How far can we go with wind and solar?

Design and Operation of Energy Systems with Large Amounts of Variable Generation

HydroConnect Open seminar
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IEA Wind Task 25: Design and operation of energy systems with large amounts of variable generation

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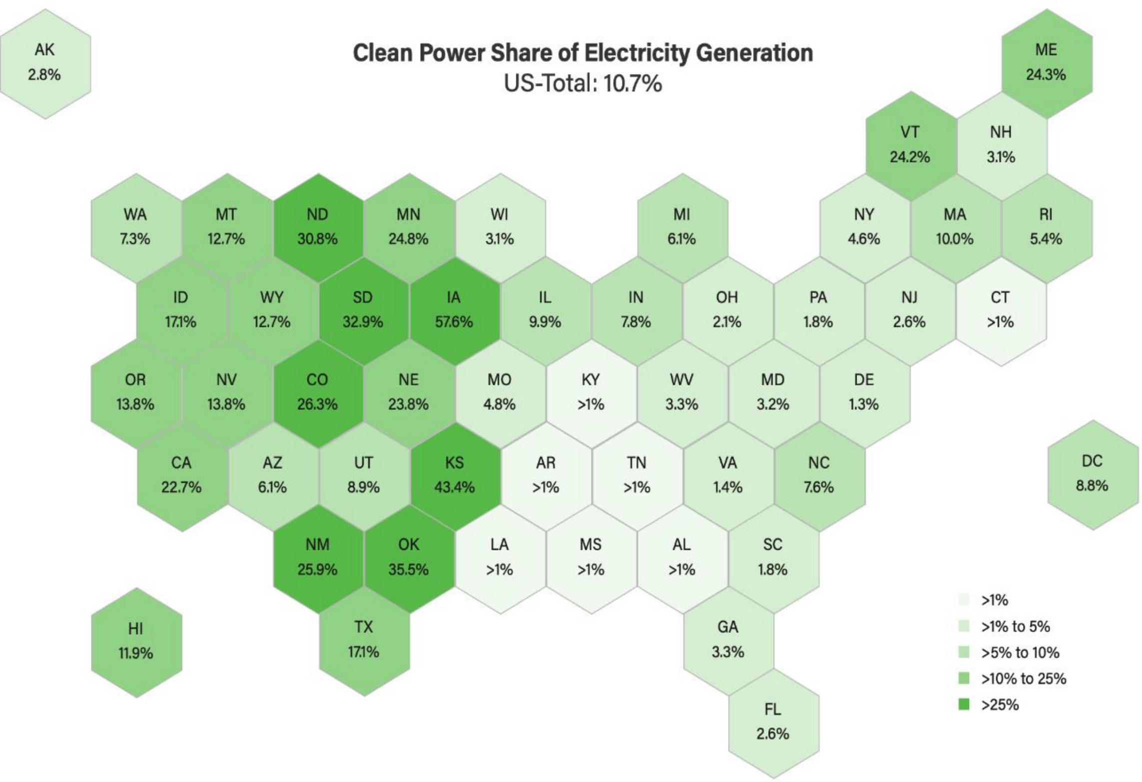
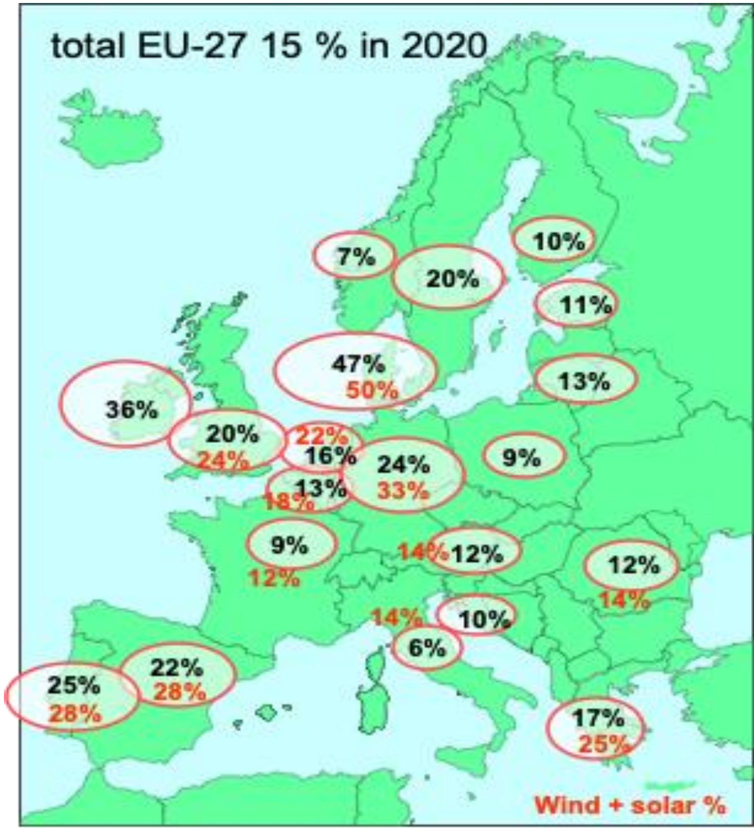
Denmark	DTU (Nicolaos Cutululis); Energinet.dk (Antje Orths); Ea analyse (Peter Börre Eriksen)
Finland (OA)	Recognis (Hannele Holttinen); VTT (Niina Helistö, Juha Kiviluoma)
France	EdF R&D (E. Neau); TSO RTE (J-Y Bourmaud); Mines (G. Kariniotakis)
Germany	Fraunhofer IEE (J. Dobschinski); FfE (S. von Roon)
Ireland	UCD (D. Flynn); SEAI (J. McCann); Energy Reform (J. Dillon);
Italy	TSO Terna Rete Italia (Enrico Maria Carlini)
Japan	Kyoto Uni (Y. Yasuda); CRIEPI (R. Tanabe)
Netherlands	TUDelft (Arjen van der Meer, Simon Watson); TNO (German Morales Sspana)
Norway	NTNU (Magnus Korpås); SINTEF (John Olav Tande, Til Kristian Vrana)
Portugal	LNEG (Ana Estanquiero); INESC-Porto (Bernando Silva)
Spain	University of Castilla La Mancha (Emilio Gomez Lazaro); Comillas (Adres Ramos)
Sweden	KTH (Lennart Söder)
UK	Imperial College (Goran Strbac, Danny Pudjianto);
USA	NREL (Bethany Frew, Bri-Mathias Hodge); UVIG (J.C. Smith); DoE (Jian Fu)
Wind Europe	European Wind Energy Association (Vasiliki Klonari, Daniel Fraile)

