Why flexibility?

Integrating large shares of variable renewables into the energy system

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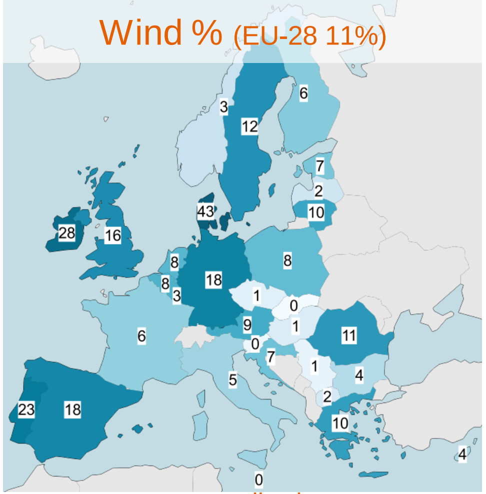
6th Central European Biomass Conference
24th January, 2020, Graz, Austria

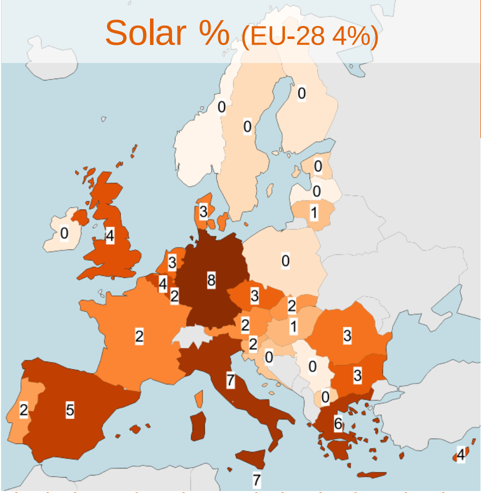
RES-E shares in Europe

- Highest yearly shares 2018
  - Wind: Denmark (42%), Ireland (28%), Portugal (24%)
  - Solar: Germany (8%), Malta (7%), Italy (7%)

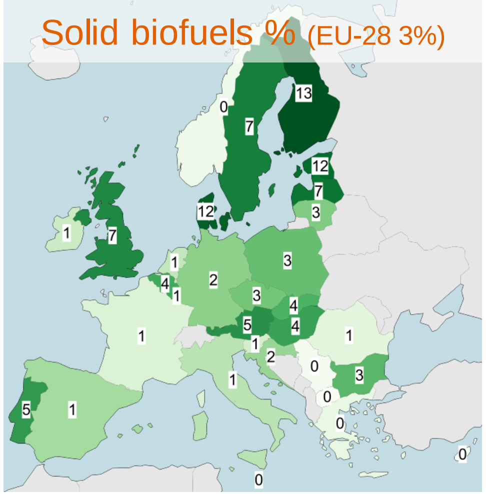
- Highest hourly/instantaneous wind shares
  - Denmark and Portugal > 100%
  - Germany 80 %
  - Ireland > 60 % of demand

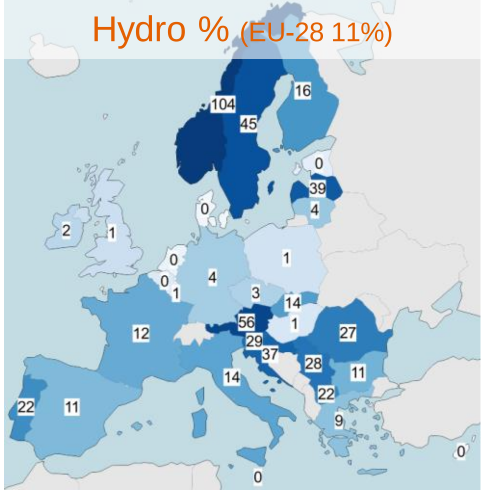


normalised



includes solar photovoltaics (PV) and solar thermal generation



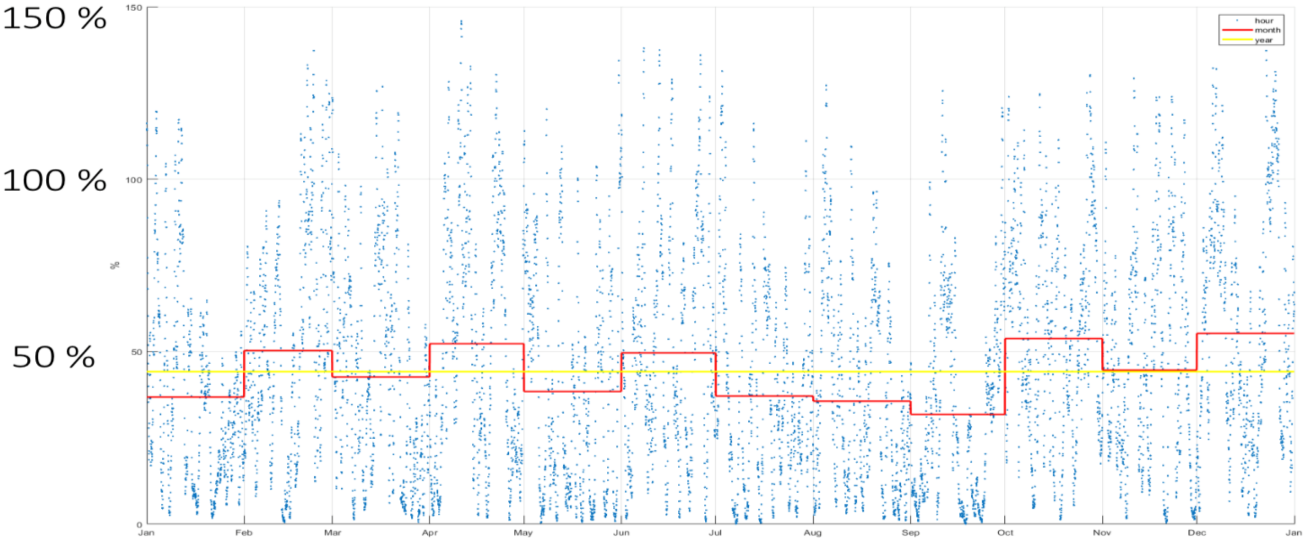


normalised and excluding pumping

Data source: Eurostat, SHARES partial provisional results 2018

Towards 100% renewable power systems

Instant 100% of VRE (variable renewable energy) operation already well before 50 % yearly share



ENERGINET

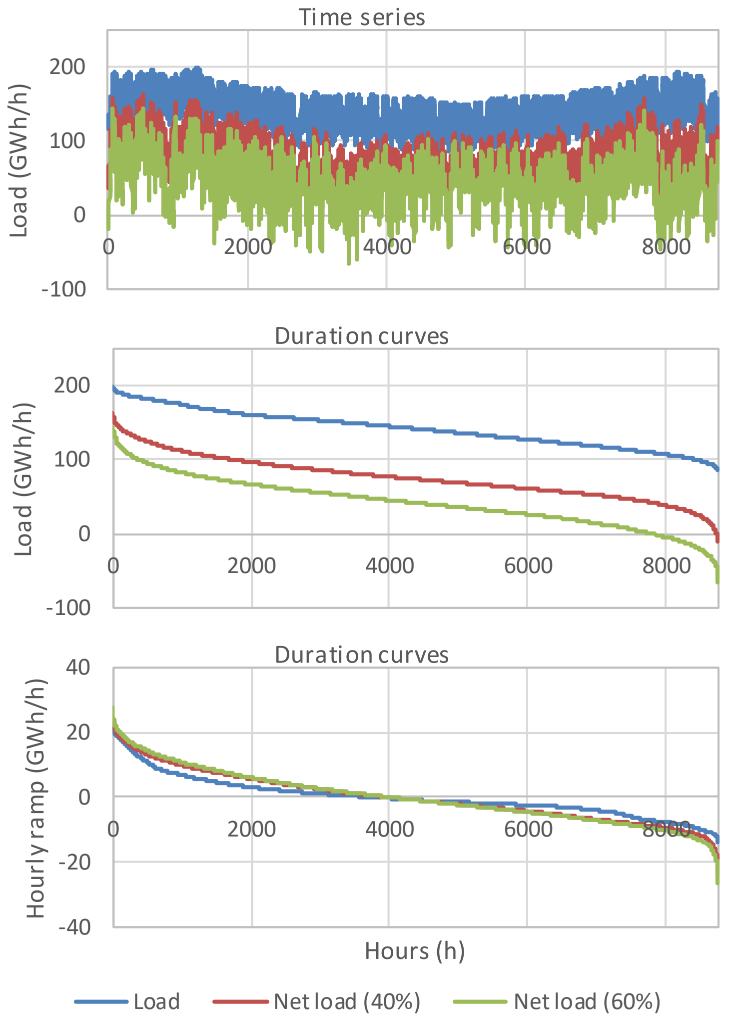
Example DK 2017: 43 % on average

Growing wind and solar shares increase net load variability

Example: Northern Europe*

- Load (no wind or solar)
  - Load alone already includes variability
- Net load with 40% wind & solar share
  - Variability increases
  - Hourly ramps become larger
- Net load with 60% wind & solar share
  - More variability
  - Almost 1000h with net load <0

