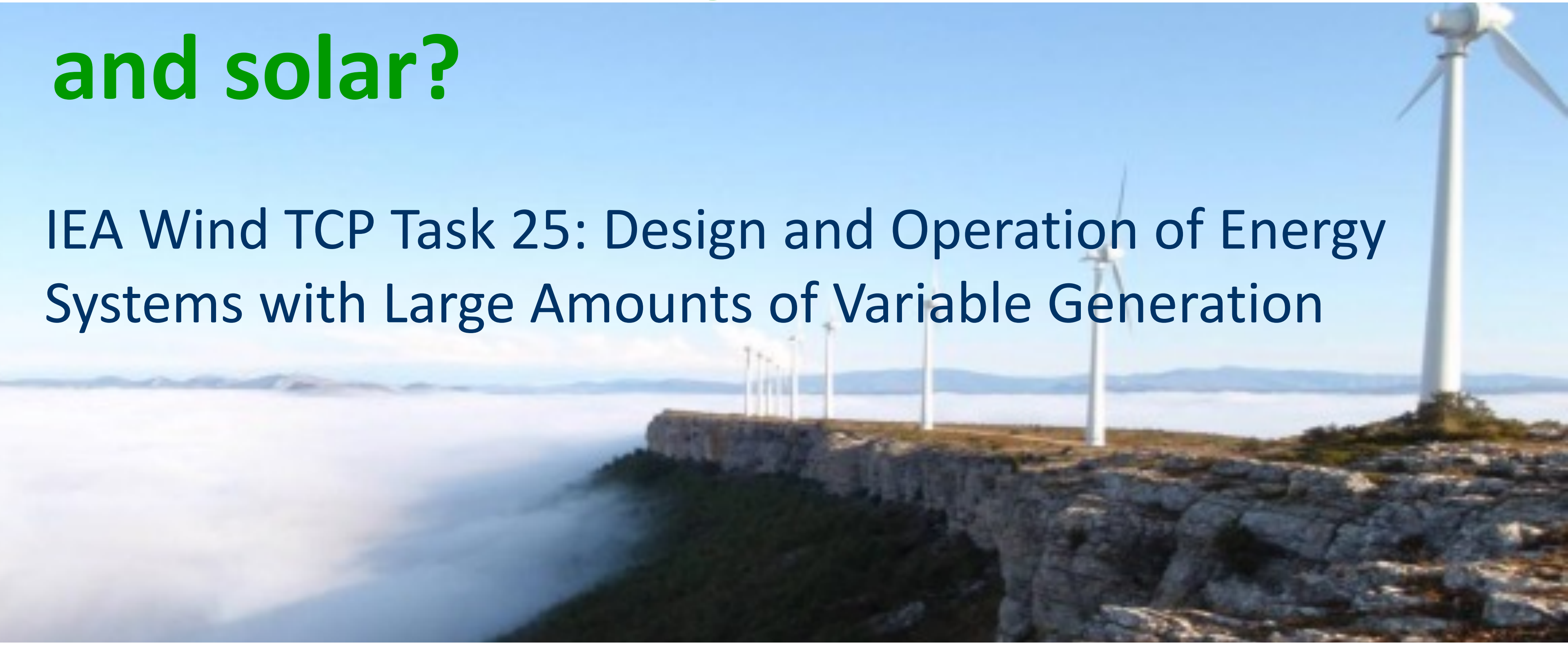
How far can we go with wind and solar?



IEA Wind TCP Task 25: Design and Operation of Energy Systems with Large Amounts of Variable Generation

Technical report presentation, 30 March, 2022

Electrification Academy webinar

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Operating Agent Task 25

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iea wind

Agenda

Task 25 Summary report contents

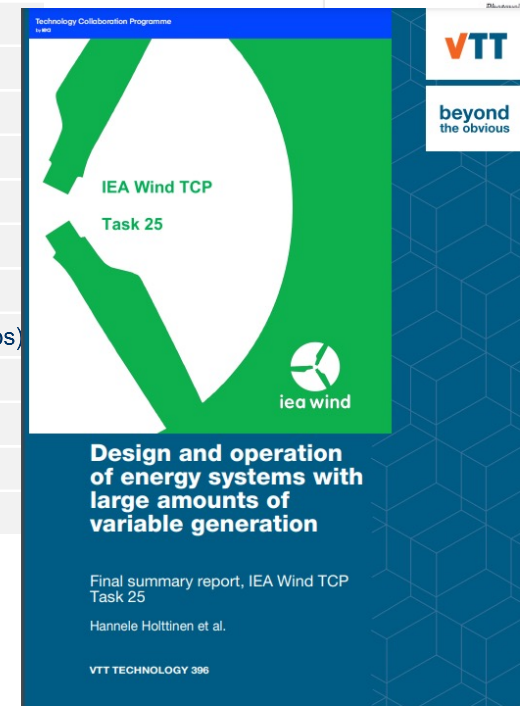
- Introduction
- Variability and uncertainty challenges
- Ensuring long term reliability: assessing transmission and resource adequacy
- Ensuring short term reliability: operating reserves and stability
- Maximising the value in operations: curtailment, flexibility and grid services
- Pushing the limits: towards 100% renewables share
- Conclusions

Q&A

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

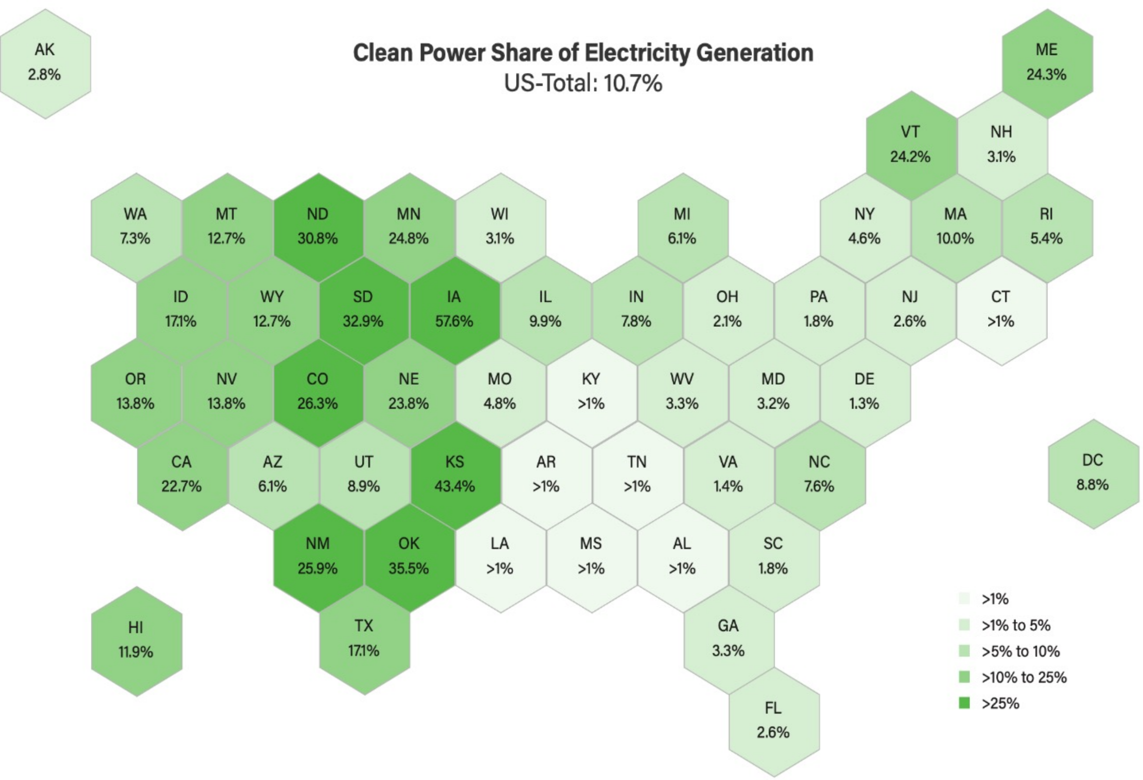
Country	Institution
Canada	Hydro Quebec (Alain Forcione, Nickie Menemenlis); NRCan (Thomas Levy)
China	SGERI (Wang Yaohua, Liu Jun)
Denmark	DTU (Nicolaos Cutululis); Energinet.dk (Antje Orths); Ea analyse (Peter Börre Eriksen)
Finland (OA)	Recognis (Hannele Holttinen); VTT (Niina Helistö, Juha Kiviluoma)
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 Espana)
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); ORE Catapult
USA	NREL (Bethany Frew, Bri-Mathias Hodge); UVIG (J.C. Smith); DoE (Jian Fu)
Wind Europe	European Wind Energy Association (Vasiliki Klonari)