https://iea-wind.org/task25/

Increasing shares of wind and solar…

11 states in the US and 9 in the EU >20% share of wind

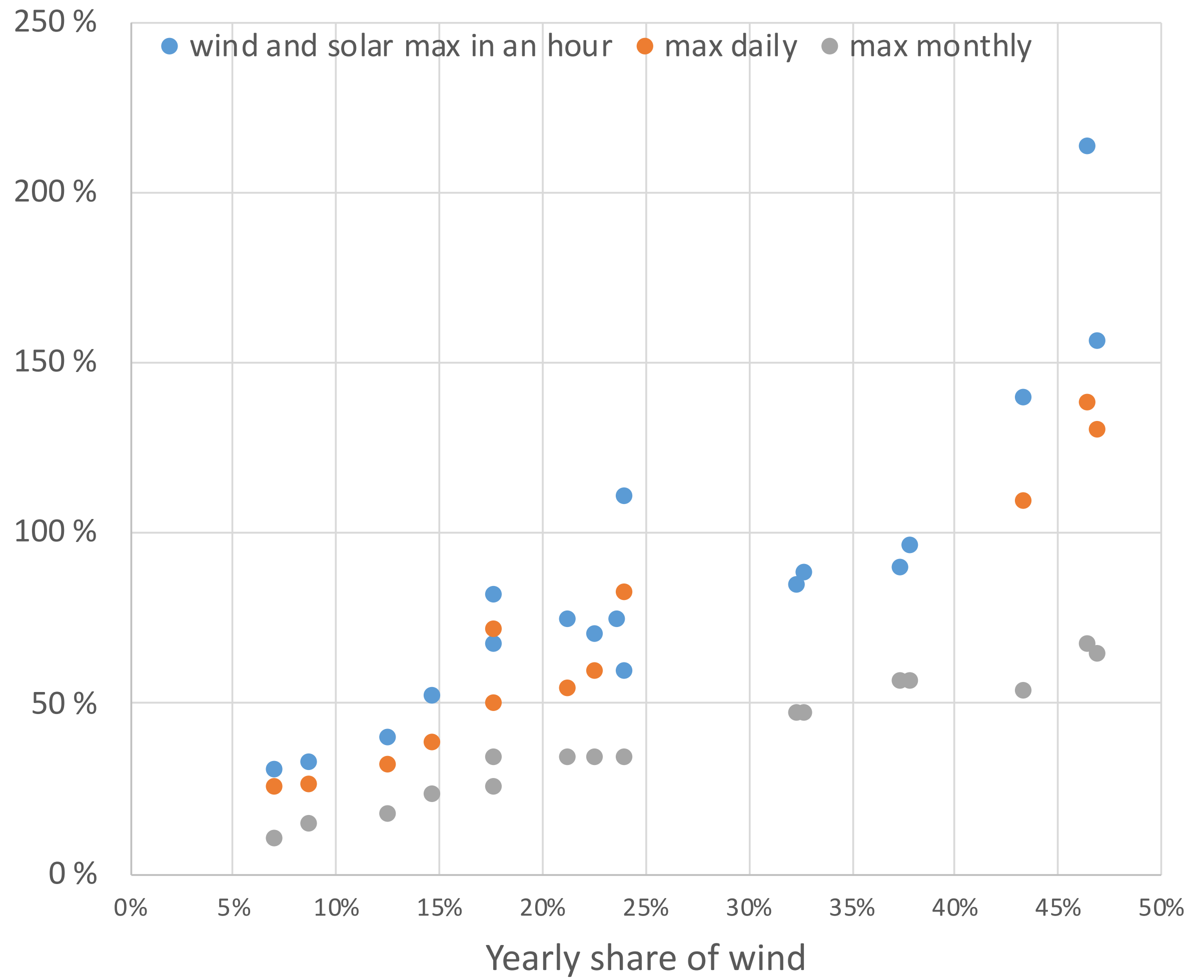




Source: ACP

..mean increasing instant shares

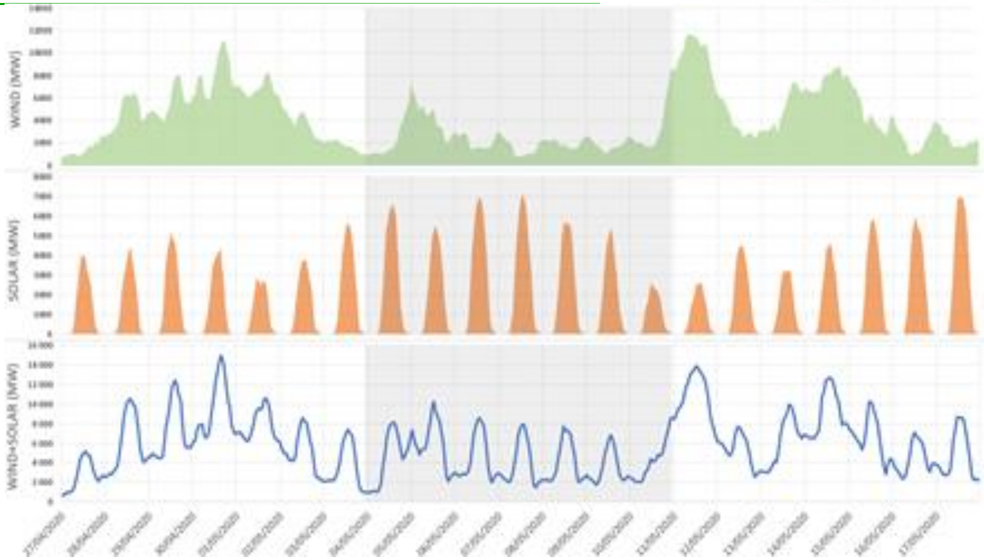
- challenges when >50% RES in synchronous power system (Island of Ireland, Texas, GB)
