Grid integration of Variable Generation – best practices from international experience

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

Hannele Holttinen, Operating Agent Task25

Partner, Recognis

Renewables Integrate Hub, Oxford, Oct 28th, 2020

iea wind

Contents

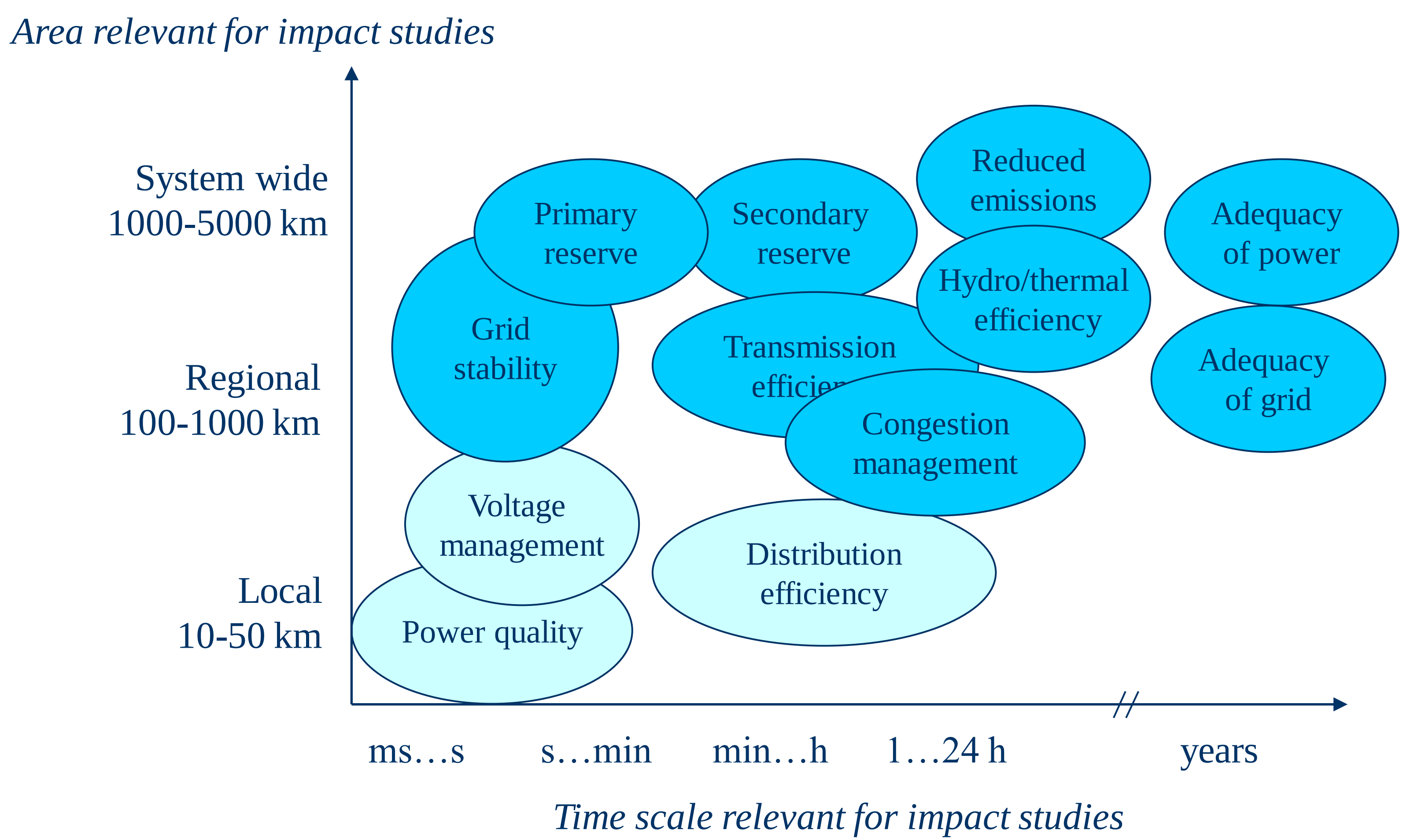
- Integration studies
- Lessons learned from challenges of wind and solar
  - For small and larger shares of wind and solar
- Long term, towards 100% renewable energy systems

IEA Wind Task 25 –
Best practice of VG integration

- Started in 2006, now 17 countries + WindEurope participate to provide an international forum for exchange of knowledge
- State-of-the-art: review and analyze the results so far (Jan 2019)
- Formulate guidelines- Recommended Practices for Wind/PV Integration Studies (RP Ed.2 July 2018)
- Fact sheets and integration study time series (wind, solar, load…)

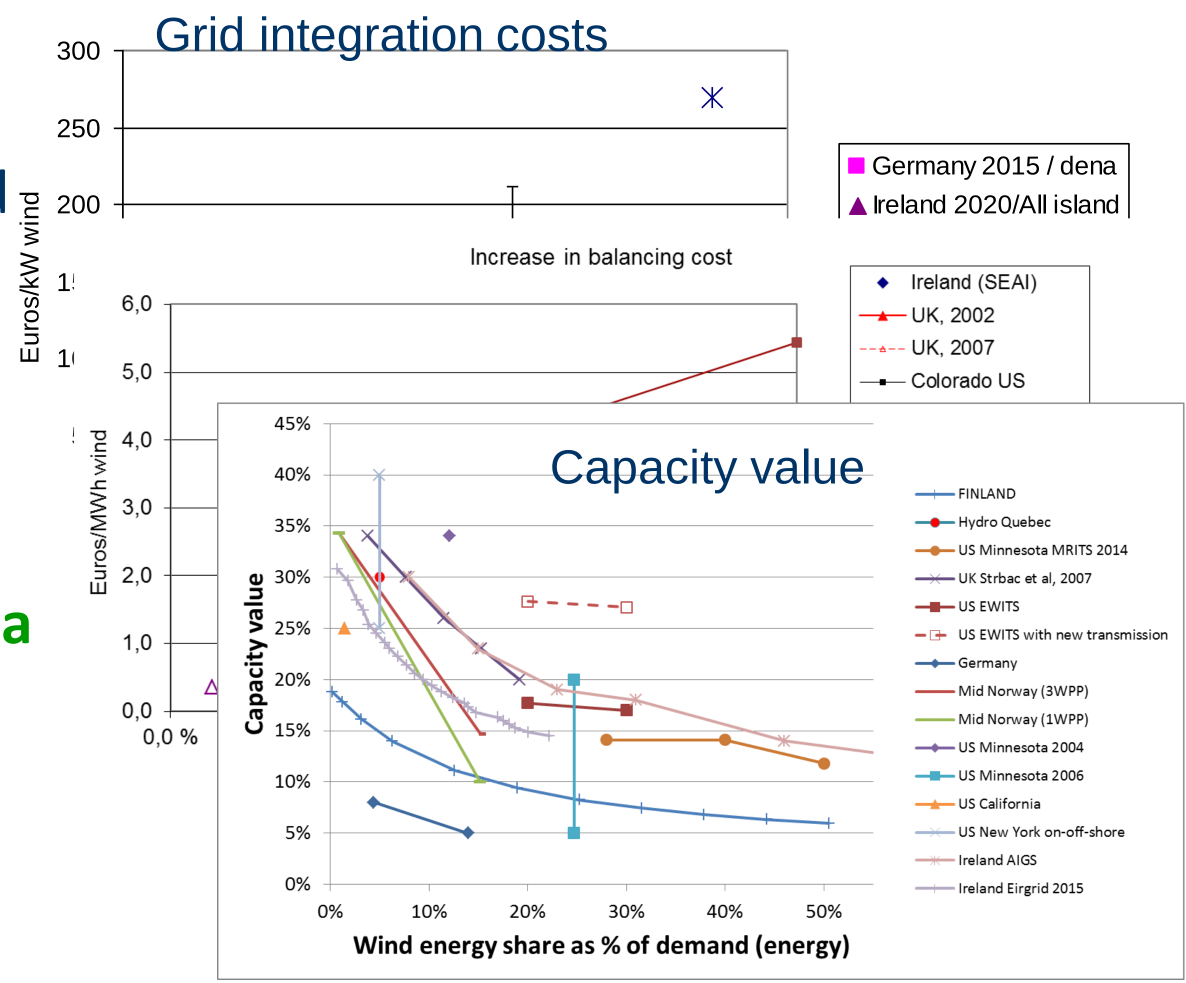
https://community.ieawind.org/task25

Possible impacts of wind power on the power system



Methods for integration costs – work of IEA WIND Task 25

- Comparing studies for Balancing costs, Grid infra costs, and Capacity value of wind
  - Depend on share of VRE and flexibility available in the system
- Recommended practices on methods: **Outcome cannot find a proper way to draw estimates of integration costs**

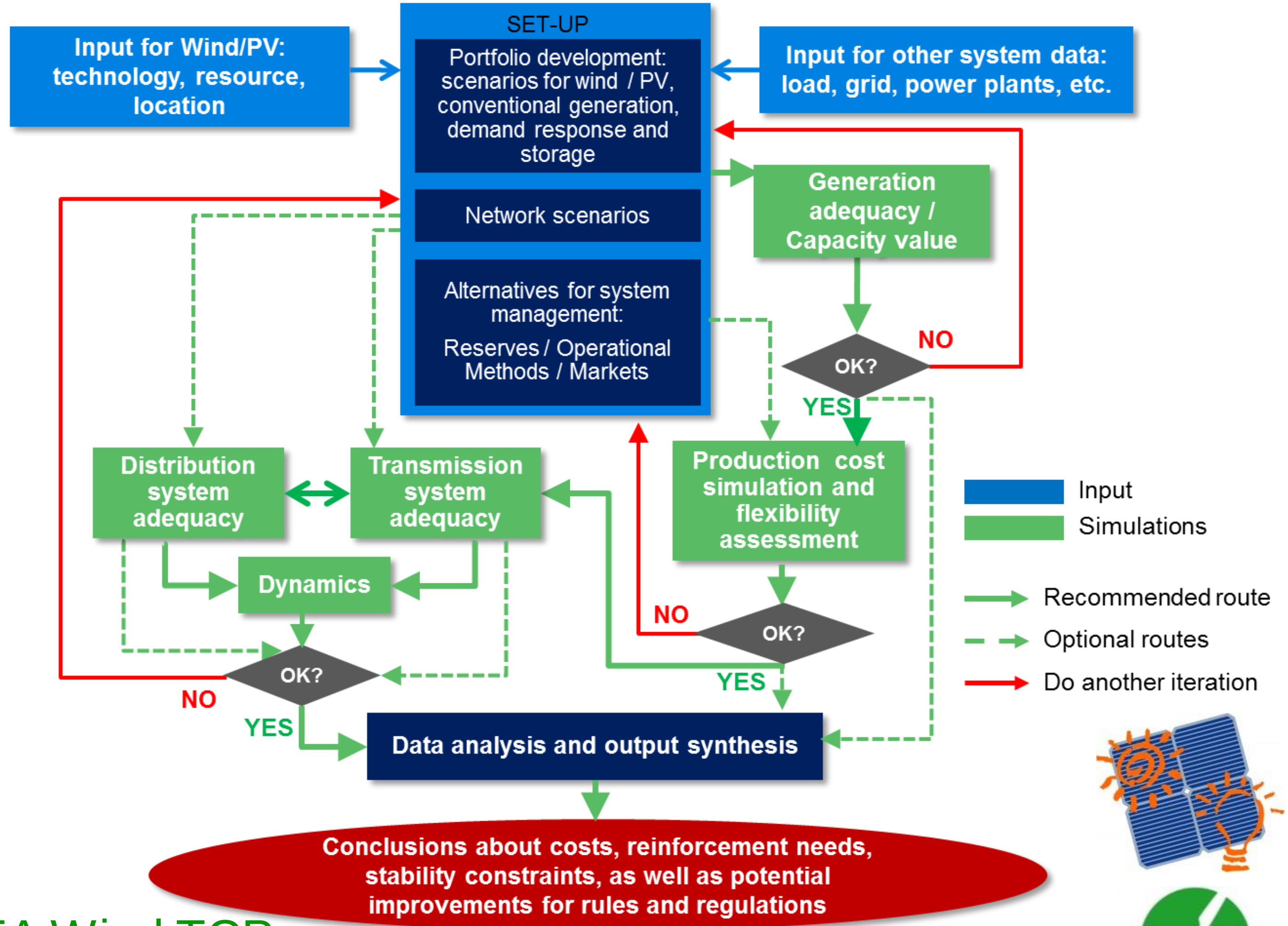


From integration costs to total cost comparisons

- Capturing “system integration cost” component is a challenge
  - Isolating/extracting integration from other costs, no good benchmark exists
  - Defining system boundaries – energy sector coupling
  - Dividing costs to variability, uncertainty, location
- Recommended to calculate total system costs – including operational and investment costs.
  - comparing different future scenarios for the system
- Even for total cost approach, results are system/share of VRE specific
  - Assumptions about future systems – and system boundaries crucial: Flexibility of generation fleet (including VRE) and demand; storages and operational practices