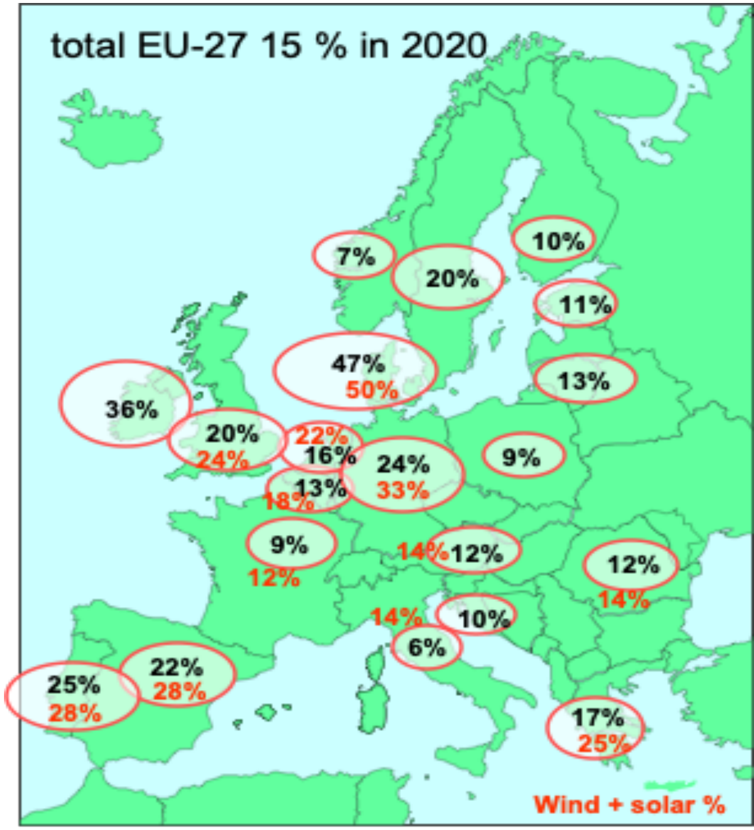
https://iea-wind.org/task25/



Higher wind (and solar) shares …

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

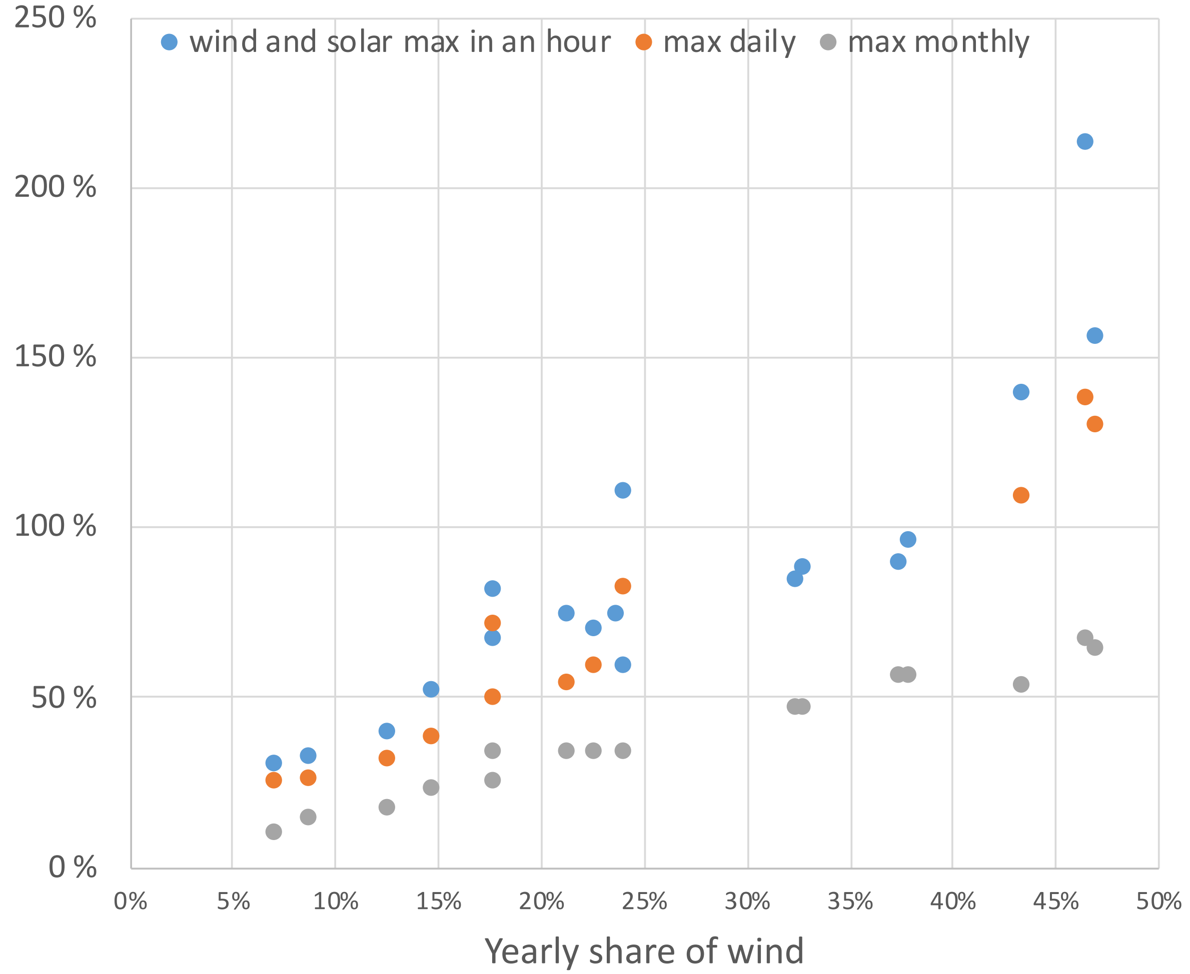




Source: ACP

..mean increasing instant shares

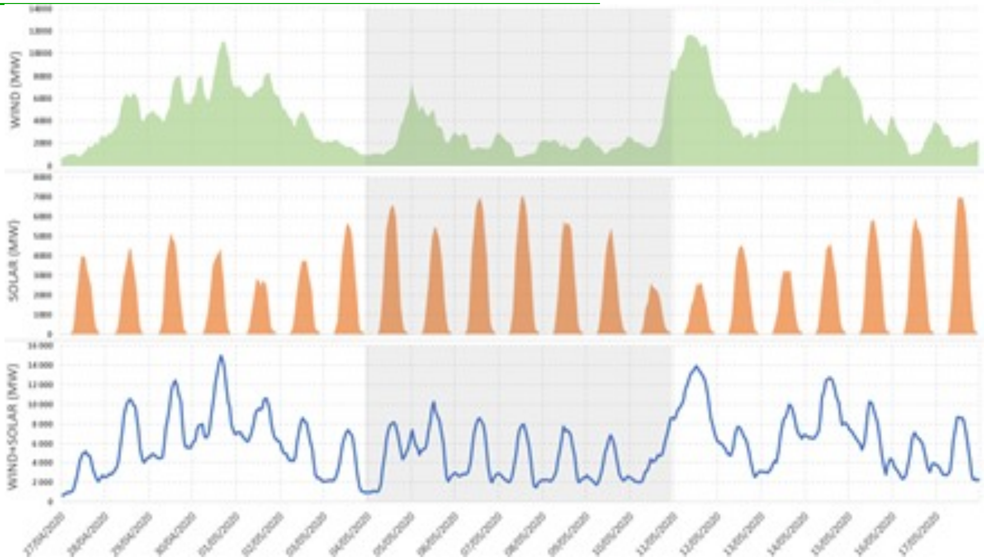
- challenges when >50% RES in synchronous power system (Island of Ireland, Texas, GB)
- larger power systems still at 10-15% share of wind & solar

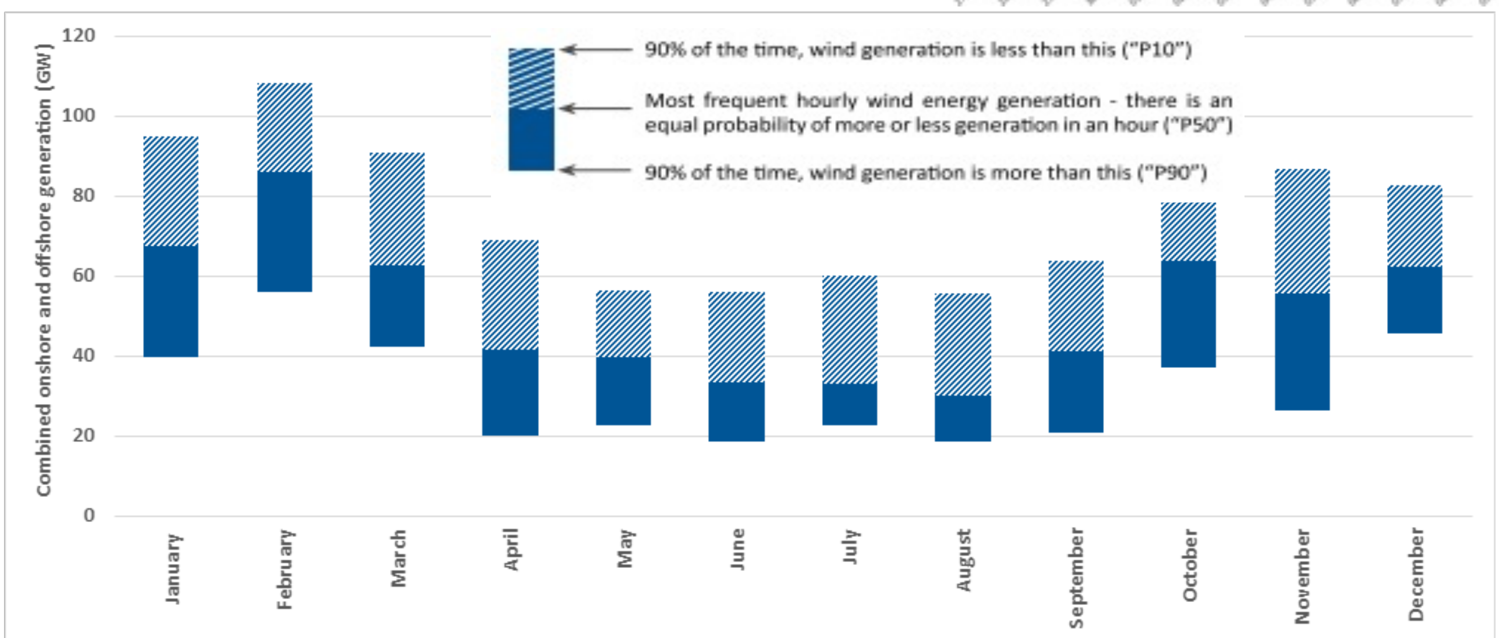


Impacts of variability and uncertainty

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

3 weeks in France, from ENTSO-E data:

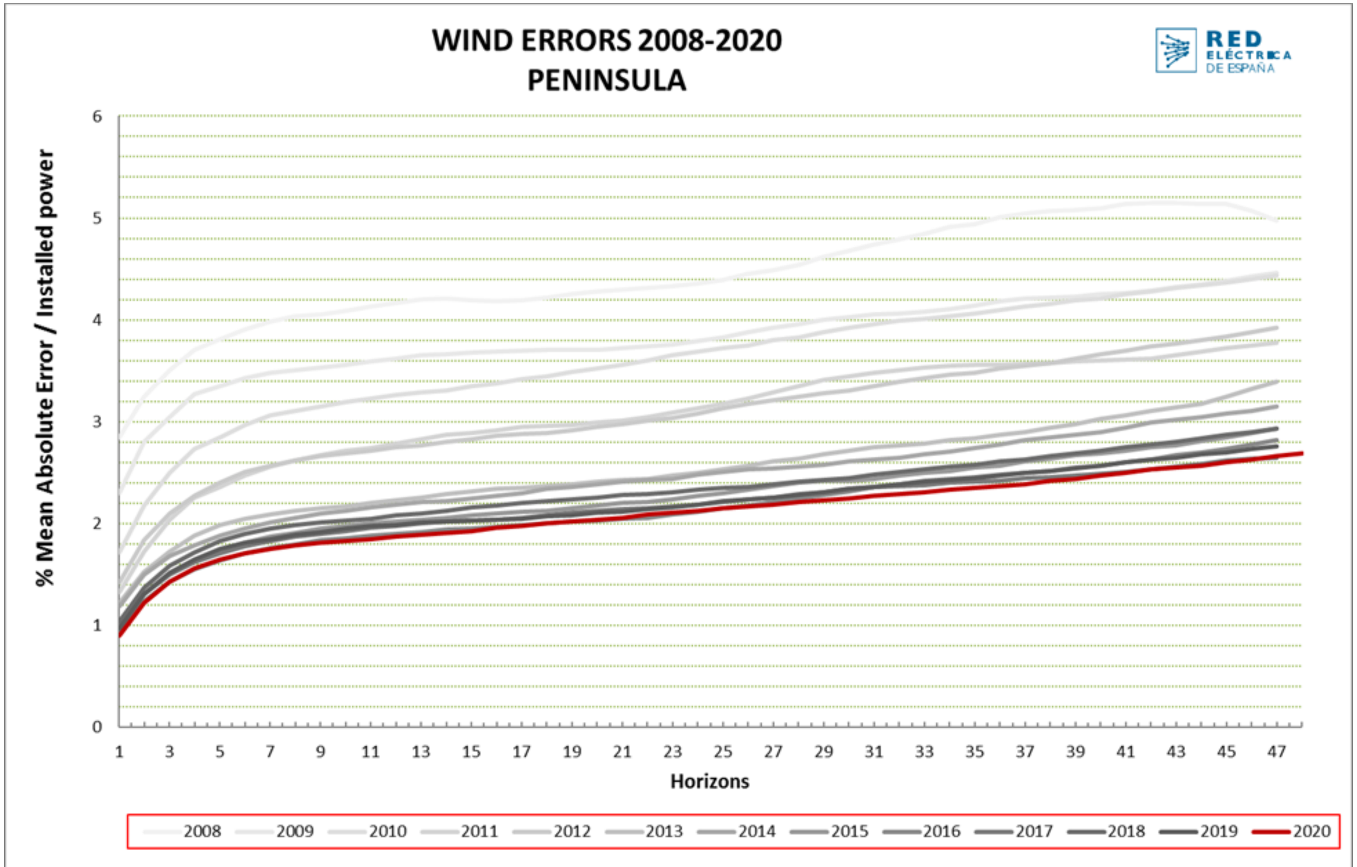




Wind Europe, year 2020 hourly data for EU-28 (~200 GW) data source ENTSO-E

Improvements in data and models

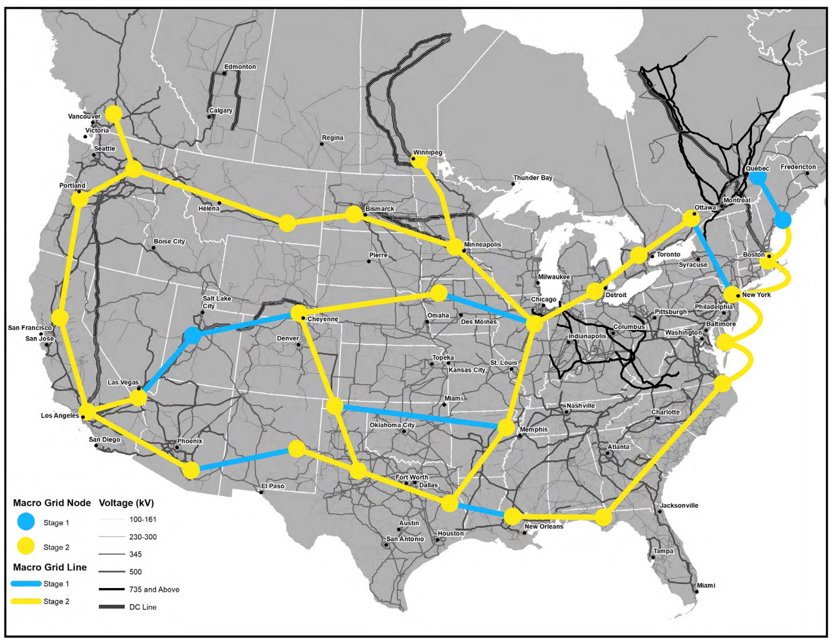
- Simulated weather data and forecasts continue to improve: future wind scenario time series for models
- Extremes important: storms and ”dunkelflaute”



Source: REE, Spain

Regional transmission planning

- Macro-grid discussions in US
- Enhancing existing corridors in Europe



Conceptual macro-grid to unite the US power systems

Source: ESIG. 2021. Transmission Planning for 100% Clean Electricity. https://www.esig.energy/wp-content/uploads/2021/02/Transmission-Planning-White-Paper.pdf

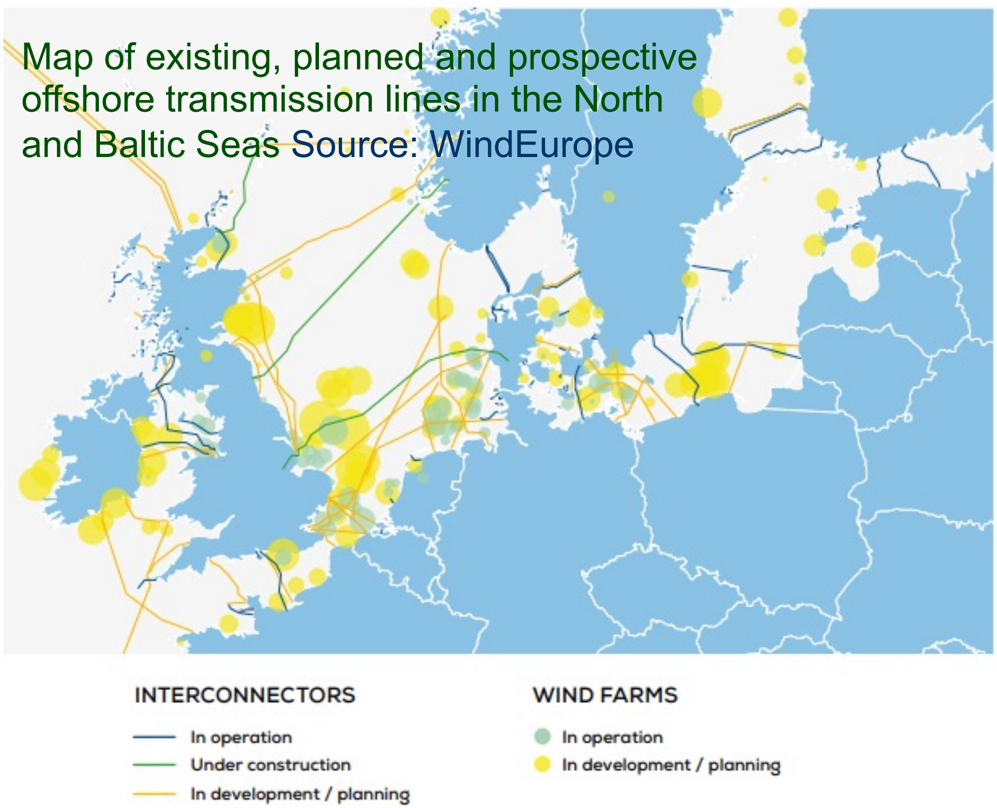
Europe-wide grid architecture for a low-carbon future, as identified by a recent ENTSO-E ten year network development plan (TYNDP)

Source: "Completing the Map 2020 – Power System Needs in 2030 and 2040; ENTSO-E, Nov 2020).

TSOs also planning offshore grids

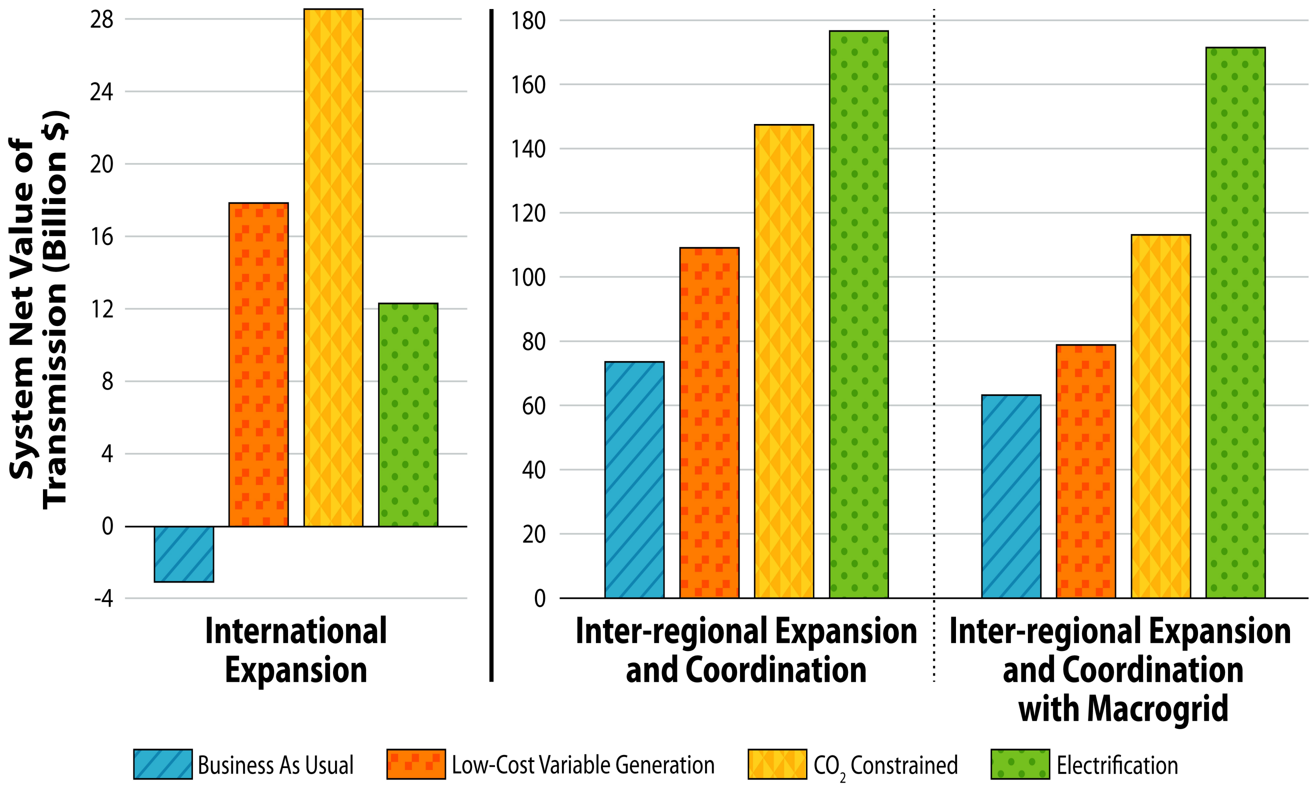
- Meshed grids, hubs, and energy islands
- HVDC technology improvements to increase cost effectiveness, reliability, and land-based grid support

