Wind power in Finland and globally – Introduction to wind power

PHYS-E6572 Advanced Wind Power Technology

Hannele Holttinen

7.9.2022

Purpose, materials

- Purpose of the course: give basic information about wind energy and wind turbines
  - Mainly for the viewpoint of developing wind power projects
- Lectures contain all that is needed for passing the course
  - Some lectures have additional material to give a bit more information
  - No assignments, no calculus - no formulas/exercise in the exam
- Background materials: these are not compulsory, only if you find the lectures difficult to follow and need some basic information
  - WExLaB (windext project) videos https://www.youtube.com/channel/UCMj6aqB-Jvv5EuViDnG5PtQ/videos
  - Guided tour / Reference pdf of (older) web material (Background.pdf)
  - ''Wind Energy Engineering'' by Letcher-2016
  - ''Wind Energy-Renewable Energy and the Environment'' by Nelson-2009
  - Wiley: Wind Energy Handbook, 3rd Ed 2022 (not open source – good for more details in aerodynamics, load cases and design)

CONTACT FOR COURSE QUESTIONS: ASSISTANT Vahid <vahid.arabzadeh@aalto.fi>

Lecture	Content	Lecturer
7.9.22 Wed remote	Introduction to the course and wind power. Wind power globally and in Finland, status, development and market forecasts.	Hannele Holttinen, Recognis
16.9.22 remote	Wind power meteorology. What is wind – profiles, distributions, turbulence. Temperature, stability, icing. Estimating wind resources, wind measurements.	Hannele Holttinen, Recognis
23.9.22	Wind turbines. Wind turbine aerodynamics. Wind turbine systems: Drive train. Yaw system. Pitch system. Electrical system.	Timo Karlsson, VTT
30.9.22	Loads & Control. Design load cases. Certification and Standards. Components: Hub, Nacelle, Tower	Timo Karlsson, VTT
7.10.22	Wind power project I – resource estimation and planning (Tuulivoimahankkeen suunnittelu).	Esa Holttinen, AFRY
14.10.22 remote	Wind power project II – economy and financing; building process (Tuulivoimahankkeen toteutus)	Esa Holttinen, AFRY
(21.10.22)	(no lecture)	
28.10.22	Wind power project: planning procedures and environmental impacts (Tuulivoimahankkeen ympäristövaikutukset ja lupamenettely.)	N.N.
4.11.22	Wind turbine noise: measurements, modeling, and annoyance (Tuulivoimalamelu: mittaaminen, mallintaminen ja häiritsevyys)	Valtteri Hongisto, Turku AMK
11.11.22	Arctic wind power. Measurements. Condition monitoring, Reliability. Operation & Maintenance. (Arktinen tuulivoima, jäätyminen. Mittaukset. Kunnonvalvonta, luotettavuus, huolto.)	Timo Karlsson, VTT
18.11.22	No lecture	
25.11.22	Network connection of wind farms (Sähköverkkoon liittäminen)	Sanna Uski, Despro
30.11..22 Wed	Wind power impacts on energy systems: variability & uncertainty; impacts on balancing, stability and capacity adequacy (Tuulivoima energiajärjestelmässä: tuotannon vaihtelut, tuotannon ennustaminen, vaikutukset sähköjärjestelmään.)	Hannele Holttinen, Recognis
2.12.22 3 hours	Wind turbine upscaling. The square-cube law. Wind turbine trends, Grand challenge of Wind energy science. (Turbiinikoon skaalaus. Teknologiatrendit) Summary of the course - main take-aways (Yhteenveto)	Hannele Holttinen, Recognis

History
Drivers and barriers

Electricity from wind, history

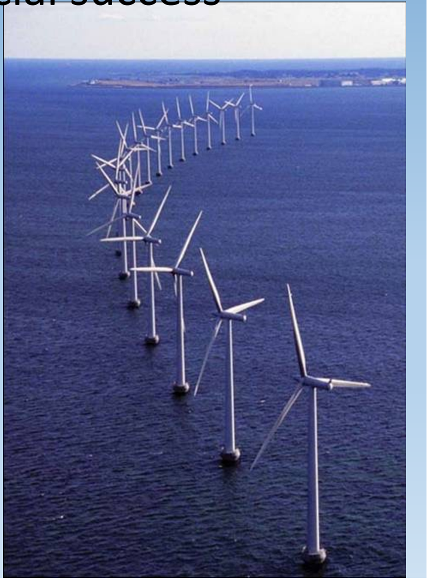
wind turbine driving a DC dynamo in 1891

1940-50

1980-1985
California wind rush
55 kW machines

History of modern wind power

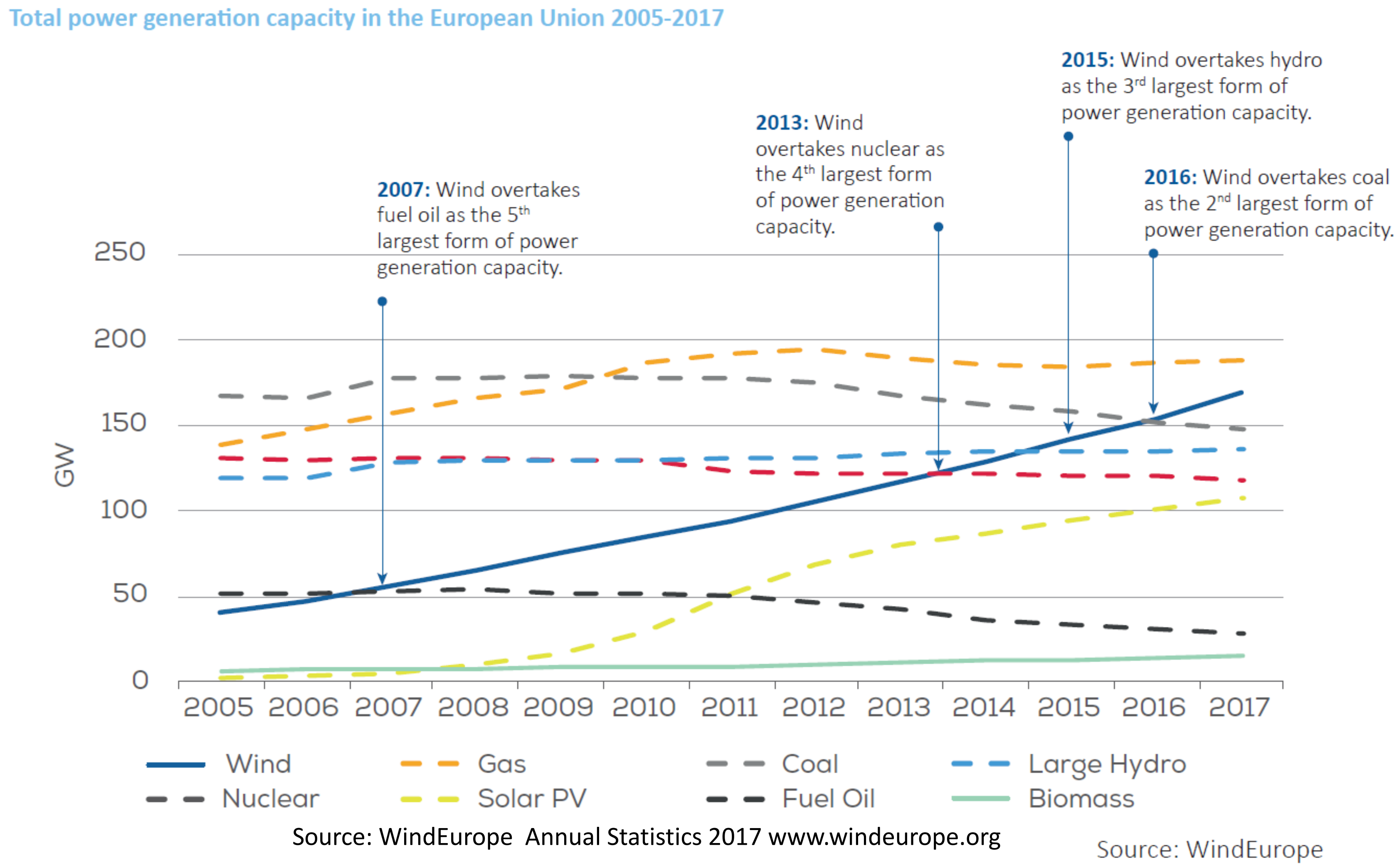
- 1970's: small pioneering companies. Started by 10-20 kW turbines, working slowly towards larger turbines
- 1980's:
  - Californian wind rush, 50-100 kW turbines → end of subsidies → most manufacturers bankrupt
  - Large (aviation)company MW demonstrations in Europe → no commercial success
- 1990's:
  - European demand for turbines starts
  - Denmark, the Netherlands, Germany
  - First offshore demos
- 2000's:
  - wind energy starts to be a significant part of electricity generation



Turbine technology start-up

- Early wind turbines 1970's and early 1980's borrowed heavily from agriculture, boat building, and aircraft design:
  - heavier (relative to their output); basic components often failed; structural loads little understood; availability (for operation) lower, need for O&M higher
  - turbines mechanically noisy, wind farm arrays not designed to minimise visual impact or wind shadow (wake effect).
- 3 bladed, horizontal axis, became the basis for the industry
  - Vertical axis turbines not cost effective in large turbines (more than 100 kW), more material for same rotor swept area, the benefits can be used in smaller machines (no yaw mechanism needed, possibility to place generator on ground)
  - Two bladed machines nearly vanished from the market, due to more disturbing visual impact, may be considered offshore

Towards the largest energy technology in Europe



2021:
236 GW wind

Source: WindEurope Annual Statistics 2017 www.windeurope.org

Status

Markets for

- onshore,
- offshore,
- cold climate,
- small wind turbines

Drivers and barriers

- Drivers/positive sides of wind power:
  - Positive environmental impacts: CO2 reduction targets
  - Decreasing dependence on fossil fuels
    - also hedge to increasing gas and oil prices
  - Increasing employment (in remote areas)
  - Property tax to municipalities where wind built

- Barriers/negative sides of wind power:
  - Planning, acquiring site permits: public acceptance, "NIMBY"
  - In some countries also grid permits has or is becoming a barrier
  - Negative environmental impacts of wind power
  - **Cost of energy** (CoE) has been higher than with conventional generation THIS HAS CHANGED TO BEING THE CHEAPEST NEW ELECTRICITY GENERATION TECHNOLOGY IN MANY MARKETS

Environmental impacts

+ No emissions or water use, safe
    - LCA emissions of wind energy ~7 gCO_2/kWh generated. Reduces emissions of electricity production: CO_2, SO_2, NOX, particles
    - Estimated benefits in CO_2 emission reductions: 800 gCO_2/kWh replacing coal (China); 300 gCO_2/kWh replacing gas; after little emissions left in electricity sector Replacing fuels from new electrification demand: electric vehicles, heat pumps, steel industry –for example replacing fuels in transport sector ~600gCO_2/kWh

- Visual impact in landscape
    - Much higher than for conventional power plants (per MWh)
    - + Wind turbines can be totally removed after use (e.g. 20-30 years)

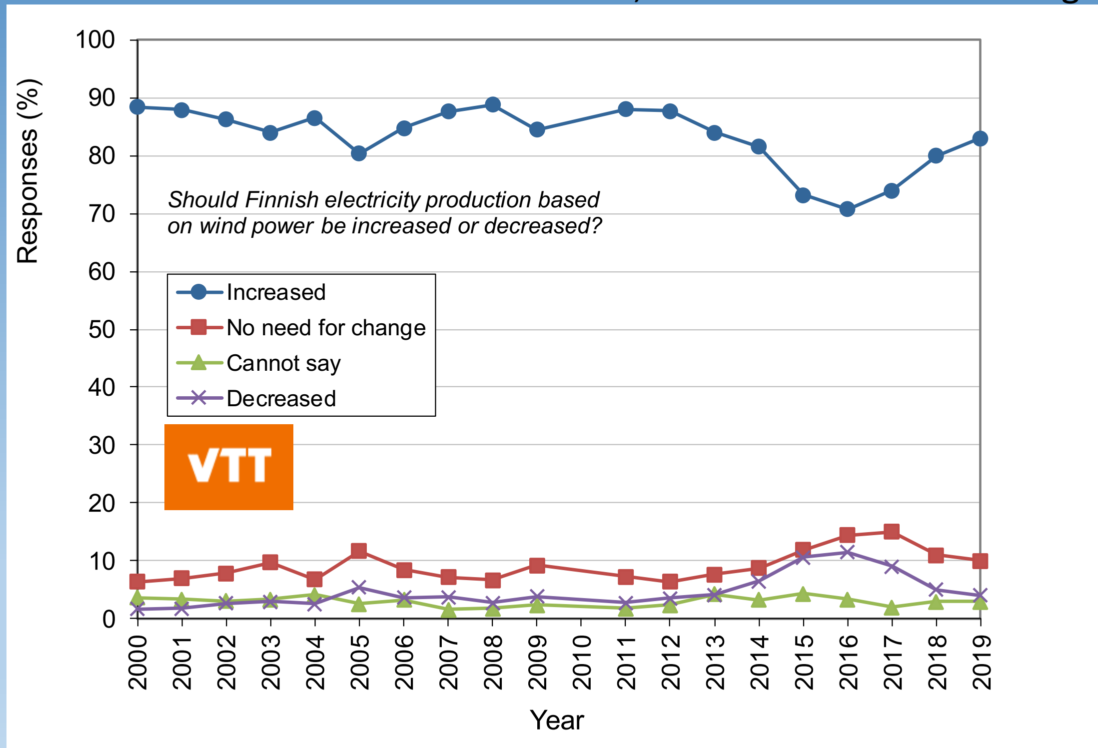
- Needs space 9-15 MW/km^2
    - + But only 2-3 % of this used by turbines and access roads, possible to use for farming, forestry etc.

