electricity grid with high security of supply requires new solutions and incentives

National research initiatives and results

Frequency services from wind power in the Swedish 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 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 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 programme VindEL
Modvion is a company developing a modular tower in laminated wood. They erected a 30 m tower in April this year. Their wood tower offers a lower cost, 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 significantly to making wind power more sustainable. In 2020, Modvion was awarded a multi-million EUR grant from the EU EIC Accelerator programme. The funding will be used to build the first commercial 100 m wooden turbine tower.

Lindskog Innovations – Supported by the research programme VindEL
Lindskog Innovations has developed a de-icing system that offers superior performance compared to existing solutions and can be retrofitted to turbines lacking de-icing systems. The solution is based on knitted copper wire that is both efficient and robust. The system now meets TRL level 7, at least. Productization of the components has enabled starting up serial



INSIDE VIEW OF THE 30 M WOODEN TURBINE TOWER FROM MODVION ON BJÖRKÖ (GOTHENBURG) (SOURCE: MODVION).

production and customizing the system for future customers.

Research programme Vindval – Environmental and Social Impact

The research programme Vindval finances four projects [12] on regional and national planning of wind power in Sweden and management of conflict of interests. These projects develop methods for finding good locations for wind power both on-shore and off-shore that minimize negative impacts on humans, animals, and nature. They address the challenges of the planning stage for a large deployment of sustainable wind power (80-120 TWh) in Sweden.

Test facilities and demonstration projects

In 2019, RISE Research Institutes of Sweden and Skellefteå Kraft established a test centre in Uljabuouda in Arjeplog. The test site will provide an opportunity to build wind turbines or other types of energy generating equipment up to a height of 330 metres for testing [13]. Here, the global wind industry will be able to test their wind turbines and other equipment in cold and icy conditions. No large demonstrations were initiated in 2020.

Collaborative research

In 2020, Swedish researchers 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 26 – Cost of Wind Energy
- 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, CO2 emissions from electricity production are relatively low because hydro, nuclear, bio, 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 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 [14], investments in wind power in Sweden (both committed and notified projects) between 2017-2023 will total 100 billion SEK (10 billion EUR). The investments will create a total of 7,832 annual jobs for construction and 12 397 for operation and maintenance. Another economic impact is lower electricity prices (minus 0,088 SEK/kWh) that create a total value for the users of 12.3 billion SEK.

> Towards 2024 the installed power is expected to reach above 16 GW nearly a doubling compared to 2019.

Next term

Based on current planned and in-construction projects, Sweden will reach more than 40 TWh by 2023, which will be 25% of the electricity production in Sweden. The installed power will reach above 16 GW, nearly a doubling compared to 2019.

Looking at the coming years, much of the focus for wind power in Sweden is expected to turn to offshore and joint production with hydrogen. Much of the deployment will be 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 offer challenges, but also opportunities for developing Baltic Sea wind solutions that further bring down the cost of offshore. All the research programmes Vindval, VindEL, and SWPTC address these challenges and opportunities.

References

List any references used directly in the text of the chapter.

- *DO NOT use automatic footnotes, formatting, or automatic numbering in MS Word. They become lost during the text translation process for layout; texts containing automatic numbering will be returned to the author for revision.*
- *Place the numbered reference at the end of the sentence in brackets [1]. For example, "…The Ministry of Economic Affairs finalized the Connect 6,000 report in May 2008 [1]."*
- *Use the following format for citation under the reference heading: [1] Author (year) Title of report or document.* Download from (provide website link).

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