Map of existing, planned and prospective offshore transmission lines in the North and Baltic Seas Source: WindEurope



North Sea Wind Power Hub joint initiative started by system operators TenneT TSO B.V. (Netherlands), Energinet (Denmark), and TenneT TSO GmbH (Germany), with transmission interconnectors (left), Energy Island concept (middle) and the option of increased regional interconnection (right)

More wind and solar … more benefits in inter-regional coordination & expansion



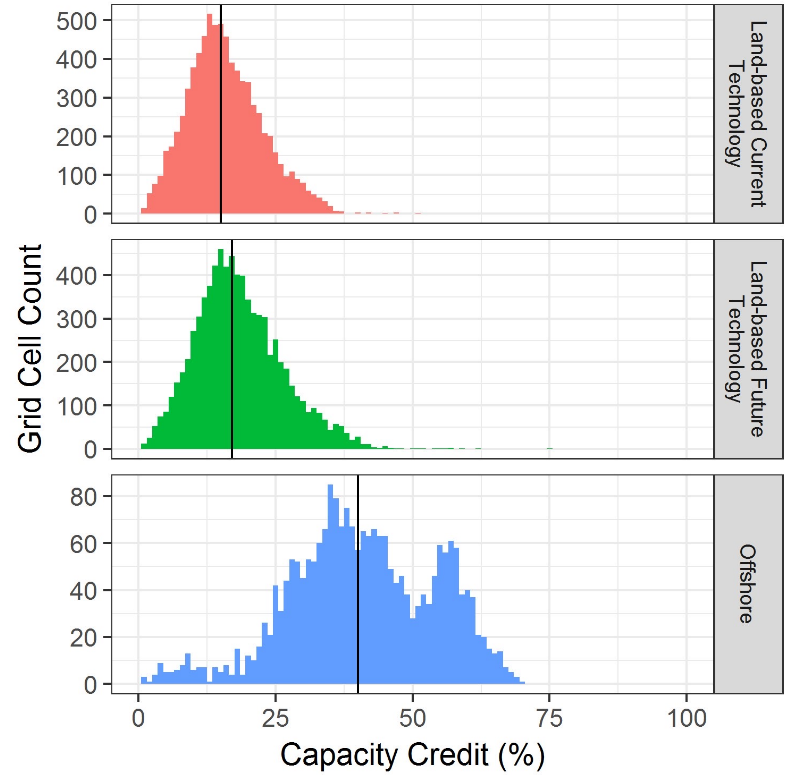
Continent-wide net value of transmission expansion for the four scenarios in the NARIS study

Source: Brinkman et al., 2021. The North American Renewable Integration Study: A U.S. Perspective. Golden, CO: National Renewable Energy Laboratory. NREL/TP-6A20-79224. https://www.nrel.gov/docs/fy21osti/79224.pdf.

Ensuring long-term reliability and security of supply

Capacity value (capacity credit) of wind

- Decreases with increasing wind share, but trend less pronounced across larger geographic areas
- More years of data are needed for robust results
- Ideally calculated with probabilistic methods, LOLP, ELCC, etc.
- Used as inputs for planning models and capacity markets

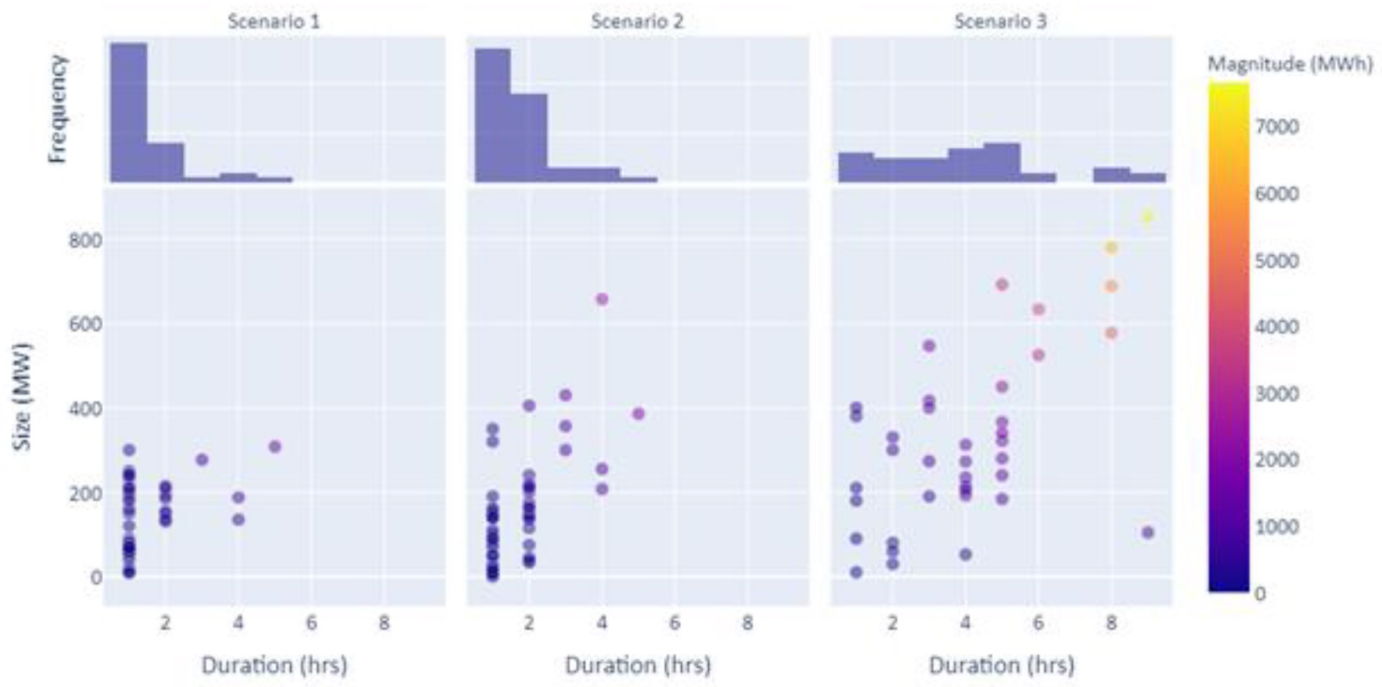


Capacity credit of wind in the Western United States. The average capacity credit is16% for land-based turbines and 41 % for offshore turbines

Source: Jorgenson, J., Awara, S., Stephen, G., Mai, T., 2021. A systematic evaluation of wind's capacity credit in the Western United States. *Wind Energy* 24, 1107–1121. https://doi.org/10.1002/we.2620

Resource adequacy in future systems

- Improvements to metrics, methods, and/or tools are needed to:
  - Include coordination with neighbouring areas
  - Reflect extreme events, including correlated outages and multiple years of data
  - Capture magnitude, duration, frequency, and timing of potential loss of load
  - Model chronology, which is essential for resources like load participation and storage

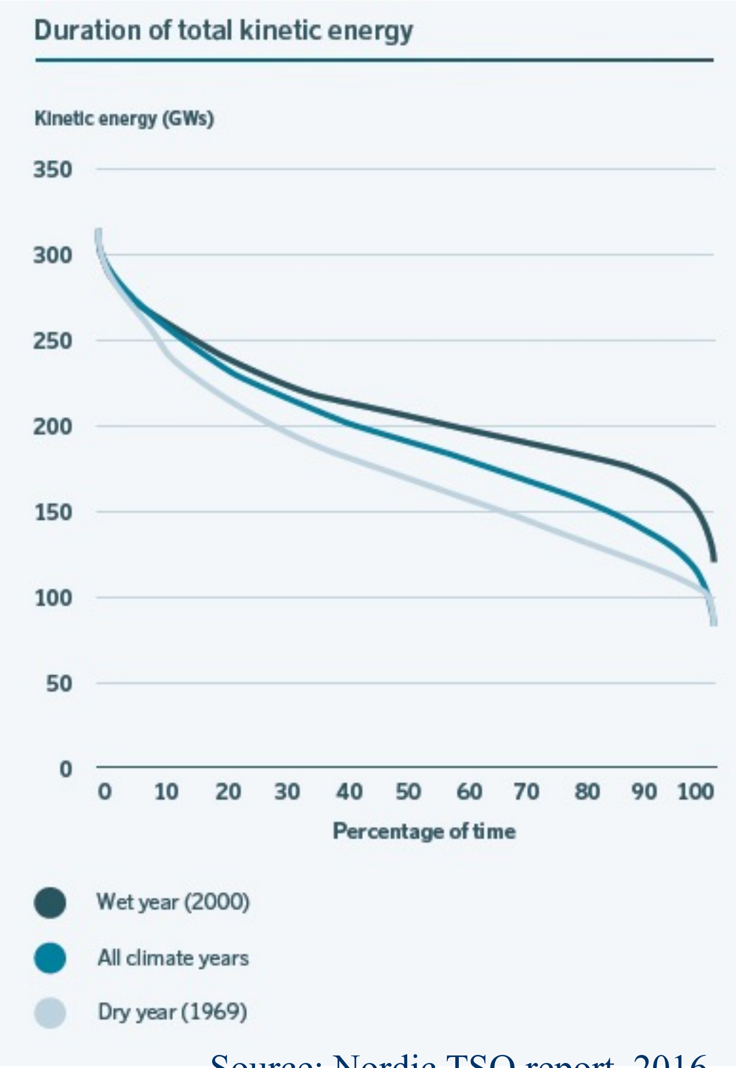


Plots of size, duration, frequency of shortfall events. Each scenario has a different resource mix but the same LOLE (i.e., number of dots)

Source: ESIG. 2021. Redefining Resource Adequacy. https://www.esig.energy/resource-adequacy-for-modern-power-systems/

Frequency stability

- Small system: Ireland case: limiting wind, SNSP
- Medium size systems: Nordic, Texas, GB new tools to monitor inertia real-time/day-ahead
- Large systems:
  - US MISO – not an issue at <60% average share of wind and solar
  - European system: system splits could happen (Iberia, EU SysFlex) Mitigation: cross-border flow limits, ensuring DC connections