- Closer to turbines:
    - noise, flicker
    - Impact on birds (and bats): sensitive sites should be avoided
    - Related infrastructure, e.g. roads & electricity network
    - Impacts during building phase

Public acceptance crucial for the many building permits needed for large scale deployment

- Even if general acceptance is high, local “Not-In-My-BackYard” NIMBY effect is strong.
- Often especially for first projects, but also as the amount of wind turbines in an area gets high

Year 2021: 81% for increase, 11% for no need to change

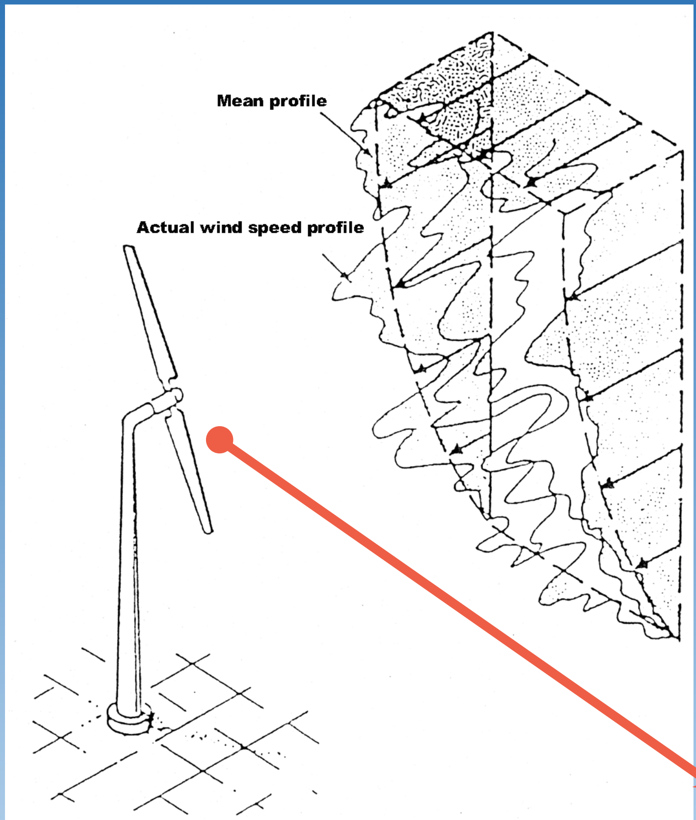


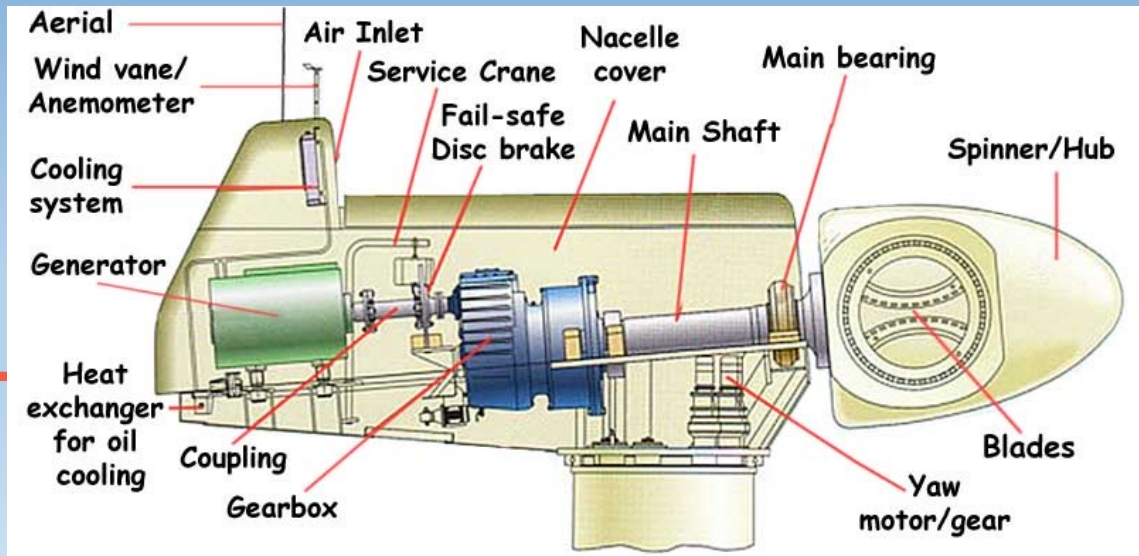
Data: Finnish Energy (ET)
https://energia.fi/jarjestona/tutkimus/energia-asenteet

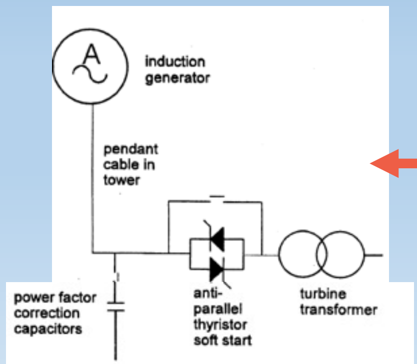
Wind turbines

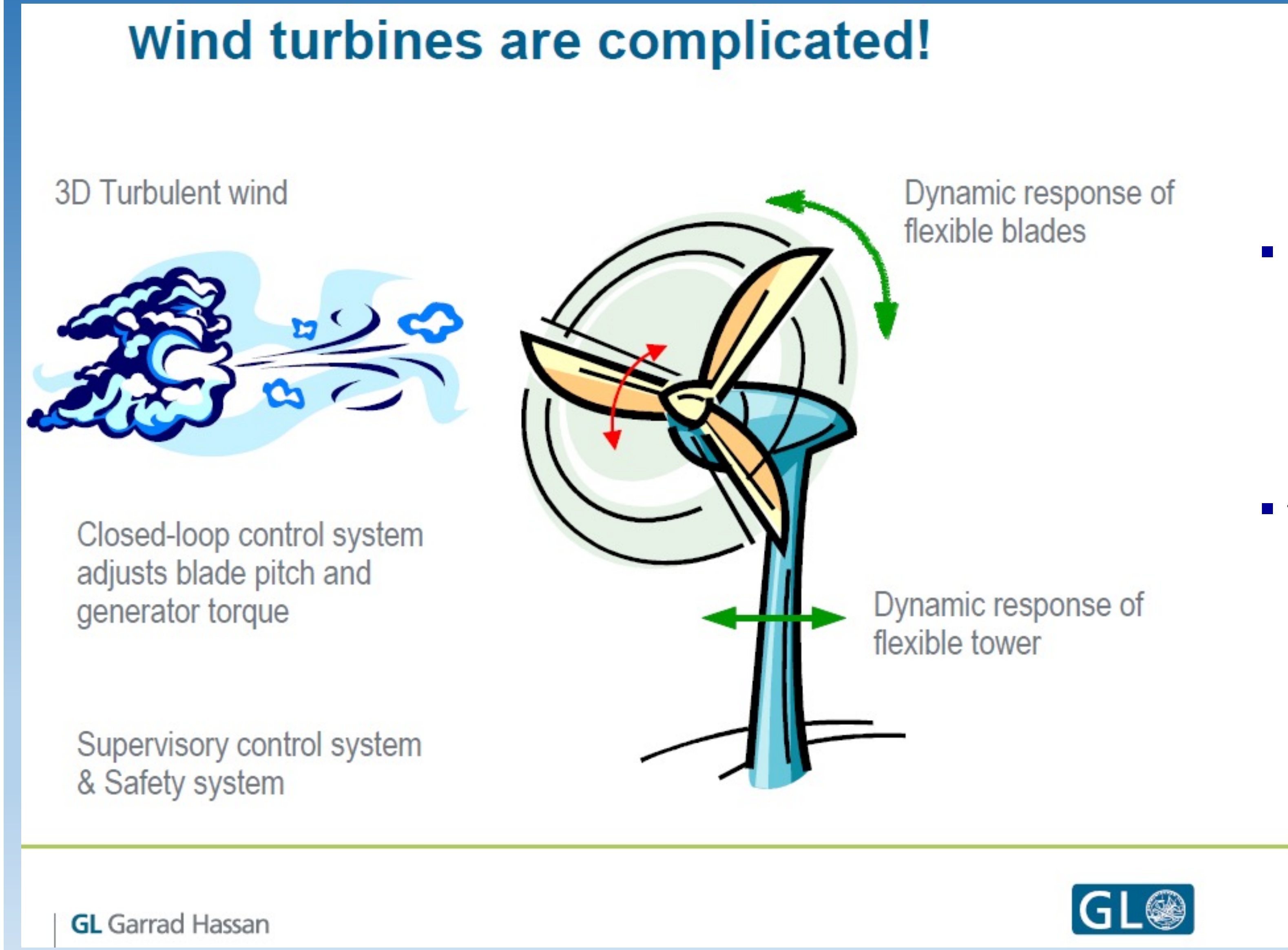
Wind power technology

- Need for:
  - Meteorology
  - Aerodynamics
  - Mechanical engineering
  - Material technology
  - Control engineering
  - Electrical engineering..



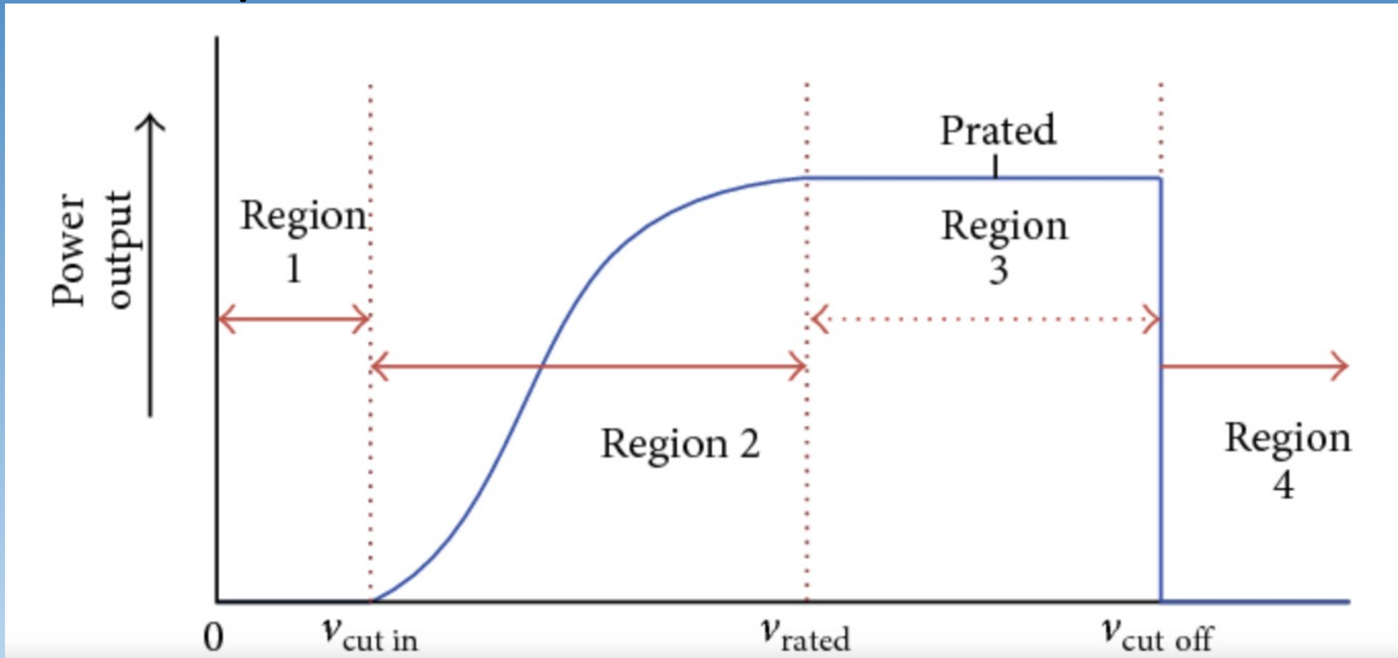






- Challenge/target:
  - Cost efficient structure
  - High reliability (maintenance 1-2 /year)
  - Long lifetime (20-33 years)
- to be achieved in varying conditions (over time, and at different sites)