- larger power systems still at 10-15% share of wind & solar

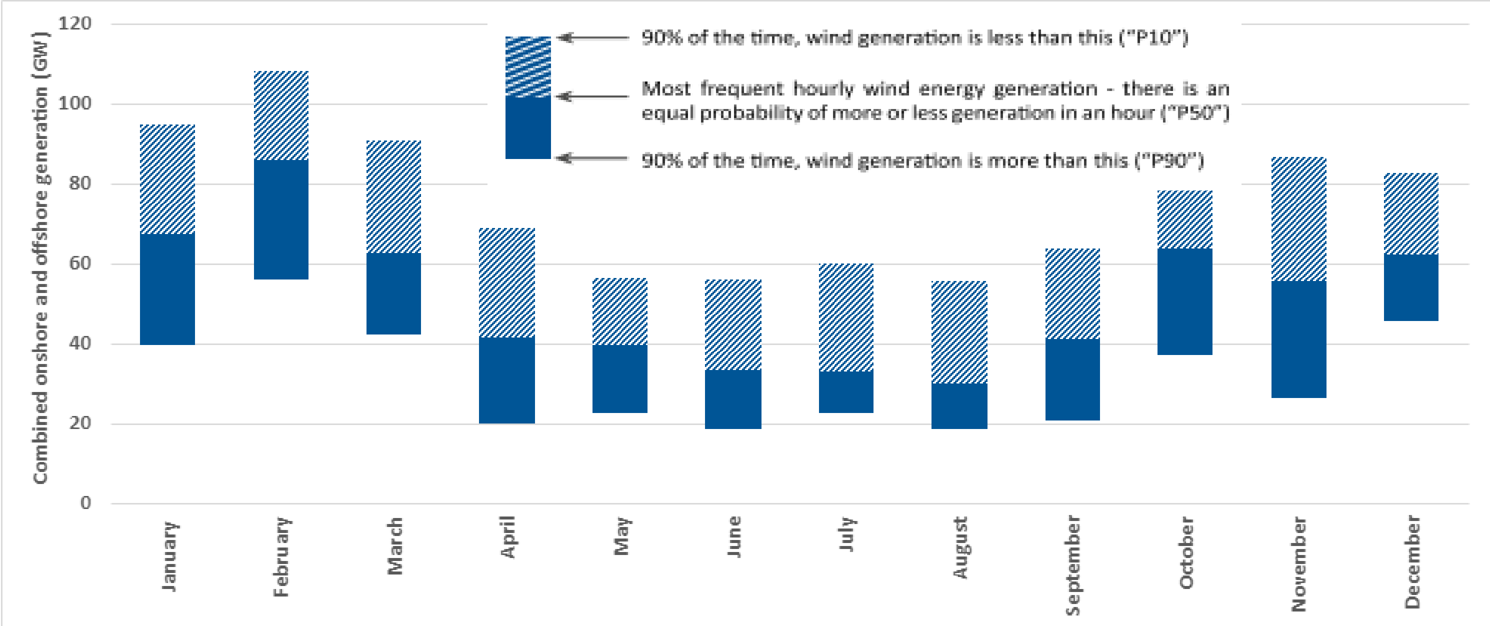


Impacts of variability and uncertainty

- wind smoothing impact (size of area, dispersion)
- wind and solar complementarity

  3 weeks in France, from ENTSO-E data:

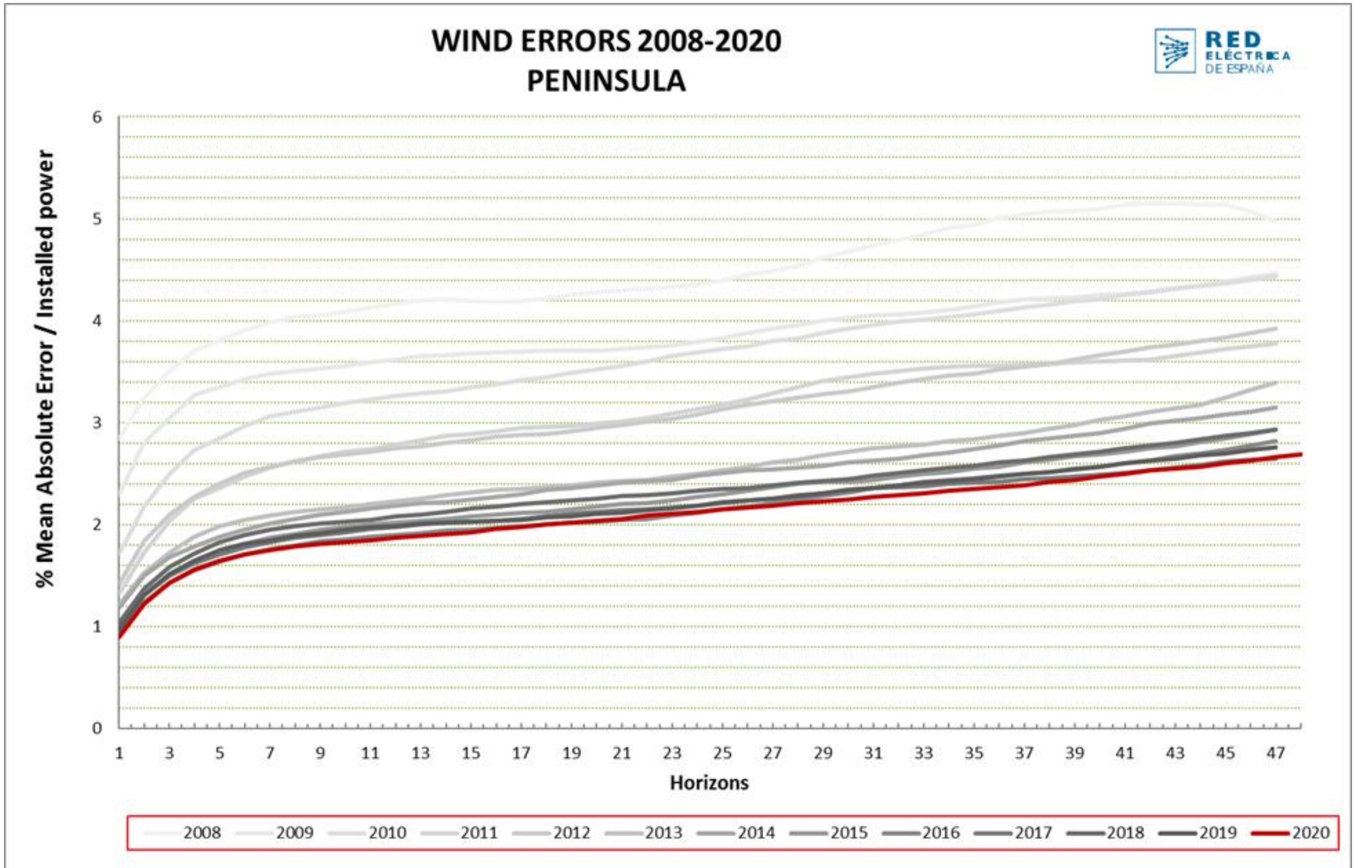




Wind Europe, year 2020 hourly data for EU-28 (~200 GW) data source ENTSO-E

Improvements in data and models

- Simulated weather data and forecasts continue to improve: future wind scenario time series for models
- Extremes important: storms and ”dunkelflaute”



Source: REE, Spain

Maximising value of wind energy

- Minimising curtailment
- Using wind power for ancillary services (AS)
- Operational practices
  - grid
  - market design
- Using existing and new flexibilities

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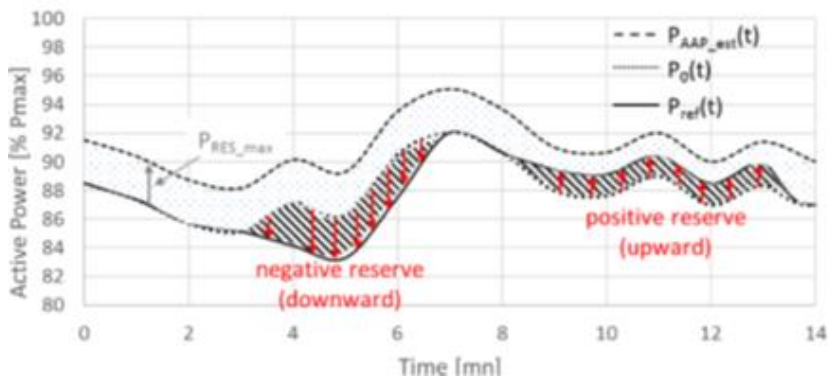
Estimating the value of wind

- Integration cost concept
  - Will be outdated when looking at net zero carbon systems of the future
  - extracting and allocating a so-called integration cost cannot be made in a consistent way
  - adding different options to a system in a different order will change the costs incurred (!)
  - More relevant to look at different options/pathways and compare costs of scenarios
- Value of wind increasingly important to assess
  - Beyond LCOE
  - from transparent and cost reflective markets