Recommended Practices for wind/PV integration studies

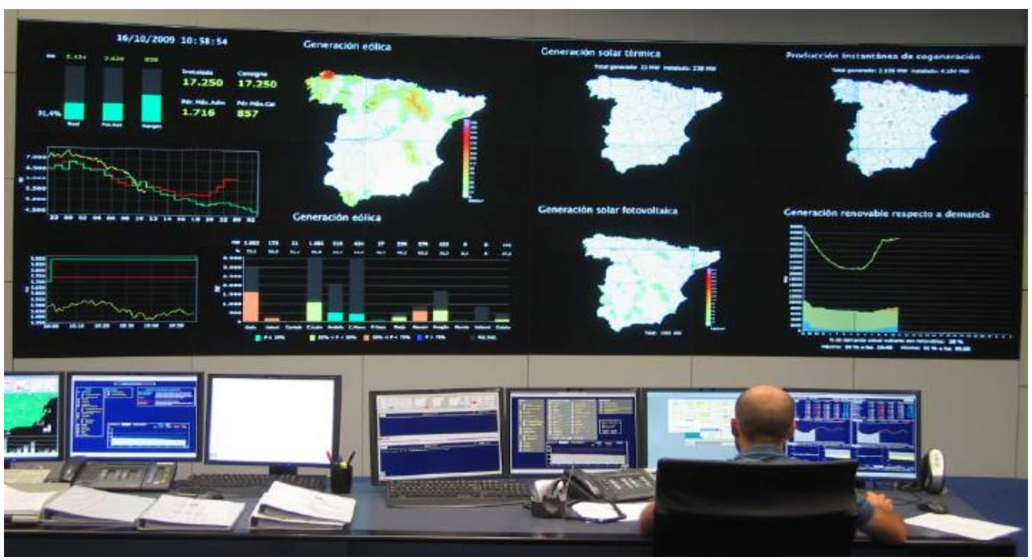
- A complete study with links between phases
- Most studies analyse part of the impacts – goals and approaches differ

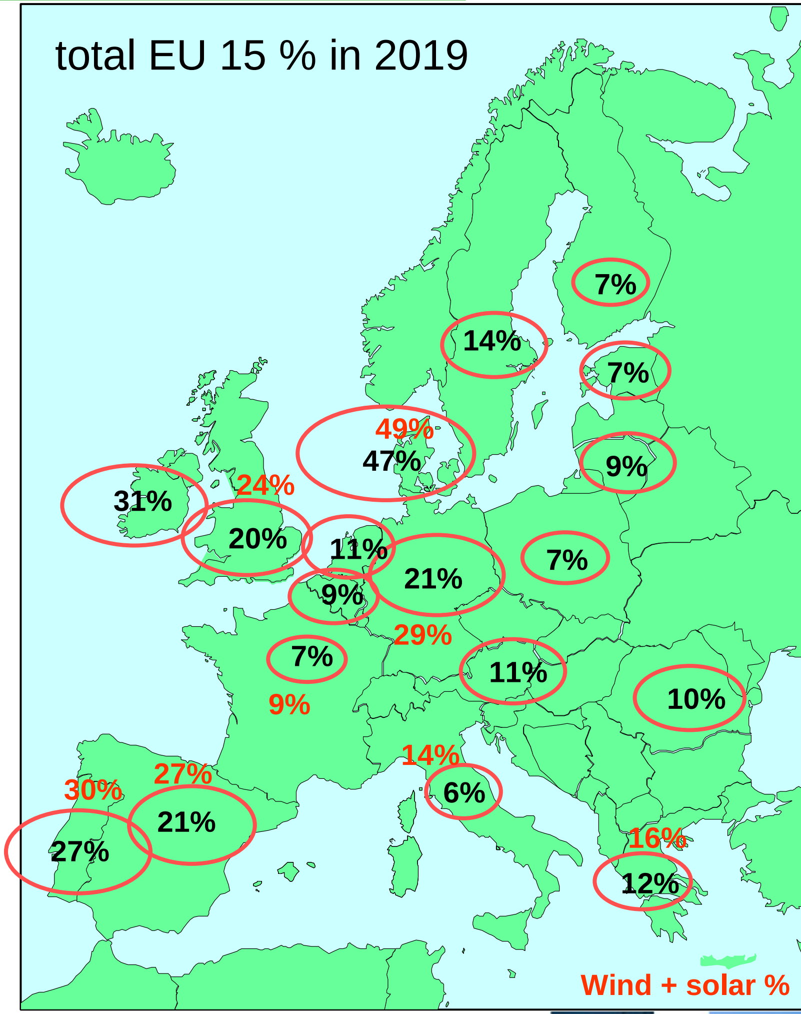


RP16 ed 2 of IEA Wind TCP: https://community.ieawind.org/publications/rp

Experience from Wind and Solar Integration is Growing

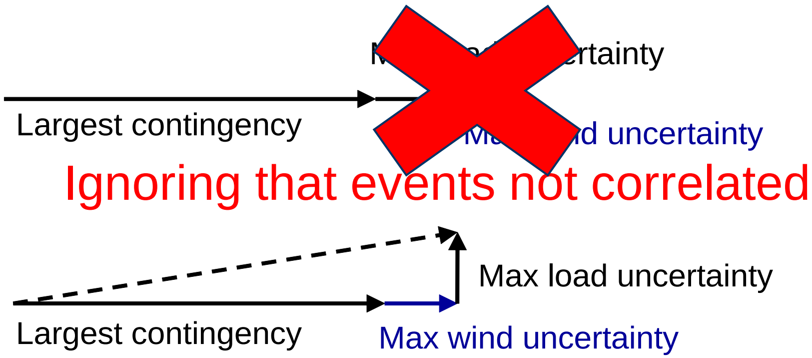
- First 10-20 % share of wind:
  - Updated information from on-line production and forecasts.
  - Possibility to curtail in critical situations.
  - Grid connection codes

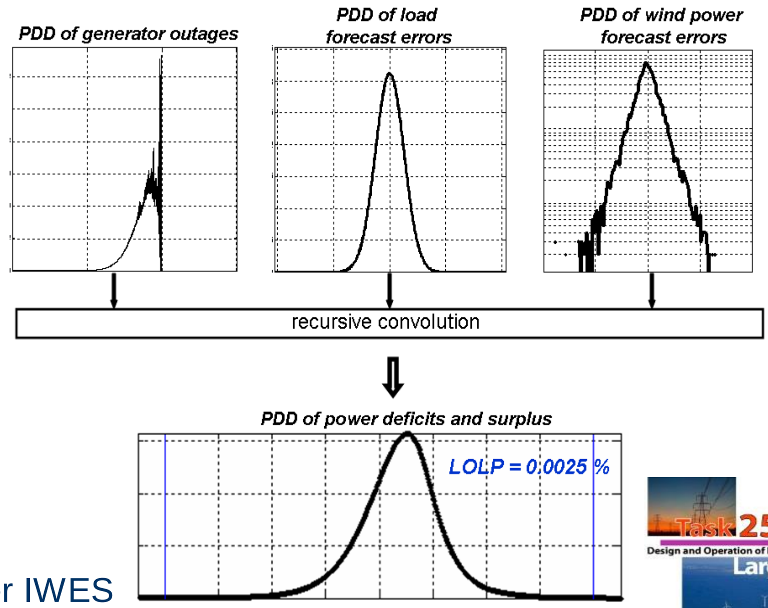




Using short term forecasting

- Wind and solar taken in the day-ahead unit commitment and dispatch, with smoothing impact
  - Energy traded at markets with forecasting
- Flexibility during operating hour – allocating reserves
  - forecast errors determine the need for operating reserve – combining uncertainty from load, wind, solar and generation

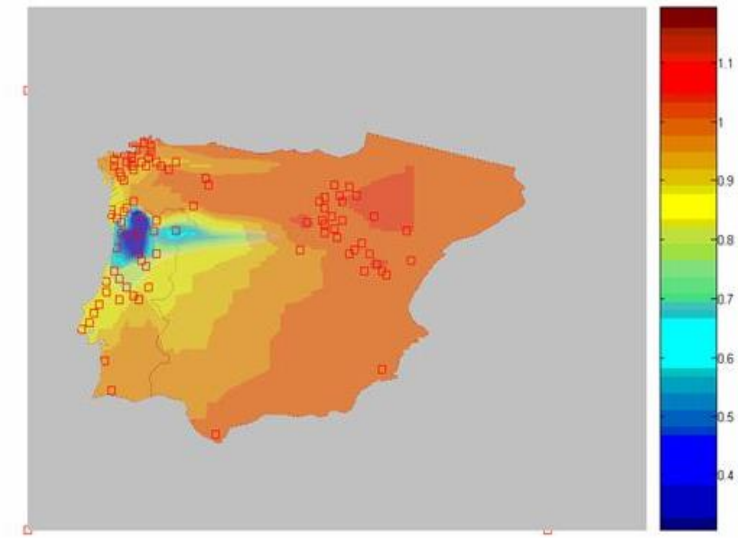




Source: Fraunhofer IWES

Experience with grid codes:

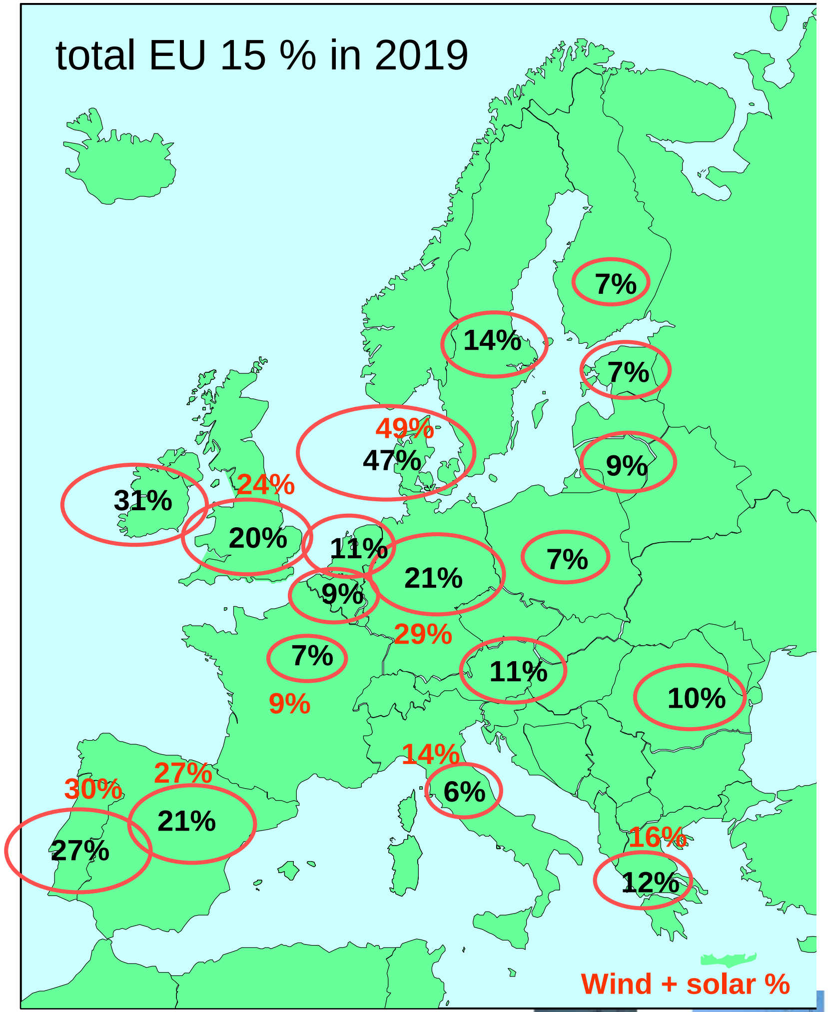
- Requiring fault-ride-through, and setting frequency/voltage limits when trip-off
  - Low voltages due to short-circuits may lead to the disconnection of large shares of generation - modern turbines comply with this
  - Australia case, for weak systems need to require riding through many consecutive faults
  - Germany, California case solar: setting of inverters to trip off at high frequency may also create an issue of losing too much generation instantly



Ride through fault capabilities attenuate the problem.