Generating power from wind: Turbine power curve

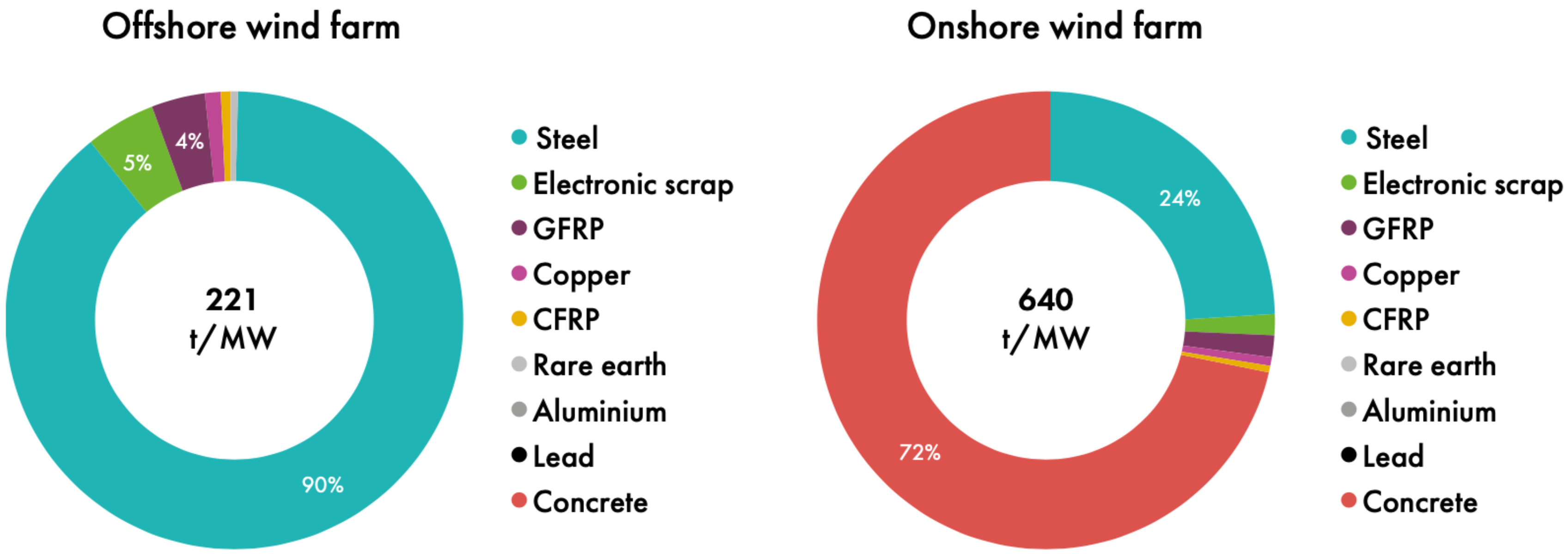


Source: Vaishali Sohoni, S. Gupta, R. Nema (2016) A Critical Review on Wind Turbine Power Curve Modelling Techniques and Their Applications in Wind Based Energy Systems. Journal of Energy

- Low wind turbines: lower rated wind speed, can have lower cut off wind speed.
- Specific rating of turbines kW/m2: trend towards larger rotor versus generator size (rated power), towards lower specific rating turbines

Materials of wind power plants

Materials breakdown for onshore and offshore wind farms

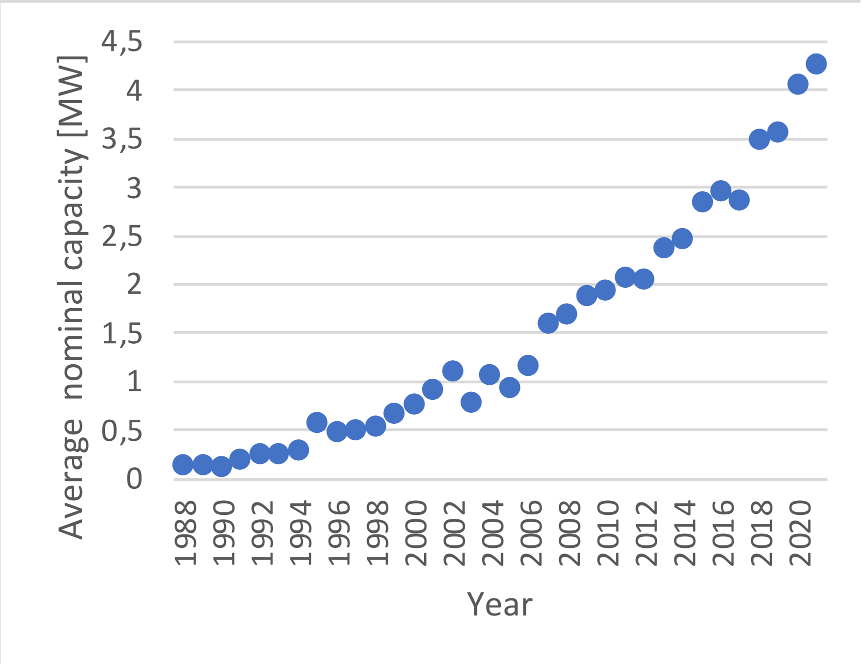


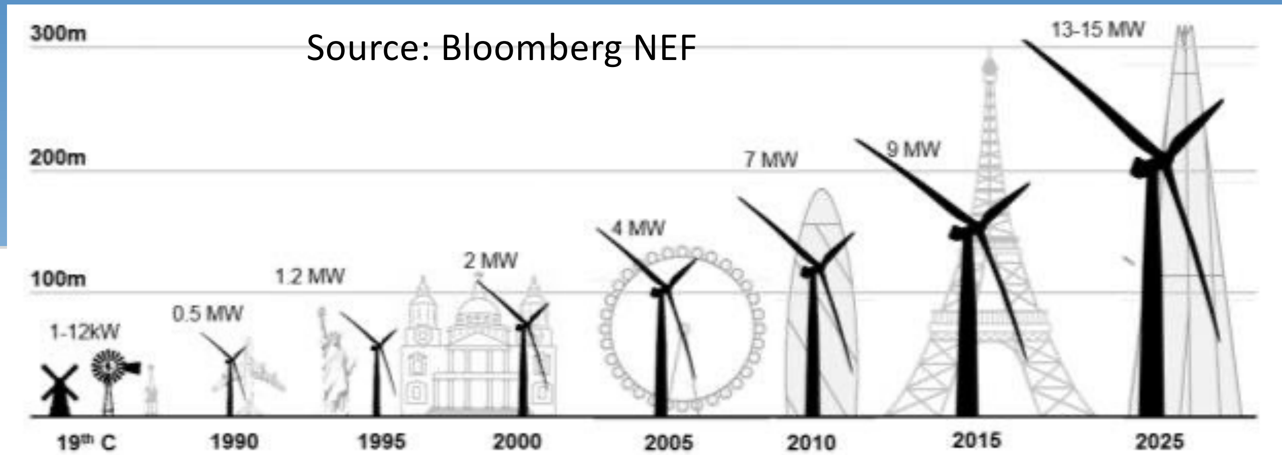
Source: BloombergNEF. Note: GFRP = Glass fiber reinforced plastic. CFRP - Carbon fiber reinforced plastic.

Source : Global Wind Energy Council http://gwec.net/

Turbine size has increased from <0.1MW to 6-7MW onshore, 15MW offshore

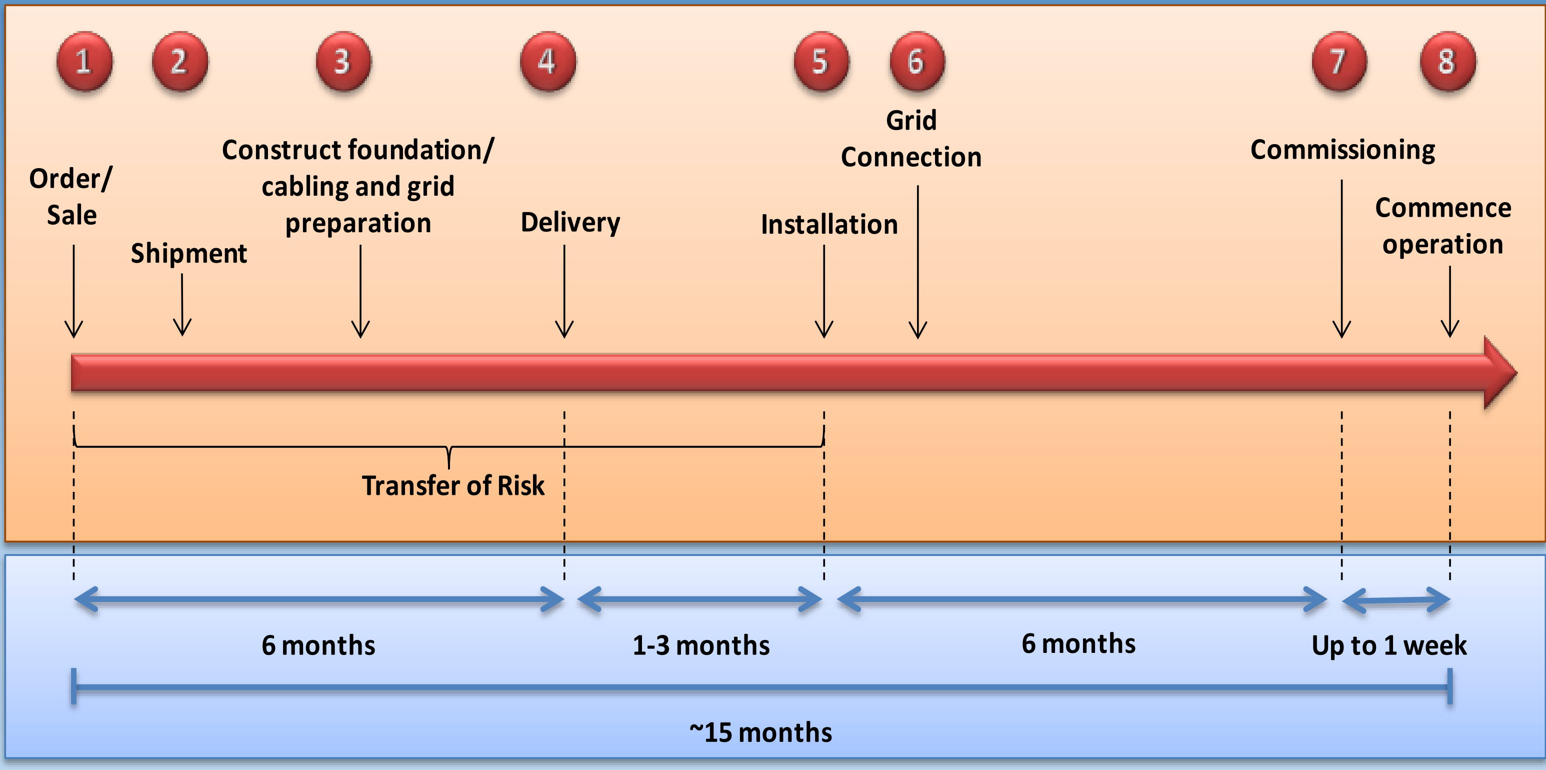
Sweden newly installed wind power statistics
Source: Sweden chapter in
IEA Wind Annual Report
https://iea-wind.org/iea-publications/





