THE BÅTSKAR WIND FARM IS THE FOCUS OF A MEASUREMENT CAMPAIGN IN PROJECT TUTTE, AIMING AT UNDERSTANDING THE WIND INFLOW AND WAKE INTERACTIONS. THE WIND FARM IS BUILT ACROSS FOUR ISLETS IN ÅLAND ISLANDS. PHOTO CREDIT: MANU HUTTUNEN

FINLAND

Year 2020 was remarkable for wind energy. Amidst the pandemic, installations continued to grow and higher-than-normal wind conditions took the wind share to 9.6% of electricity consumption [1].

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Wind power in Finland has rapidly consolidated an unsubsidized model. All the wind power projects that completed in 2019 and 2020 were constructed without subsidies, and more are under construction.

New wind power of 302 MW capacity was installed in Finland. By the year's end, installed wind power capacity amounted to 2,586 MW with 7.8 TWh of production—a 30% increase from 2019. Renewables provided about 42% of the country's electricity consumption in 2020:

TABLE 1. KEY NATIONAL STATISTICS 2020: FINLAND

Total (net) installed wind power capacity*	2.586 GW
Total offshore capacity	0.073 GW
New wind power capacity installed	0.302 GW
Decommissioned capacity (in 2020)	0 GW
Total electrical energy output from wind	7.8 TWh
Wind-generated electricity as percent of national electricity demand	9.6%
Average national capacity factor**	35%
Target	51% RES in 2030
National wind energy R&D budget	2.58 million EUR (2020

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

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.]

19.3% from hydropower, 12.4%from biomass, and 9.6% from wind power.

In 2020, Finland consumed 81 TWh of electricity, the lowest value since 2009. Peak demand was 12.7 GW. Electricity consumption went down by 5.2 TWh, the largest drop since 2011. The decrease was influenced by the warm winter and lower consumption in industry.

Carbon emissions from power generation in Finland totaled only 63 g CO2/kWh [1]. The value has dropped 70% in the last decade (Figure 1).

Market development

Targets and policy

- As part of the EU's 20% target, Finland's renewable energy source (RES) goal is 38% of the final energy consumption by 2020. The target was achieved in 2020 reaching precisely 38% [3]. Finland exceeded the target for the first time in 2014.
- The new target sets a 51% share of RES of the gross final energy consumption for Finland in 2030. In connection with this target, the estimated share of