Experience from Wind and Solar Integration for higher shares

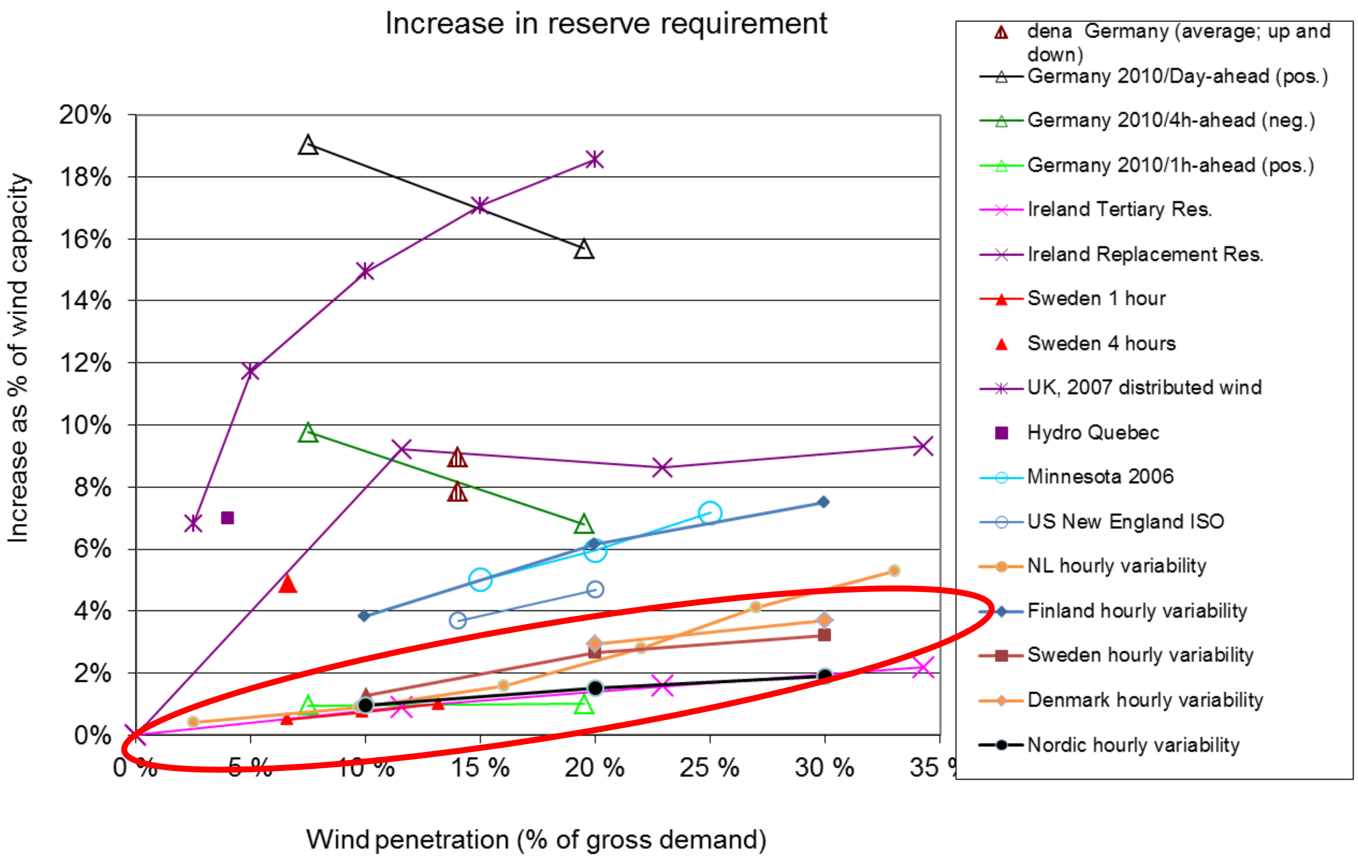
- Sharing balancing
- Enabling also wind and solar in grid support
- Generation flexibility and adequacy
- Transmission a key enabler, with regional planning efforts
  - Local markets, PV and storages emerging as another solution



Task 25 Design and Operation of Power Systems with Large Amounts of Wind Power

Results of studies for increase in operating reserves

- Combing uncertainties results in moderate increase in operating reserve due to wind power
- Time scale of uncertainty brings large differences in results Results for hourly variability similar



Trade with neighbouring areas will help balancing more than wind adds

- Sharing balancing task with neighbouring system operators in Germany has resulted in reduction of use of frequency control, while wind and solar have increased
- Denmark integration of close to 50% wind share is based on using Nordic hydro power system flexibility

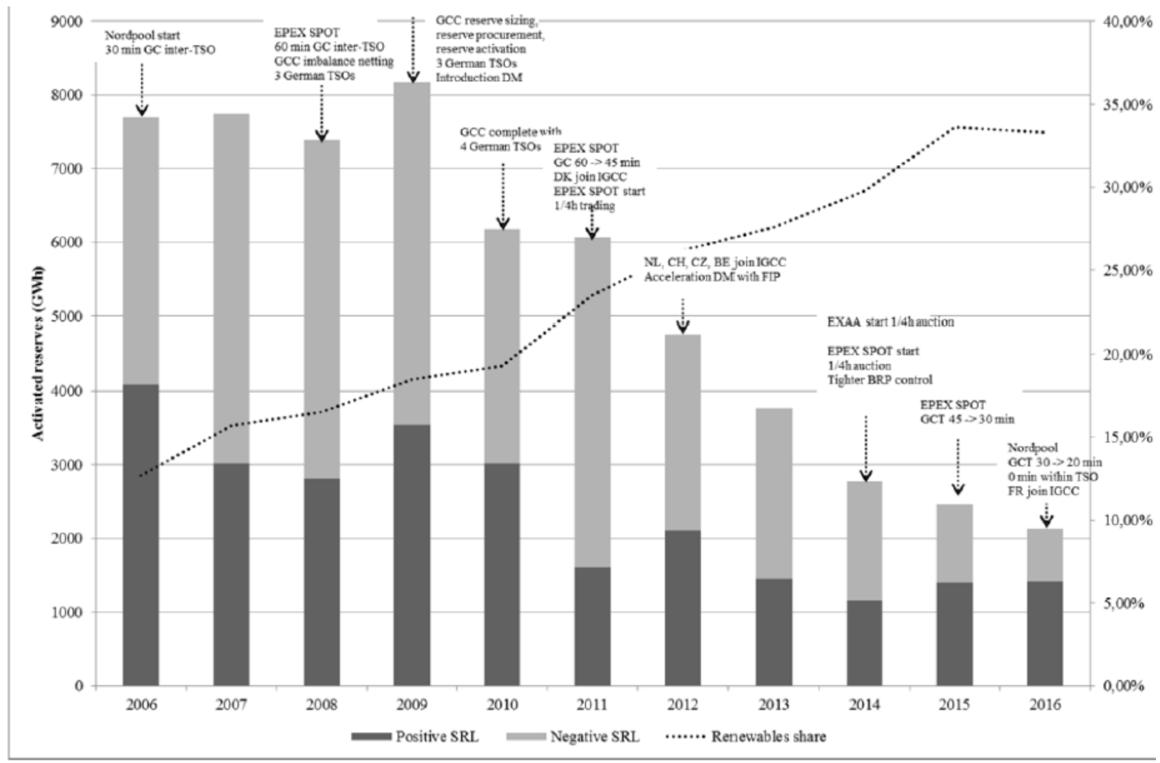


Figure 13: Total activated German Secondary Reserves (or aFRR) per year marked with events considered in this paper.

Rena Kuwahata, Peter Merk, WIW17

Using flexibility of thermal plants. Case Denmark.

- Changing the tariffs of smaller CHP plants to operate according to market prices
- Retrofitting the larger thermal plants

HIGH FLEXIBILITY OF POWER PLANTS

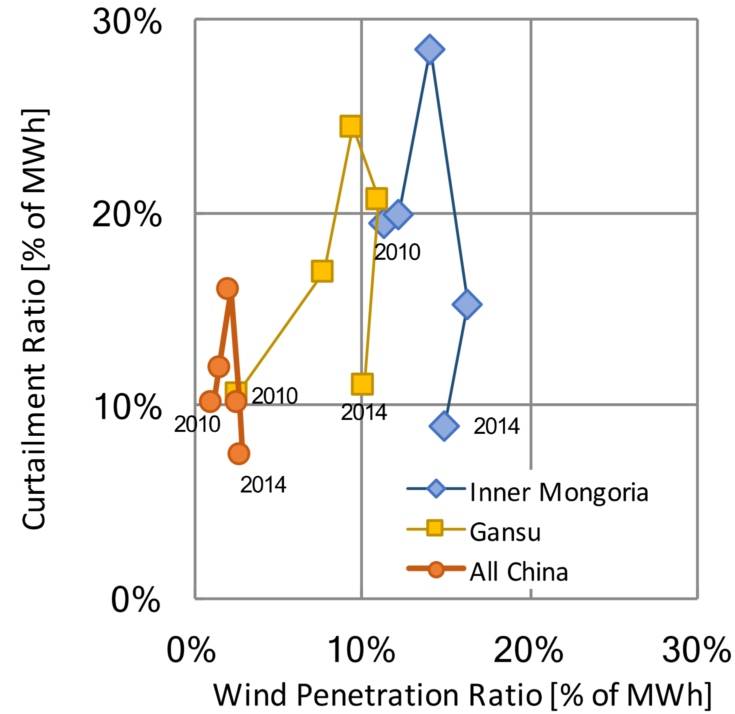
Operational range:
10–100%

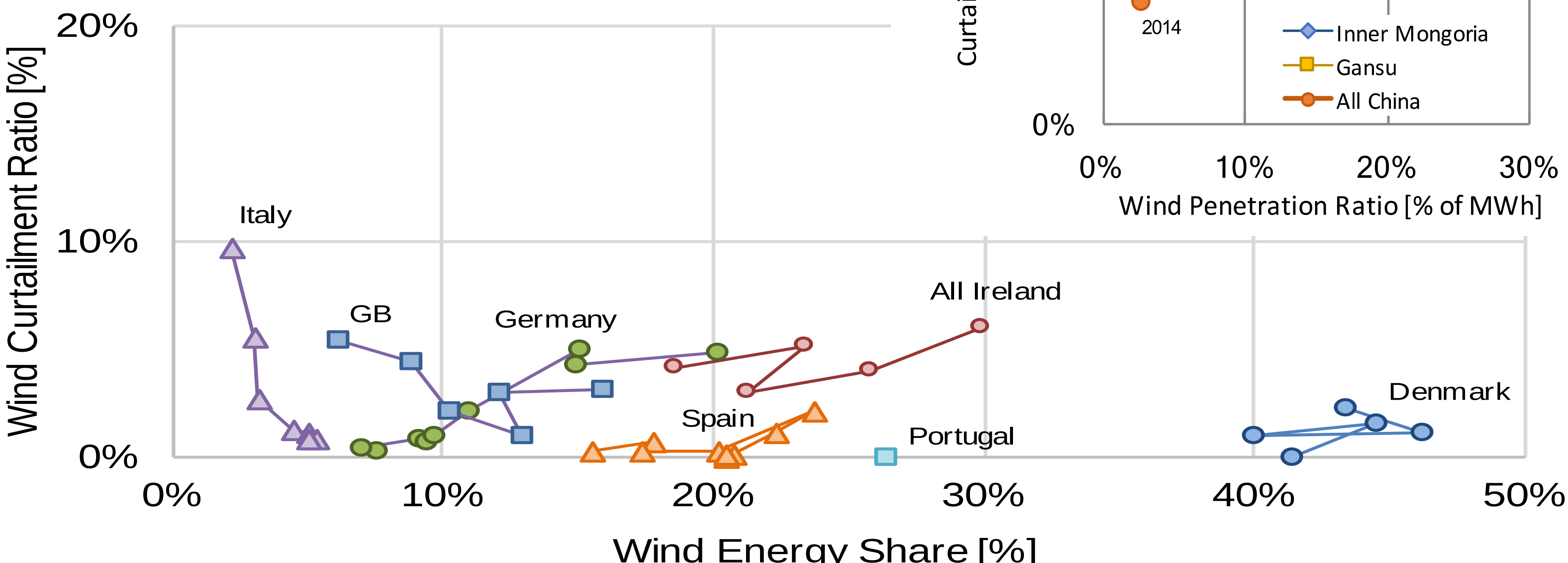
Regulating rate:
3-4% per minute

ENERGINET

Curtailments are a signal of lack of flexibility

- Delays of transmission: Italy and Texas – diminished after grid build out. Germany, still an issue
- Inflexibilities of coal power plants and tariffs: China
- Limiting max share of asynchronous generation: Ireland