Note – getting building permit can take 3-5 years

Typical onshore wind turbine development timeline

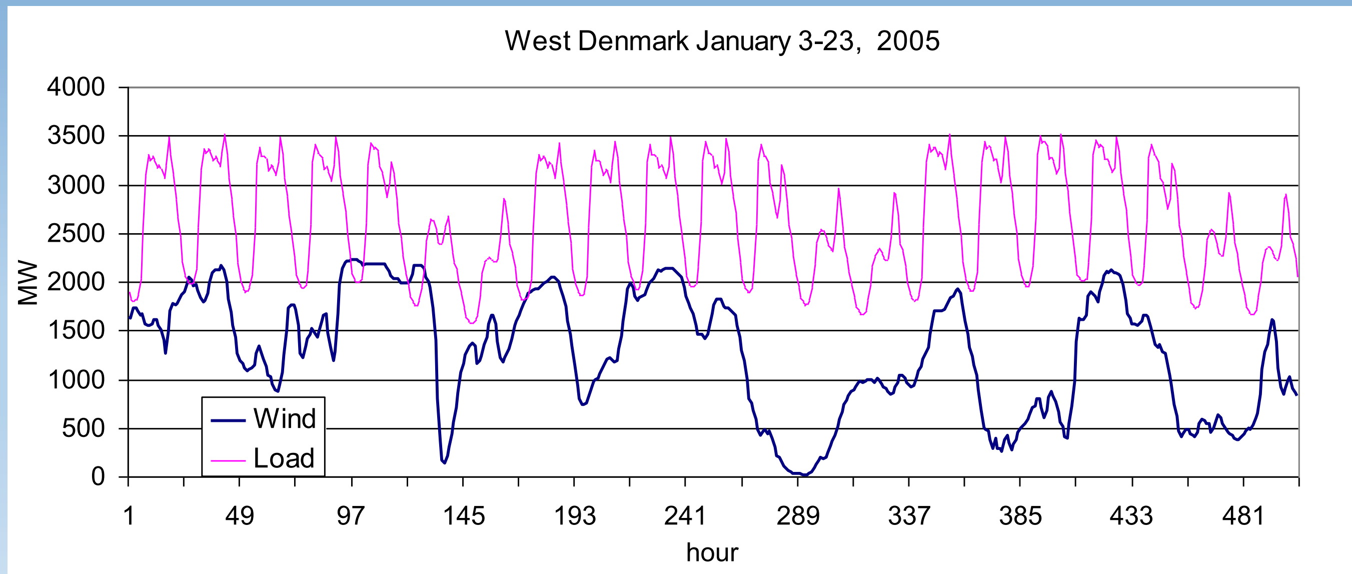


www.navigantresearch.com
Phone: +45 97 32 52 99 / Fax: +45 97 32 55 93

For more information about Navigant, go to: www.navigant.com

Special features of wind energy

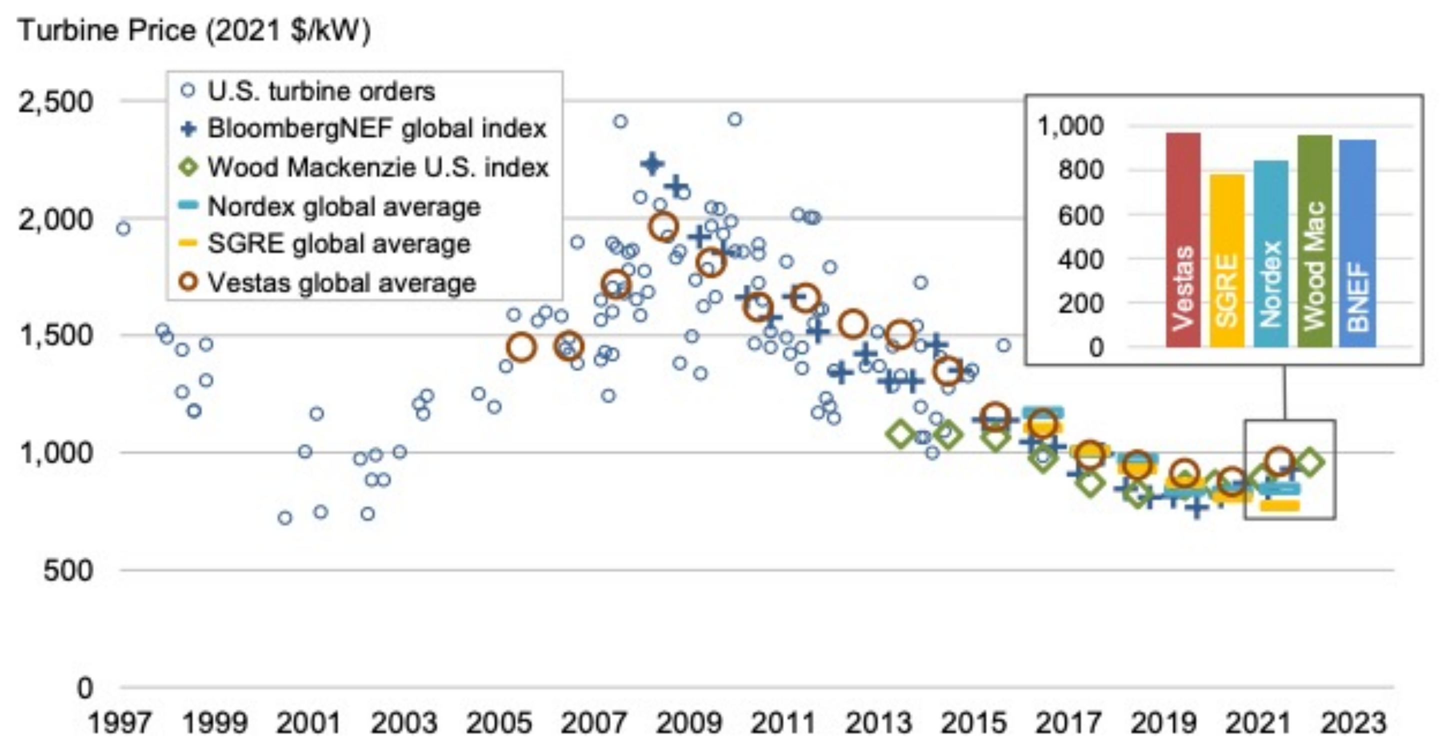
- Producer point of view:
  - Variability: production varies according to wind speed
    - Annual variation ± 15 %, monthly variation ± 50 %, from one day to another, hourly level, minutes…
  - Production cost will vary depending on the site



- Manufacturing industry point of view: Technology development still on-going, new models every 2-3 years

Costs

Cost trends – turbine cost

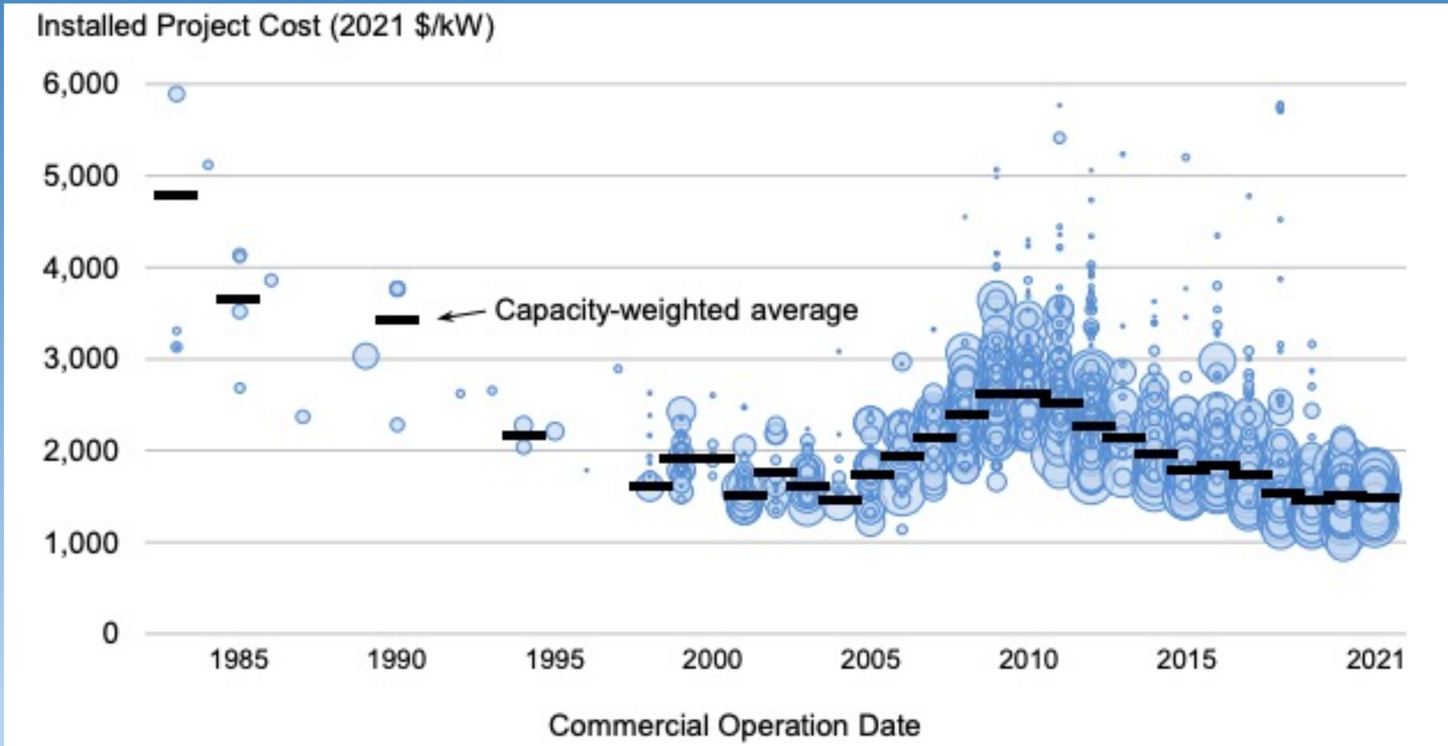


Sources: Berkeley Lab, annual financial reports, forecast providers

Figure 41. Reported wind turbine transaction prices over time

Source: US Wind technology Market report
https://emp.lbl.gov/publications
https://emp.lbl.gov/wind-technologies-market-report

Cost trends – investment cost



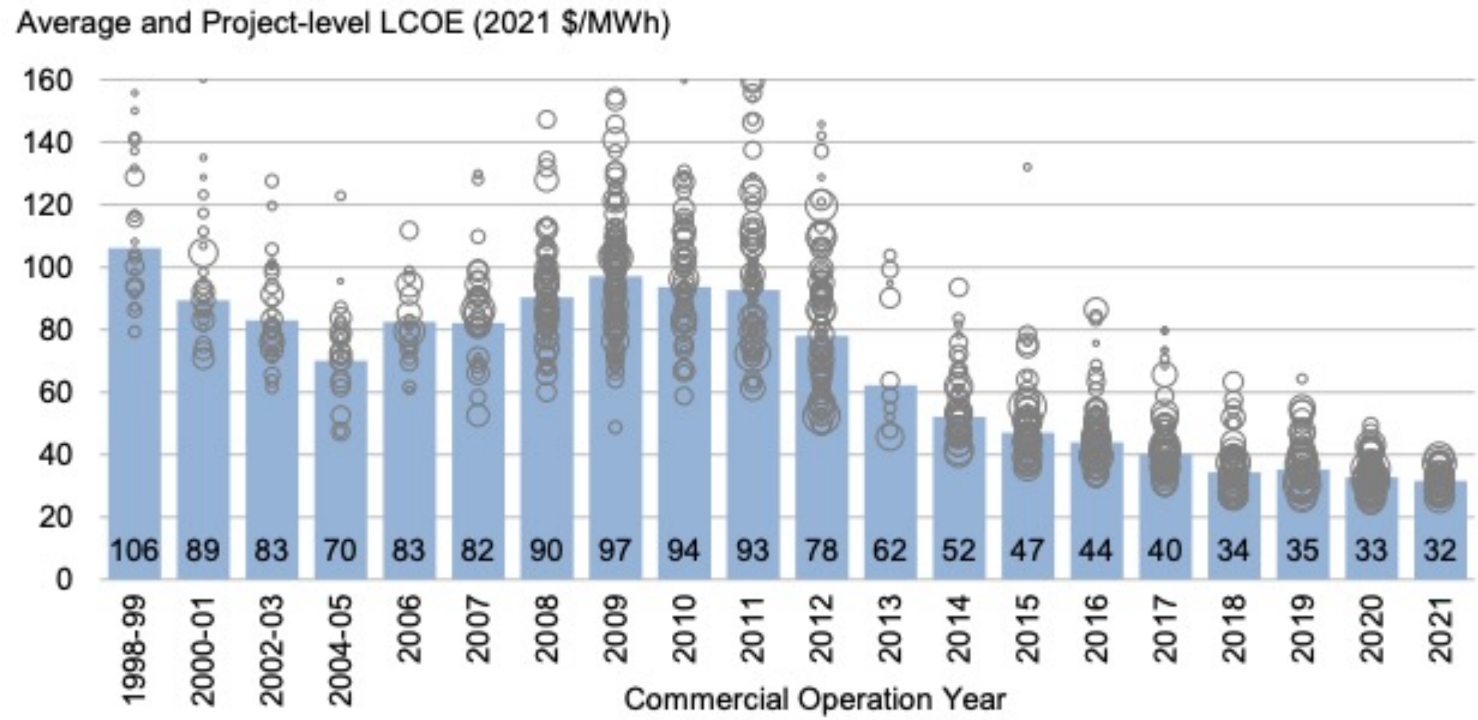
Note: Area of "bubble" is proportional to project capacity

Sources: Berkeley Lab, EIA (some data points suppressed to protect confidentiality)

Figure 42. Installed wind power project costs over time

Source: US Wind technology Market report
https://emp.lbl.gov/publications
https://emp.lbl.gov/wind-technologies-market-report

Cost trend – cost of energy



Note: Size of bubble reflects project capacity.

Source: Berkeley Lab

Figure 51. Estimated levelized cost of wind energy by commercial operation date

Note: Yearly estimates reflect variations in installed cost, capacity factors, operational costs, cost of financing, and project life; includes accelerated depreciation but exclude PTC. See full report for details.