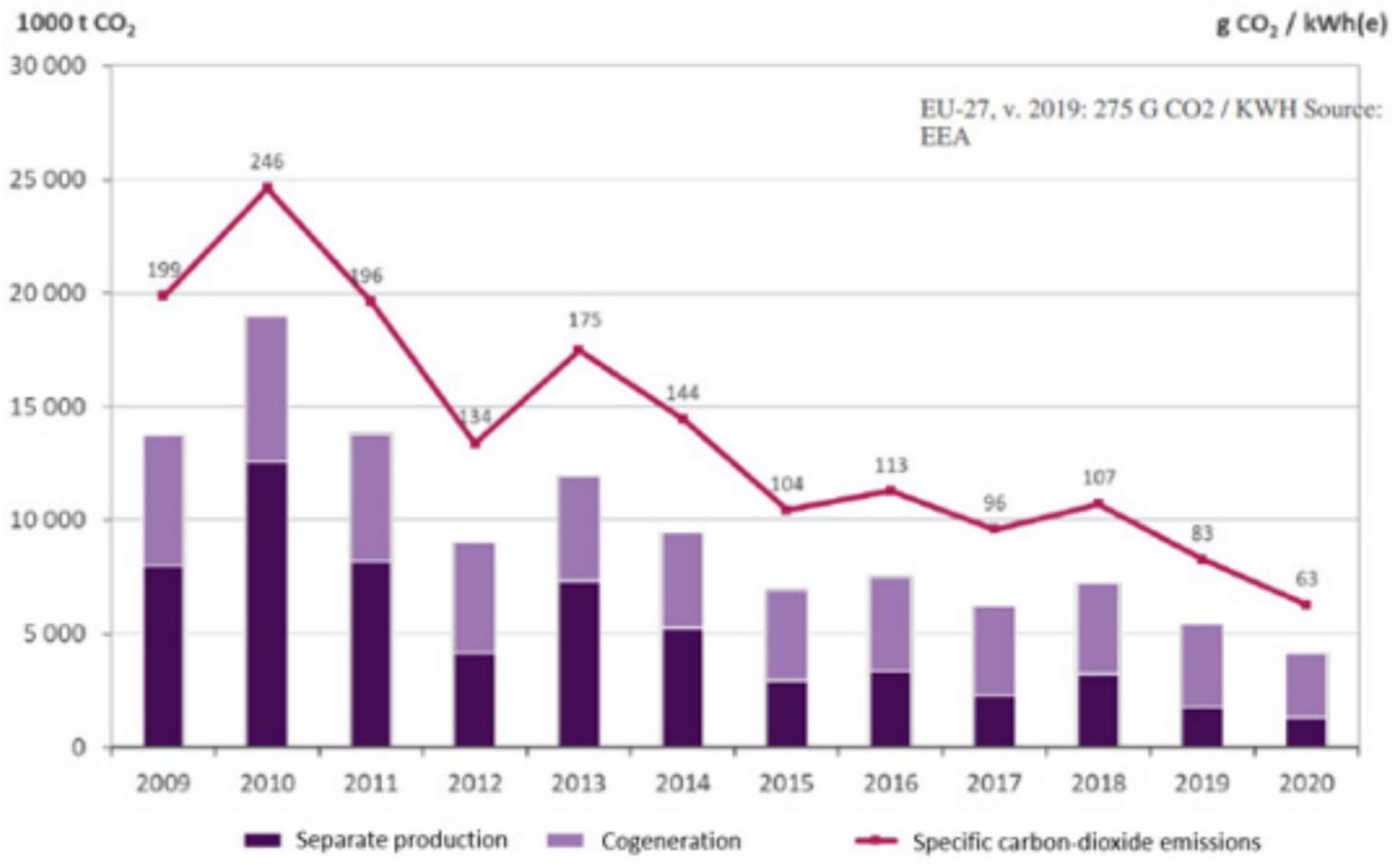

FIGURE 1 SPECIFIC CARBON-DIOXIDE EMISSIONS IN ELECTRICITY GENERATION CONTINUED TO DROP IN 2020 [1]. THIS YEAR, RENEWABLE ENERGY SOURCES CONTRIBUTED WITH 51% OF DOMESTIC ELECTRICITY DEMAND. WIND SHARE CONTINUED TO INCREASE.