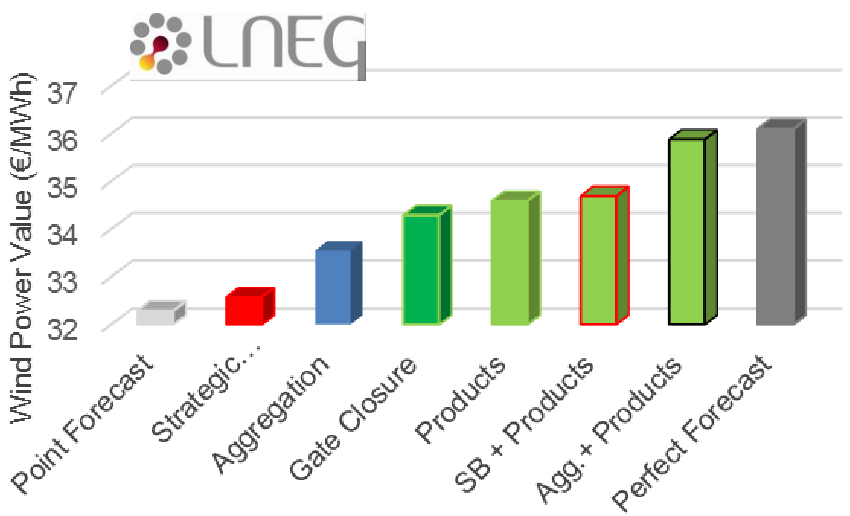




Source: Prof Yasuda, Kyoto University

Operational practices: market design to enable wind integration

- Enabling wind power plants to bid their flexibility to the markets
- With extra gains from balancing products



Enabling system services from wind and solar

- Asking for capabilities in grid codes, and paying for services of system support if needed/used
- Experience of frequency response: Very fast (inertial) in Quebec, fast (primary) response in Texas, secondary in Colorado. Market compliance in Spain, Denmark.

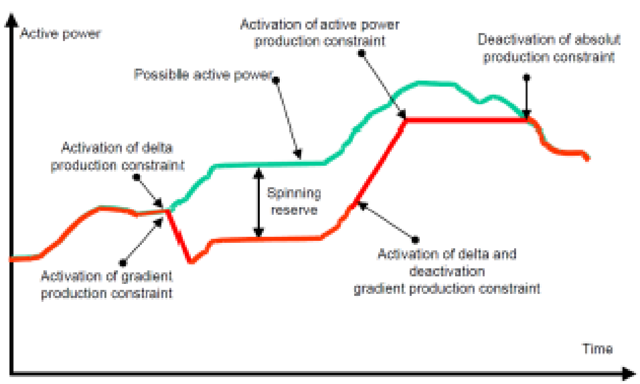


Figure 12: delta control mode – denoted with spinning reserve (Energinet.dk, 2010)

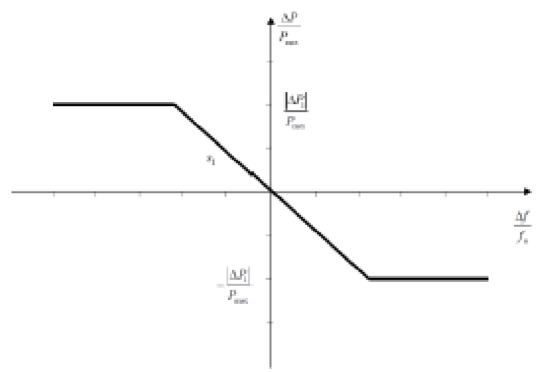
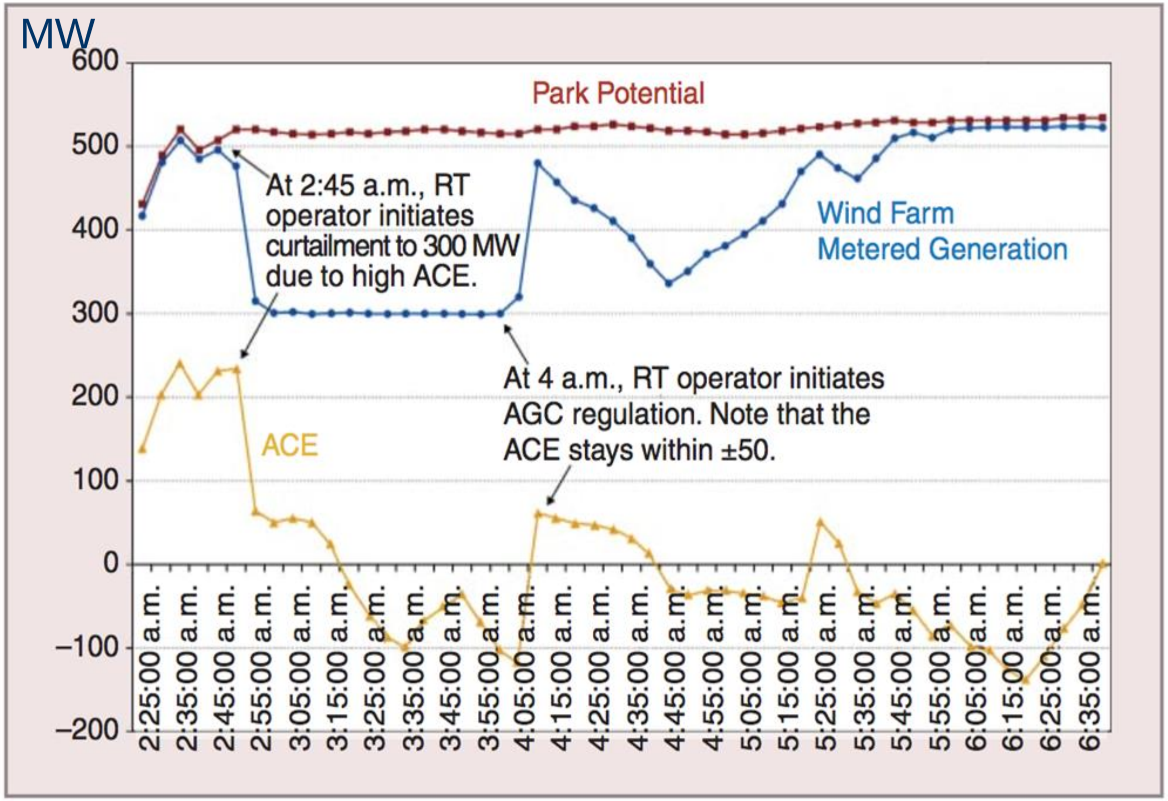


Figure 13: active power setpoint as a function of frequency deviation (ENTSO-E, 2012)

Use wind power plants at AGC when otherwise curtailed

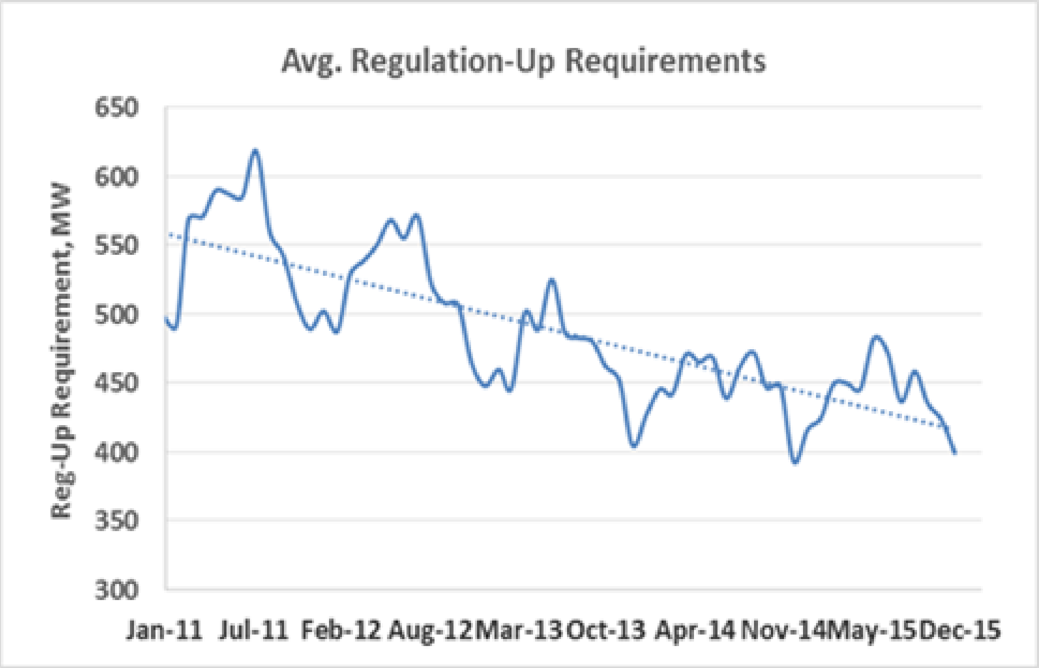
- Wind power plant in Xcel/PSCO is first manually block curtailed and then put on Automatic Generation Control.
- Resulting Area Control Error is shown in yellow.



Source: Xcel

Experience: Wind power frequency response is fast and high quality

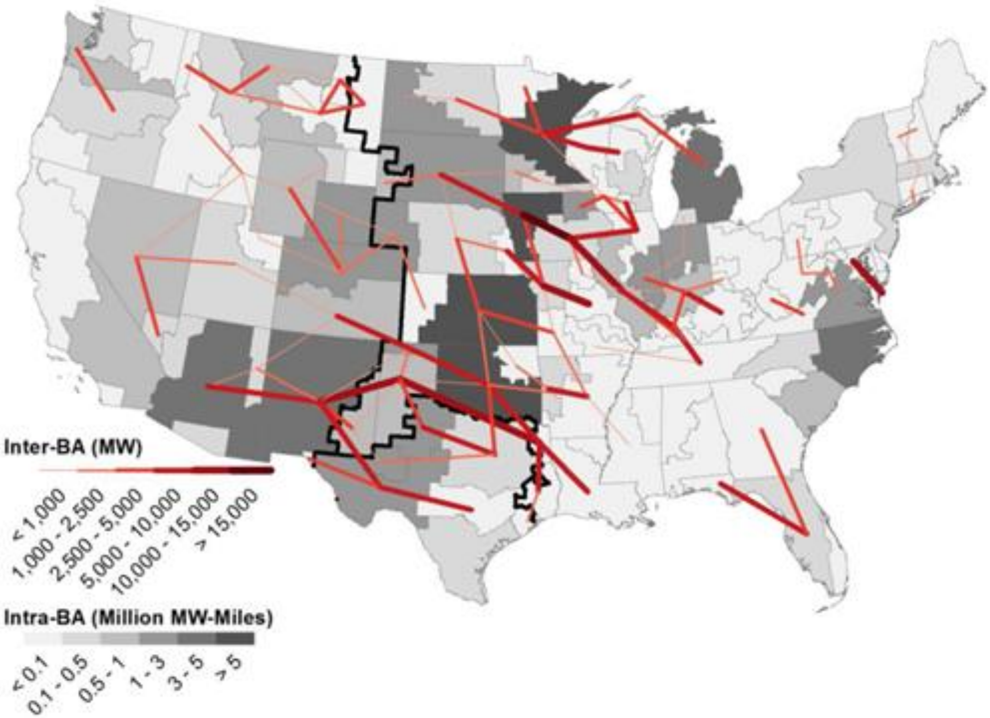
- ERCOT in Texas:
  - fast response of WPPs reduce the overall need for automatically activated frequency support services
- California report showing responses from PV better than conventional generators [https://www.caiso.com/Documents/UsingRenewablesTo OperateLow-CarbonGrid.pdf](https://www.caiso.com/Documents/UsingRenewablesToOperateLow-CarbonGrid.pdf)