Using wind power for AS

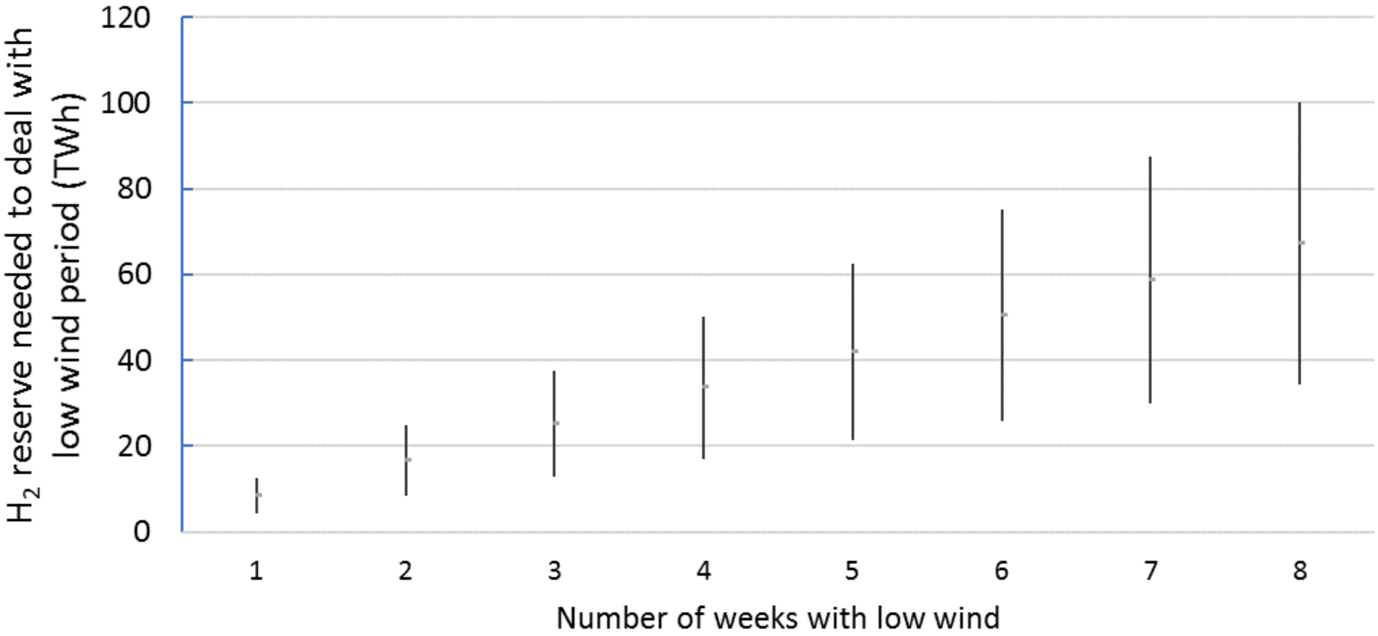
- When wind and PV surplus, important to provide AS, otherwise risk being curtailed to commit a synchronous generator for providing the services
- Frequency control, and balancing markets already have experience from several power systems
  - **Spain:** 17 of 27 GW wind power participate in the ancillary services, increasingly being used:
    - of total downward reserves 14.4% in 2018 and 14.8% in 2019
    - of total upward reserves, 4.8% in 2018 and 7.5% in 2019



Source: EU Sysflex project

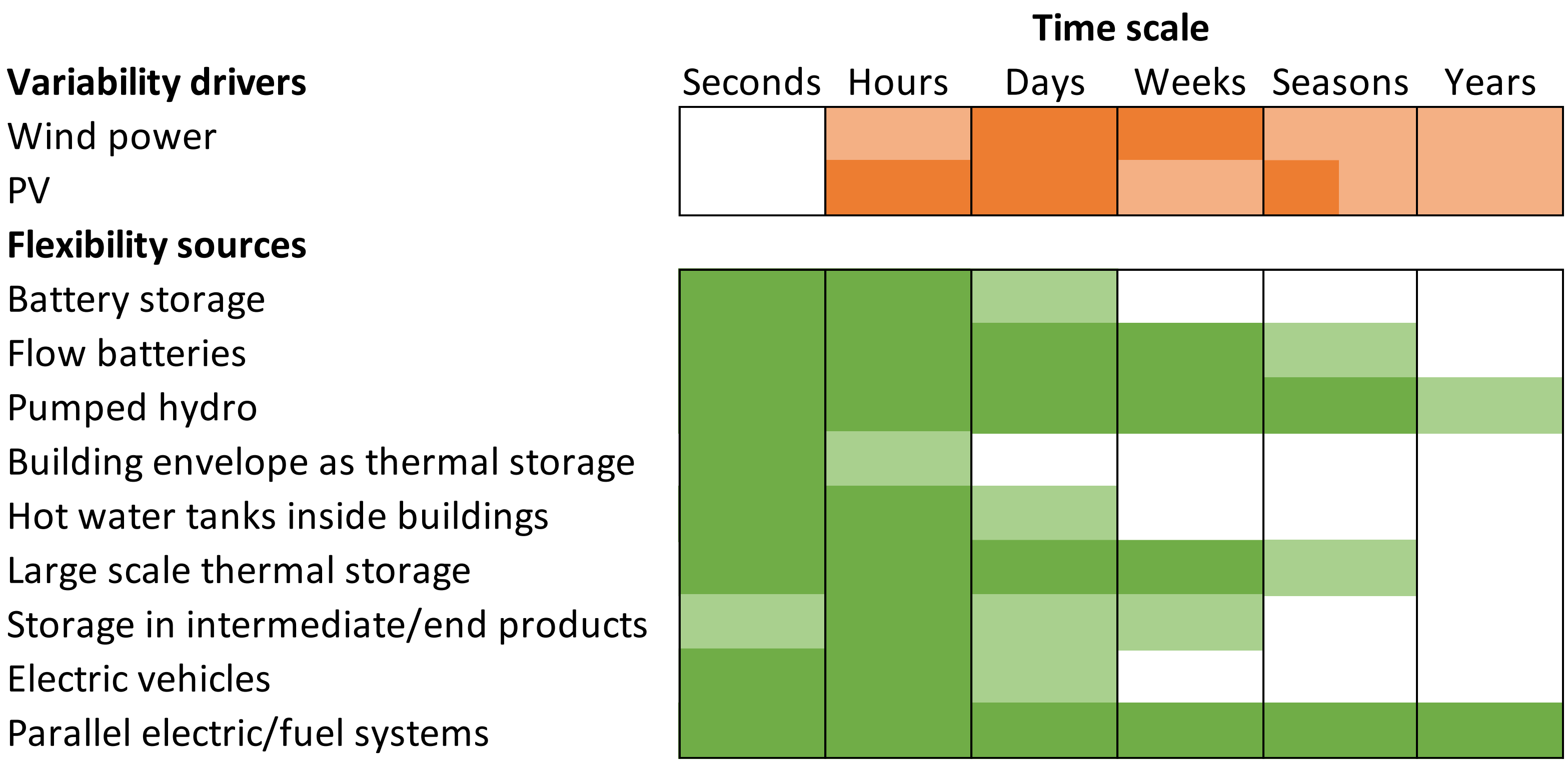
Long term flexibility crucial for decarbonised energy systems