BERKELEY LAB

Interactive data visualization: https://emp.lbl.gov/levelized-cost-wind-energy

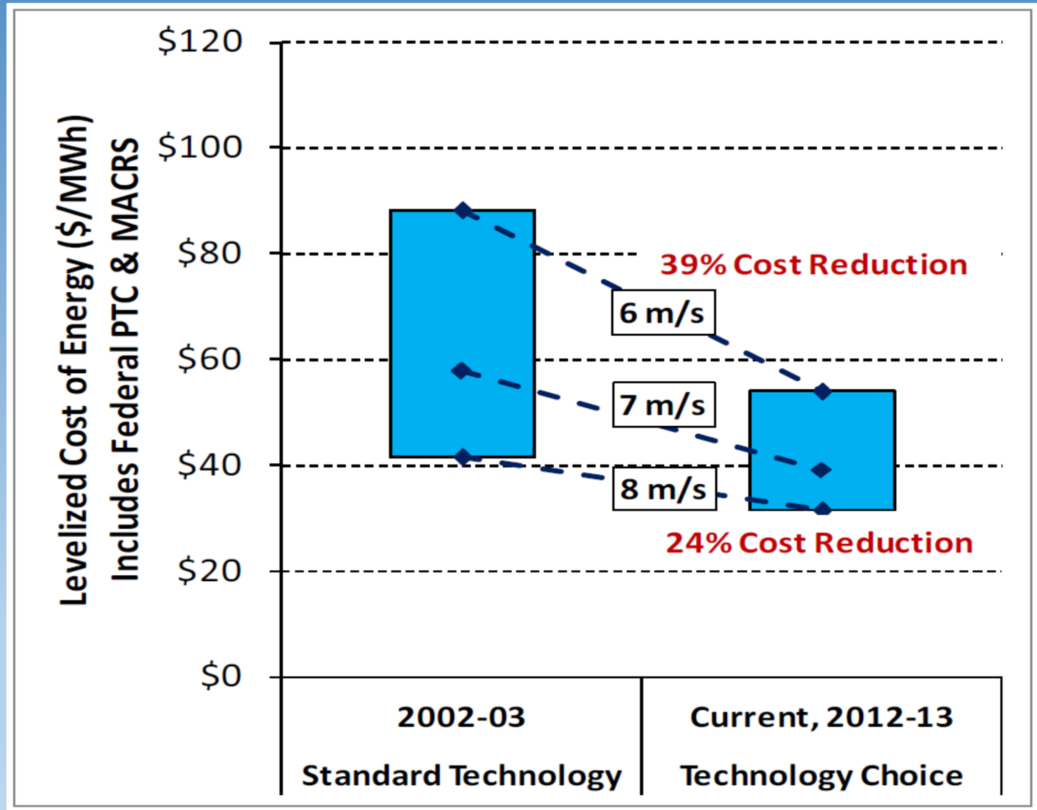
66

Source: US Wind technology Market report
https://emp.lbl.gov/publications

https://emp.lbl.gov/wind-technologies-market-report

Cost reduction achieved in 2010’s

- Achieved by larger rotors and higher towers
- Increase in generation (capacity factors from 20% to 30%), while keeping the turbine costs
- note: especially for lower wind sites



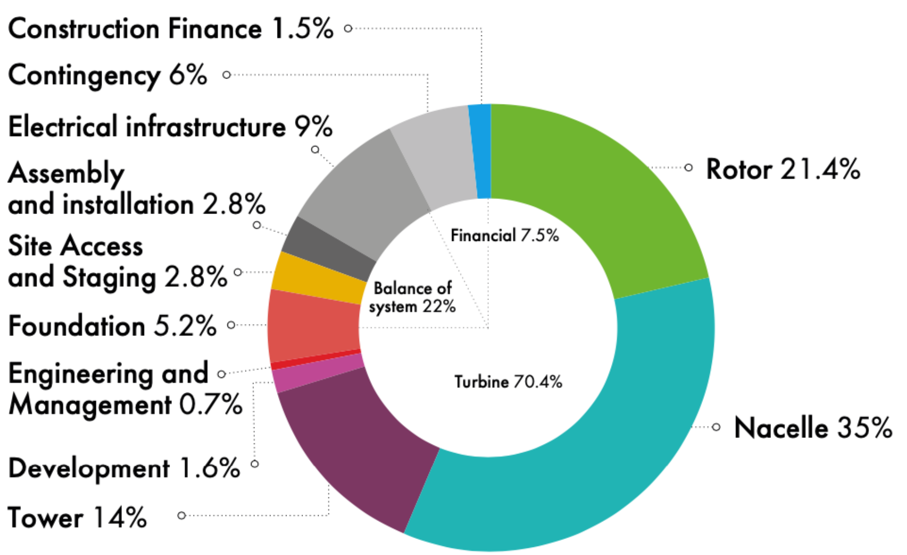
Source: IEAWind Task 26 Available at http://www.ieawind.org/task_26.html

Further cost reduction in wind power production by

- design improvements and weight reduction (35 %)
- improved performance (5 %)
- economy of scale, manufacturing optimisation (50 %)

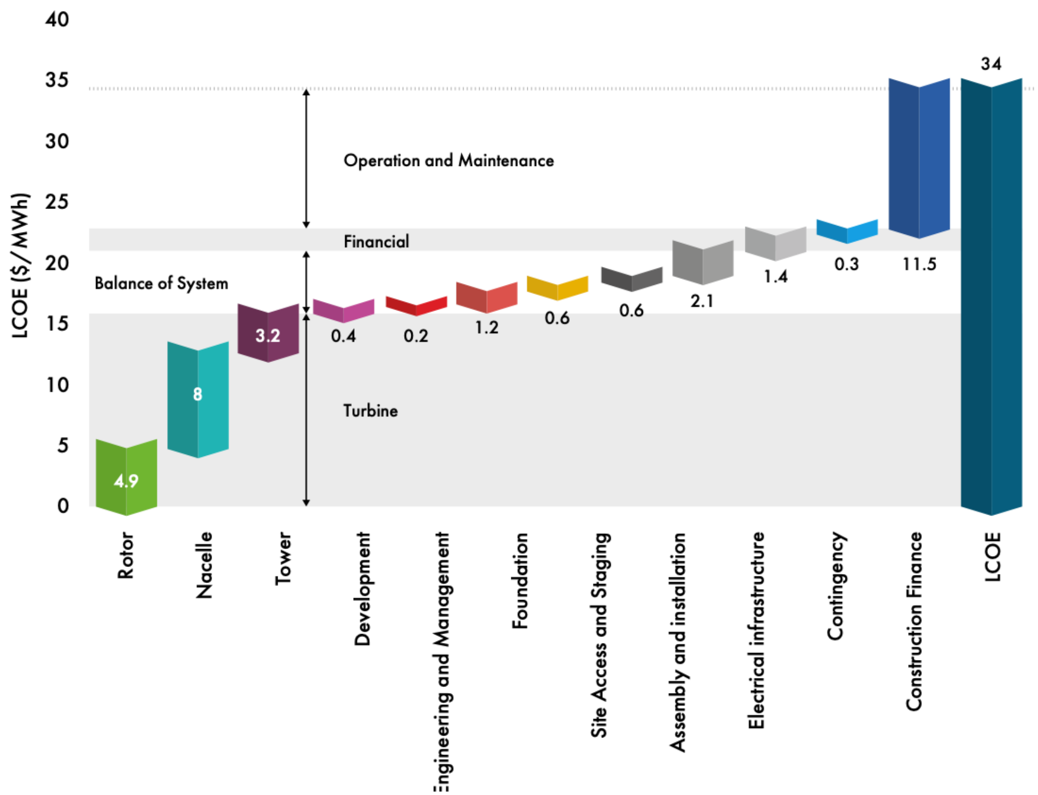
Costs: capital intensive

CAPEX for typical onshore wind farm, 2020



Source: 2020 Cost of Wind Energy Review, Tyler Stehly and Patrick Duffy, National Renewable Energy Laboratory, 2021.
Note: The reference project represents a typical 600 MW fixed-bottom offshore wind project comprising 75 wind turbines at 8.0 MW each, operating for 25 years with no major O&M events.

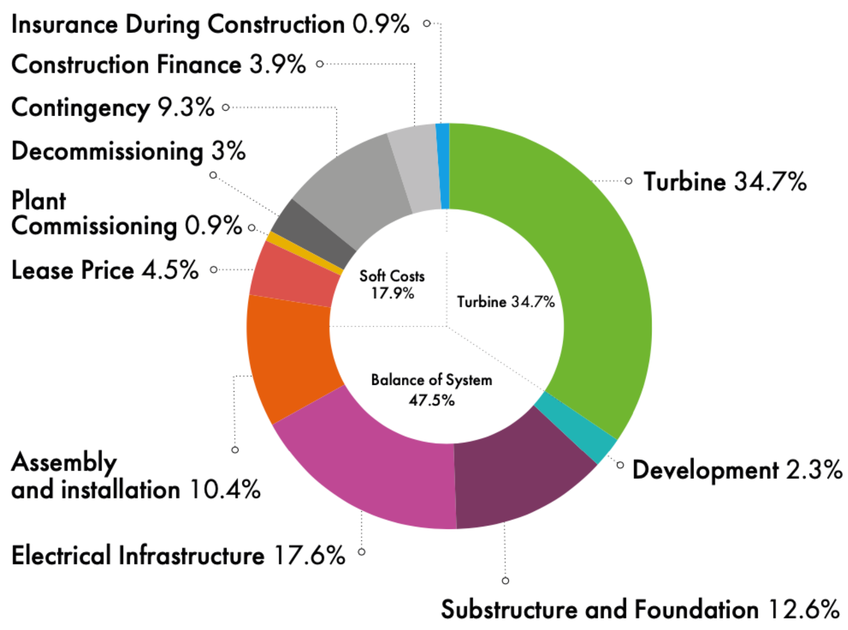
Component-level LCOE breakdown for typical onshore wind farm operating for 25 years, 2020



Source : Global Wind Energy Council http://gwec.net/

Offshore: turbines are a smaller part of total costs

CAPEX for typical fixed-bottom offshore wind farm, 2020



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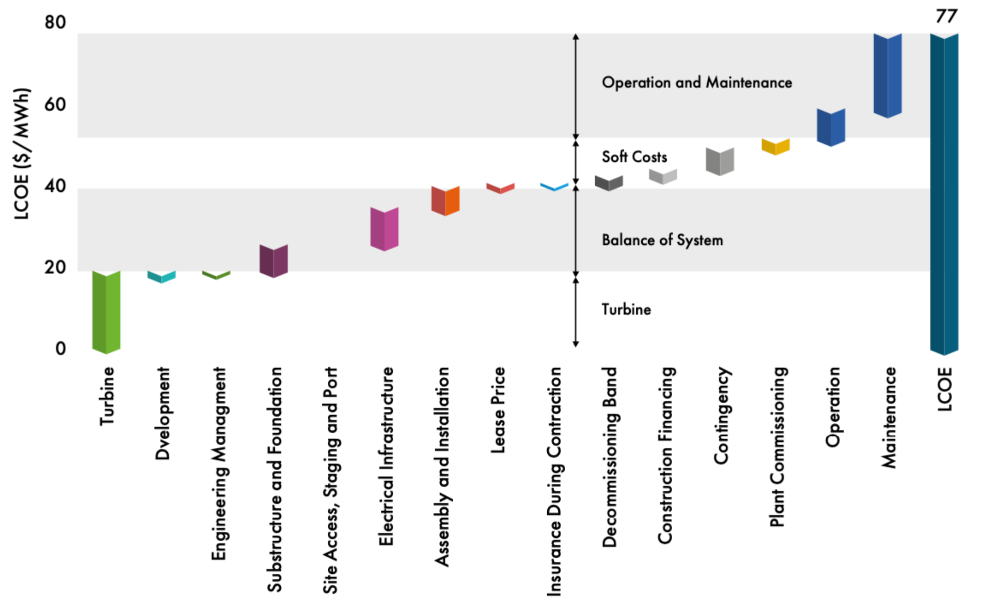
Component-level LCOE breakdown for typical fixed-bottom offshore wind farm operating for 25 years, 2020



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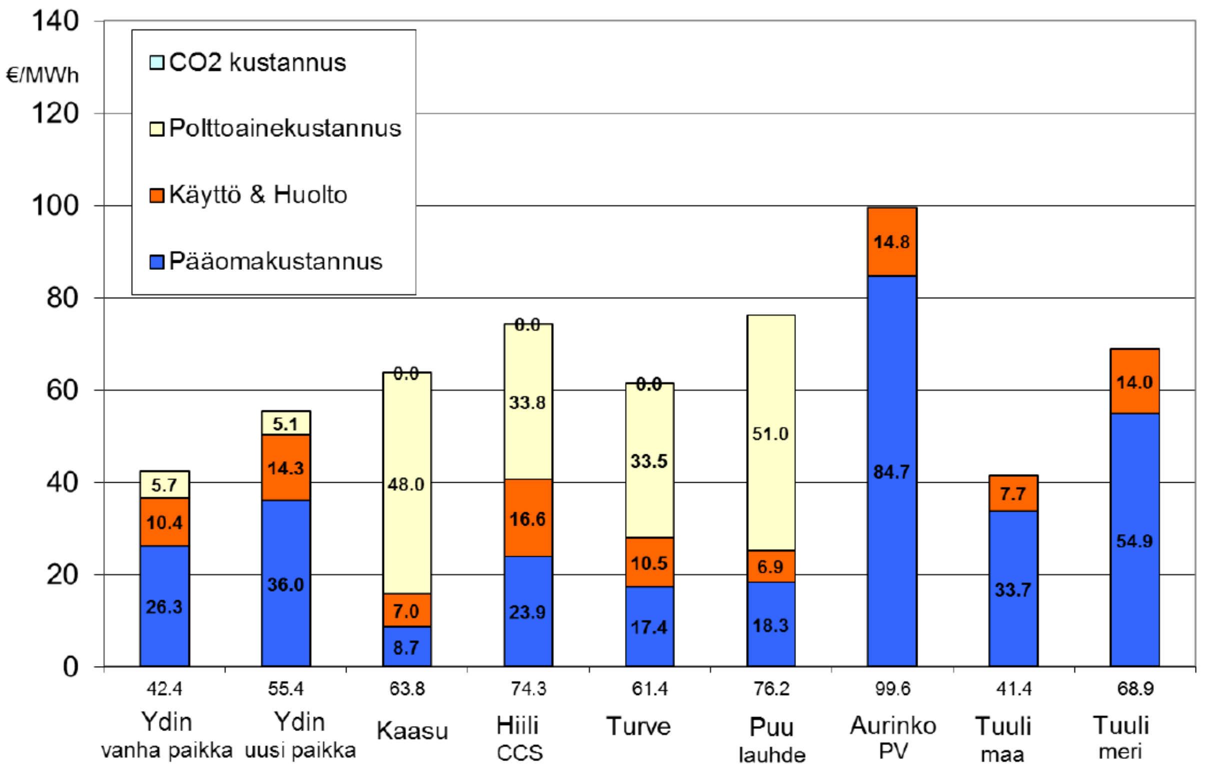
Source : Global Wind Energy Council http://gwec.net/