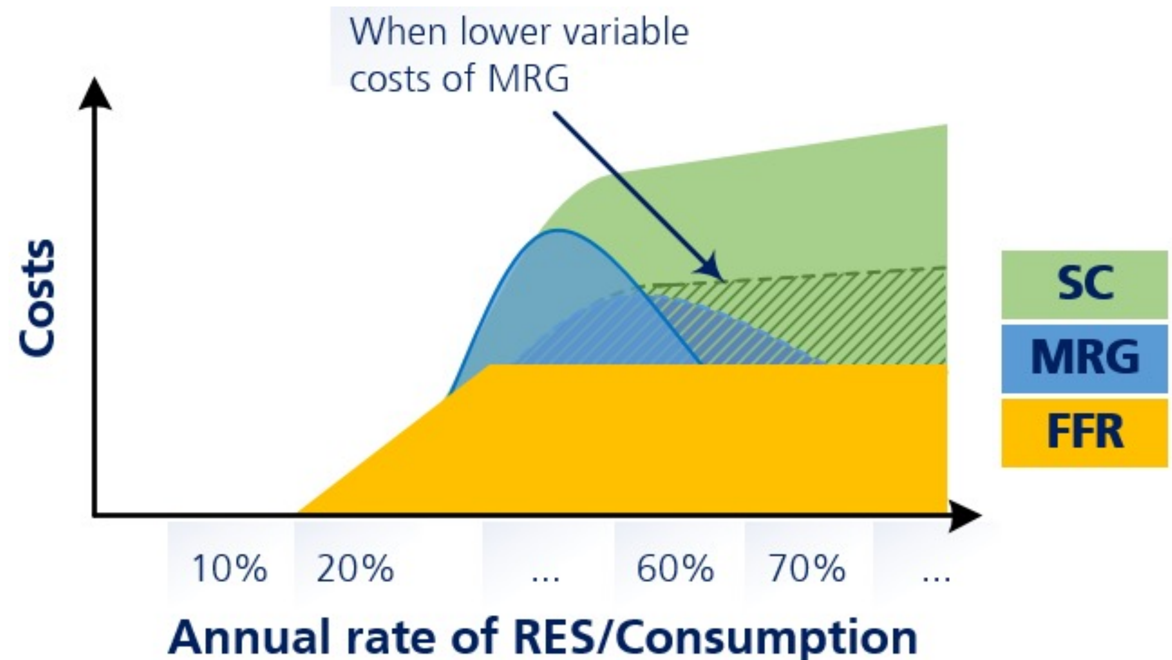


Source: Nordic TSO report, 2016

Supporting frequency stability

- Maintain online inertia by keeping synchronous machines running (MRG) or other sources of synchronous inertia (SC, synchronous condensers)
- Speed up frequency response, Faster primary frequency response (on sync machines), Fast frequency response (FFR)

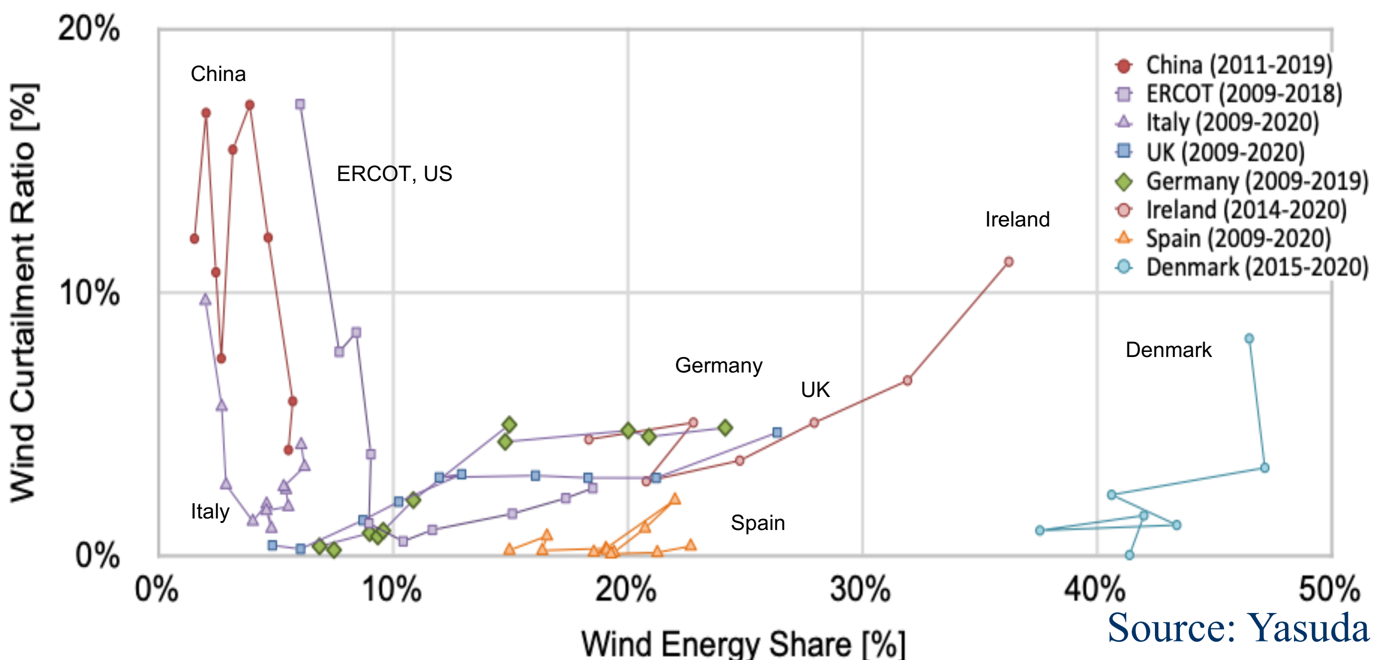
ERCOT, Texas: FFR (0.5 s) High wind, low load: 1,400 MW of FFR provides same response (and reliability impact) as 3,300 MW of PFR



Source: EdF (Primes et al. 2019)

Maximising wind energy value: curtailment

- up in Europe, down in China
- Reasons: grid inadequacy, inflexibility, system limits
- Solved by building grid (IT, CHI); increasing instantaneous penetration limits (SNSP in IE)
- market based curtailment, bidding down-reg (ES, DK)



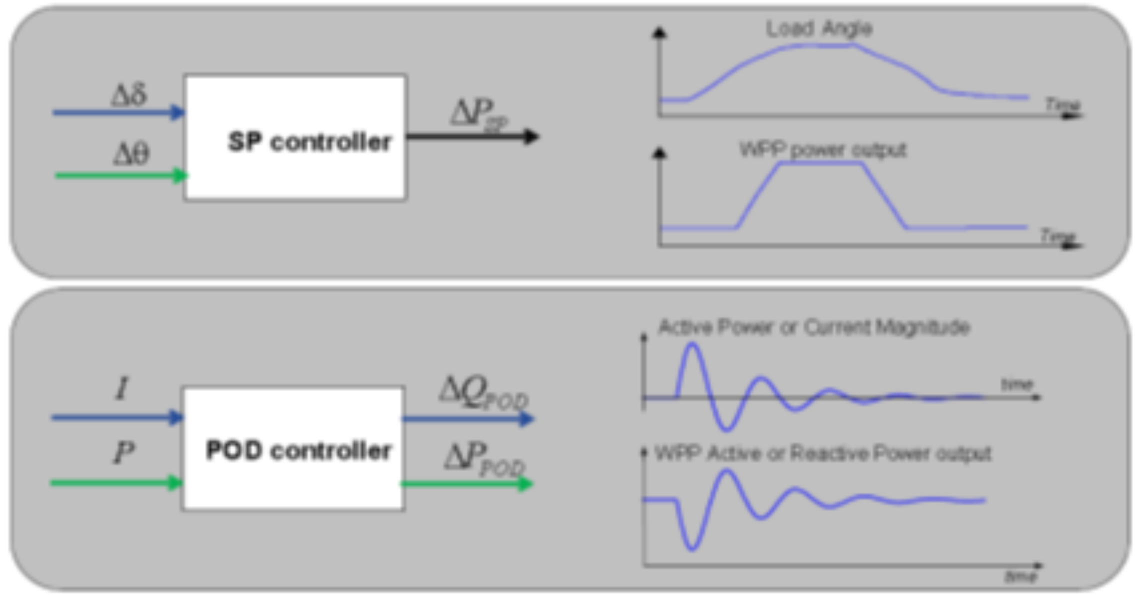
Source: Yasuda et al. 2022

Maximising wind energy value: using wind power for AS

- With surplus wind and PV, important to provide AS, otherwise risk being curtailed to commit a synchronous generator to provide the same services
- Frequency control and balancing markets as well as voltage control from transmission connected power plants - experience already from several power systems
- **Spain:** 17 of 27 GW wind power compliant for (mainly tertiary) freq control. Use of reserves from wind power is increasingly being used:
  - 14.4% of total downward reserves in 2018 and 14.8% in 2019
  - 4.8% of total upward reserves in 2018 and 7.5% in 2019
- Regulation /AGC and faster responses: good compliance and value for system shown (TX, CO, HQ)

New services + paying for them

- New: Power oscillation damping POD, Synchronising power SP, Restoration, Grid-forming inverters
- Start paying for Inertia, FFR, Ramping, Voltage
- Timing: introducing services when system actually needs them