- Hydropower with reservoirs or pumped hydro are used as longer-term storage.
- Hydrogen storage could also be an alternative
  - Amount of hydrogen that needs to be stored, as a function of number of weeks, with low wind output for the Great Britain system (range, min–max, of wind energy that needs to be compensated)



GB zero emissions study, 241 TWh wind. Illustration of storage for longer low wind cases (time series analysis) Source: Imperial College

Time scales of flexibility – the long term flexibility challenge



Estimated time scales for the drivers of variability and sources of flexibility (darker colour – primary impact, lighter colour – secondary impact, white – not usually relevant).

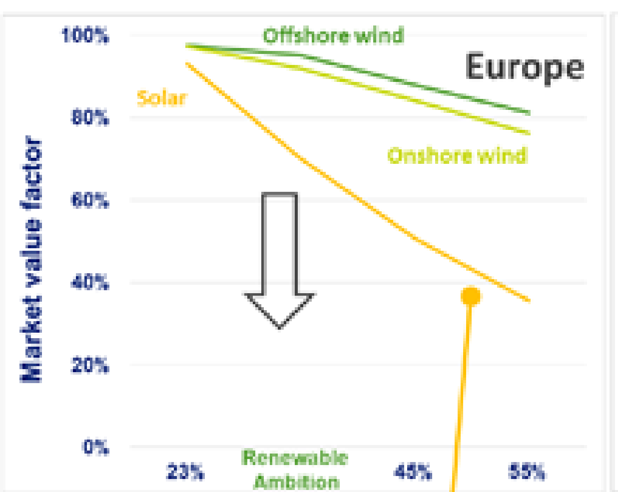
Source: Kiviluoma et al. Flexibility from the electrification of energy. IEEE PES magazine Nov/Dec 2022

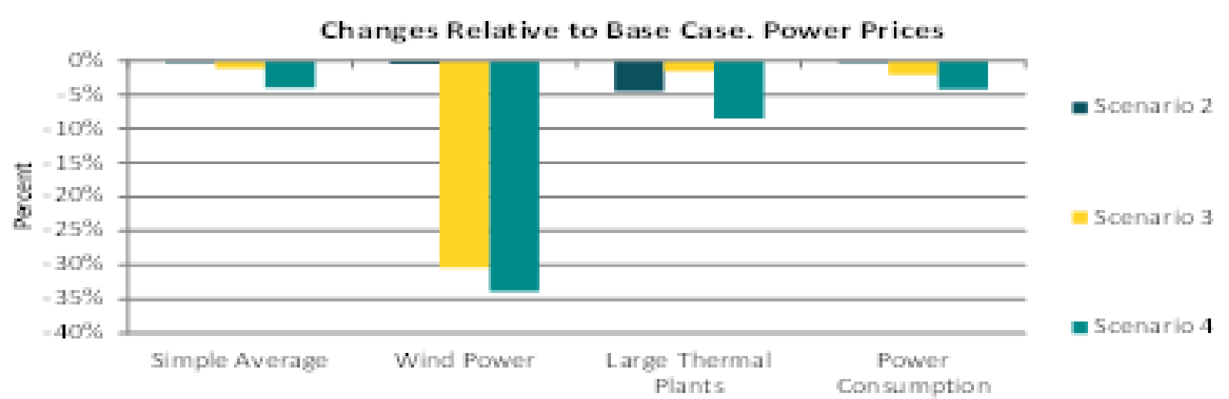
Market challenges

- merit order effect and missing money problem;
- integration of new smaller and variable assets to energy and ancillary services markets;
- design of an effective carbon emissions market;
- capturing of full value of (distributed) flexibility resources;
- geographic integration of different market segments, including harmonisation of pan-European markets and co-ordination of emerging local energy markets

Flexibility will increase value of wind energy in markets

"Profile losses" of wind and solar are lower when other generation and loads operate more flexibly, according to wind and solar availability





Changes in market prices in case of non-flexible system in Denmark (Source: Energinet)