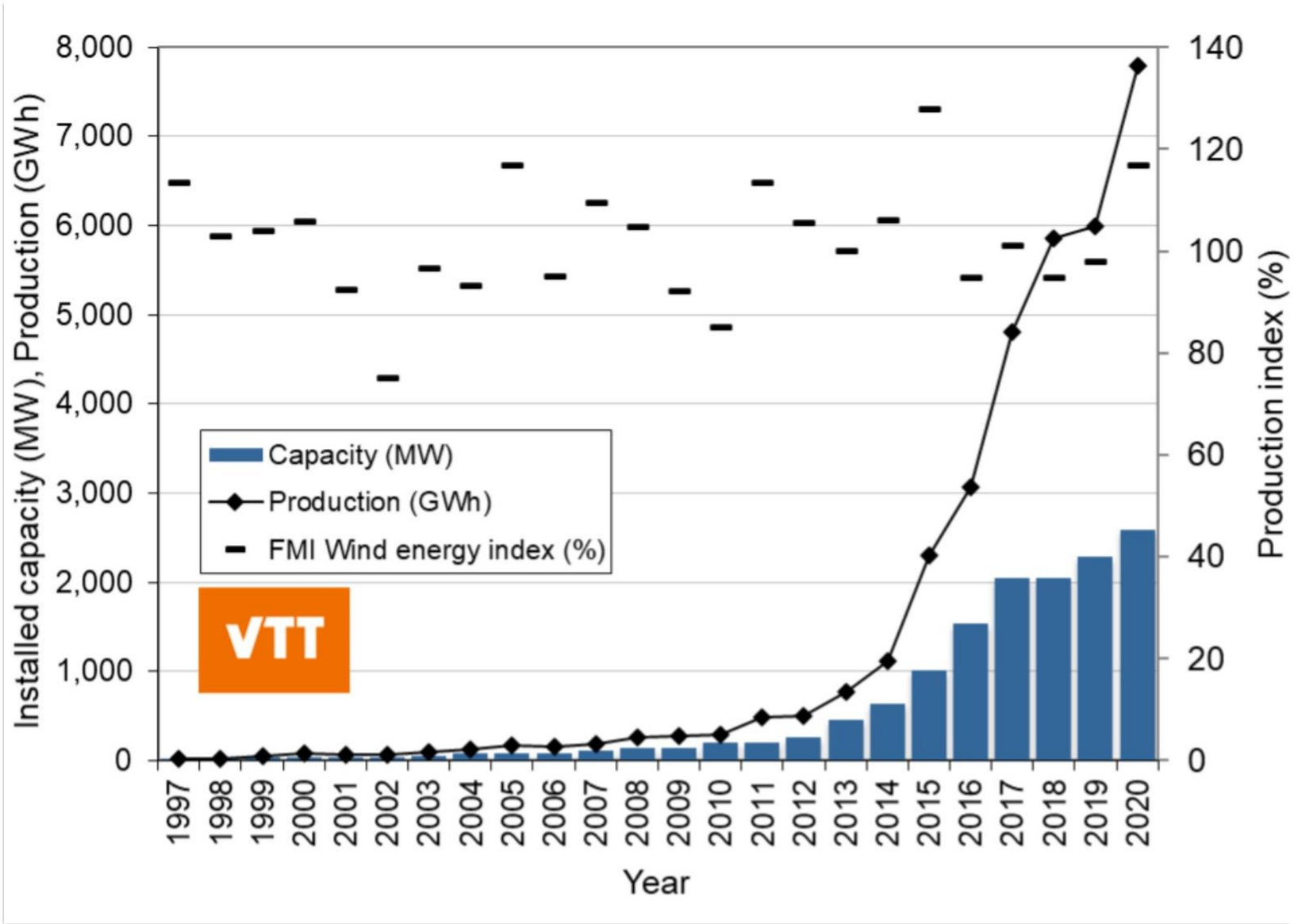

FIGURE 2 DEVELOPMENT OF WIND POWER CAPACITY AND PRODUCTION IN FINLAND. PRODUCTION INDEX GIVES THE YEARLY GENERATION COMPARED TO LONG-TERM AVERAGE (100%), BASED ON FINNISH METEOROLOGICAL INSTITUTE (FMI).

electricity consumption from renewables (RES-E) would increase from 41% in 2020 to 50% in 2027 and 53% in 2030 [4].

> 9.6% of national electricity demand was met by wind in 2020 [1].

- Finland's wind power goal for 2020 was 6 TWh/yr, set by the 2008 Climate and Energy Strategy. The country produced 7.8 TWh of wind-generated electricity, significantly exceeding its target. The substantial 30% year-on-year increase is due to the 14% more installed capacity, and the exceptional wind year with a production index of 117, meaning 17% over long-term average according to the Finnish Meteorological Institute (FMI).

- The Finnish government set an ambitious target reaching carbon neutrality already in 2035. There is no specific target on how the installed capacity of each technology will develop in the future. However, the estimated wind power capacity could reach 5.5GW in 2030 [4] assuming 3200 peak load hours (36.5% average capacity factor). It would be sufficient for Finland to continue adding capacity at the current rate of 0.3 GW/year during the decade 2021-2030 to reach this prediction and replace decommissioned wind.

- Looking further ahead to 2040, a government sponsored study [17] envisages a wind installed capacity in the range of 14 – 16 GW on the assumption of substantial electrification of the economy to reach the carbon neutrality target.

Progress and operational details

- Arguably Finland has achieved 'cruise speed' in wind power capacity additions in 2020 by installing 302MW new onshore capacity [4]. The figure envisaged by the Finnish government [4] of 5.5GW wind in 2030 translates into 320MW annual capacity additions for the decade 2021-2030, being enough to replace wind being decommissioned.Finland had in 2020 a pipeline of 3.6GW onshore wind capacity approved, which in principle is enough to reach the anticipated figure of 5.5 GW in 2030.

- Government supports wind power deployment by offering more leases in state lands for construction . The state-owned agency responsible for forests, Metsähallitus, administers more than 12 million hectares of state land and water areas [5].

- In 2020 already 51% of domestic electricity generation came from renewables (up from 47% in 2019) [1]. This high value has been largely the result of a great wind year.