*Nordic + Baltic + Germany + Poland



Role of baseload and flexible power plants changes

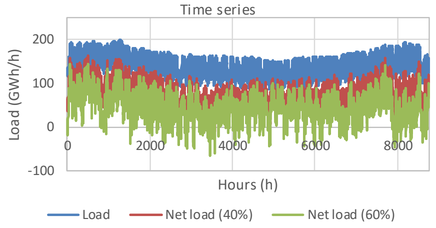
The time of base load power plants is over

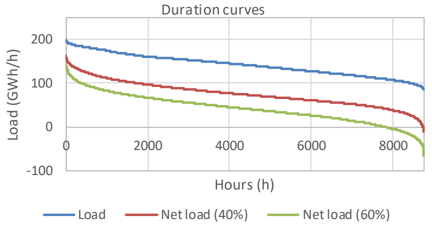
- Less and less time operating (full load hours), resulting in costs/MWh getting high

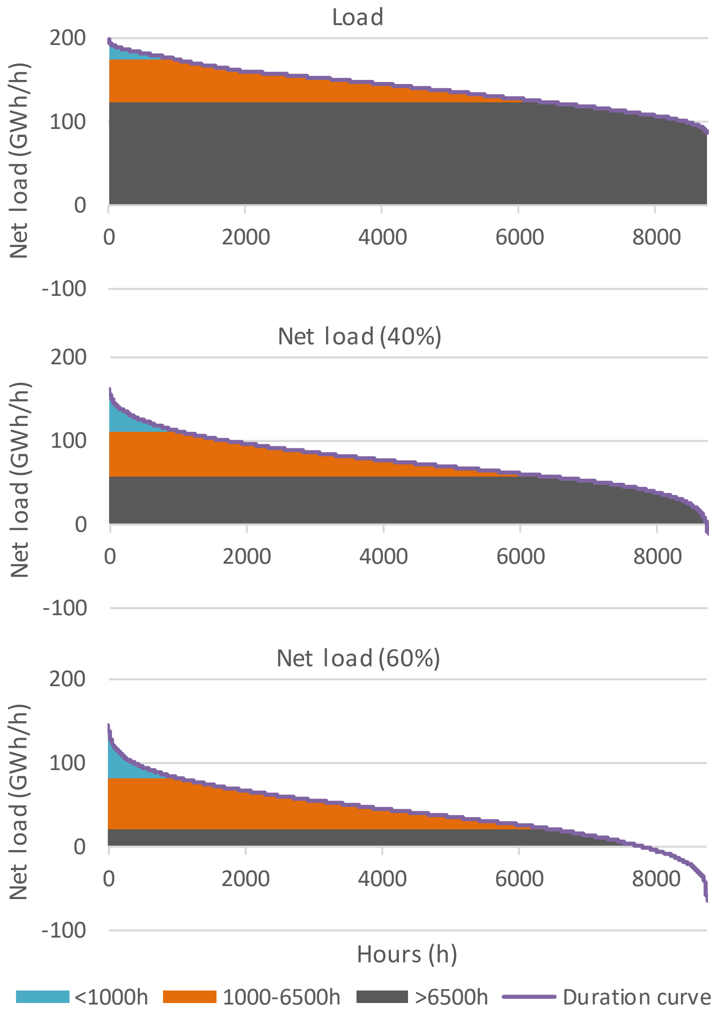
The time of flexible power plants is here

- Producing less than 6500 hours per year, much of that time at part load operation

There are also other options for managing the net load: curtailment, storage, transmission, demand response, new loads





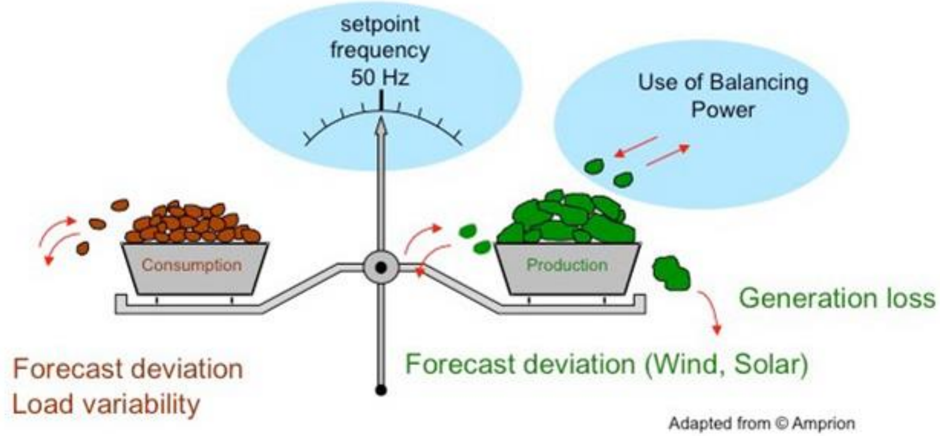


Flexibility needs in future

Flexibility can be described as *the ability of the power system to respond to changes*

Flexibility needs occur due to variability as well as forecast errors of generation

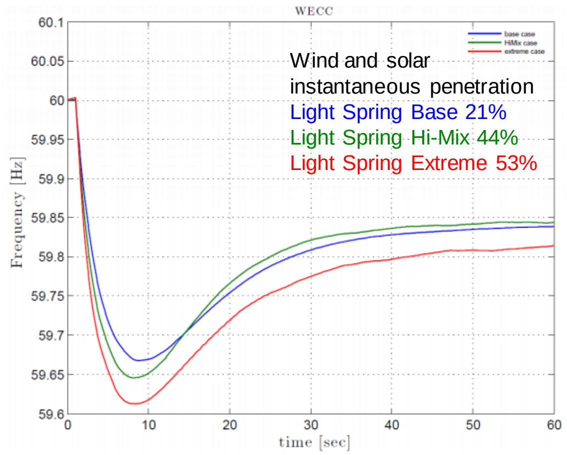
- Temporal scales
  - Stability (seconds or less)
  - Net load ramps (minutes to hours)
  - Weather patterns (days)
  - Seasonal variations (months)
- Spatial scales
  - Local (e.g. voltage)
  - Regional (e.g. uneven distribution of VRE resource)
  - System-wide (e.g. transmission bottlenecks)



Temporal scales of flexibility needs – simplified examples

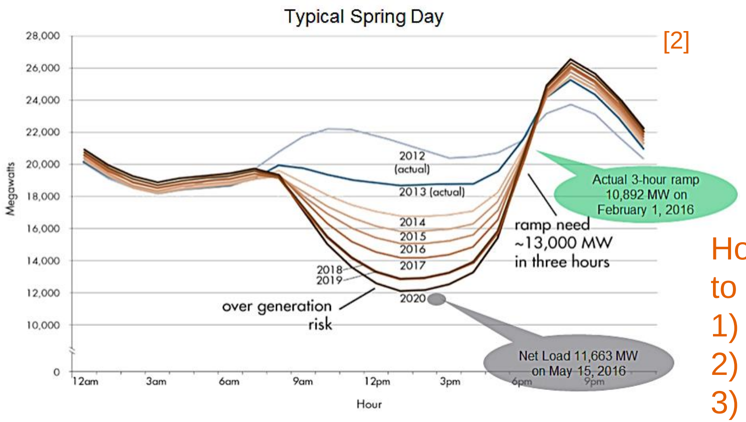
VTT

Stability (seconds or less)



[1]

Net load ramps (minutes to hours)

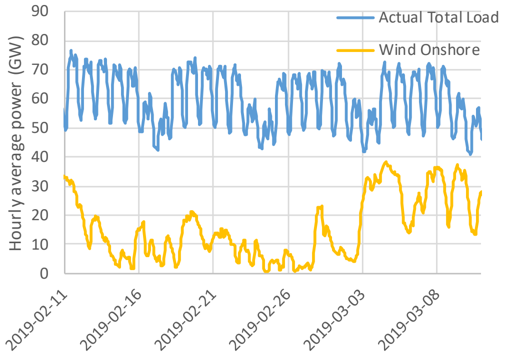


[2]

How bioenergy could contribute to the flexibility needs?

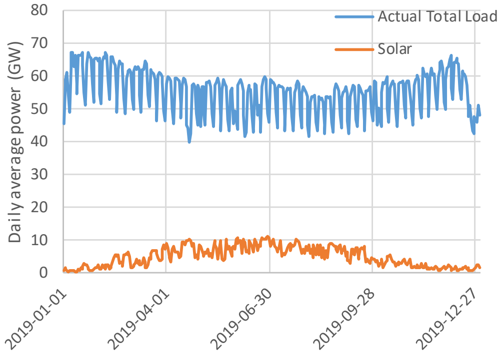
1) Synchronous inertia
2) Ramping, min. load
3) Start/stop cycling, min. load
4) Biofuel storage?

