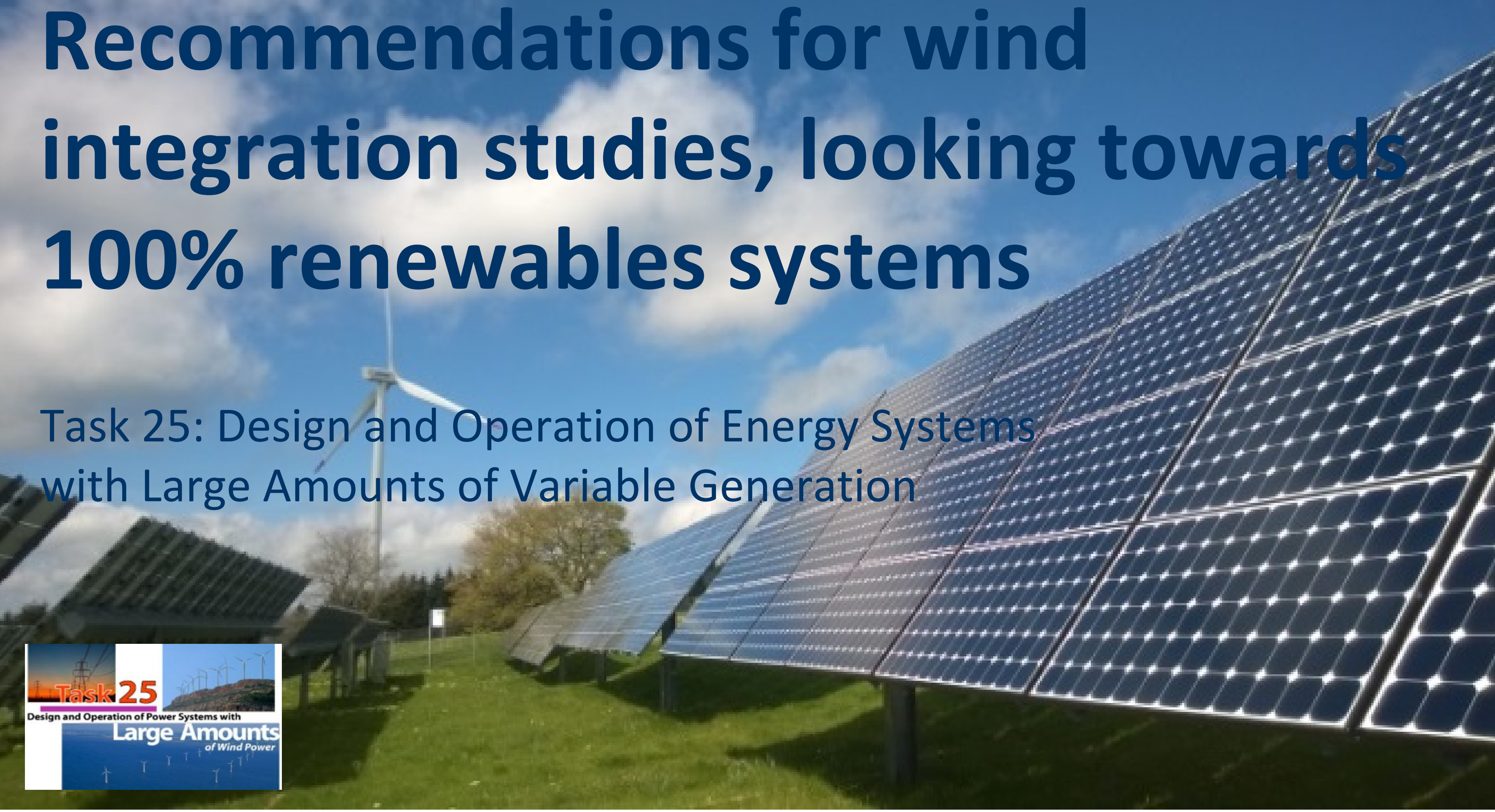
Recommendations for wind integration studies, looking towards 100% renewables systems



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

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Partner, Recognis

WinGrid June 15, 2021

iea wind

Contents

- Recommendations for how to perform integration studies: Future power system impact studies with high shares of renewables
- Towards 100% renewables studies
  - Challenges and Mitigation options
  - Status and Gaps in simulation model tools
  - First recommendations for studies

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://iea-wind.org/task25/ *(old web: https://community.ieawind.org/task25)*