Source: DTU

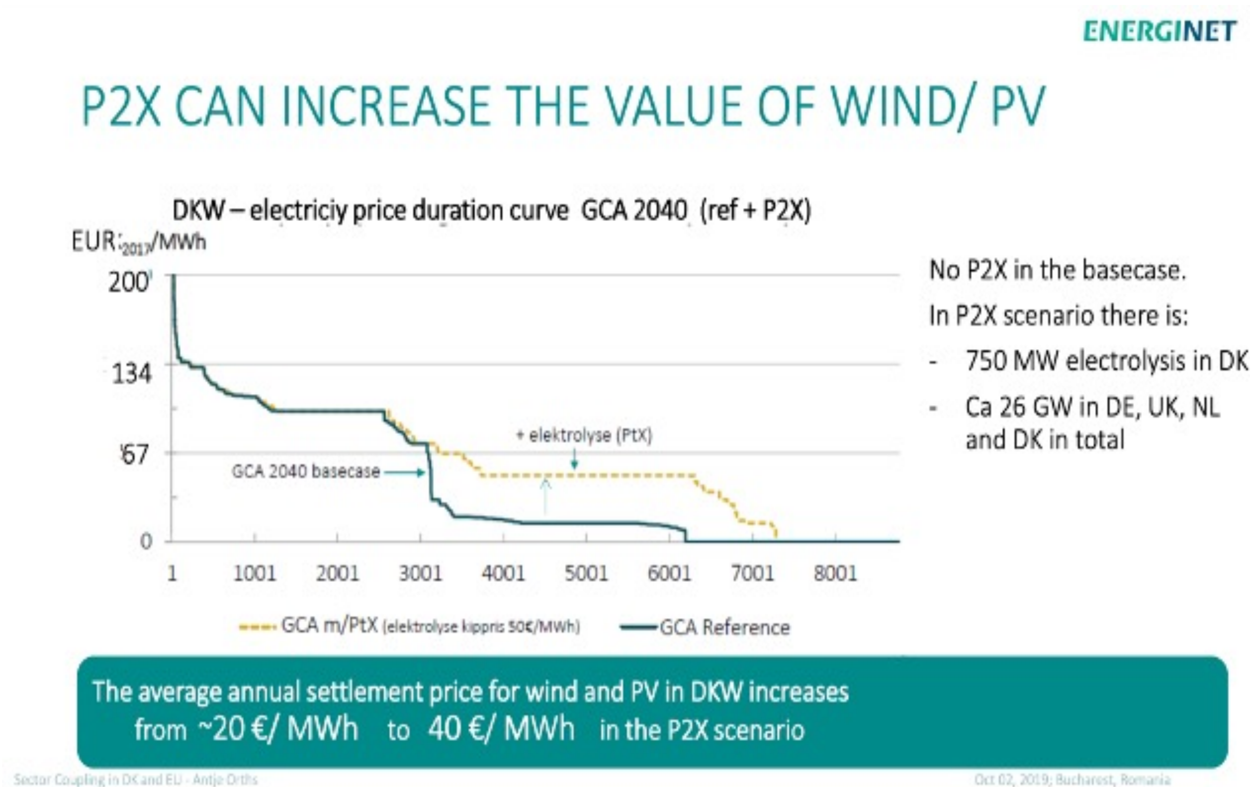
Paying for all services – many now required in grid codes without compensation

Maximising wind energy value: flexibility

- Thermal power
  - Retrofits to lower minimum on-line power helps reduce curtailment
  - Combined heat and power (CHP) and heat pumps, with heat storage
- Increasing transmission has good cost benefit
- Hydro power
  - Pumped hydro useful for longer than few hours, hydro storage costs driven by the kW costs (cables + reversible pumps)
  - Larger reservoirs enable long term storage
- Storage
  - Batteries provide short-term balancing over one to some hours, reduce the need for peaker power plants
- Demand response
  - Short-term flexibility for existing loads and longer-term flexibility for Power2X loads – with hydrogen/derivative storage

Flexibility increases wind energy market value

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



Source Energinet

Pushing the limits: operation in Denmark without central power plants

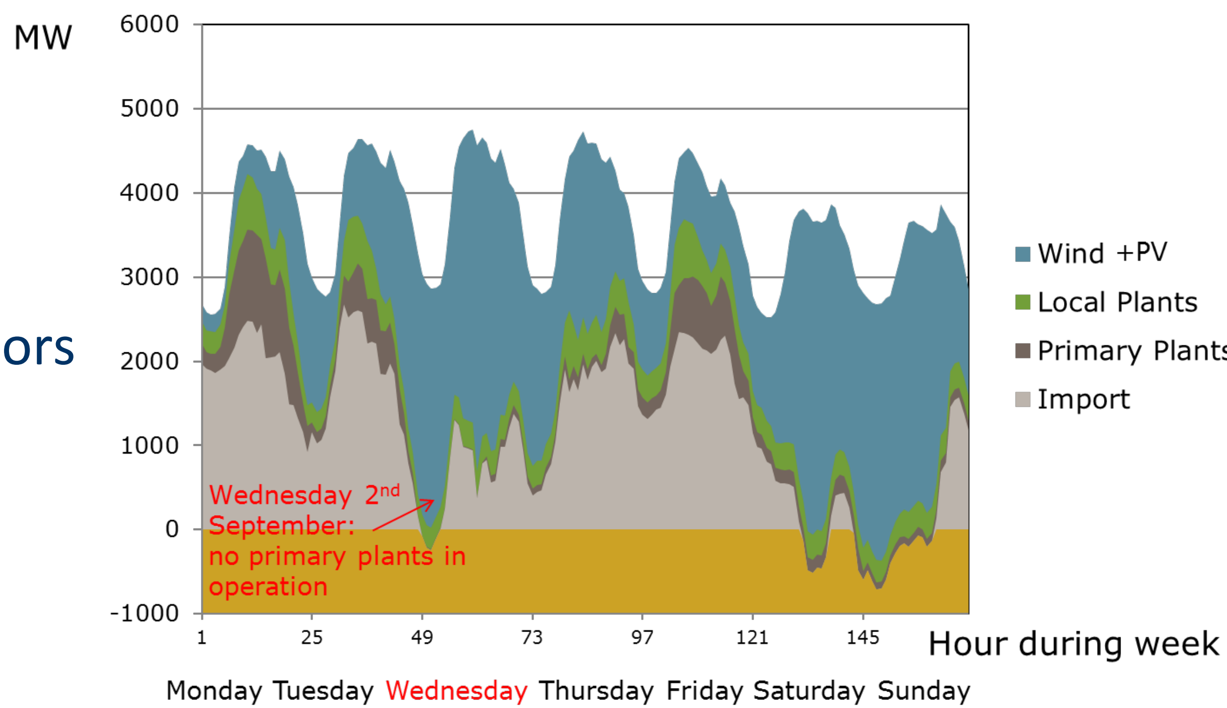
First time in 2015, and several times since then, all central power plants shut down. Necessary system support obtained from:

- HVDC link: 700 MW Denmark-Norway
- synchronous compensators 4 in DK-W and 2 in DK-E
- and small-scale power plants

ENERGINET

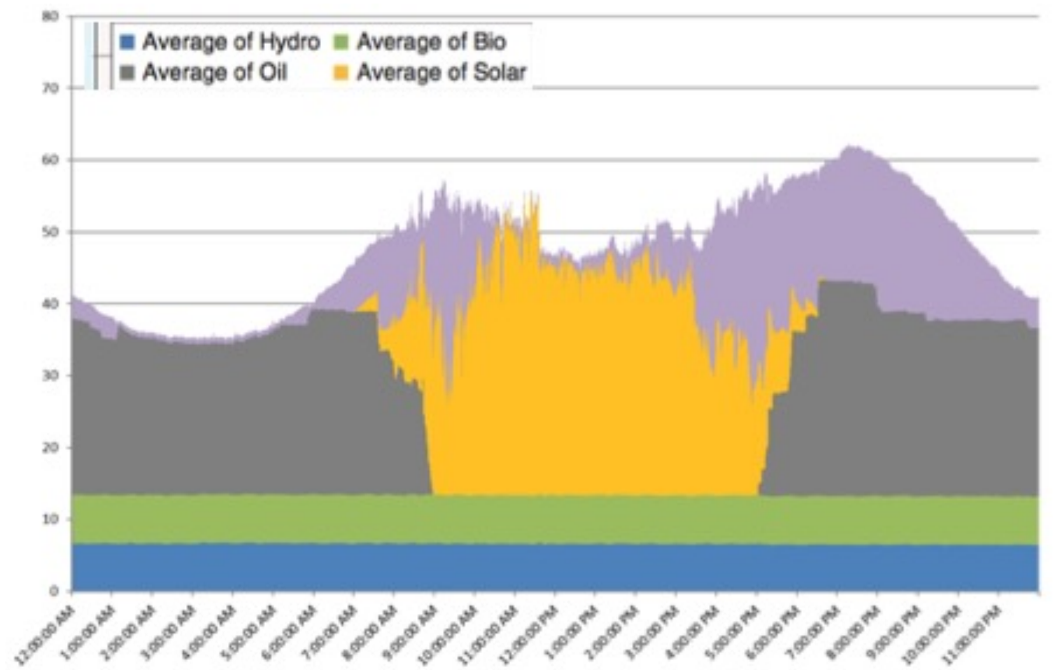
2nd September 2015 without central plants

- hourly dispatch 31 August – 6 September 2015



Small island power system: Kauai in Hawaii

- Quick-start diesel reciprocating engines
  - Fast reserves (start up in minutes); one engine operating in synchronous condenser mode: inertia and system strength
- PV/battery hybrids for fast response
  - (Passing cloud events of order of seconds) hold 50% of real-time output as spinning contingency reserve

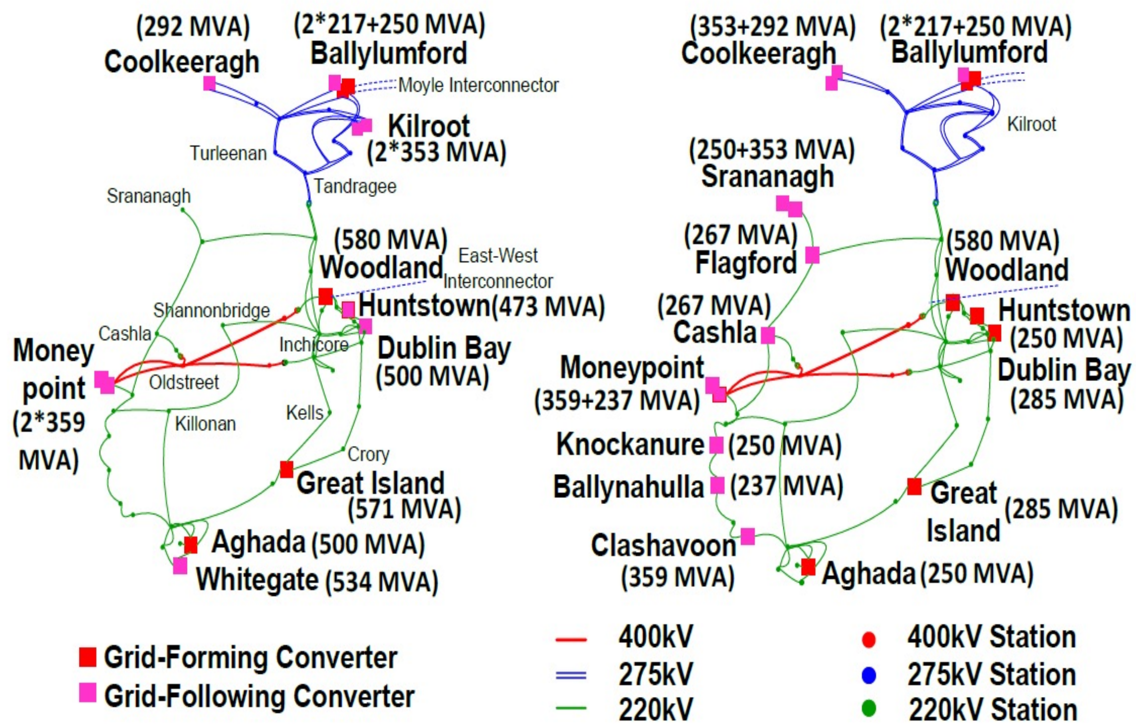


KIUC system dispatch on 3/14/20 with 8 hours of 100% renewables operations. Purple shows PV/battery hybrid output. (Source: Brad Rockwell, KIUC)