Weather patterns (days)



[3]

Seasonal variations (months)



[4]

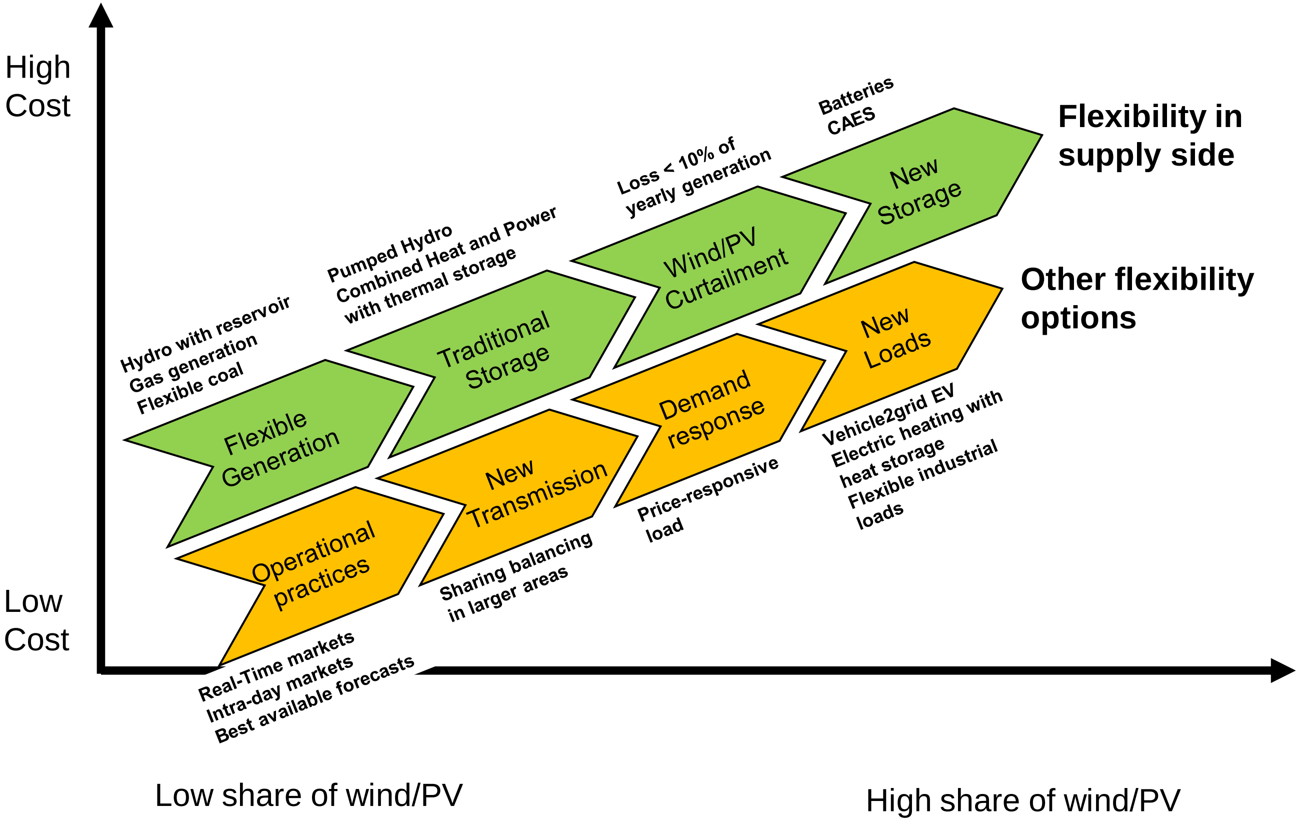
[1] Miller et al. 2014. Western Wind and Solar Integration Study Phase 3 – Frequency Response and Transient Stability.

[2] California Independent System Operator (CAISO)

[3] Data from Germany (ENTSO-E)

[4] Data from Germany (ENTSO-E)

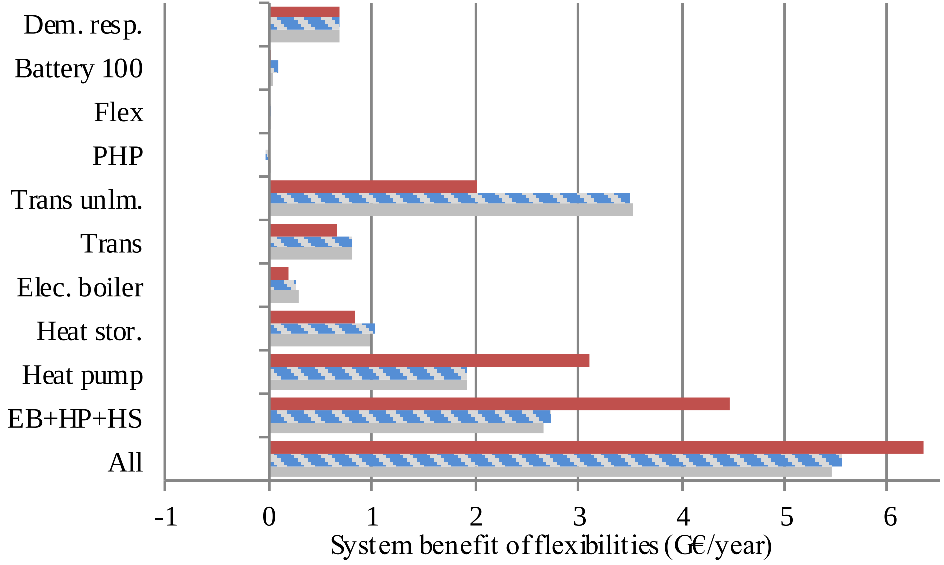
Ways to increase flexibility in power systems



Original source: UWIG

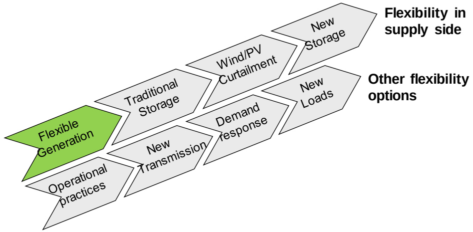
Flexibility options will also compete – using the more cost effective options first

- Case North Europe: comparing the benefit of flexibility as difference in yearly system operational costs, with the cost of each flexibility source
  - Demand response: in this example without costs
- Using all available options is not equal to the sum of individual options

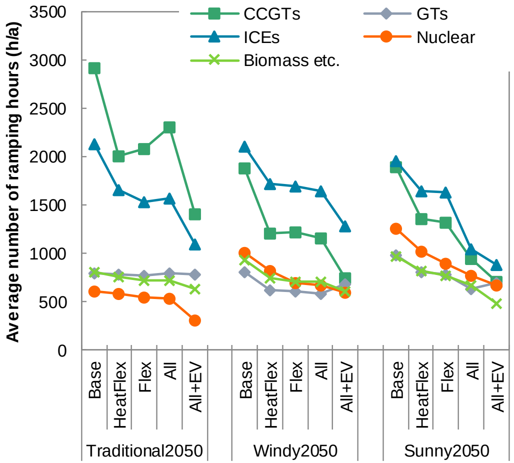


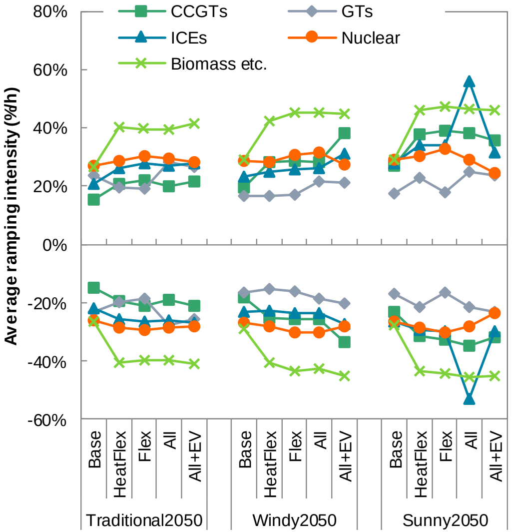
Kiviluoma, J., Rinne, E., & Helistö, N. (2018). Comparison of flexibility options to improve the value of variable power generation. *International Journal of Sustainable Energy*, *37*(8), 761–781. https://doi.org/10.1080/14786451.2017.1357554

Flexible generation



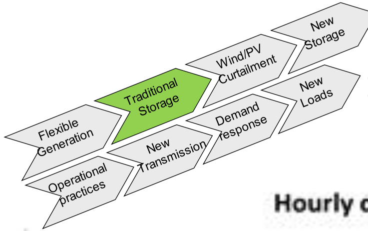
- Thermal power plants will be valuable for less frequent larger ramps
- Increasing amount of wind and solar does not necessarily result in more frequent ramping of thermal power plants if other flexibility sources are available
- Cycling characteristics: minimum load, part-load efficiency, ramping capability and costs, start-up capability and costs, minimum uptime and downtime