Source: EU-SYSFLEX D2.5

Flexibility will increase value of wind energy in markets

New demand from decarbonisation and power to X, can be utilised especially during times of surplus wind and solar and revive close-to-zero market prices

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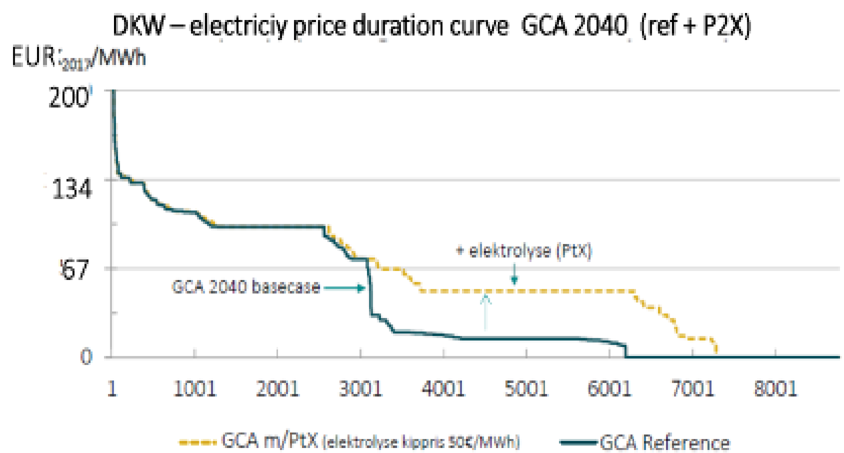
P2X CAN INCREASE THE VALUE OF WIND/ PV



No P2X in the basecase.

In P2X scenario there is:

- 750 MW electrolysis in DK
- Ca 26 GW in DE, UK, NL and DK in total

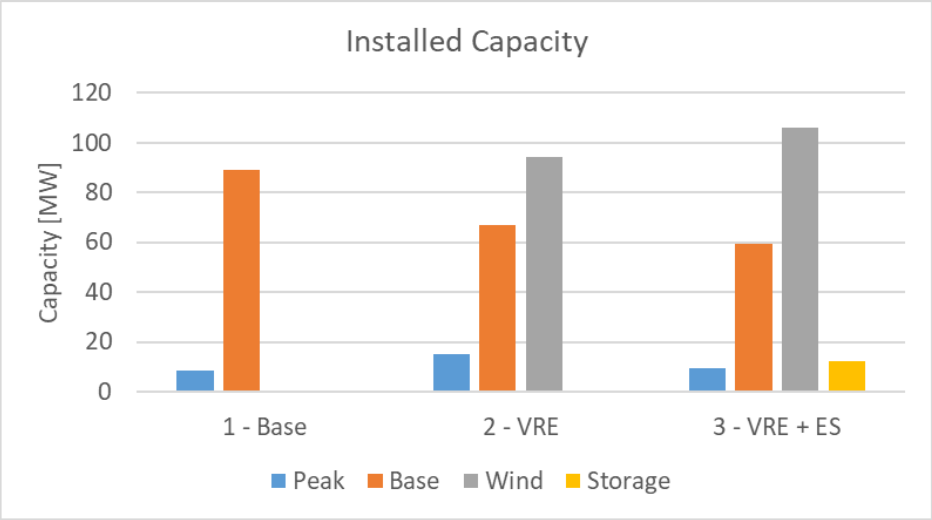
The average annual settlement price for wind and PV in DKW increases from ~20 €/ MWh to 40 €/ MWh in the P2X scenario

Source Energinet

Flexibility will increase value of wind energy in markets

Storage and flexible demand creates new price segments which increases profitablity of wind energy

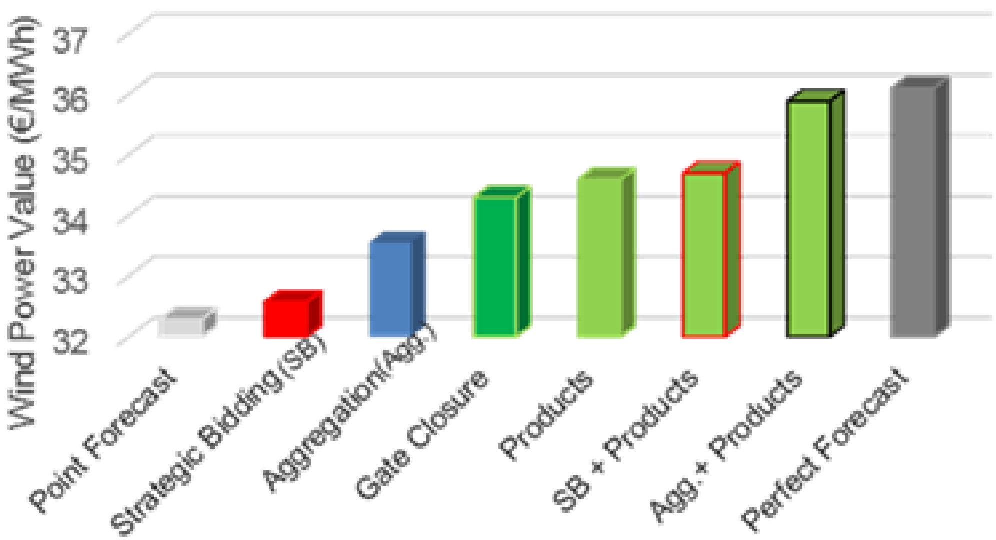
→ Lead to more installed wind power in competitive markets