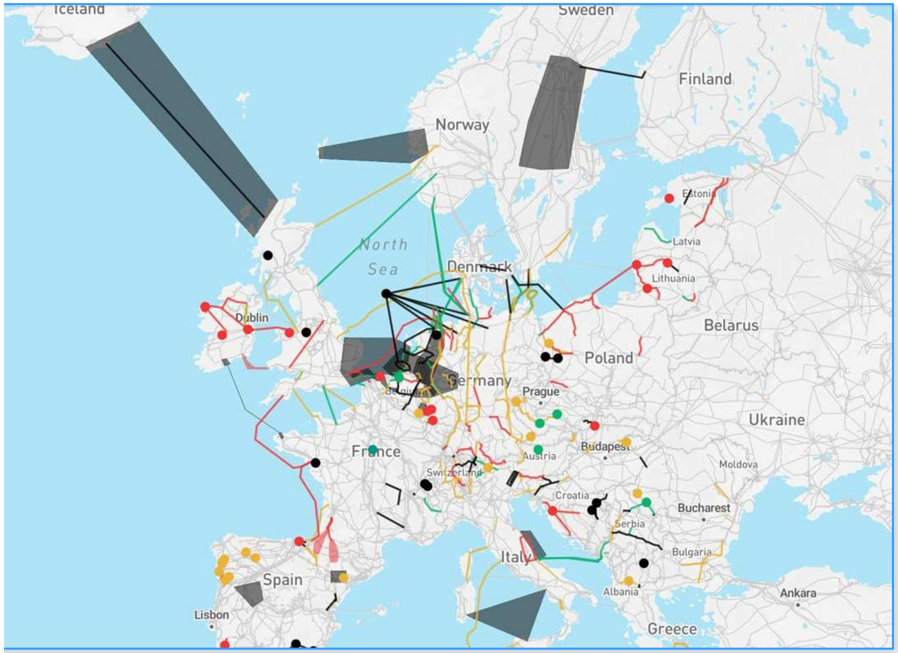


Source: Julia Matevosjana, ERCOT

Long term planning for grid adequacy

- Transmission planning – towards regional planning





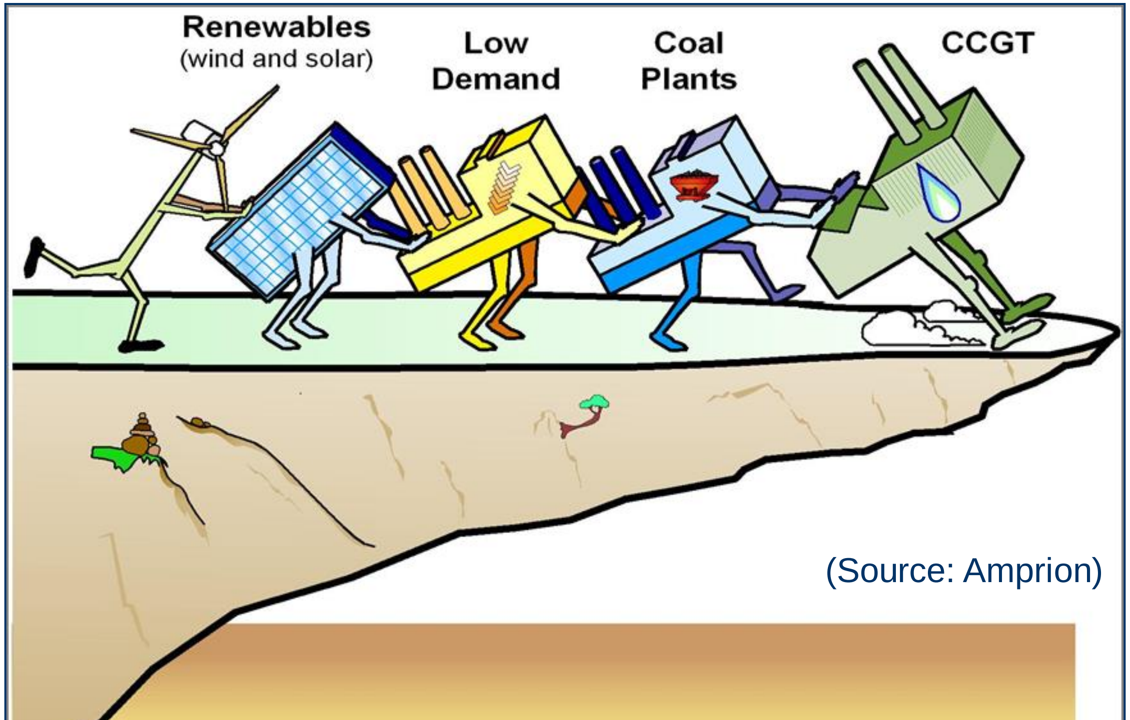
Source [NREL – National Renewable Energy Laboratory]
http://www.nrel.gov/analysis/re_futures/

Source TYNDP (ENTSO-E, 2018)

Task 25
Design and Operation of Power Systems with Large Amounts of Wind Power

Challenge- conventional power plant retirement

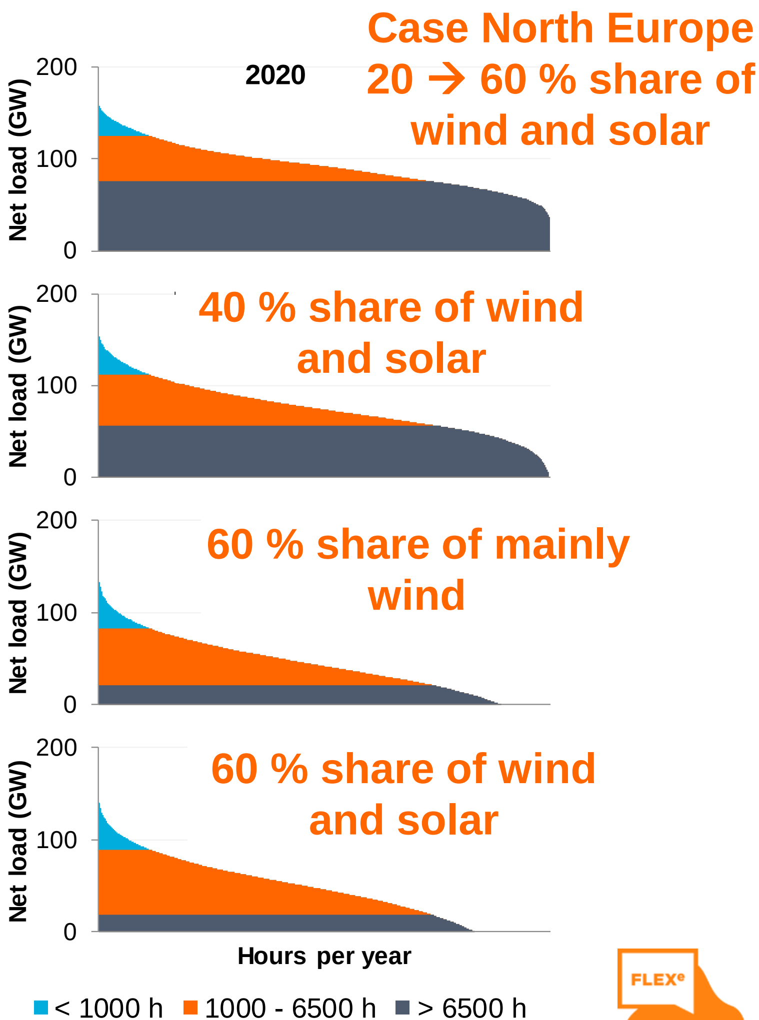
- Total operating time reduces, but capacity still needed
  - Challenges differ for high-growth systems and where load growth no longer substantial



(Source: Amprion)

Towards higher shares of wind and solar energy

- The time of base load power plants is over
  - Less and less time operating (full load hours), resulting in costs/MWh getting high
- The time of flexible power plants is here
  - producing less than 5000 hours per year, much of that time at part load operation
- Beware of stranded costs when investing in conventional power plants



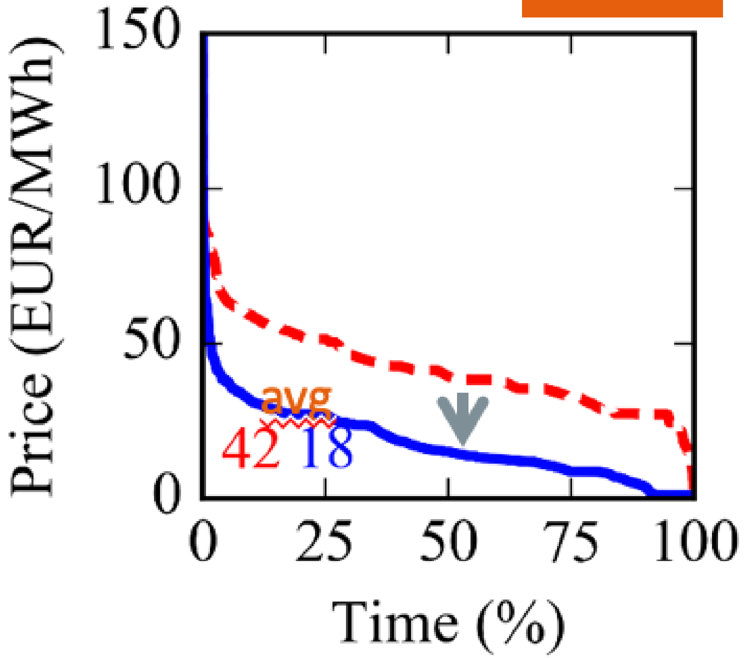
EL-TRAN

strategic RESEARCH

FLEXe Future Energy System

Market challenge: revenue sufficiency

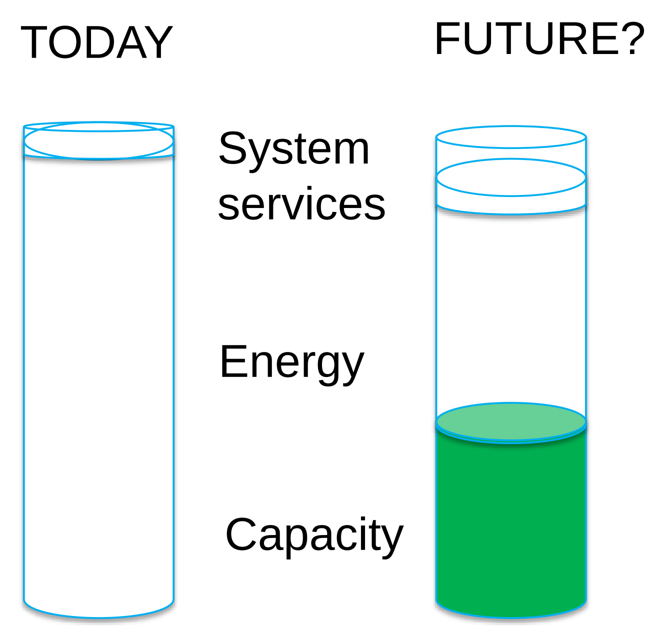
- Due to 0 marginal cost renewables
- Due to flexible loads
- Stakeholder changes
- Can P2X loads change the picture?
  - If timing when wind/PV available
- Storage may be an option