Matters affecting growth and work to remove barriers

- The trend toward a market-driven wind sector in Finland is underpinned by the success of the first

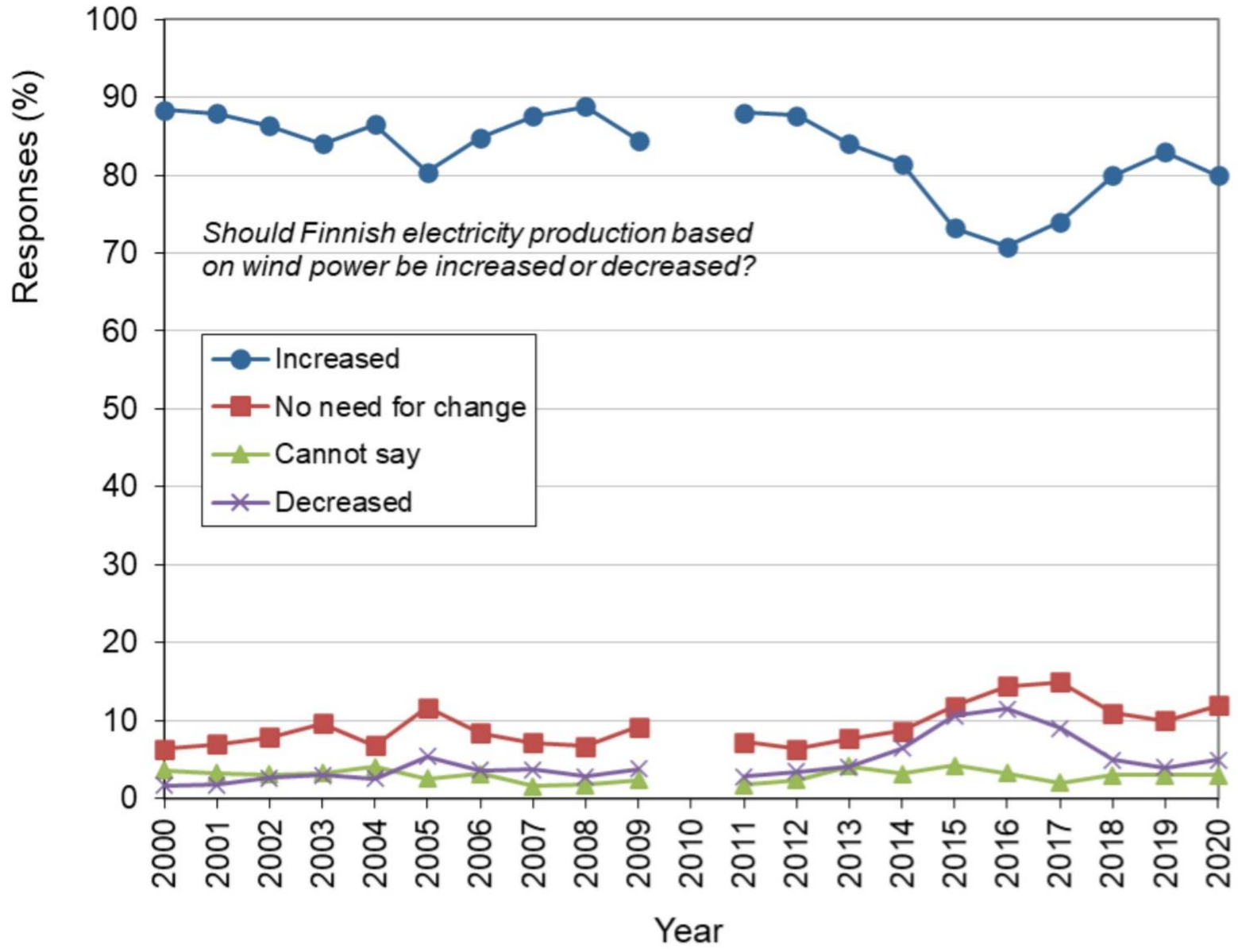

FIGURE 3 ATTITUDES OF FINNS TOWARDS WIND POWER HAVE BEEN COLLECTED BY ASKING WHETHER FINNISH ELECTRICITY PRODUCTION BASED ON WIND POWER SHOULD BE INCREASED OR DECREASED [9]. DATA FOR 2010 IS MISSING. THE FEED-IN TARIFF SCHEME CLOSED FOR NEW WIND POWER PROJECTS IN 2017.

competitive bidding scheme for RES and the fact that substantial wind development is in progress without subsidies. The progress is largely due to PPAs and large electricity consumers buying completed projects from developers.