Source Korpås, Botterud, 2020

Market design to enable grid support services income to wind

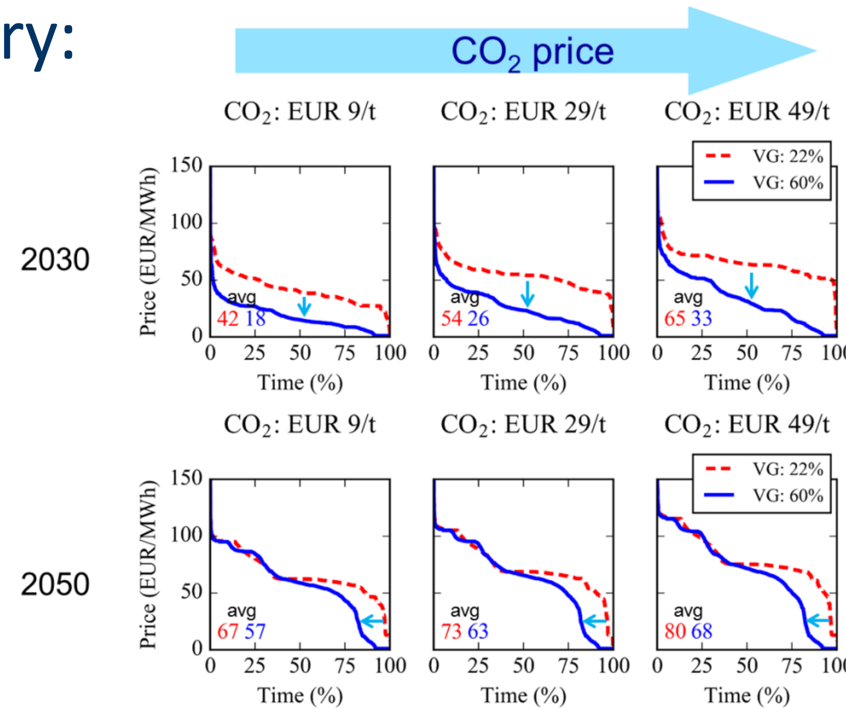
- Possibility to bid close to delivery (for example, hour ahead); smaller amounts of MW; only down-reg
- Local flexibility markets – DSO/TSO coordination



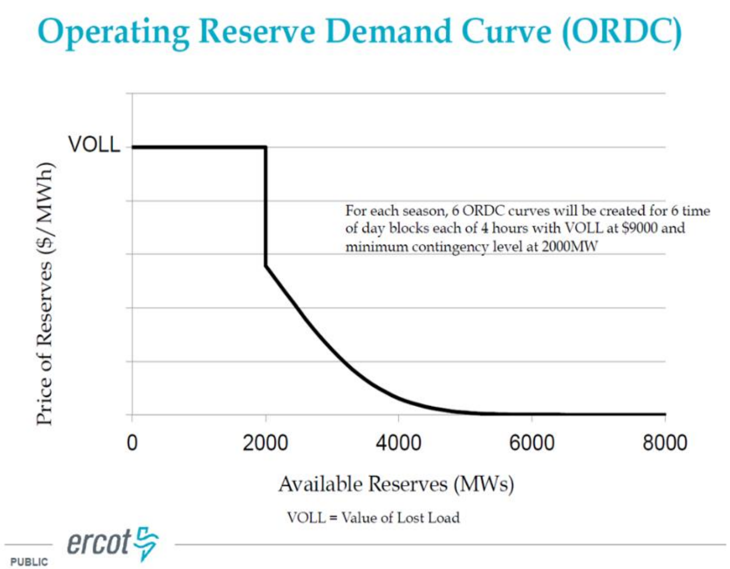
Increasing wind energy value to the market using different approaches: strategic bidding based on probabilistic forecast (SB), aggregation (Agg.), shorter gate closure and balancing products (Source: Algarvio & Knorr, 2017).

Revenue sufficiency

- Ideal energy-only markets can recover costs
  - Also valid for systems with thermal generation, energy storage and VRE (Source: Korpås, Botterud 2020)
- Ways to improve cost recovery:
  - CO_2 pricing
  - Scarcity pricing



Source: VTT



Pushing the limits – towards 100% VIBRES operation

- Studies for 100% renewable power system, hourly energy balances
- Studies for net zero carbon energy systems
- Stability of 100% VIBRES power system

…with new tools and methods developing

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Based on IEA WIND Task 25 collaborative publications

- Summary report **”Design and operation of energy system with large amounts of variable generation”,** September 2021
- ”**Towards 100% Variable Inverter-based Renewable Energy Power Systems**” by Bri-Mathias Hodge, C Brancucci, H Jain, G Seo, B Kroposki, J Kiviluoma, H Holttinen, J C Smith, A Estanqueiro, A Orths, L Söder, D Flynn, M Korpås, T K Vrana, Yoh Yasuda. WIREs Energy and Environment vol 9, iss. 5, e354 https://doi.org/10.1002/wene.376
- “**System impact studies for near 100% renewable energy systems dominated by inverter based variable generation**” by H Holttinen; J Kiviluoma; D Flynn; C Smith; A Orths; P B Eriksen; N Cutululis; L Söder; M Korpås, A Estanqueiro, J MacDowell, A Tuohy, T K Vrana, M O’Malley , IEEE TPWRS Oct 2020 open access https://ieeexplore.ieee.org/document/9246271

- https://www.researchgate.net/project/IEA-Task-25-Design-and-Operation-of-Power-Systems-with-Large-Amounts-of-wind-power