VTT

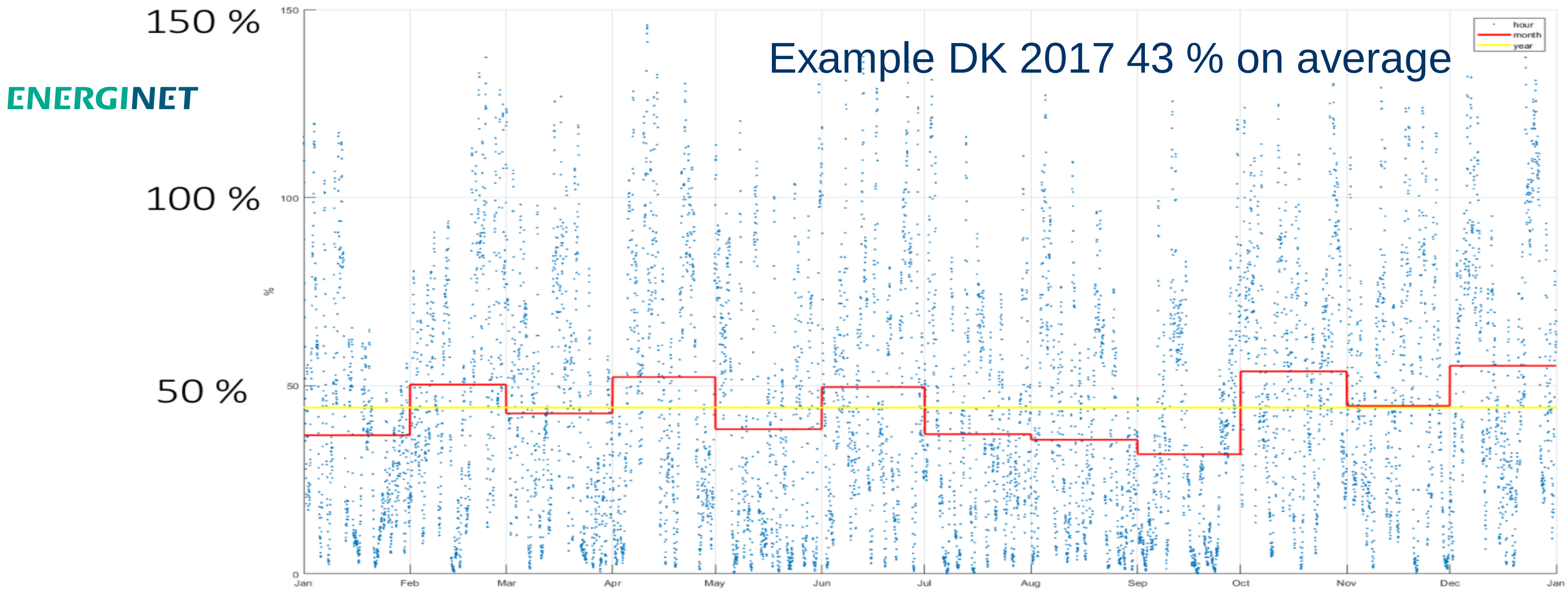
Market income for revenue sufficiency

- Larger market area – keeping prices up
  - less correlated wind power production
- Faster markets – balancing costs down
  - Improved load/net load following dispatch
- Frequency control from wind and solar
  - where surplus energy /very low prices, wind/PV can operate part load and offer fast up- and down-regulation
  - Often this becomes cost effective at larger (>20%) shares of wind and solar



High share of VRE operation already well before 50 % yearly share

- Instant 100% will be faced already when less than 25 % on average

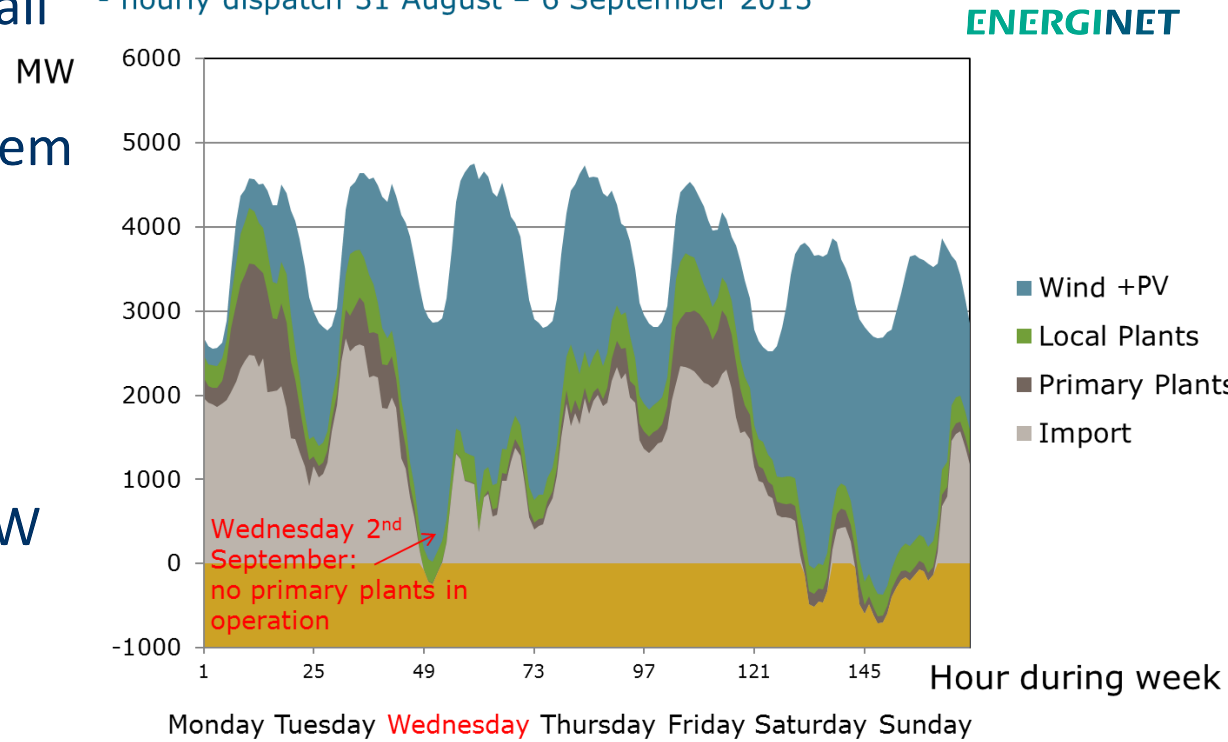


Pushing the limits: Denmark operating the system without central power plants

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

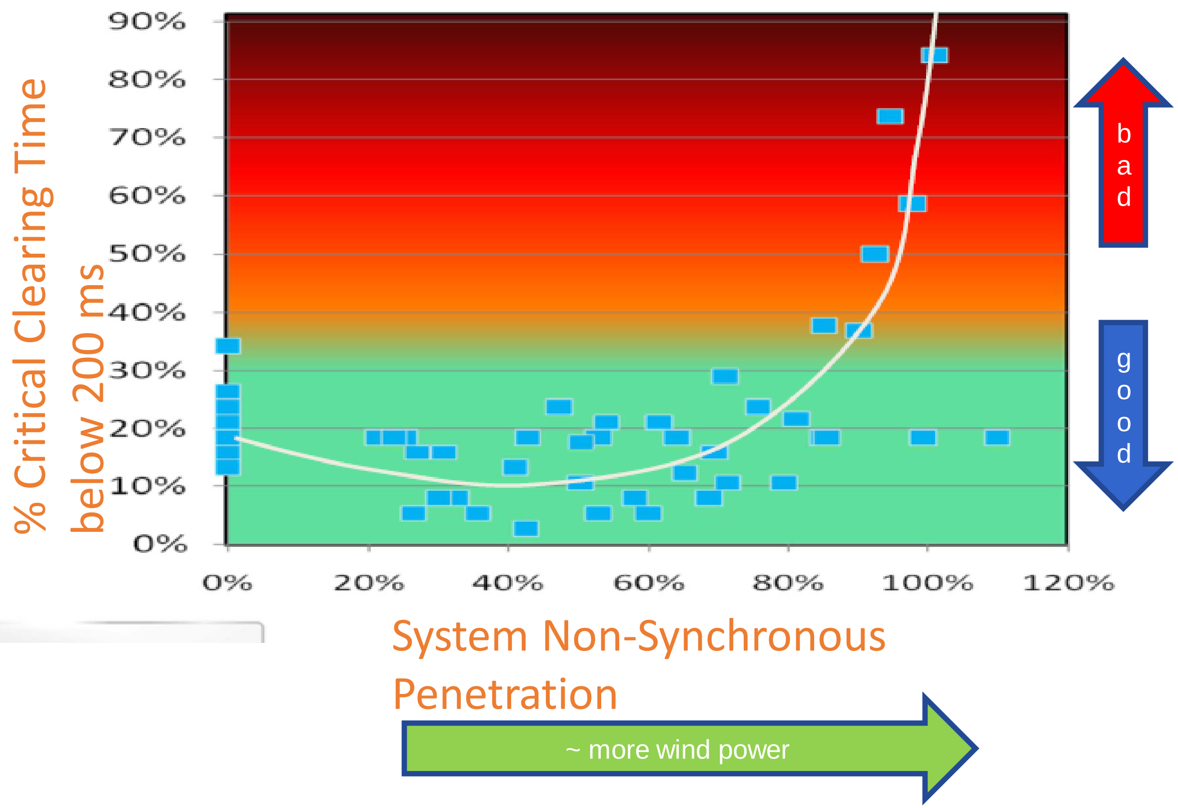
- HVDC link: 700 MW Denmark-Norway
- synchronous compensators 4 in DK-W and 2 in DK-E
- and small scale power plants

2nd September 2015 without central plants
- hourly dispatch 31 August – 6 September 2015



Ireland study: current power systems ok for 80-90% wind

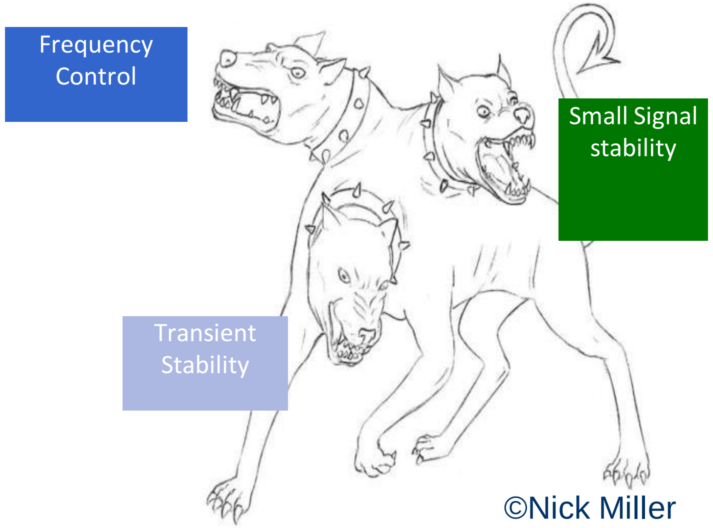
- Transient stability (as measured by critical clearing time) first slightly improves, until around 80-90%, where instability becomes a big issue.