Cost comparison, 2017 Finland (LUT)



Kuva 1. Eri voimalaitostyyppien sähköntuotantokustannukset, päästökauppa 0 €/tCO2.

http://urn.fi/URN:ISBN:978-952-335-124-0

Subsidy systems

- Support has been given as cost for most sites have been above electricity market prices
  - Feed-in-tariff, guaranteed price for producer (GER, AUS, FR, SP, PT, NL, FI)
  - Green certificates (SE, IT, UK, NO)
  - Tendering (for offshore DK/NL/UK)
  - Older ones: Investment subsidy (FI, NO until 2011/12)
- Move towards auctions, also for land based wind power
- China, Norway phasing out subsidy systems in 2021
- PPA power purchase agreements, sell wind power production for fixed price for 10-20 years directly for larger consumers

Wind power in Finland

Production support for wind electricity

– Case Finland 2011-17, 2 GW / 6 TWh/a

Legislation

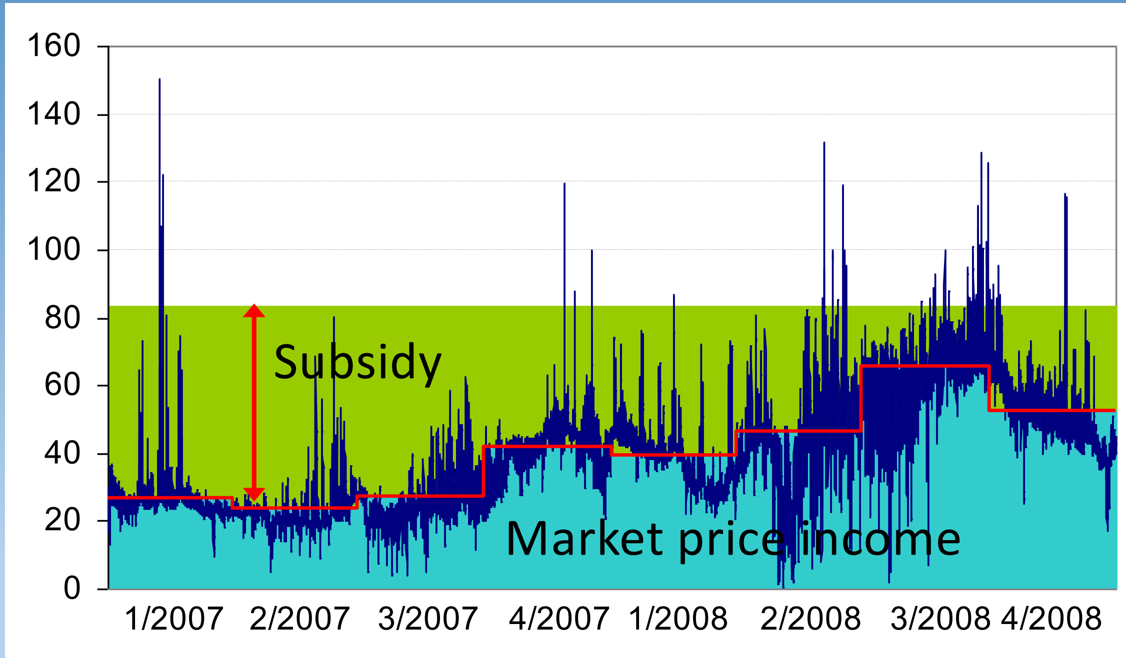
- From 2011 to 2017
- Available for new turbines > 0,2 MW in rated capacity
- Guaranteed level of total remuneration 83.5 €/MWh for 12 years
- Higher level of 105.3 €/MWh, guaranteed until end of 2015
- each quartile, difference between tariff level and average spot price will be paid (the green area)

Pro's

- producers participate in the electricity markets

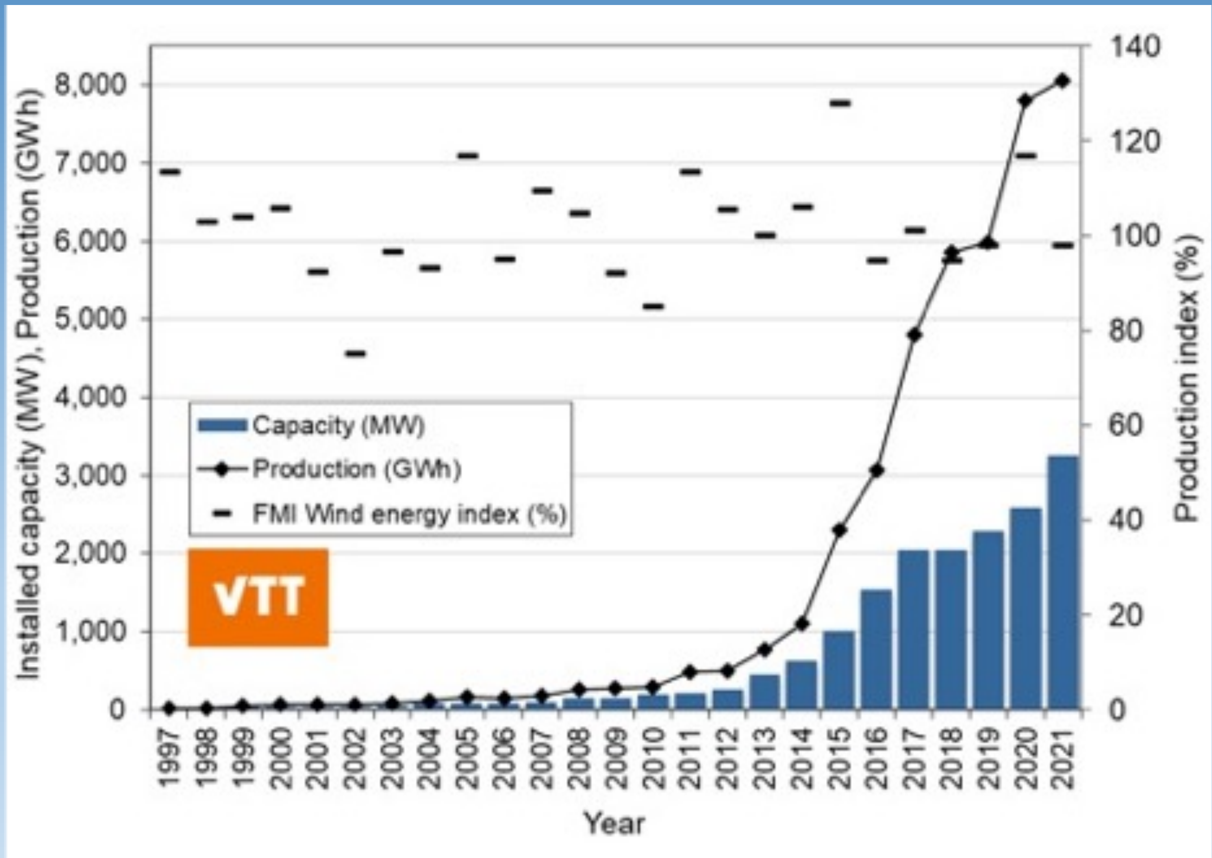
Con's

- Guaranteed level not enough for offshore
- Financing collected in taxes – political risk



Wind power in Finland 2019

– capacity 3257 MW – new installations 671 MW, all without subsidy (PPA)
– generation 8 TWh – share of wind 9 % of electricity demand



Average national capacity factor 32 %
Wind index – much higher than average generation in 2020 and close to average in 2021

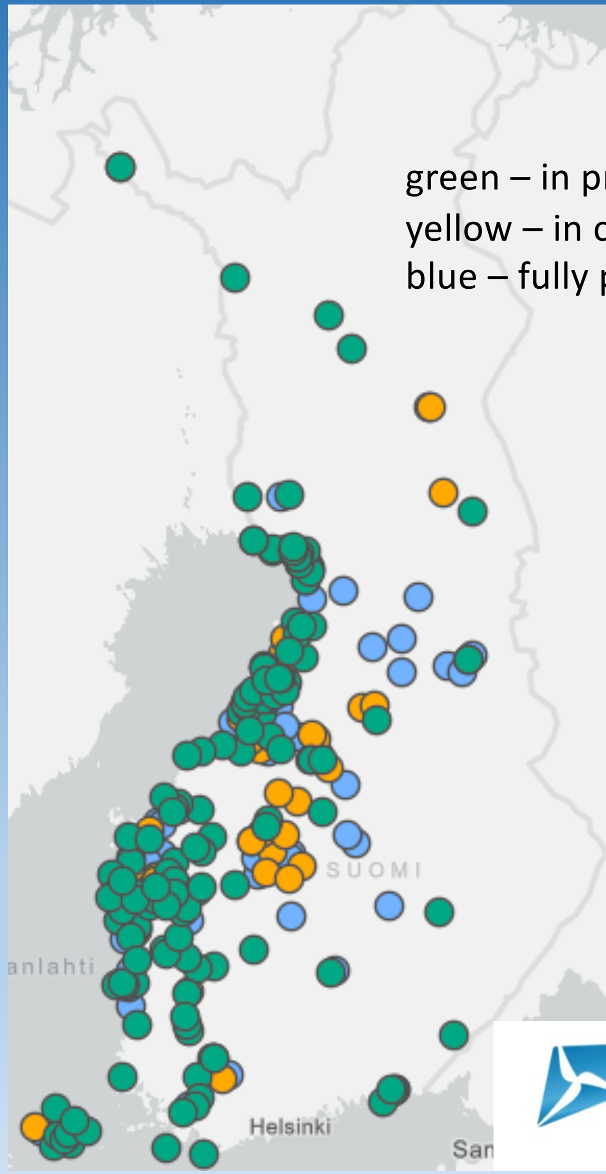
Share of all renewables (hydro/biomass/wind) in electricity demand 43 %

Source: Finland chapter in IEA Wind Annual Report
https://iea-wind.org/iea-publications/

recognis

Installed wind power on the map

- Challenge to install to East – radar interference was solved for Northern part of West coast, as cost /turbine was moderate, but so far not for East



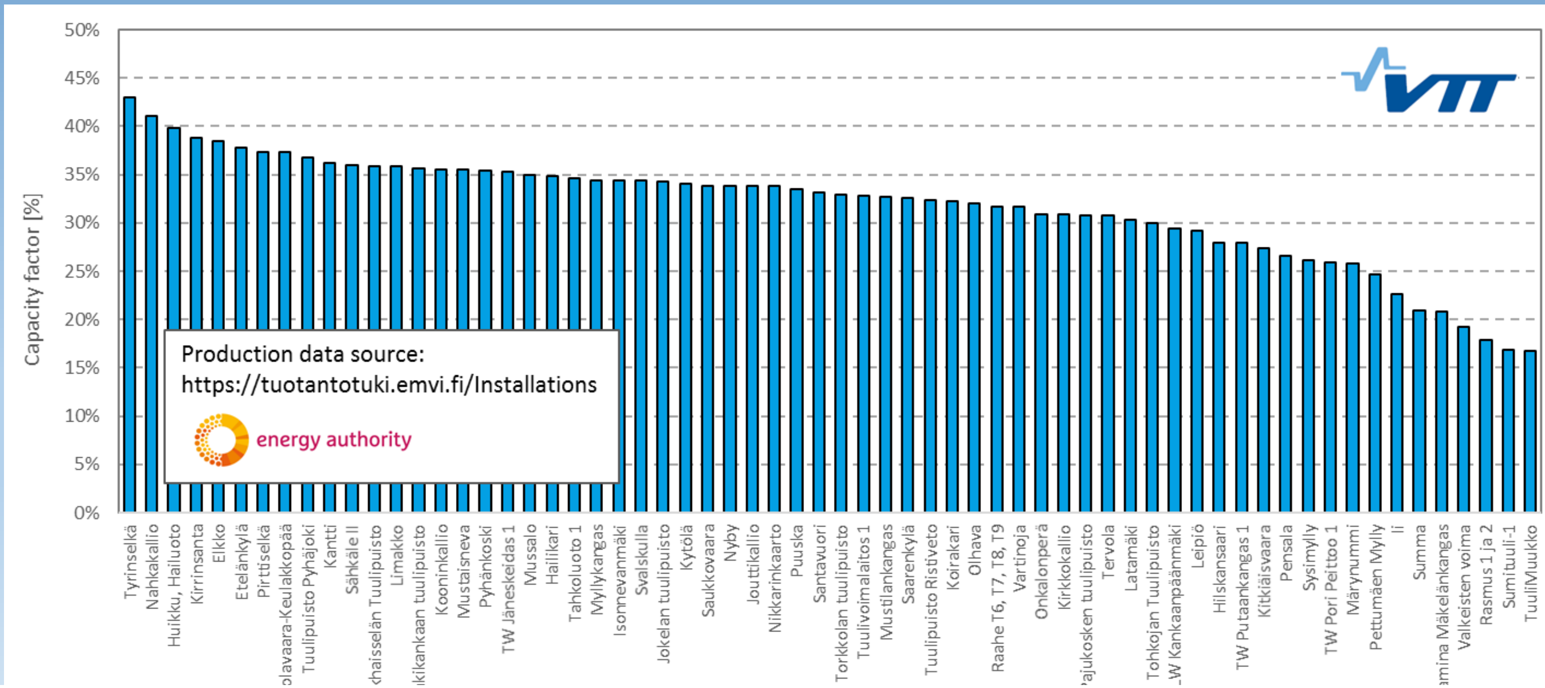
green – in production
yellow – in construction
blue – fully permitted

