Why flexibility?
Integrating large shares of variable renewables into the energy system

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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

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

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

Stability (seconds or less)

Net load ramps (minutes to hours)

Weather patterns (days)

Seasonal variations (months)

How bioenergy could contribute to the flexibility needs?
1) Synchronous inertia
2) Ramping, min. load
3) Start/stop cycling, min. load
4) Biofuel storage?

[3] Data from Germany (ENTSO-E)
[4] Data from Germany (ENTSO-E)
Ways to increase flexibility in power systems

Low share of wind/PV

High share of wind/PV

Flexible Generation

Flexible Transmission

Flexible Storage

Operational practices

New Transmission

New Storage

Demand response

New Loads

Pumped Hydro

Combined Heat and Power

with thermal storage

Loss < 10% of yearly generation

Batteries

CAES

Hydro with reservoir

Gas generation

Flexible coal

Real-Time markets

Intra-day markets

Best available forecasts

Sharing balancing in larger areas

Price-responsive load

Vehicle2grid EV

Electric heating with heat storage

Flexible industrial loads

Low Cost

High Cost

Flexibility in supply side

Other flexibility options

Low Cost

High Cost

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

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.

Traditional storage

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

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
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

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

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

Demand response

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

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 than the loads today
  - Heating and cooling, electric transport, industrial processes, …


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

08/06/2020 | VTT – beyond the obvious
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.

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

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[https://community.ieawind.org/task25/](https://community.ieawind.org/task25/)
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
Total RES % (EU-28 32%)

Wind % (EU-28 11%)

Solar % (EU-28 4%)

Solid biofuels % (EU-28 3%)

Hydro % (EU-28 11%)

All other RES % (EU-28 3%)

**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.
Frequency response

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
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