EIRGRID GROUP

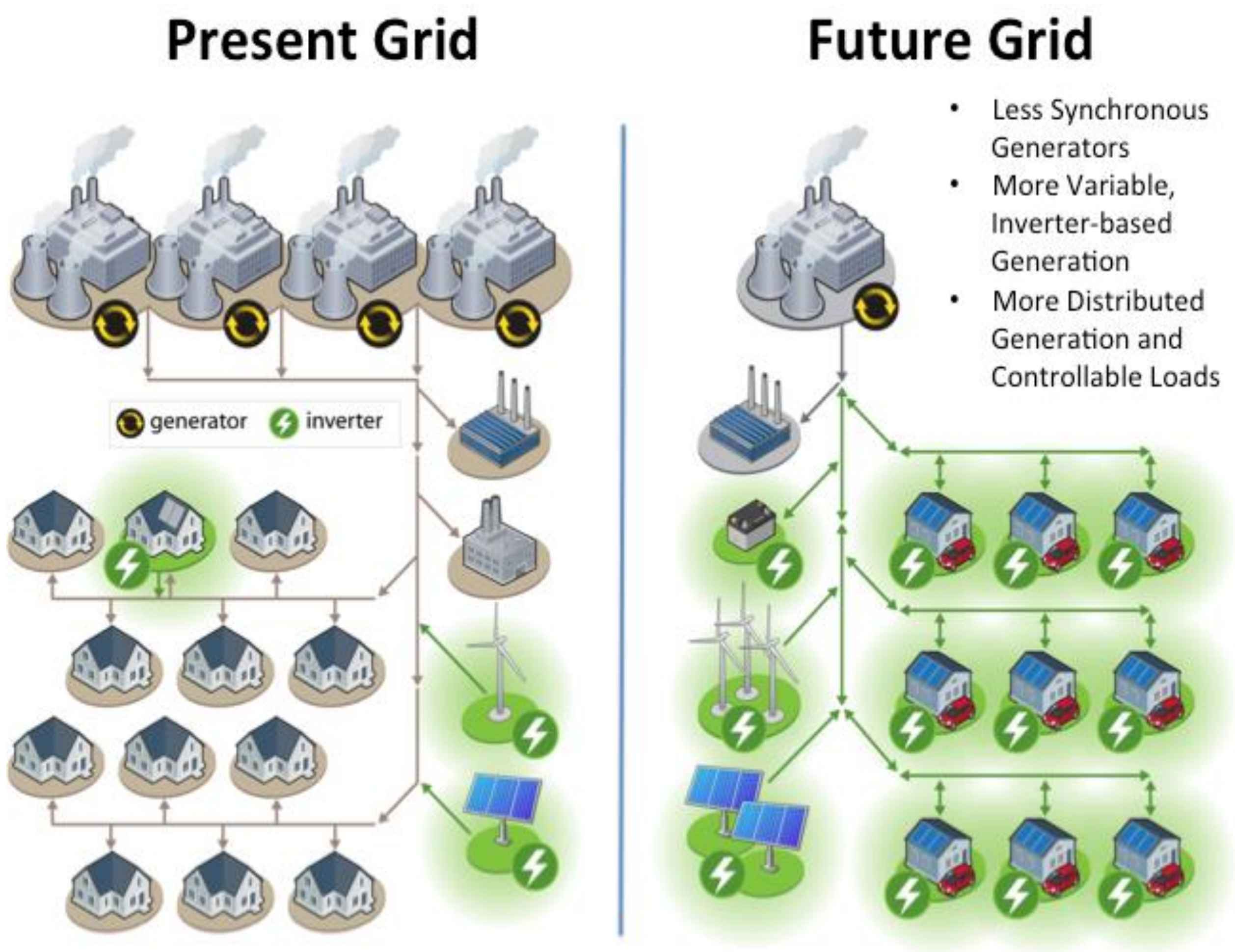
Challenges to tackle for close to 100% renewables systems

- Stability at high VIBRES. What new methods and technologies to use?
- Balancing, flexibility and adequacy: how much new loads can help, for short term operation and for seasonal mismatch?
- Market operation: market design with new services, how to design so that paying for the new services as they become beneficia for the system? Local versus global, DSO/TSO collaboration



VIBRES – Variable Inverter Based Renewable Energy Sources

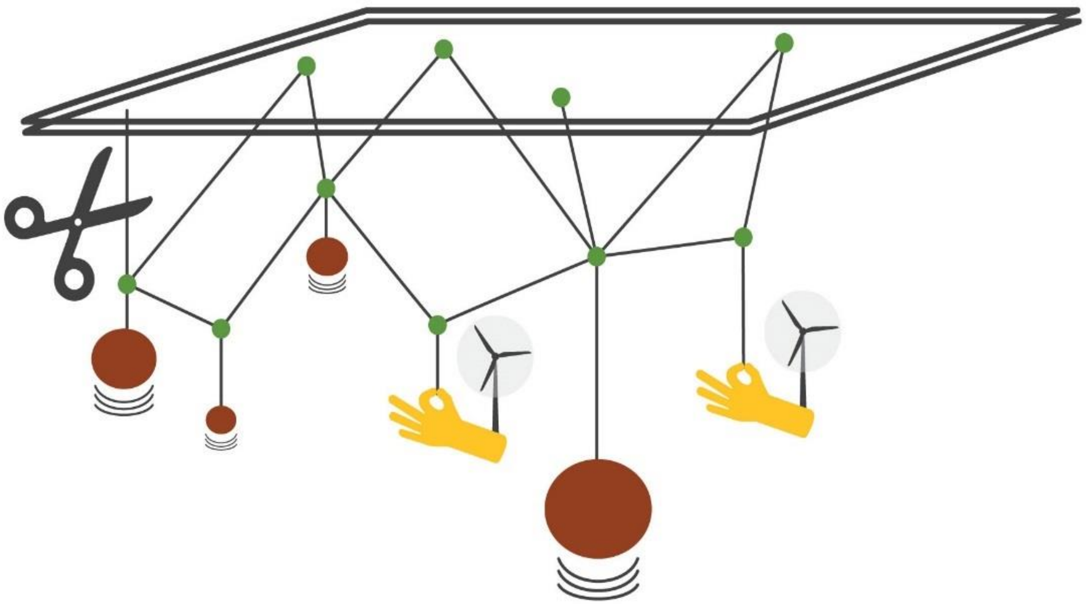
Stability challenge



Source: B-M Hodge et al: Towards 100% Variable Inverter-based Renewable Energy Power Systems. WIREs Energy and Environment vol 9, iss. 5, e354 https://doi.org/10.1002/wene.376

Stability challenge

- Is it stable?*



Source: NREL based on a figure created by Nick Miller, formerly GE Energy Services

*Wind turbines are all brains, no mass

So… maybe even better than physical inertia!

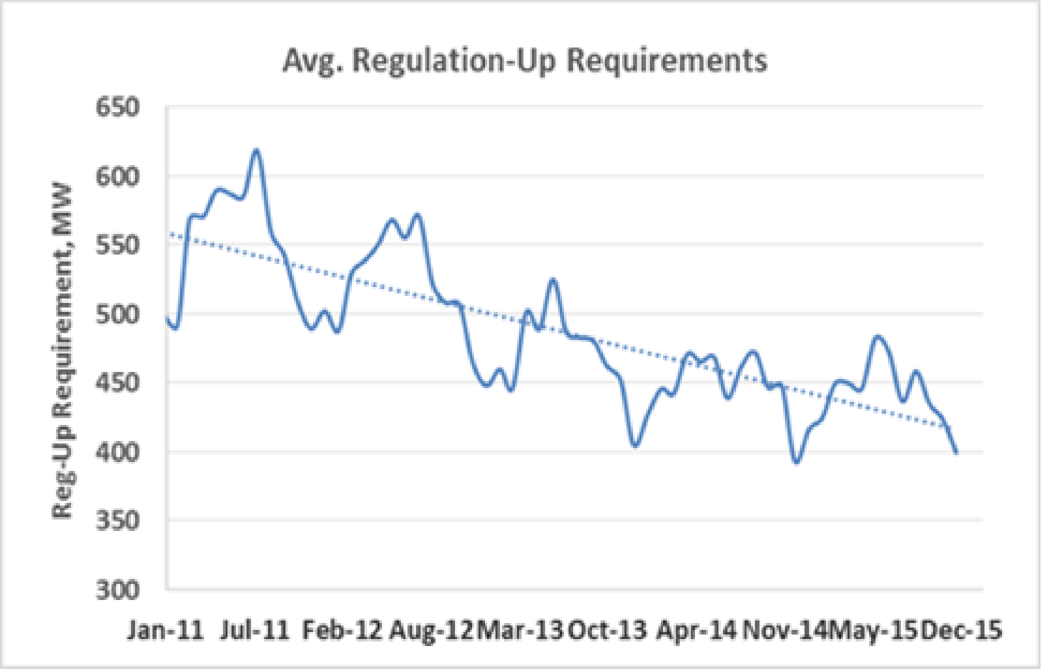
Options to support stability

- Maintain inertia
  - Keep synchronous machines running that would otherwise not run
  - Find other sources of synchronous inertia (i.e. synchronous condensers)
- Speed up frequency response
  - Faster primary frequency response (on synchronous machines)
  - Fast frequenncy response and other clever frequency controls, especially on inverters
- Make inverter behavior “better”
  - Grid forming inverters and Virtual synchronous machines

Courtesy of Nick Miller

Wind and solar power plants have unused opportunities:

- Inverter controls: rapid responses, synchronous machine characteristics and they don't swing against each other (more stable).



Texas experience, less need for fast frequency support after wind power plants provide good response (Source: Julia Matevosjana, ERCOT)

REVIEW SUMMARY

RENEWABLE ENERGY

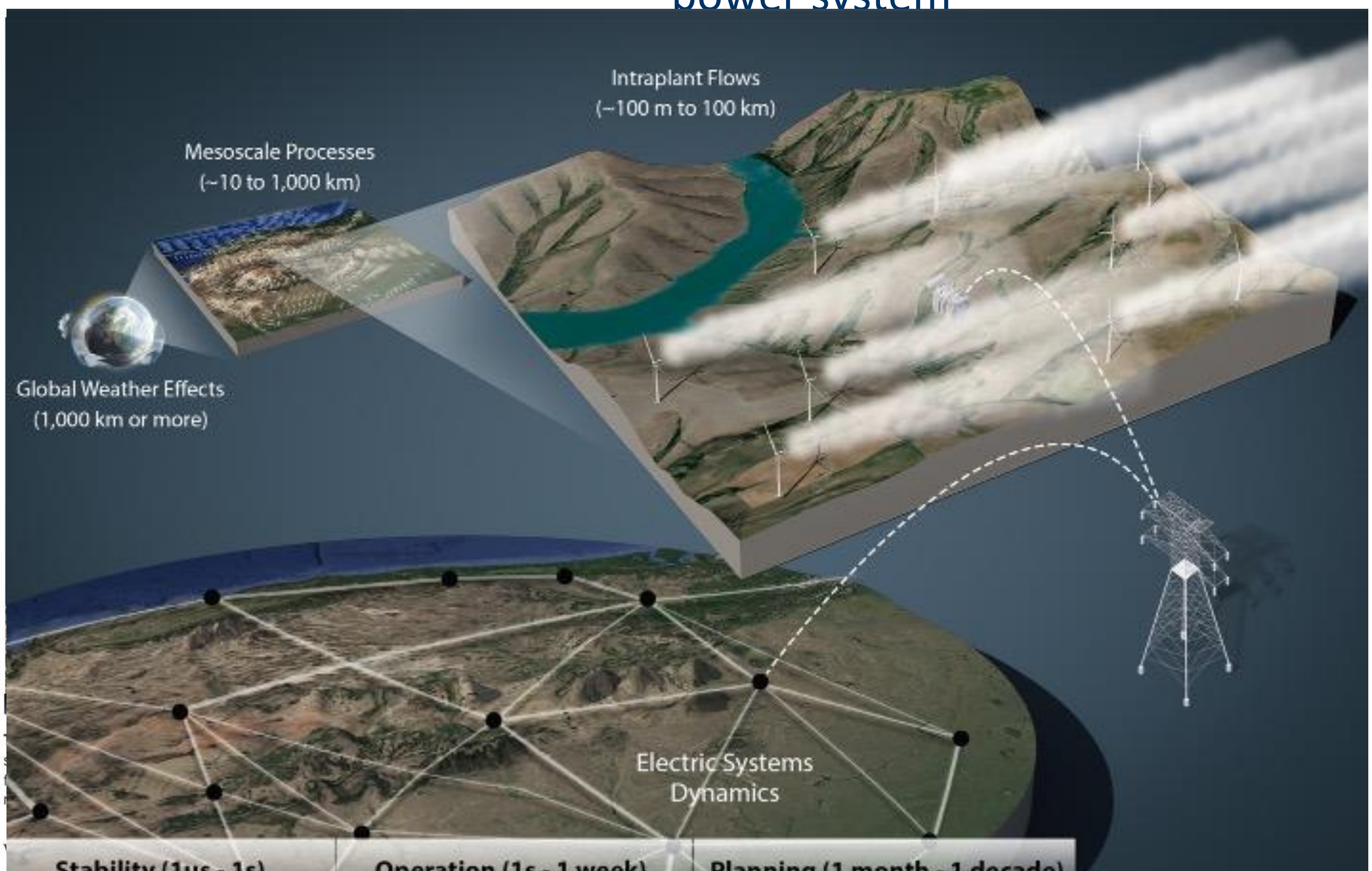
Grand challenges in the science of wind energy

Paul Veers*, Katherine Dykes*, Eric Lantz*, Stephan Barth, Carlo L. Bottasso, Ola Carlson, Andrew Clifton, Johney Green, Peter Green, Hannele Holttinen, Daniel Laird, Ville Lehtomäki, Julie K. Lundquist, James Manwell, Melinda Marquis, Charles Meneveau, Patrick Moriarty, Xabier Munduate, Michael Muskulus, Jonathan Naughton, Lucy Pao, Joshua Paquette, Joachim Peinke, Amy Robertson, Javier Sanz Rodrigo, Anna Maria Sempreviva, J. Charles Smith, Aidan Tuohy, Ryan Wiser