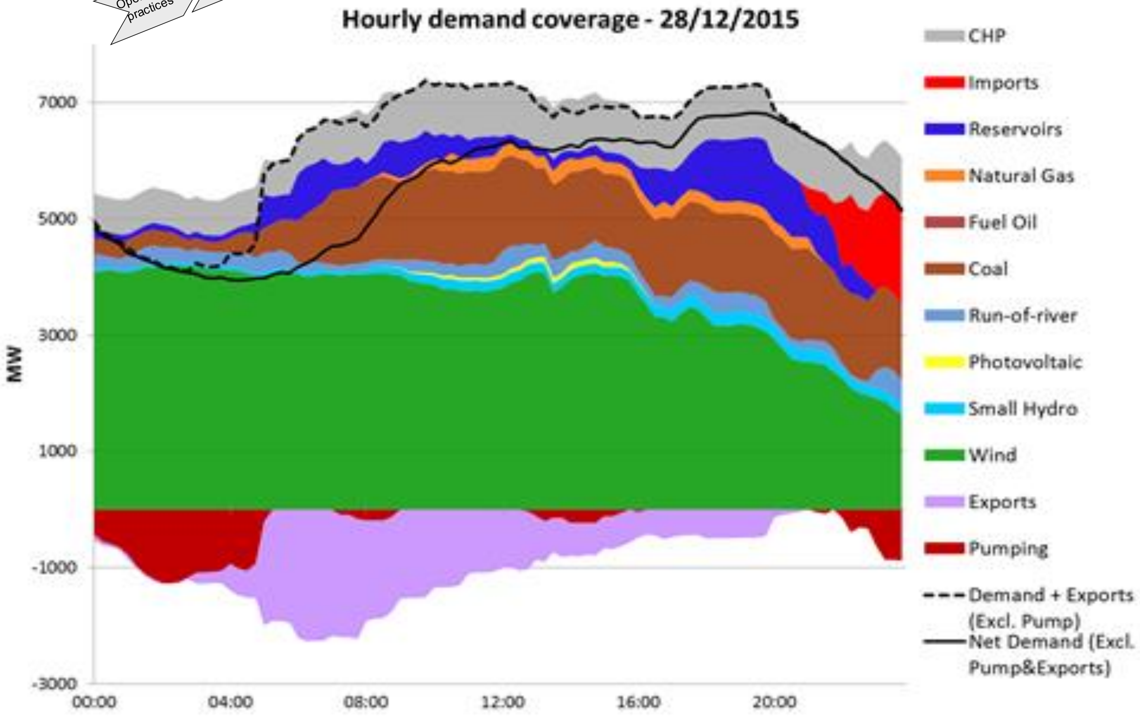


Helistö, N., Kiviluoma, J., & Holttinen, H. (2018). Long-term impact of variable generation and demand side flexibility on thermal power generation. *IET Renewable Power Generation*, *12*(6), 718–726. https://doi.org/10.1049/iet-rpg.2017.0107

Traditional storage

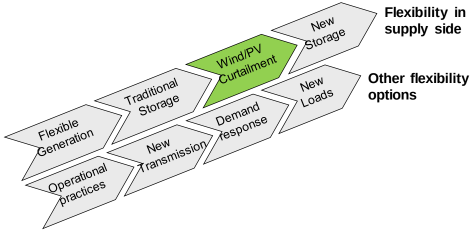


- Large hydro reservoirs and pumped hydro already used today – and projects to build more ongoing

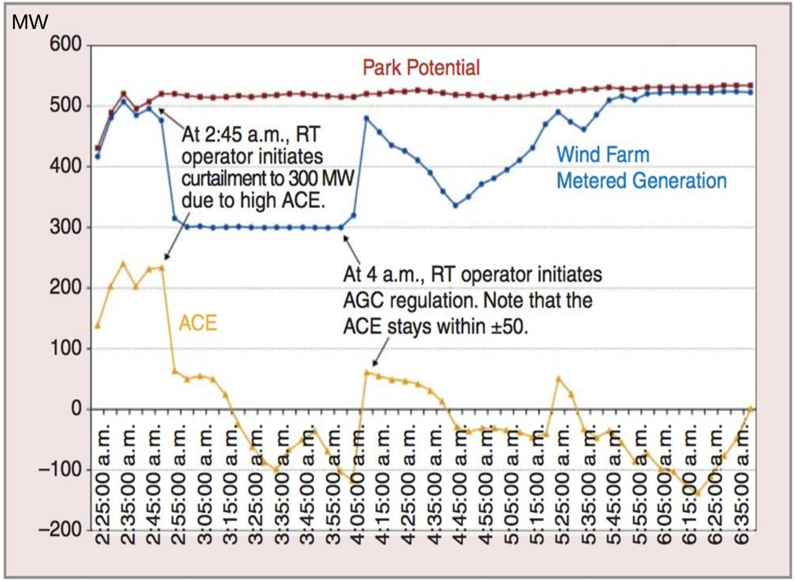


Source: Summary report, IEA WIND Task 25, June 2016.
http://www.vtt.fi/inf/pdf/technology/2016/T268.pdf

Wind/PV curtailment



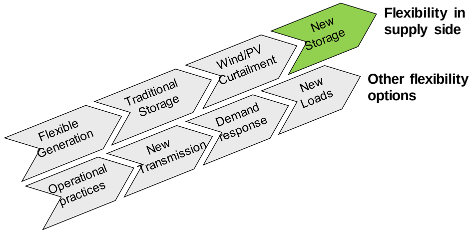
- Curtailments are signals of lack of flexibility…
  - Delays of transmission (Germany), inflexibilities of coal power plants and tariffs (China), limiting max share of non-synchronous generation (Ireland)
- …but can enable system services from wind and solar
- Experience of frequency response:
  - Very fast (inertial) in Quebec, secondary in Colorado
  - Market compliance in Spain, wind was providing ~ 5 % of downward reserves in 2017
  - California: responses from solar PV better than conventional generators



Wind power plant in Xcel/PSCO is first manually block curtailed and then put on AGC regulation.

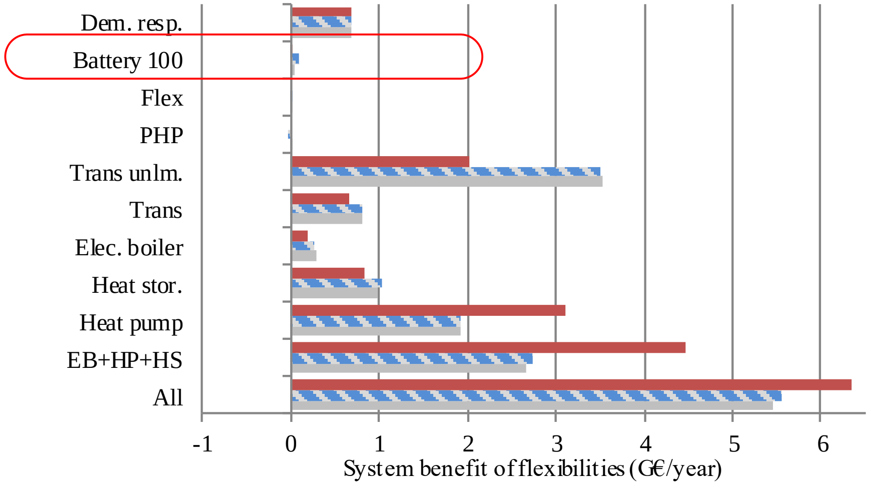
Source: Drake Bartlett, Xcel

ACE area control error | AGC automatic generation control



New storage

- Batteries have net benefit on system level when their price drops below 100 €/kWh
  - Especially in systems with strong daily cycles – more beneficial in solar-dominated systems than in wind-dominated systems
- Using vehicle-to-grid charging for electric vehicles may bring enough short term storage for the system if all vehicles electric



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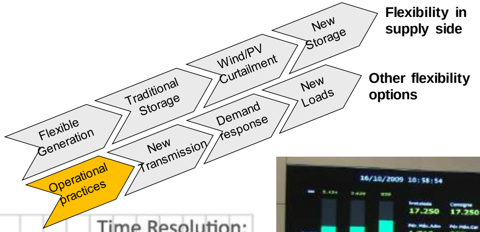
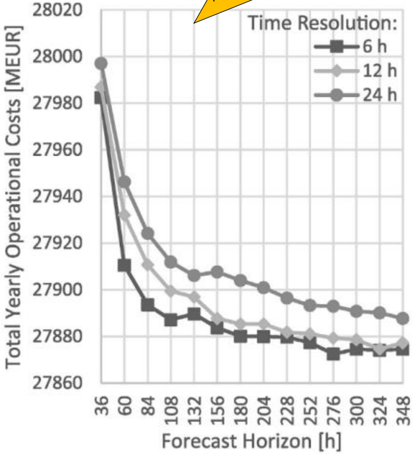
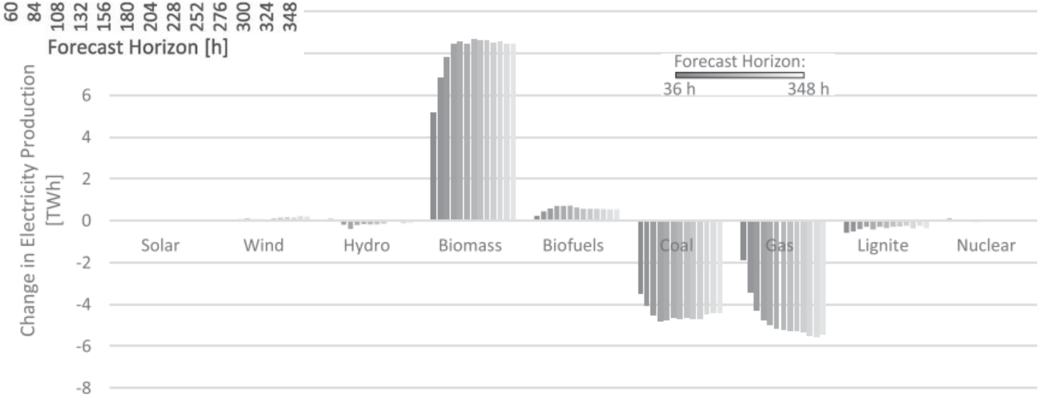
Operational practices