Stability of 100% IBR grid – first grid forming studies emerging

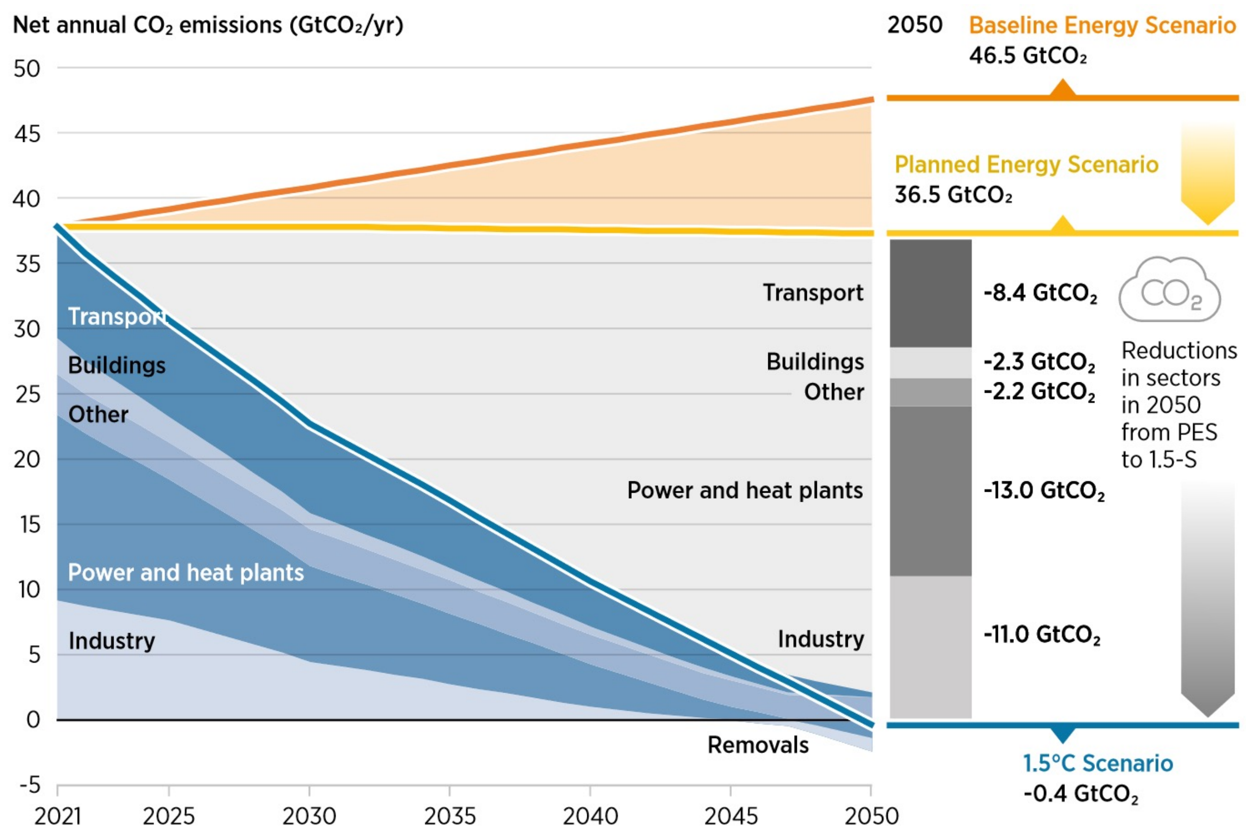
- Grid forming inverters to replace synchronous machines ('shepherds') for the grid following inverters ('sheep')
  - GB system: 65% IBR share with modified grid-following control; combining grid-following and grid-forming controls to a theoretical 100% (MIGRATE D1.6, 2019)

Ireland system: ~30% of grid-forming feasible for 100% IBR simulation
Source: UCD, MIGRATE project



Net zero plans affecting power systems: role for electrification

Achieving a 100% sustainable system doesn't end in carbon-free power production. What is needed for heating, transport and industries to support the transition?

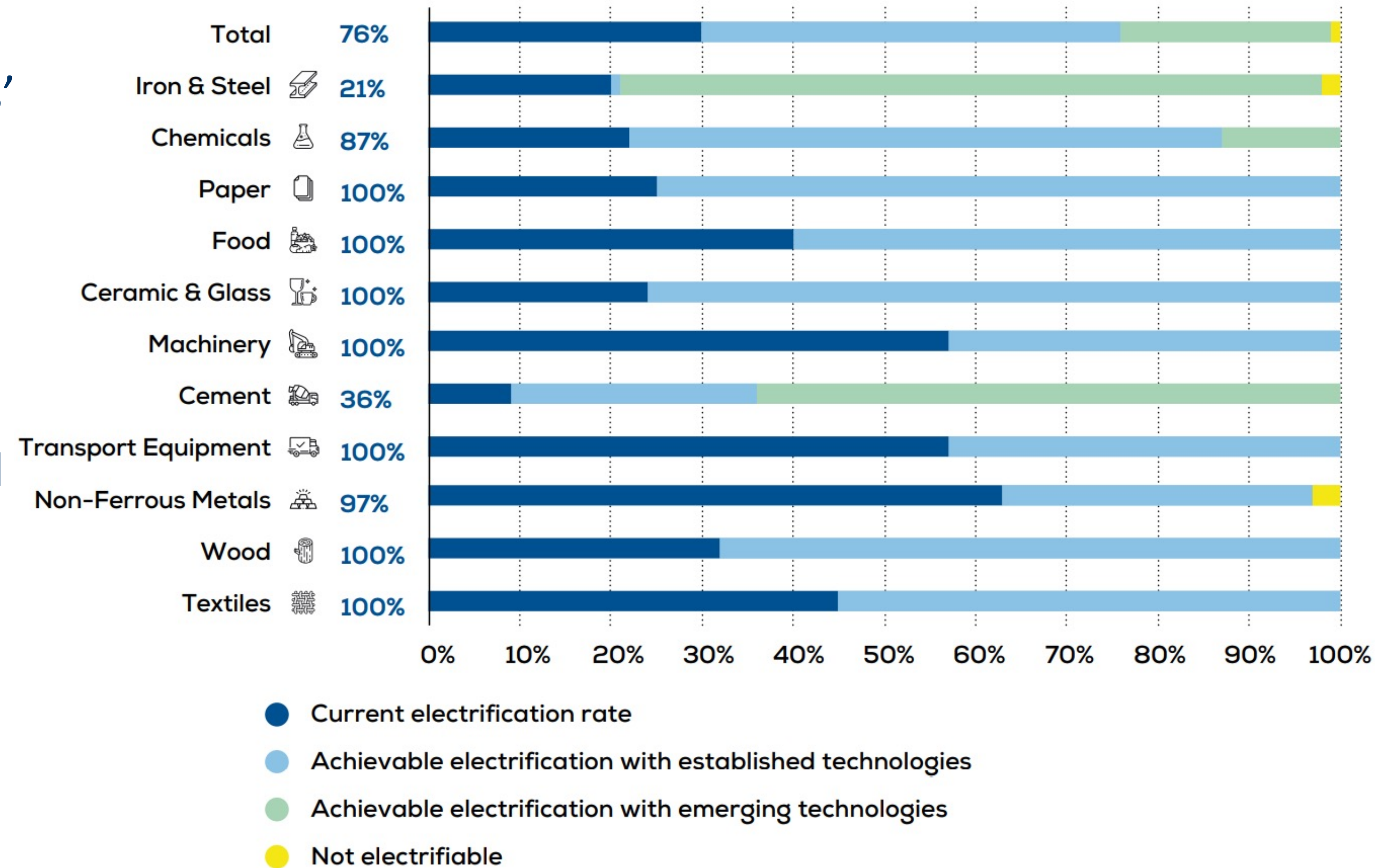


IRENA scenario "Target pathway to 1.5 °C" demonstrates the reduction needs of different energy sectors. Electrification is a key solution in decarbonizing transport, buildings, and industry. (World Energy Transitions Outlook: 1.5 °C Pathway, International Renewable Energy Agency 2021)

Electrification potential

Comparison of different industries' electrification potential:

76% of Europe's industrial energy and heat demand could be electrified with existing technology



Source: ETIPWind and WindEurope: Getting fit for 55 and set for 2050 - Electrifying Europe with wind energy, 2021. ETIPWind based on Madeddu et al. 2020

Pushing the limits: carbon neutrality and sector coupling

- Capturing all energy sectors and their coupling
- Some liquid fuels remain, from biomass or electricity, different pathways, such as ammonia
- Looking at energy balances, no stability