- The impact of wind farms on radar systems is preventing some projects in Finland, especially in the Southeast, Eastern and Northern parts of the country. According to a law from 2013, turbines located in a certain area in the Bothnian Bay are ordered to pay a fee for compensating radar costs [7]. The grid capacity continues to limit new project development in some areas, where the project pipeline is large due to good wind conditions.

- The subsidies paid to the wind power producers in the support scheme depend on the electricity spot price and are funded from the state budget. The average spot price in Finland was 28 EUR/MWh (34 USD/MWh) in 2020. Government paid out a record 345 million Eur in subsidies to wind energy, due to a combination of windy conditions and low energy prices [7],[8]. On average government paid 44.2 EUR/MWh in subsidies in 2020.

- The feed-in tariff scheme closed for new wind power plants in 2017, and by 2030 the subsidy system will be phased out completely [7].

- Combination of high wind and low electricity demand drove down electricity prices to 28.02€/MWh, the lowest value since 2004, and a drop of 36% vs. previous year. This situation was caused by the high wind year, the warm winter, and the pandemic context [6].

- Electricity prices were negative three times. First time ever on 10th Feb due to high water reservoir levels and high wind power production as well as warm weather. The minimum was during 2nd Nov: -1.73 €/MWh.

- Public acceptance of wind power remains high (Figure 2). According to the 2020 annual survey on energy attitudes, 80% of Finns support increasing wind production capacity (83% in 2019) [9].

> Double-digit growth in wind installed capacity for second year in a row, with 302 MW new wind capacity.

R,D&D activities

National R,D&D priorities and budget

- The Finnish Funding Agency for Technology and Innovation, Business Finland (BF), continues to be

FIGURE 4 COMBINED MEASUREMENTS OF WIND, ATMOSPHERIC DATA, AND BLADE LOADS ARE KEY TO BETTER MODELLING OF INFLOW AND WAKES, AND ONE OF THE KEY OUTCOMES OF ONGOING TUTTE PROJECT (2020-2022). THE PICTURE SHOWS ONE OF THE MEASUREMENT STATIONS IN TUTTE INSTALLED IN A FINNISH WIND FARM (SOURCE VTT).

the main public funding organization for research, development, and innovation in the country. Being a change agent for sustainable business is one of the current strategic priorities. BF supports new business from idea to commercialization, having a focus on the export potential of Finnish companies.

- Business Finland's new strategy for 2025 supports wind energy, which is aligned with the following themes:
  - o Cleantech, circular economy, and bioeconomy: innovative solutions and services to support sustainable businesses.
  - o Digitalization: creating a competitive advantage as a global innovation and technology leader
- Since 1999, Finland has not had a national research programme for wind energy. Instead, Business Finland funds individual industry-driven projects. National R&D funding supports individual SMEs and large companies, but also increasingly Ecosystems which integrate industrial and academic partners.
- The public funding level for wind power R&D projects in 2020 was around 2.28 million EUR (3.15 million USD) according to Business Finland, the largest investment since 2013.

Projects currently under construction increased by 81% vs 2019 to a pipeline of 2.4 GW [2].

National research initiatives and results

In 2020 wind research in Finland continued in the topics of characterization of environmental aspects affecting wind operation (atmospheric icing, wind resource forecasting), and exploring wind farm flow in connection with production optimization.

- A research project [10] aimed at assessing whether wind turbine infrasound has harmful effects on human health. A questionnaire study, sound measurements, and provocation experiments were conducted. The participants who had previously reported wind turbine infrasound related symptoms were not able to perceive infrasound in the noise samples and did not find samples with infrasound more annoying than those without previous wind turbine infrasound related symptoms. Further, wind turbine infrasound exposure did not cause physiological responses.
- A study [11] mainly funded by VaGe project and partly by the Strategic Research Council was conducted to improve probabilistic forecasts for weak and moderate winds by utilizing statistical

methods and new types of wind observations in the development of weather models.

- A study evaluating atmospheric icing forecasts, relevant for wind power, with ground-based ceilometer-measurements was conducted [12].