- Operating the system with longer time horizon forecasts will benefit at larger wind and solar shares
- Nordic case study: Biomass replaces coal and gas when increasing forecast horizon from 1 day ahead to 15 days ahead

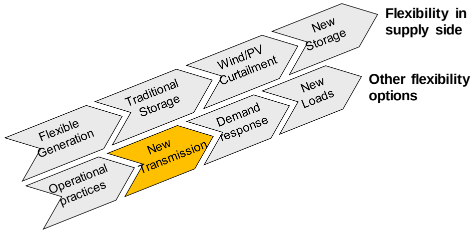




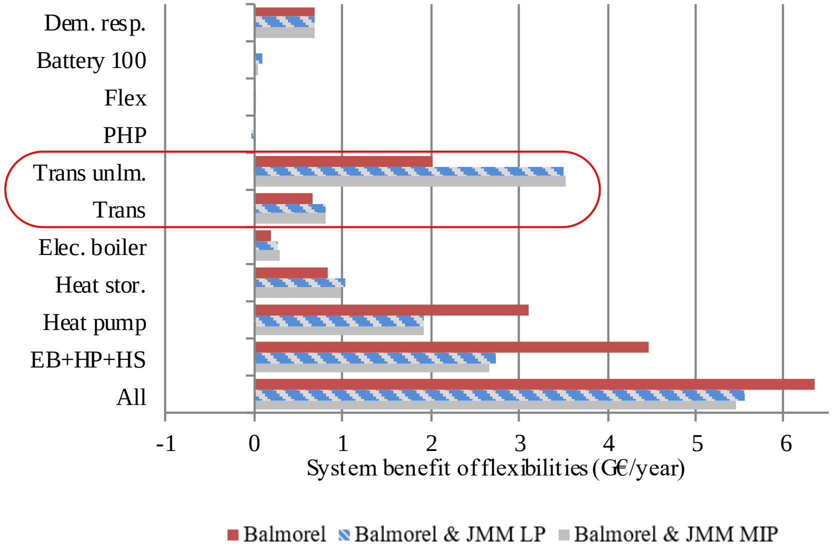
Total electricity generation by source, compared to the 36-hour-ahead forecast horizon

Rasku, T., Miettinen, J., Rinne, E., & Kiviluoma, J. (2020). Impact of 15-day energy forecasts on the hydro-thermal scheduling of a future Nordic power system. *Energy*, *192*, 116668. https://doi.org/10.1016/j.energy.2019.116668

New transmission



- Benefits from the smoothing effect of wind power production
  - Reduction of variability from a single country to a wider region
- Benefits from using flexible generation/storage/load resources in neighboring countries
- New interconnections are beneficial especially in wind-dominated systems
- Transmission grid reinforcements may also be needed to connect good wind/solar resources to high load areas



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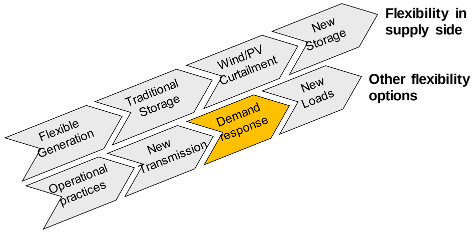
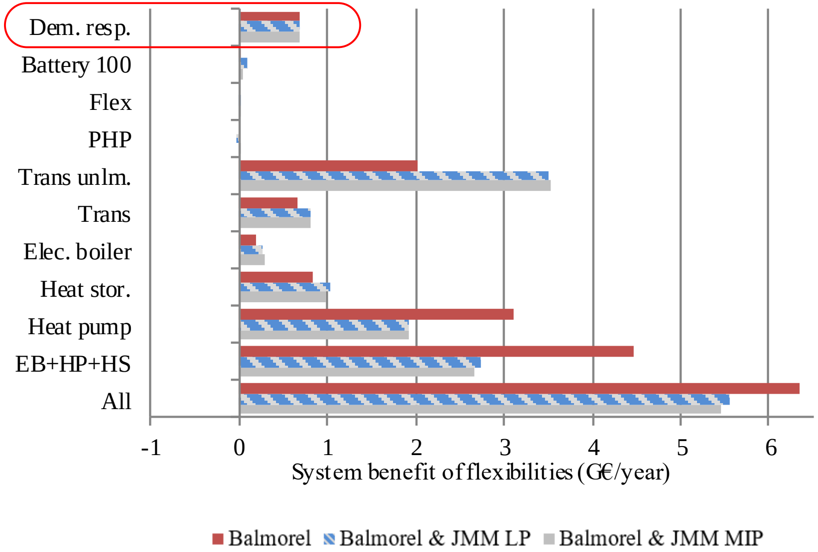
Demand response



- Demand response schemes can decrease the need for additional generating capacity
- Demand response can be useful for primary reserves



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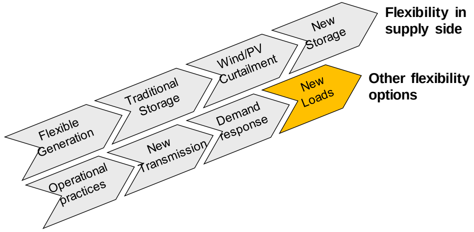
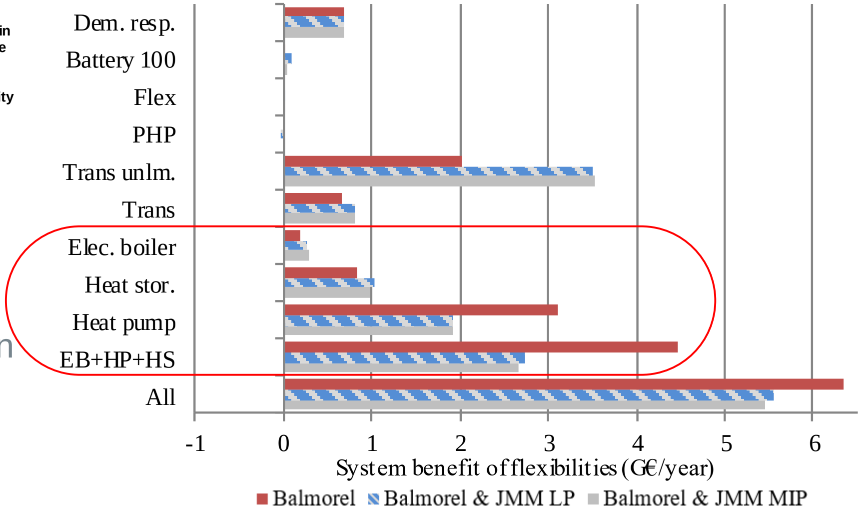
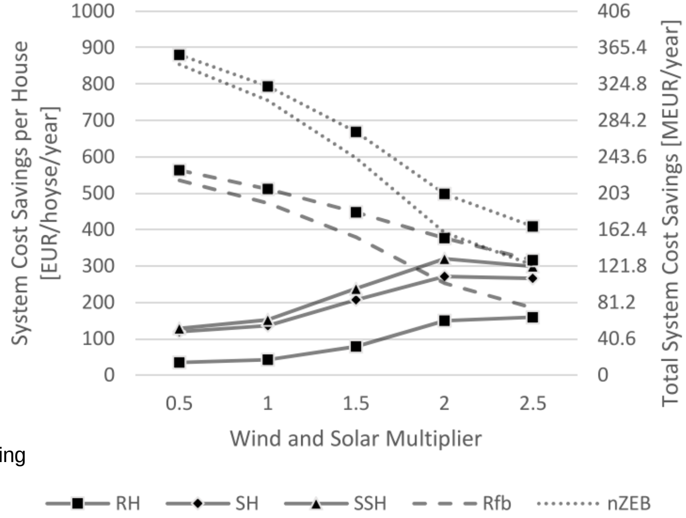
New loads