Suomen Tuulivoimayhdistys

https://tuulivoimayhdistys.fi/tuulivoima-suomessa/toiminnassa-olevat-puretut

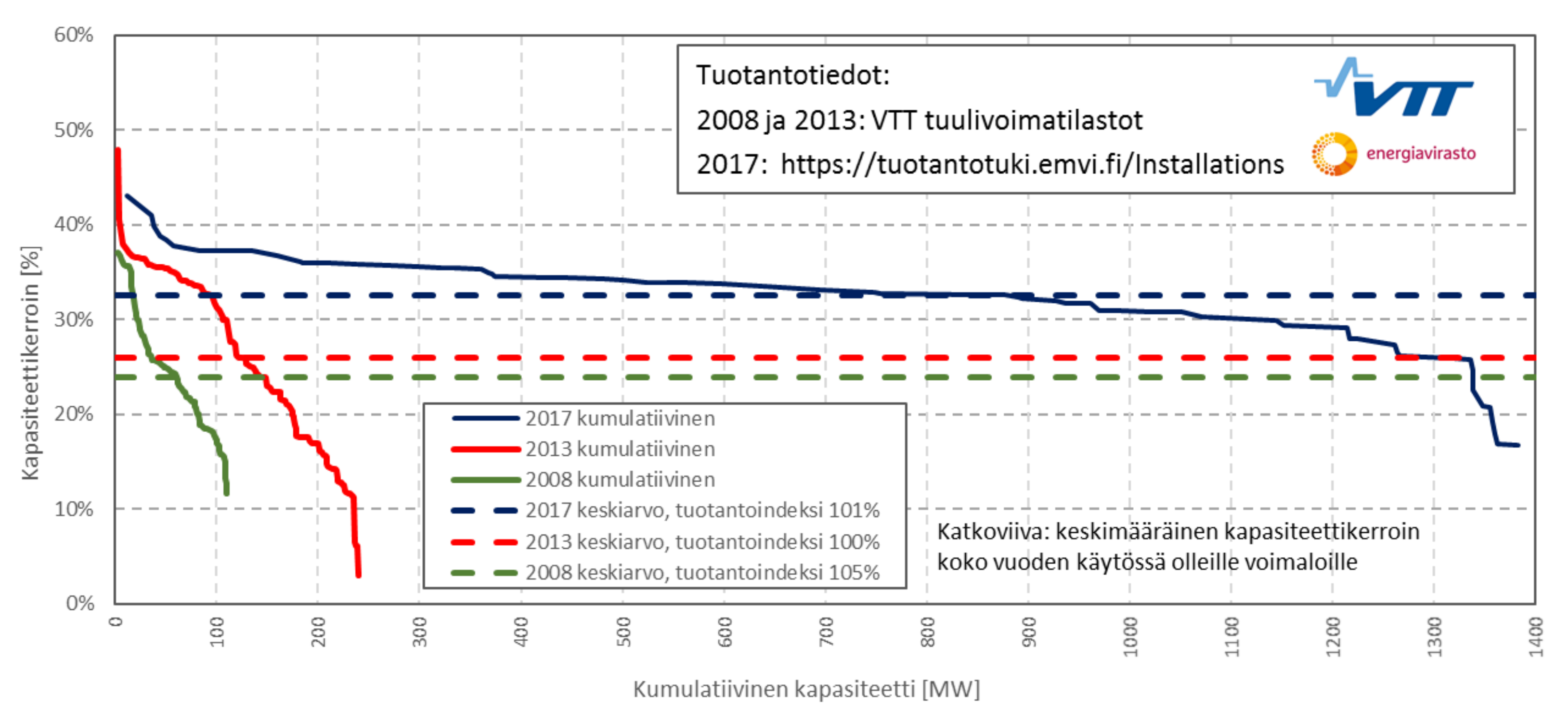
Comparing production from different turbines

- Rotor size relative to generator size will impact the key figures
  - Capacity factor (average power relative to rated power) (20-45 %)
  - Full load hours (huipunkäyttöaika) h/a, **theoretical figure** expressing how many hours in the year needed to achieve yearly production if producing only at full power (2000-4000 h/a)
  - Production relative to rotor swept area (> 900 kWh/m^2)



Source VTT 2017 Wind power statistics

Increasing capacity factors with technology development



VTT on laskenut tuotantoindeksit tuulivoimaloiden sijoituspaikkojen ja tehojen perusteella Ilmatieteen laitoksen alueellisista tuulisuusindekseistä.

Tuulivoimatilastot 2017

What impacts wind generation / capacity factor?

Wind resource:
- site /resource
- year /resource
- height above ground

Technology:
- technology /rotor size versus capacity
- technical availability /faults

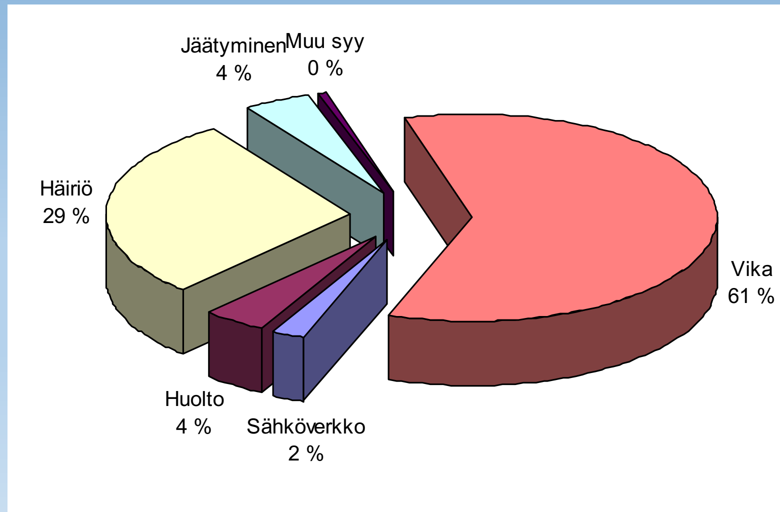
Grid/market:
- curtailments (grid congestion or spot price negative)

Technical availability - Downtime

	Downtime reason	Total downtime 1996–2008 (h)	Downtime by power plant (h)	Power plant- and year-specific downtime (h) seisokkiaika (h)	Downtime share of time [%]
Electricity network	Sähköverkko	5 504	76,4	5,9	0,07 %
Maintenance	Huolto	10 699	148,6	11,4	0,13 %
Disturbance	Häiriö	72 824	1 011,4	77,8	0,89 %
Icing	Jäätyminen	11 120	154,4	11,9	0,14 %
Other reason	Muu syy	1 214	16,9	1,3	0,01 %
Failure	Vika	152 428	2 117,1	162,9	1,86 %
Total	**Yhteensä**	**253 789**	**3 524,8**	**271,1**	**3,03 %**

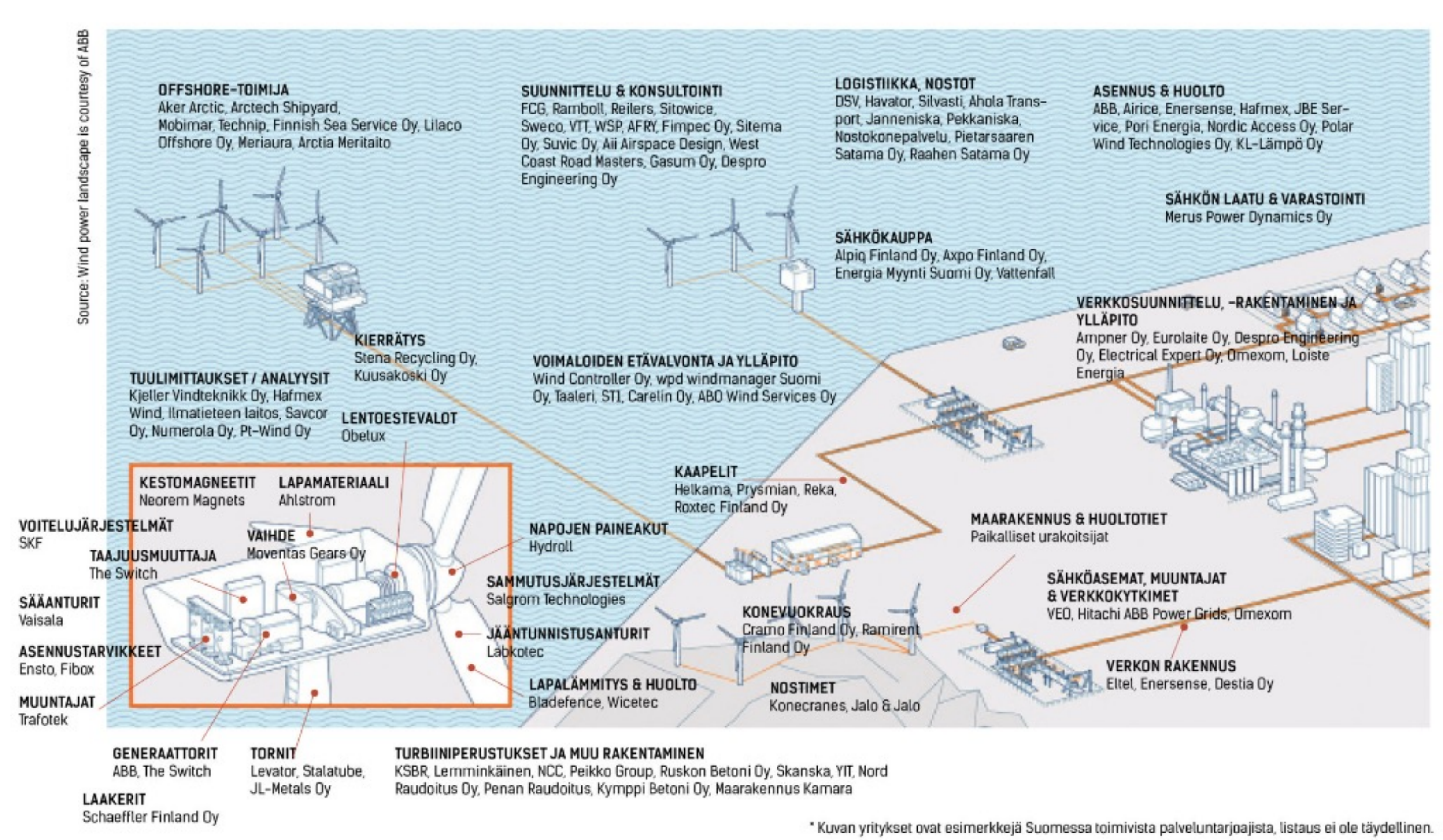
- Average downtime is 3,0 % of time
- Technical availability is 97,0 %

- The share of technical failures of downtime is 61 % (breakdown of these by components)



Source: VTT tuulivoimatilastot /A.Stenberg DI työ 2010

Finnish companies involved in wind power



Component and material manufacturers

Service providers
- Planning
- Construction
- O&M
- Trading
- Recycling

Energy companies
- Own development
- Shared development

Project developers
- Foreign companies
- Domestic players

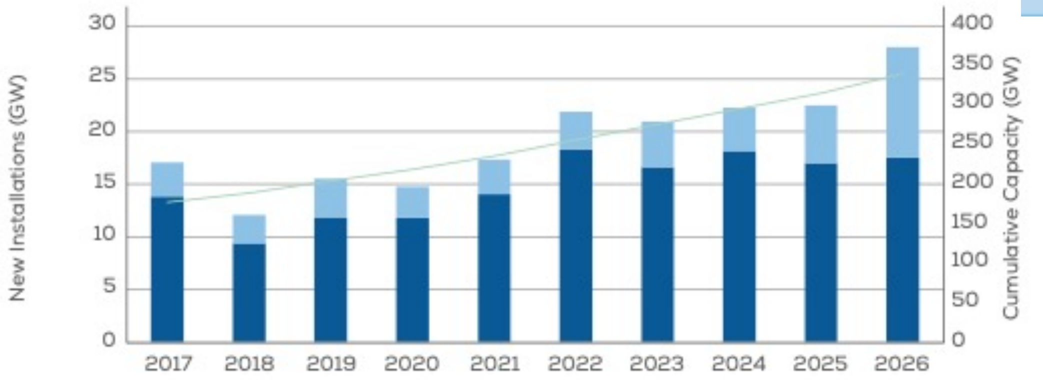
https://tuulivoimayhdistys.fi/media/komponentitpalveluntarjoajat_2021_17.6-1-scaled.jpg