BACKGROUND: A growing global population and an increasing demand for energy services are expected to result in substantially greater deployment of clean energy sources. Wind energy is already playing a role as a mainstream source of electricity, driven by decades of scientific discovery and technology development. Additional research and exploration of design options are needed to drive innovation to meet future demand and functionality. The growing scale and deployment expansion will, however, push the technology into areas of both scientific and engineering uncertainty. This Review explores grand challenges in wind energy re-

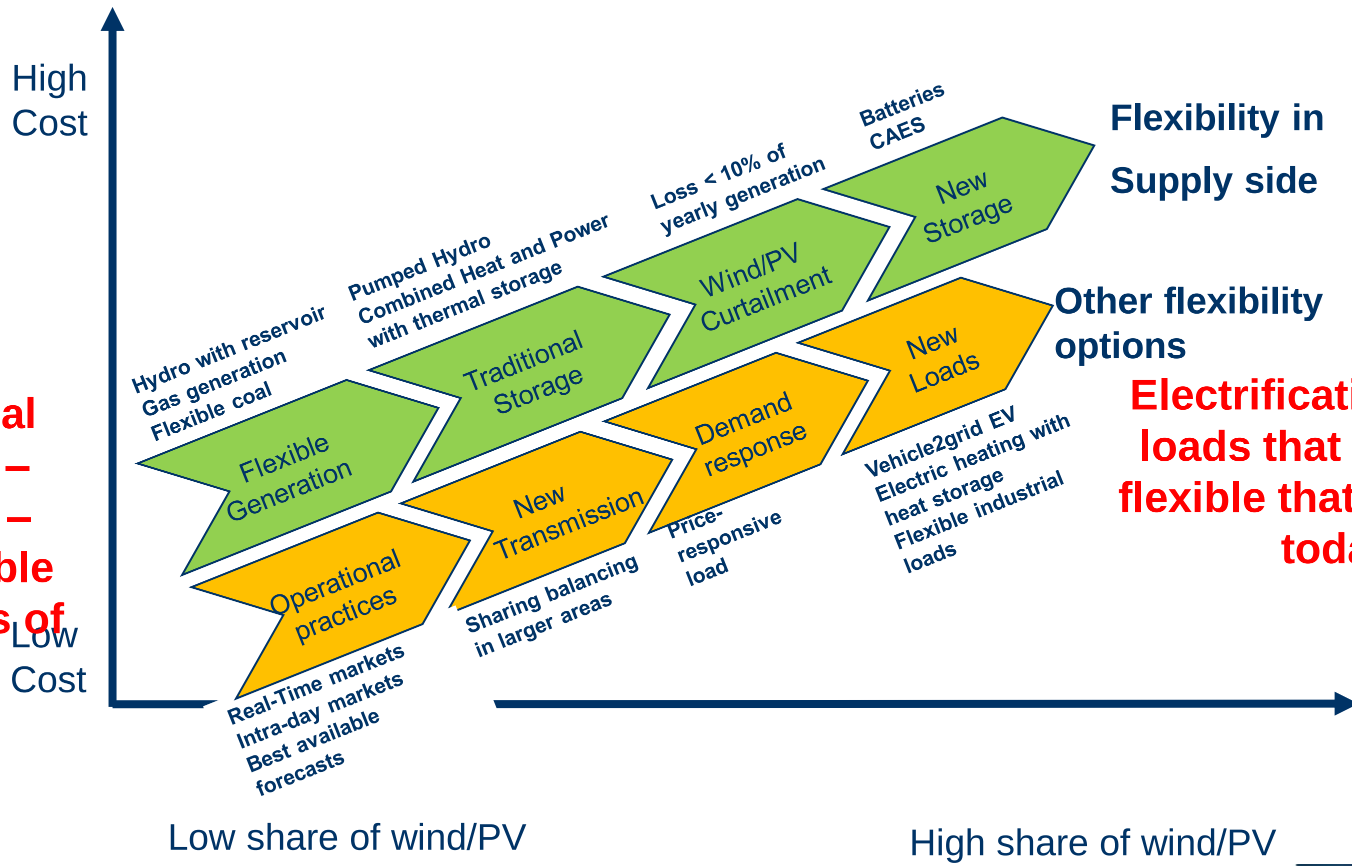
Grand Challenge 3

Systems science and control of wind power plants to orchestrate wind turbine, plant, and grid formation operations to provide low cost energy, stability, resiliency, reliability and affordability in the future power system



NREL
Transforming ENERGY

Balancing challenge: Using more of the flexibility solutions we know



Operational practices – and tools – key to enable high shares of VIBRES

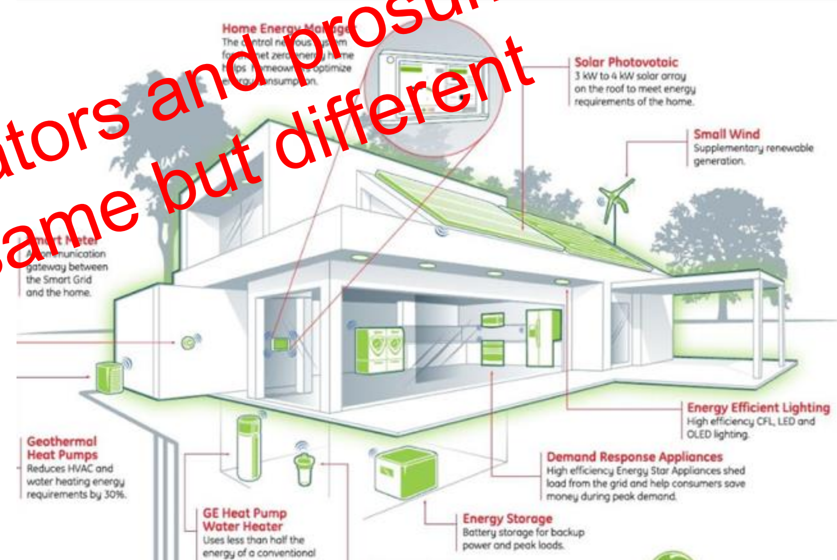
Electrification – new loads that are more flexible that the loads today

VIBREs – and loads and electrical storage can provide the system support services provided by generators today

Energy transition - opportunities

- Smart grids:
  enabling distributed resources, prosumers, HEMS/BEMS operating with price signals

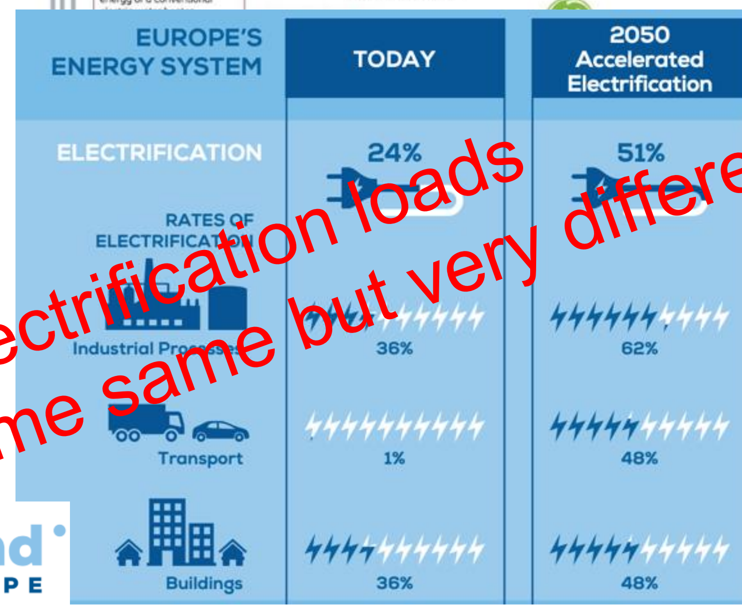
Aggregators and prosumers same same but different



Load transition:

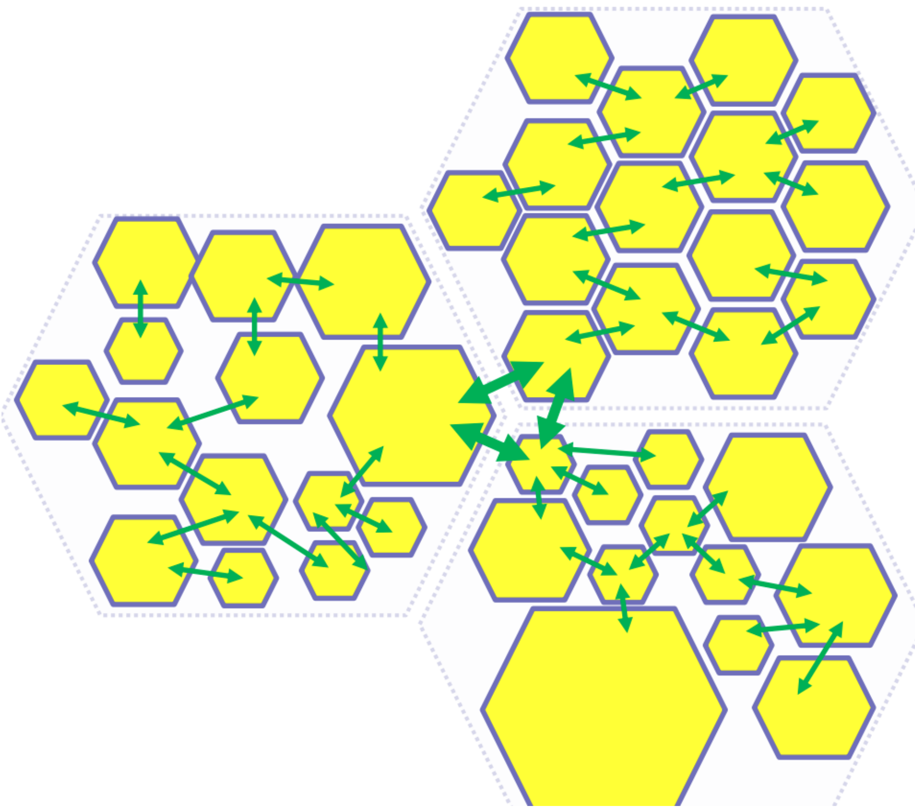
- Energy system decarbonisation brings electrification ~double the electricity demand
- changing the fixed load paradigm

New electrification loads not same same but very different



Using the local flexibility to system benefits

- Market based DSO/TSO collaboration through local flexibility markets
- Flexibility value as price signals to DER
- Vision: web of cells, with local smartness, utilising large system benefits when no grid bottlenecks



EERA
European Energy Research Alliance
Smart Grids Joint Programme

Task 25
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Long term flexibility challenge

- Traditionally build gas turbines for back up – expensive use as peakers <1000h/a
- With wind/solar dominating, this will be expensive. Two other pathways possible:
  - Load becomes flexible – also in weeks time scale, electrolysers for power2X, thermal storages for heat etc
  - Electric storage becomes very cheap, and new seasonal options for storage developed
- Probably a mix of these three?

Need for research

- Stability: better understanding, which requires improved simulation tools and generator models and better predictive tools and metrics

New ways of modelling loads for all of these!

- System operation: agile market rules to make revenue from solutions that are optimal for the system – also taking benefits from local trade
- Adequacy: new methods to optimise the varying generation and flexible loads (from LOLP metrics)

+ Wind turbine and wind farm controls, and grid forming capabilities

Based on

- ESIG https://www.esig.energy/resources/toward-100-renewable-energy-pathways-key-research-needs/ and background document ”100% Renewables” by GE, Debbie Lew and Nick Miller
- Science article: Veers P., Dykes K., Lantz E., Barth S., Bottasso C.L., Carlson O., Clifton A., Green J., Green P., Holttinen H., Laird D., Lehtomäki V., Lundqvist J.K., Maxwell J., Marquis M., et al. (2019). Grand challenges in the science of wind energy. Science Vol. 366, Issue 6464, https://doi.org/10.1126/science.aau2027
- IEA WIND Task 25 collaborative articles:
  - ”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 Holttinen et al, accepted to IEEE TPWRS Oct 2020

Thank You!!

Hannele Holttinen

Hannele.Holttinen@recognis.fi

+66 61 473 5255

+358 40 5187055

recognis