- Heat pumps and electric boilers allow replacing fuels in the district heating sector when there is a surplus of electricity generation
  - Heat storages further increase opportunities to utilise this fuel saving
- With sufficient amounts of wind and solar, residential power-to-heat with thermal storage yields more system cost savings than simple energy efficiency improvements
- Electrification – new loads that are more flexible that the loads today
  - Heating and cooling, electric transport, industrial processes, …



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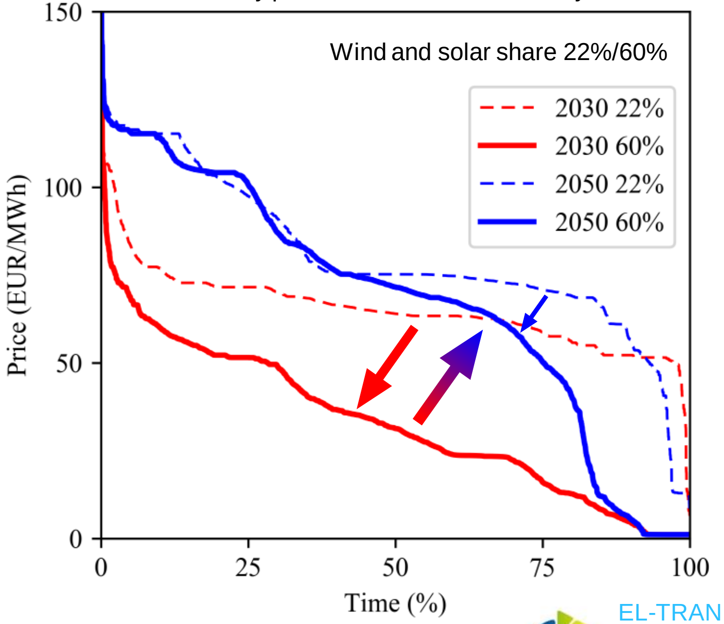
Rasku, T., & Kiviluoma, J. (2019). A comparison of widespread flexible residential electric heating and energy efficiency in a future Nordic power system. *Energies*, *12*(1). https://doi.org/10.3390/en12010005

RH Resistive heater | SH Storage heater | SSH Super storage heater | Rfb Refurbished | nZEB Nearly zero-energy building

Impacts of generating capacity mix on electricity prices

- Very low average electricity prices are likely to occur when large volumes of wind and solar are pushed into power systems that already have enough generating capacity
- Average electricity prices may return to higher levels if excess base load generating capacity is retired
  - Rest of the generation capacity mix can be optimized for the new system conditions

Electricity price duration curves over a year

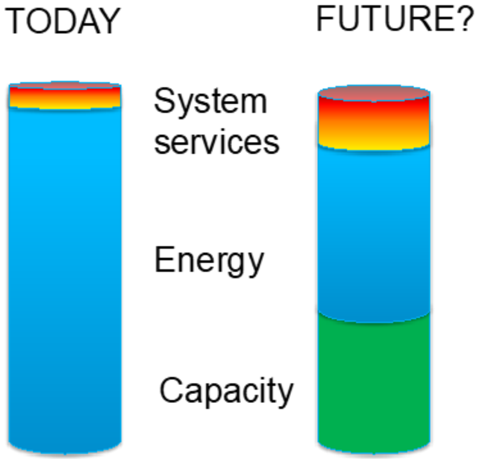


EL-TRAN strategic RESEARCH

Helistö, N., Kiviluoma, J., & Holttinen, H. (2017). Sensitivity of electricity prices in energy-only markets with large amounts of zero marginal cost generation. In *International Conference on the European Energy Market, EEM*. Dresden, Germany. https://doi.org/10.1109/EEM.2017.7981893

Revenue sufficiency from markets– mitigating low prices

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



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)	VTT (Hannele Holttinen, 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); TSO Amprion (P. Tran)
Ireland	UCD (D. Flynn); SEAI (J. McCann); Energy Reform (J. Dillon, M. O'Malley);
Italy	TSO Terna Rete Italia (Enrico Maria Carlini)
Japan	Tokyo Uni (J. Kondoh); Kyoto Uni (Y. Yasuda); CRIEPI (R. Tanabe)
Mexico	INEEL (Rafael Castellanos Bustamante, Miguel Ramirez Gonzalez)
Netherlands	TUDelft (Arjen van der Meer, Simon Watson)
Norway	NTNU (Magnus Korpås); SINTEF (John Olav Tande, Til Kristian Vrana)
Portugal	LNEG (Ana Estanquiero); INESC-Porto (Ricardo Bessa)
Spain	University of Castilla La Mancha (Emilio Gomez Lazaro)
Sweden	KTH (Lennart Söder)
UK	Imperial College (Goran Strbac); Strathclyde Uni (Olimpo Anaya-Lara)
USA	NREL (Bri-Mathias Hodge); UVIG (J.C. Smith); DoE (Jian Fu)
Wind Europe	European Wind Energy Association (Vasiliki Klonari, Daniel Fraile)

https://community.ieawind.org/task25/

beyond the obvious

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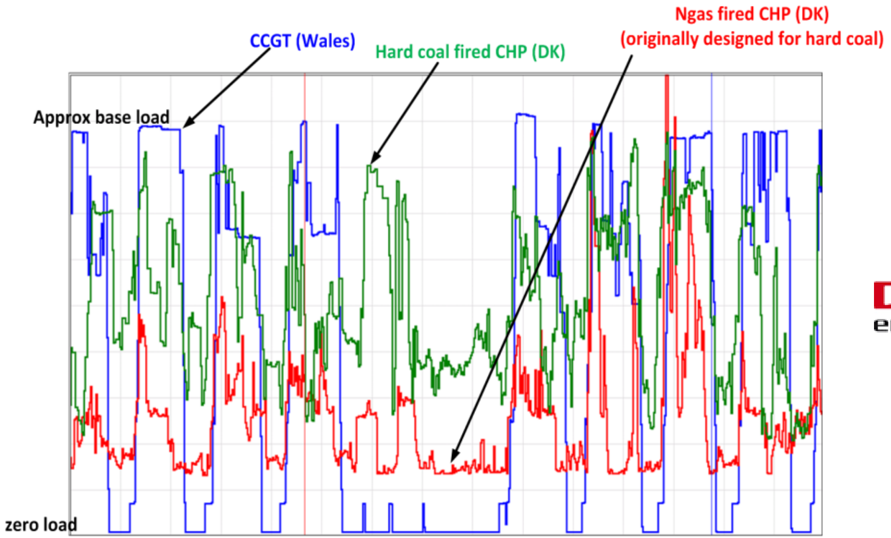
08/06/2020

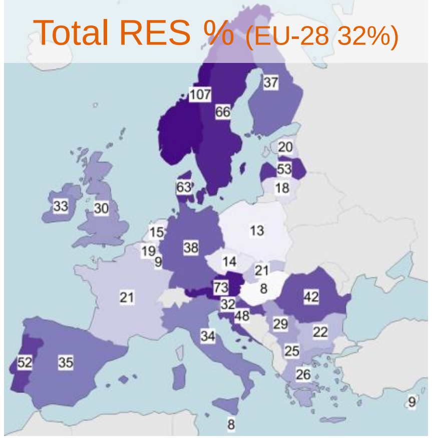
Examples of Enhancing Flexibility – Denmark

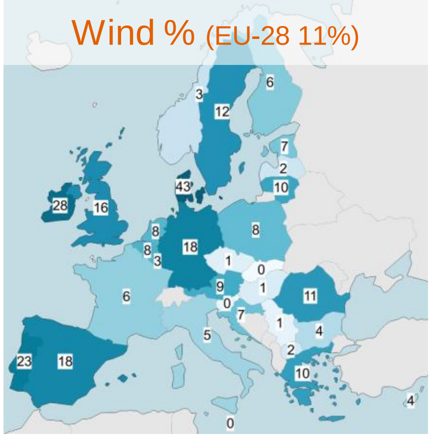
- Combined heat and power plants – operation according to electricity prices, electric boilers (heat from electricity)
- Lowering minimum on-line requirement of larger power plants
- More interconnections to Nordic market
- DSM and heat/gas and transportation system integration to enable 50% penetration of wind