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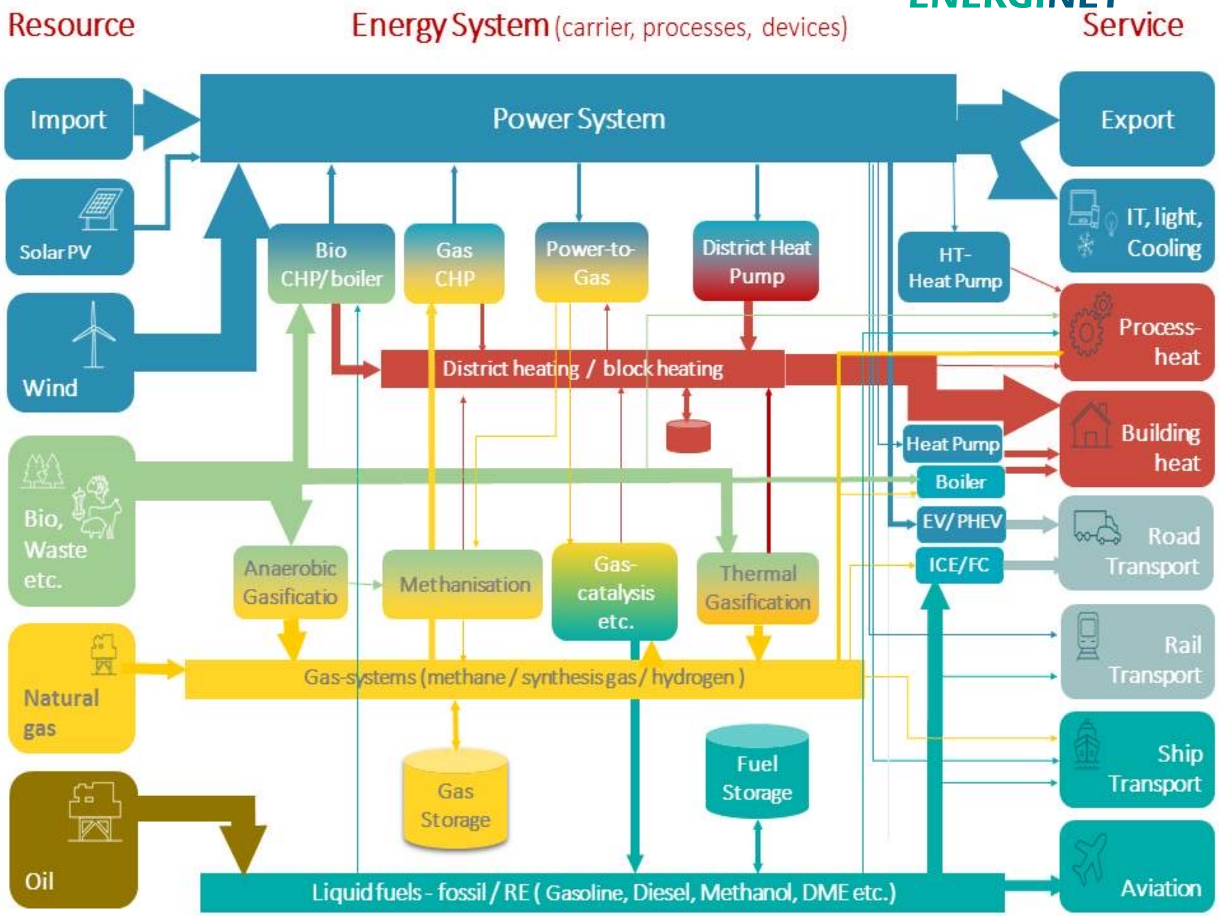
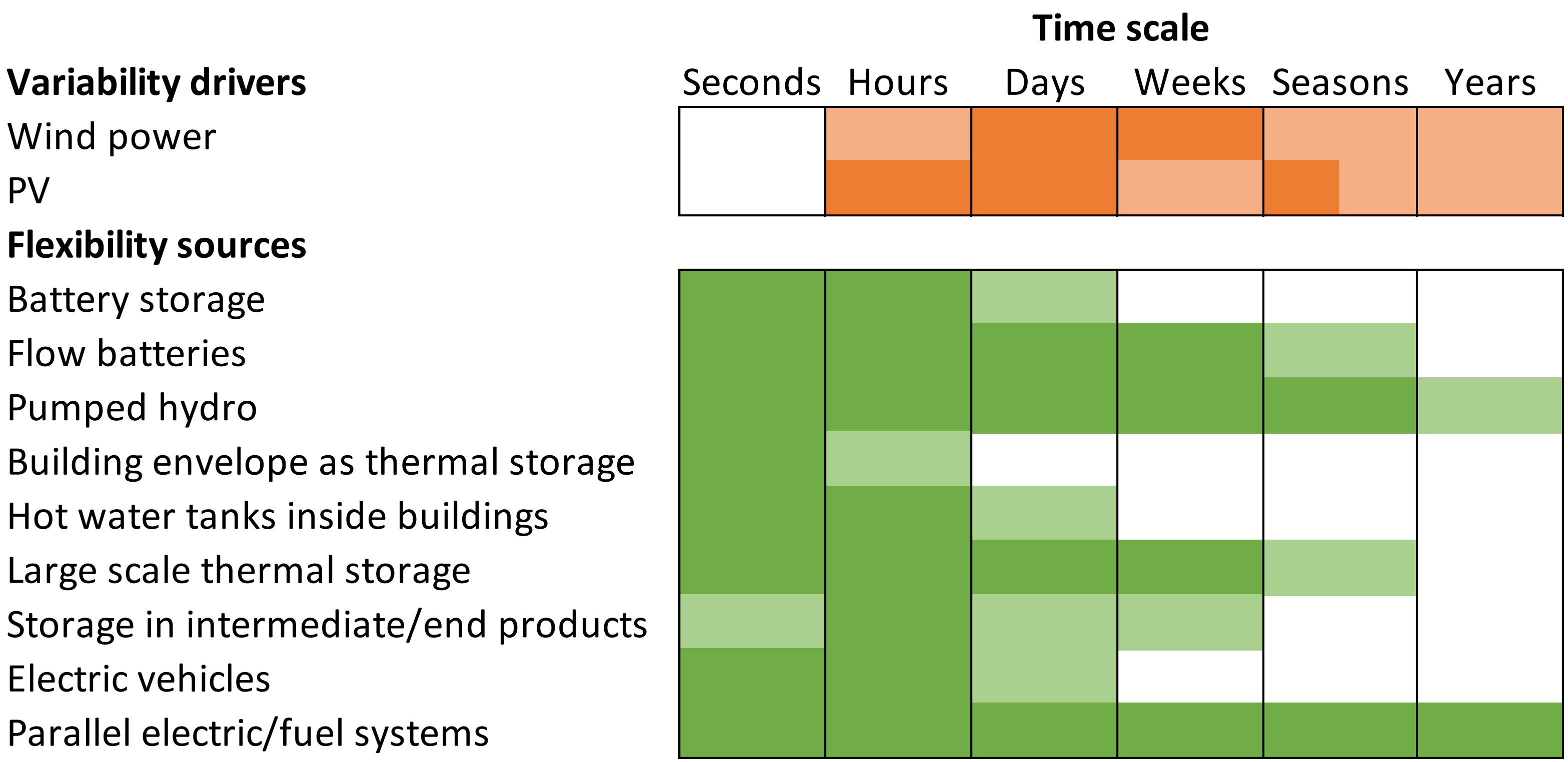


Energy flow in the Danish energy system for 2035: sector-coupling in future energy systems. Power-to-X, storage and parallel solutions are needed to support development towards 100% clean systems. DME: dimethyl ether; PHEV: plug-in hybrid EV; ICE: internal combustion engine; FC: fuel cell; RES: renewable energy source; PV: photovoltaic; Bio: biomass; IT: information technology; HT: high temperature

Source: Energinet

Time scales of flexibility – the long term flexibility challenge

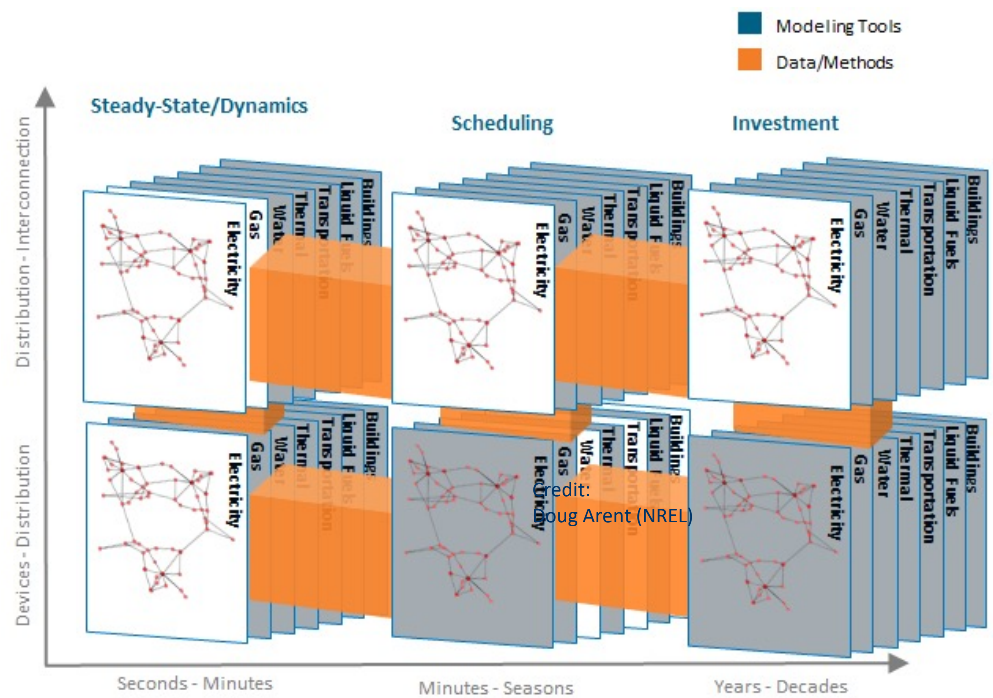


Estimated time scales for the drivers of variability and sources of flexibility (darker colour – primary impact, lighter colour – secondary impact, white – not usually relevant).

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

Pushing the limits: Tools

- Modelling complexity
  - VIBRES (variable inverter-based renewable energy source)
  - Need for higher resolution (temporal and spatial)
- Larger areas
  - Entire synchronous systems
- Integrated planning, operational, stability tools
- Cost versus risk
  - Price responsive demand
  - Differentiated reliability



NREL's Scalable Integrated Infrastructure Planning (SIIP) modeling framework.

Source: Doug Arent (NREL)

Conclusion

- VIBRES (wind and solar) will make a large contribution to future decarbonised energy systems
  - Potential to form the backbone of future power systems when full range of inverter capabilities are used
  - New paradigms of non-synchronous power system operation and long-term resource adequacy are being developed, with a suite of new tools and methods for system operators
- Experience of operating and planning systems with large amounts of VIBRES is accumulating
  - Research to tackle challenges, and opportunities of inverter-based, non-synchronous generation is on the way
  - Energy transition and digitalisation also bring new flexibility opportunities, both short and long term

Based on IEA WIND Task 25 collaborative publications

- Summary report **”Design and operation of energy system with large amounts of variable generation”** https://doi.org/ 10.32040/2242-122X.2021.T396
- ”**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

Thank You!!

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