Wind power in Europe and globally

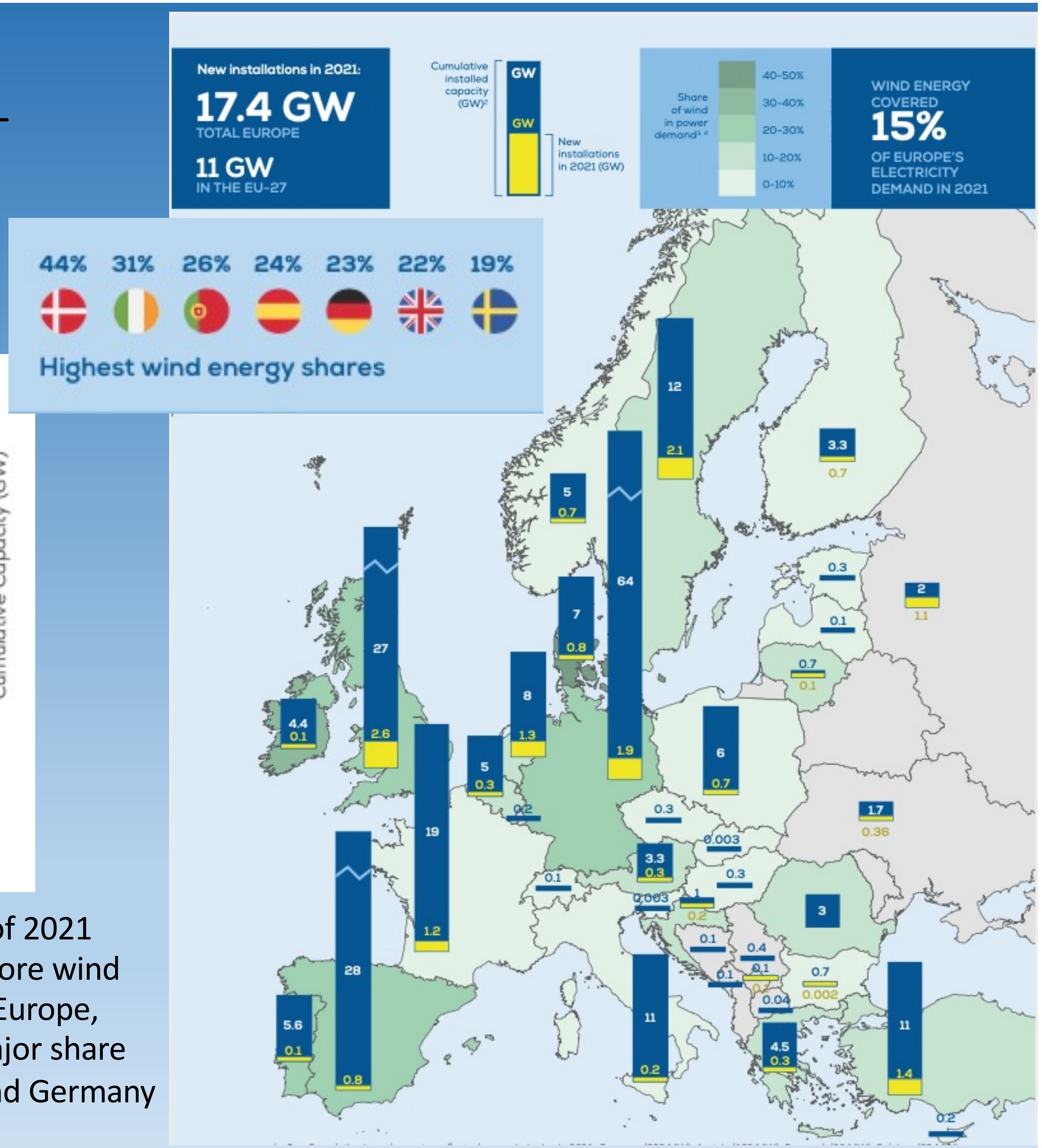
Wind power in Europe end of 2021

236 GW (189 GW EU-27), 17 GW increase annually,
covering 15 % of electricity consumption.
Strong wind power industry

Expected new installations 2022-26 - Realistic Expectations Scenario

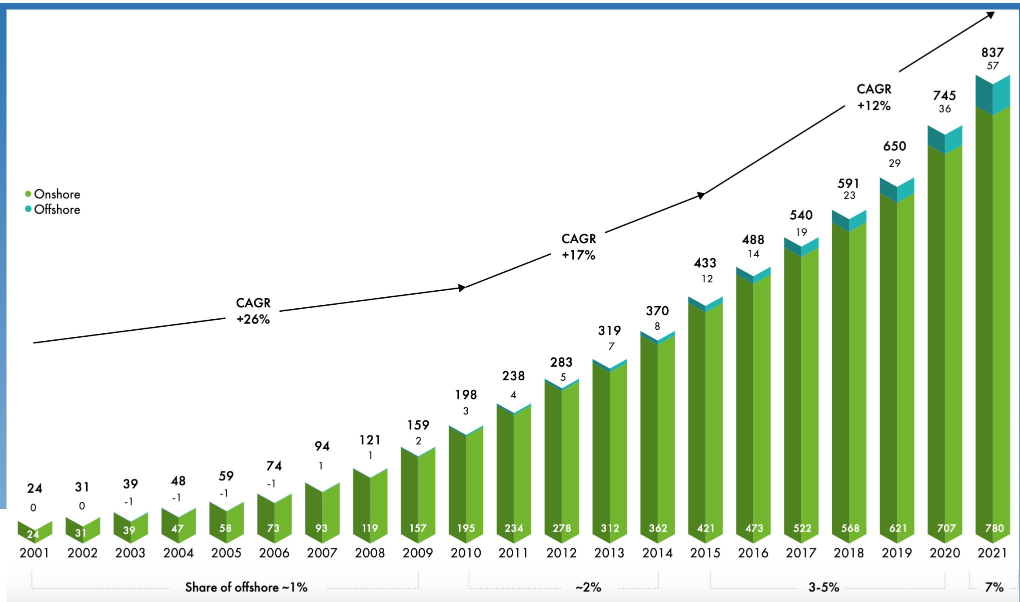


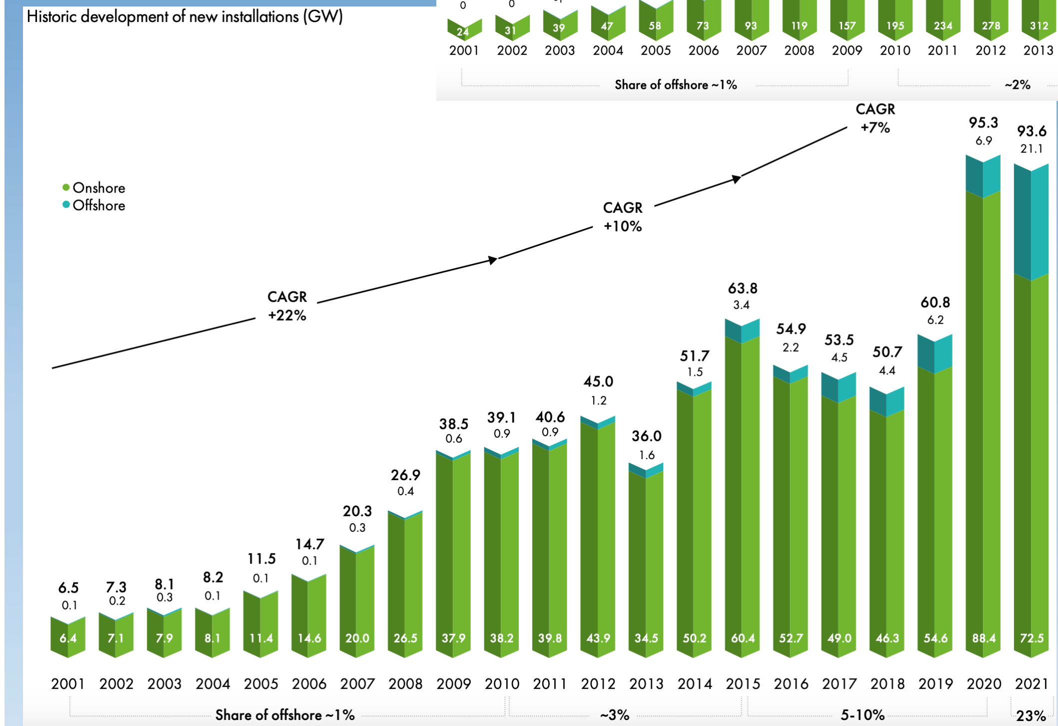
	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026
Offshore	3.2	2.7	3.6	2.9	3.3	3.5	4.4	4.1	5.4	10.4
Onshore	13.9	9.4	11.9	11.8	14.0	18.3	16.6	18.1	17.0	17.6
Cumulative	177	189	204	219	236	256	276	296	315	341



At the end of 2021
28GW offshore wind
installed in Europe,
of which major share
in the UK and Germany

Source:
European Statistics, www.windeurope.org ;

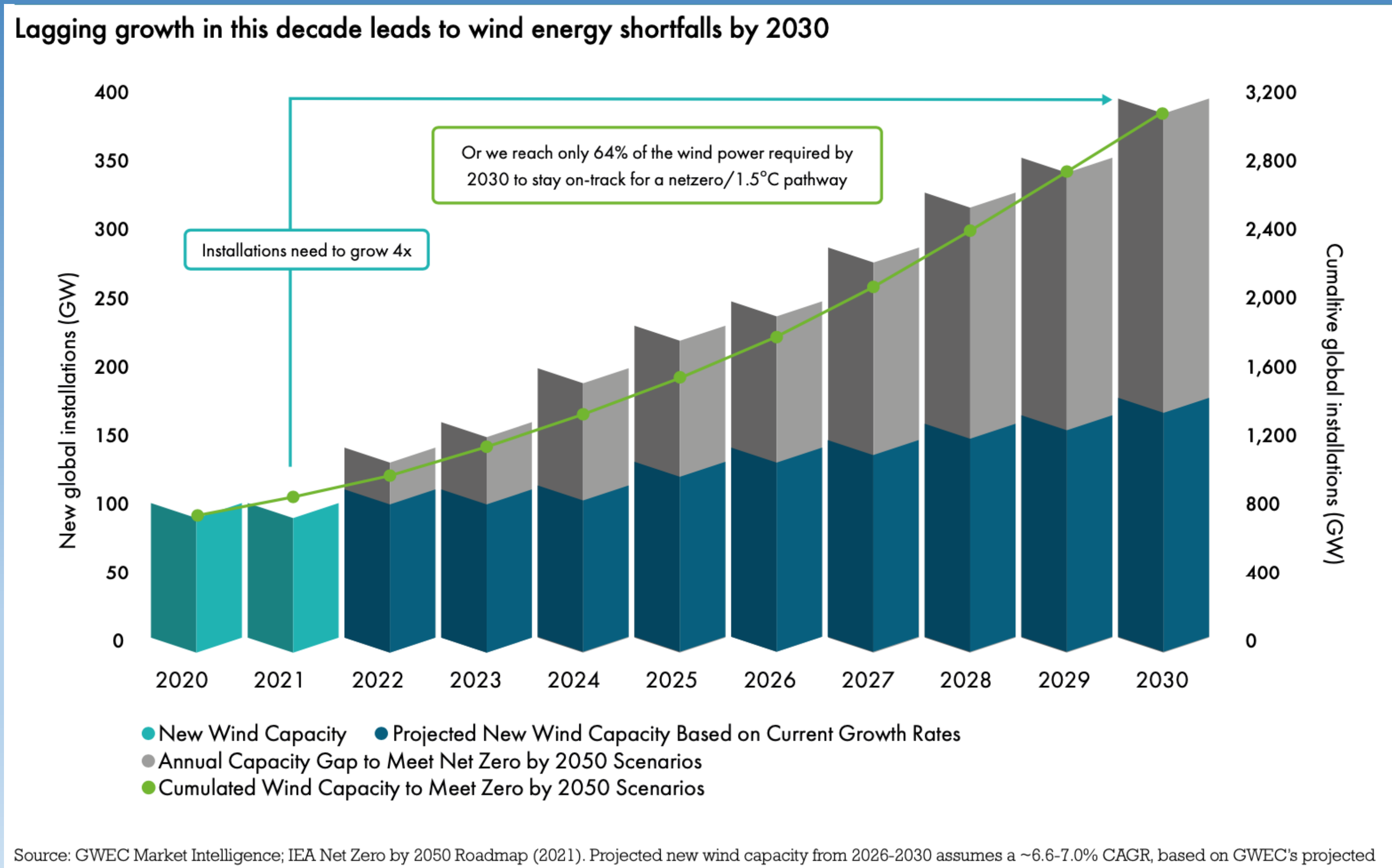




Global wind power capacity end 2021: 837 GW, new capacity 93 GW, of which 21 GW offshore

Source : Global Wind Energy Council http://gwec.net/

Stepping up deployment to meet targets



Source : Global Wind Energy Council
http://gwec.net/

Summary

- Drivers and barriers, special features compared to conventional generation
- Costs now and cost reductions
- statistical information for comparison of turbines
- Large industry, and demand to increase the market globally

References

Useful sites for yearly updated wind power deployment information

- IEA Wind Annual Reports (deployment and research in countries)
  - https://community.ieawind.org/publications/ar
- GWEC and REN21 (global deployment)
  - http://gwec.net/
  - http://www.ren21.net
- USA Market report (also costs)
  - https://emp.lbl.gov/sites/default/files/2020_wind_energy_technology_data_update.pdf
- Wind Europe www.windeurope.org (also investments, and history https://windeurope.org/about-wind/history/)
- Finnish Wind Power Association (also list of ongoing projects in Finland)
  - http://www.tuulivoimayhdistys.fi

Videos

- onshore
  - pystytys Taaleri https://www.youtube.com/watch?v=Ki9RsIX7hUo
  - Lakiakangas CPCFinland https://venusvisual.com/portfolio/lakiakangas3/
- offshore Hornsea https://www.linkedin.com/company/orsted/videos/

(see recent videos: Hornsea 2, the world's largest windfarm, enters full operation)

Thank you for your attention

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