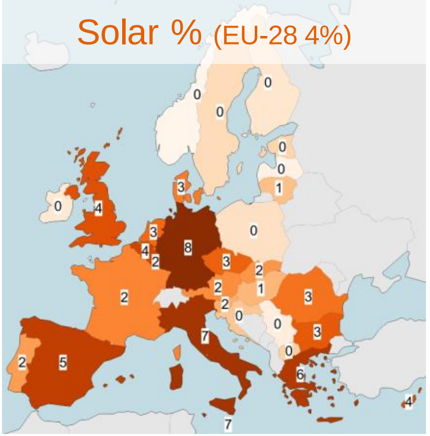


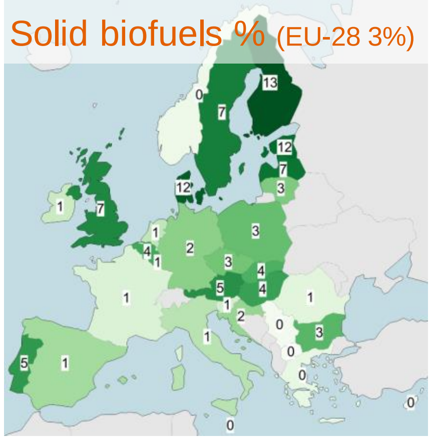
DONG energy

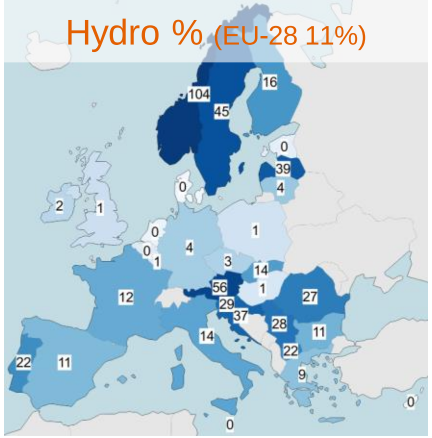
RES-E shares in Europe

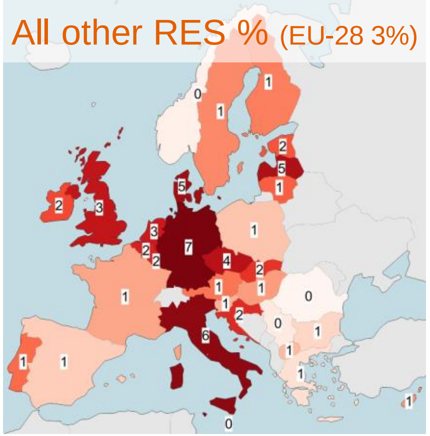












Hydro is normalised and excluding pumping.

Wind is normalised.

Solar includes solar photovoltaics and solar thermal generation.

All other renewables includes electricity generation from gaseous and liquid biofuels, renewable municipal waste, geothermal, and tide, wave & ocean.

VTT

Frequency response

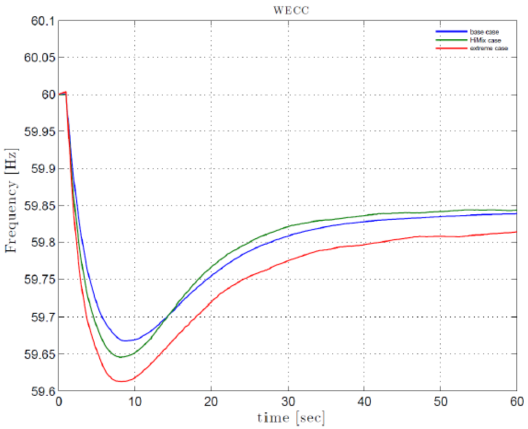


Figure 57. Frequency response to two Palo Verde unit trip – LSP Base vs. Hi-Mix vs. Extreme.

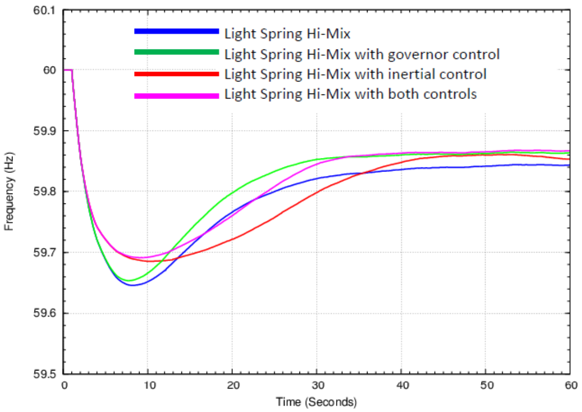


Figure 74. Frequency response to two Palo Verde unit trip for LSP Hi-Mix case with three combinations of frequency controls on wind plants.

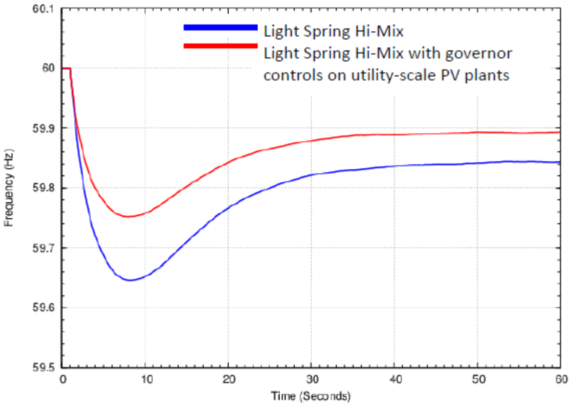


Figure 76. Frequency response to two Palo Verde unit trip for LSP Hi-Mix – with and without governor control on utility-scale PV plants.

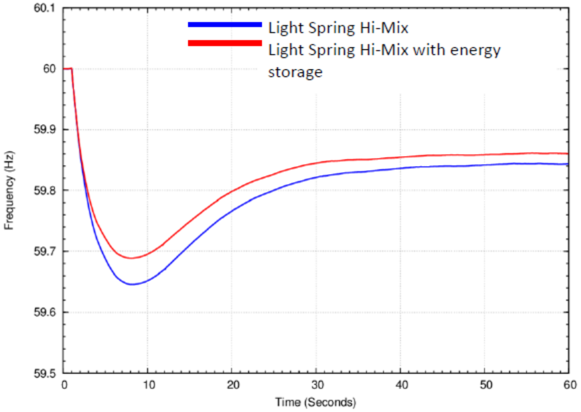
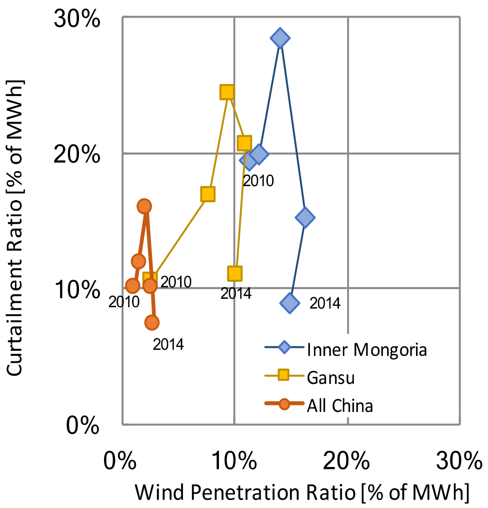


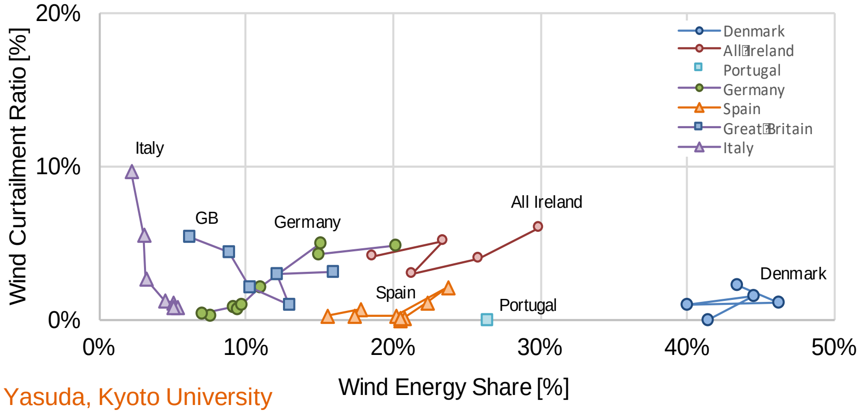
Figure 79. Frequency response to two Palo Verde unit trip for LSP Hi-Mix – with and without energy storage.

Source: Miller et al. 2014. Western Wind and Solar Integration Study Phase 3 – Frequency Response and Transient Stability.