- R&D on Probabilistic forecasting of spatially aggregated wind power generation was started and will continue in 2021 as part of HOPE (Highly Optimized Energy Systems) project funded by Business Finland. Further, R&D on Estimating thrust coefficients of a wind turbine for wake effect calculation was conducted as part of BC-DC project.

- The Baltic Offshore Wind ecosystem [16] continues as an industrial ecosystem with 10+ companies promoting the deployment of offshore wind in the Baltic.

Test facilities and demonstration projects

- TUTTE project (wind power production and efficiency) started in 2020, with the objective of researching new methods for wind flow observation (inflow, wake) in connection with production optimization of wind farms.

- Gearbox manufacturer Moventas and VTT joined forces with European partners in project INNTERESTING [13], aiming to build up a virtual prototype and testing method for a next generation gearbox concept featuring hydrodynamic plain bearings. This gearbox concept enables to increase the load carrying capacity with less material spend, resulting in a lighter gearbox.

Collaborative research

- VTT is active in several EU, Nordic, and IEA research project frameworks. Within the IEA Wind TCP, Finland takes part in:

  - Task 11 Base Technology Information Exchange, which produces valuable information in identifying issues important for wind R&D in Finland

  - Task 19 Wind Energy in Cold Climates (Operating agent VTT): Finland has a national interest in addressing the challenges of adapting wind energy to cold climate. The Task has been instrumental to the deployment of wind energy in harsh environments.

  - Task 25 Design and Operation of Energy Systems with Large Amounts of Variable Power (Finnish organizations VTT and Recognis serve as co-operating agents).

  - Task 28 Social Acceptance of Wind Energy Projects: Acordi has participated in the task and facilitated workshops on the topic of social acceptance.

  - Task 36 Forecasting for Wind Energy: Vaisala is a lead provider of weather instrumentation, and the Finnish Meteorological Institute conducts research related to wind forecasting (e.g., in Business Finland project HOPE), and is responsible for operational numerical weather prediction and model development as part of joint international efforts (MetCoOp).

  - Task 46 Erosion of wind turbine blades. Finland serves as co-operating agent in this new task approved in 2020.

Impact of wind energy

Environmental impact

- Wind energy is flagged by Finland's Integrated Energy and Climate plan as a contributor to the decarbonization of the energy system, together with nuclear energy. The Finnish government plan anticipates in the With Additional Measures (WAM) scenario, that Wind energy will continue to grow its share of electricity generation to reach approximately 20% of electricity demand in 2030. In connection with this scenario, the government estimates a future wind installed capacity of 5.5GW[4].

Economic benefits and industry development

- According to a survey, the economic benefits of the approximately 2,000 MW of wind power capacity built in Finland by 2018 are substantial [14]. During the entire life cycle, the wind power projects will bring a turnover of 12.6 billion euros (14.1 billion USD) in Finland, of which 5.5 billion euros (6.2 billion USD) come directly from the value of the sold electricity during the operational phase. The tax revenues are estimated to be 3.4 billion euros (3.8 billion USD), including 1,573 million EUR (1,766 million USD) value added tax, 639 million EUR (718 million USD) municipality tax, 400 million EUR (449 million USD) real estate tax.

- The employment impact of the current Finnish wind power fleet over its lifetime (20 years) was estimated to be around 2600 full time equivalent (fte) employment years directly, and 53,200 fte employment years indirectly in industries other than wind power[15].

Next term

A total of 302 MW of wind power projects were completed in 2020 and 2432 MW of capacity were

under construction and to be completed in 2021 – 2023, with no subsidy involved.

Offshore wind plans continue moving forward, with 2GW capacity having completed the Environmental Impact Assessment (EIA). Suomen Hyötytuuli, the operator of the first offshore wind farm commissioned in 2017 is studying an extension by 500-700MW, which could be online in 2025 [18]. Further, a new offshore wind farm in Korsnäs is performing the EIA for a 1400 MW wind farm, which could be online in 2028 [19].

Over the next decade this will result in a total installed capacity of 5.5GW wind [4]. The Finnish government drive towards carbon neutrality in 2035, together with the advent of green hydrogen and its potential synergy with maritime transport may contribute to push the objectives towards more ambitious targets.

> Electricity generation from RES now represents 42% of domestic electricity demand [1].

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