Curtailments
are signals 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





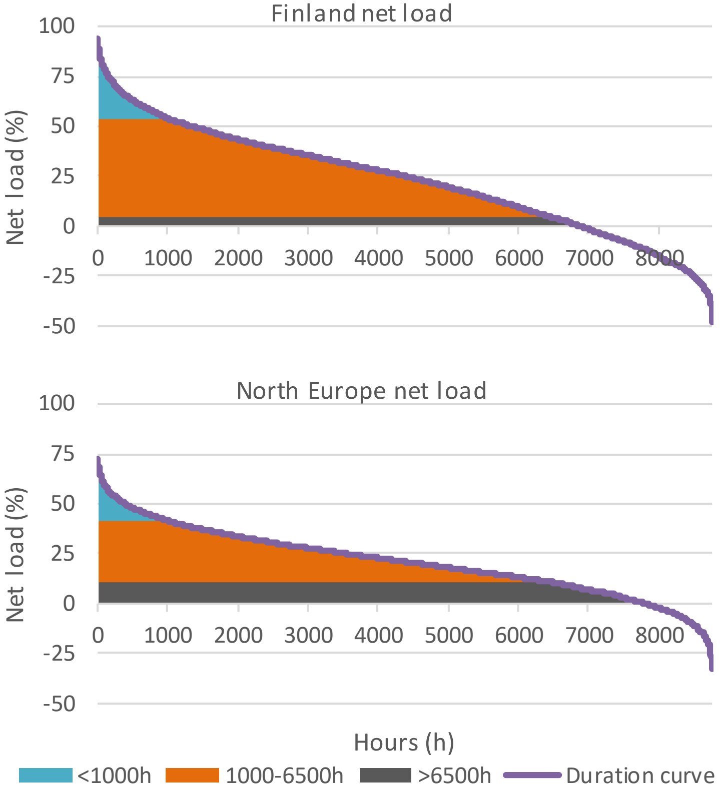
Source: Prof Yasuda, Kyoto University

New transmission
for benefitting from the smoothing effect

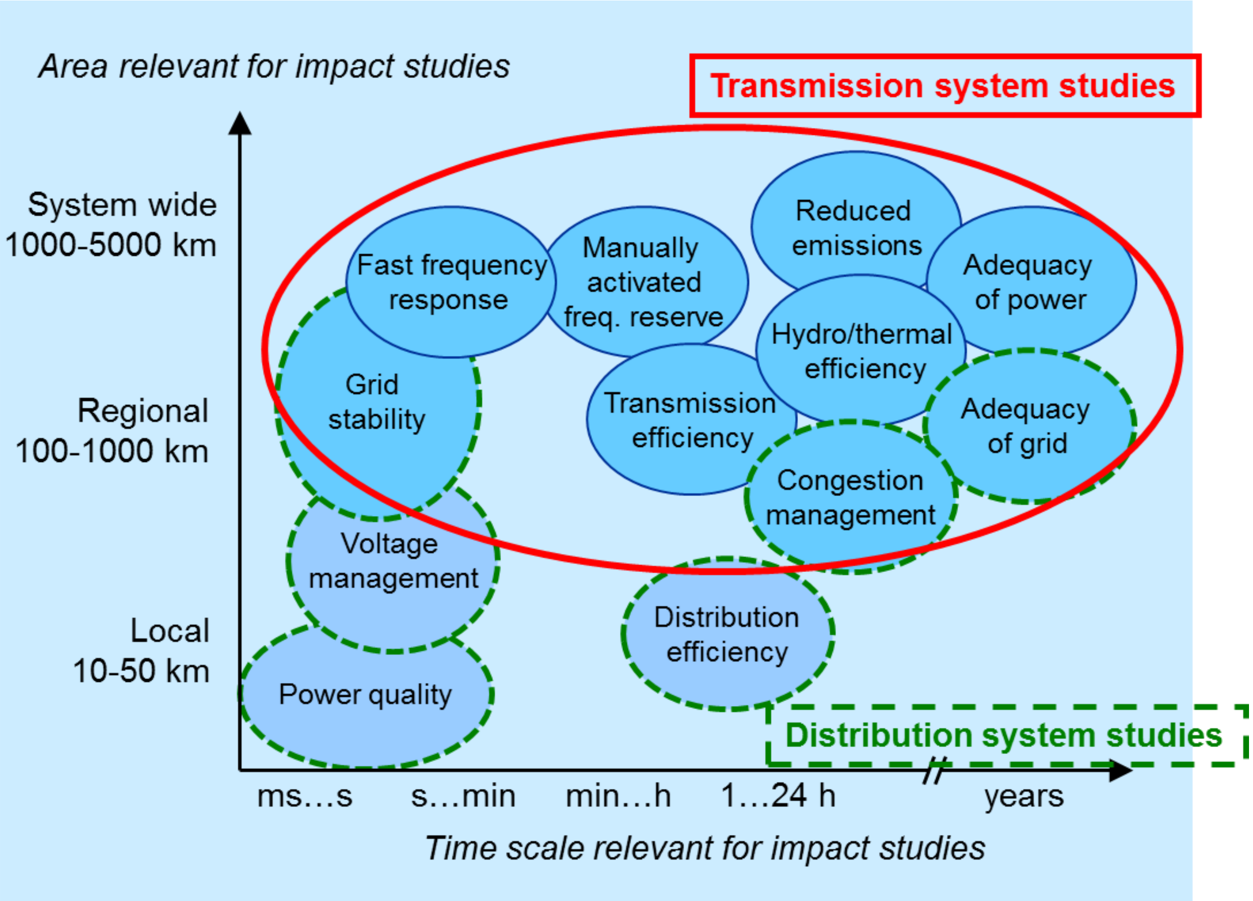
Smoothing effect of wind power production can be seen in the reduction of variability from a single country to a wider region

Example: Net load in Finland vs. Northern Europe

- Finland 60% wind & solar share
  - Max. net load 94% of the original peak load
  - Min. net load −49% of the original peak load
  - ~1900h with net load <0
  - Capacity of power plants with high operating hours (>6500h): 4% of the original peak load
- Northern Europe 60% wind & solar share
  - Max. net load 73% of the original peak load
  - Min. net load −33% of the original peak load
  - ~1000h with net load <0
  - Capacity of power plants with high operating hours (>6500h): 11% of the original peak load

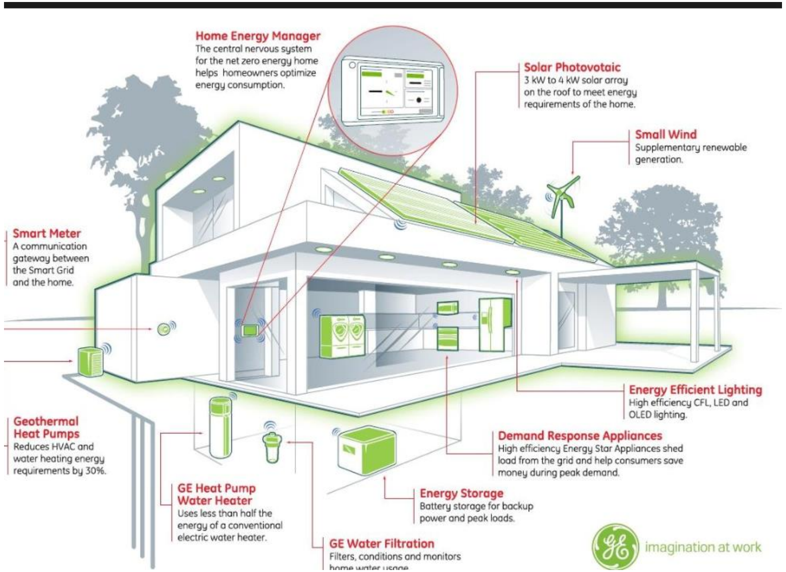


Other system integration issues



The traditional load becomes active

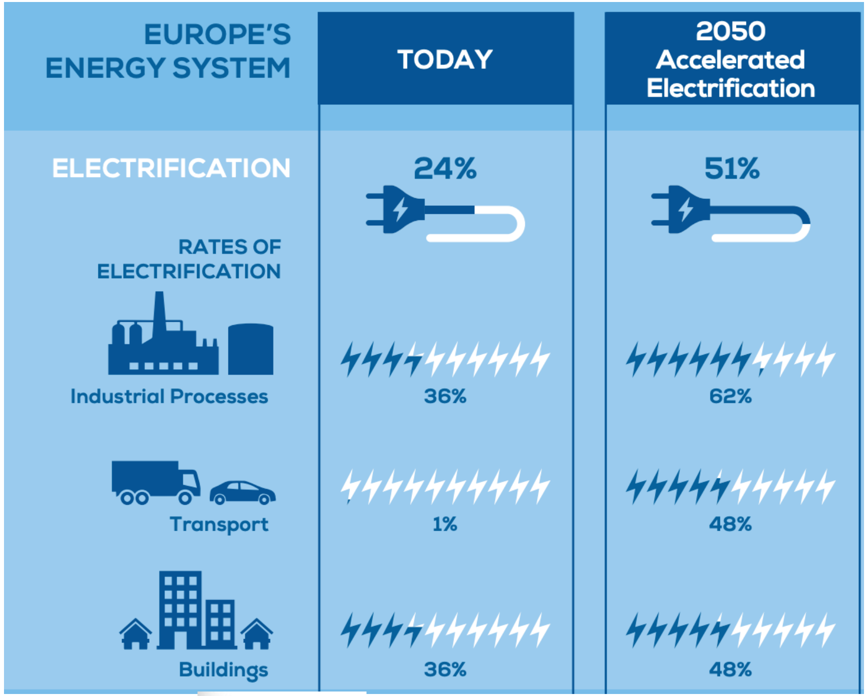
- Aggregators: offering same comfort/service and aggregating flexibility
- Prosumers: optimise use of (solar) generation. HEMS, BEMS, energy communities, local markets



VTT

Sector coupling will more than double electricity demand

- Heating and cooling with air pumps
  - Combined with thermal storage
- Electric transport
  - Vehicles used less than 50 % of time
- Electrolysers for synthetic gas, industry processes



WindEurope

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