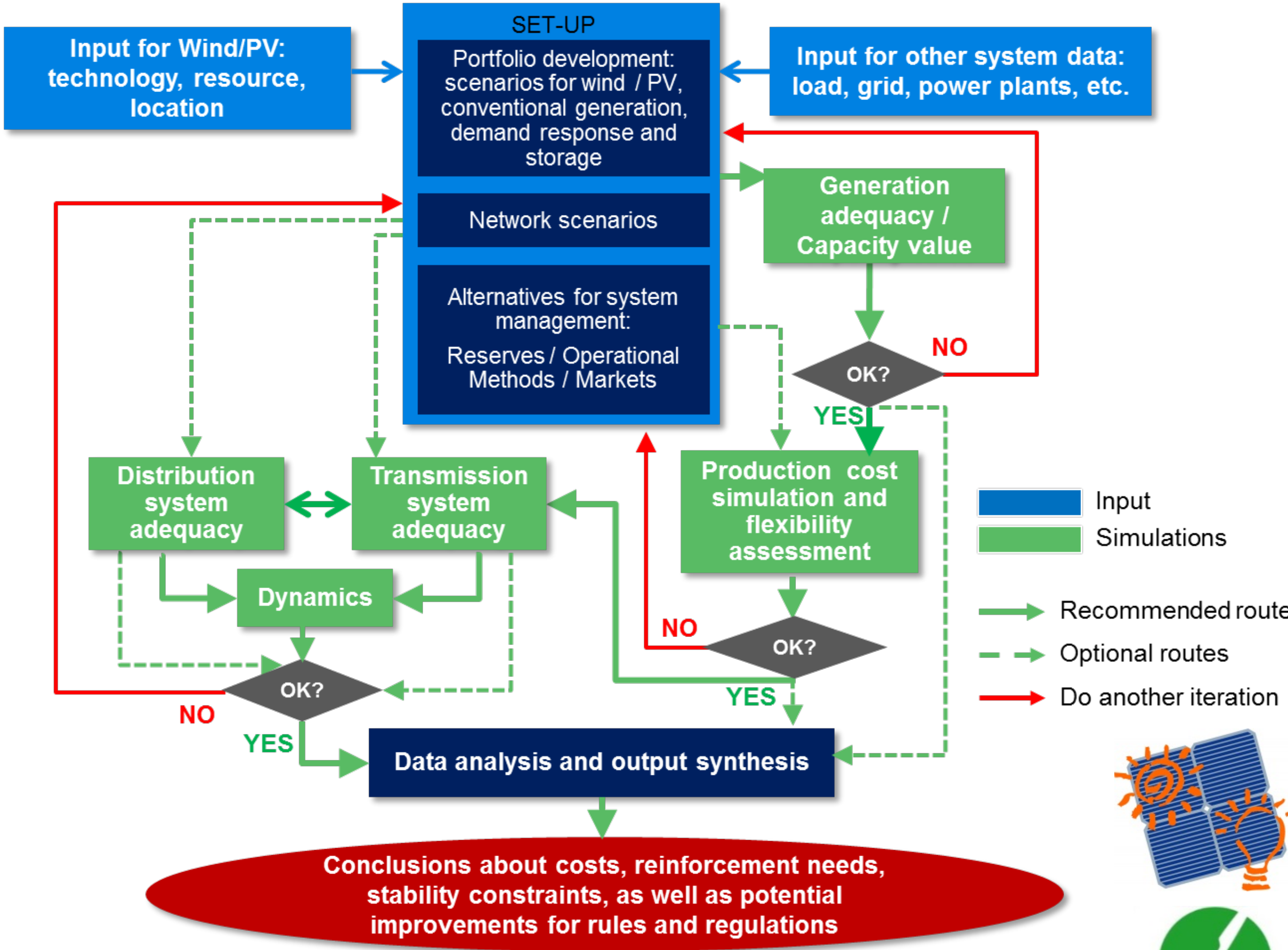
Recommended Practices – what, why and for whom

- Recommendations on how to perform studies describe the **methodologies, assumptions, and inputs** needed to conduct a grid integration study
  - No results, just discussion on methods
- to provide research institutes, consultants, and system operators with the **best available information on how to perform** an integration study
- can also be used as a **benchmark for any future power system study** - what is taken into account and what is not

RP16 ed 2 of IEA Wind TCP:
https://iea-wind.org/iea-publications/

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



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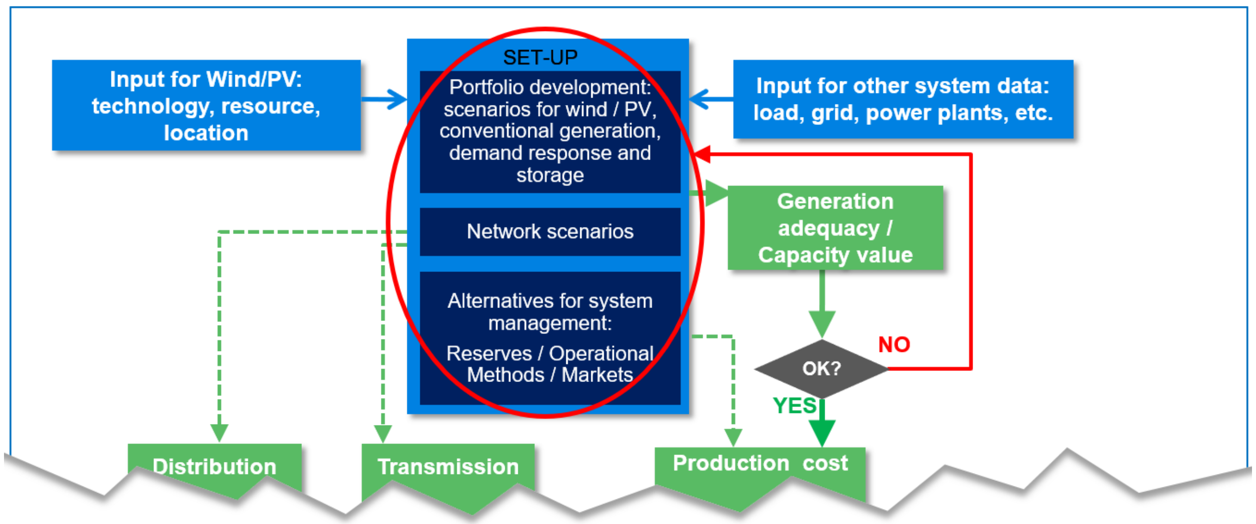
What to study - Portfolio Development and System Management

- Set-up of study
- Main assumptions – Critical for results!
- Future system, how wind/PV is added, what is remaining generation mix, operational practices



For larger shares and longer term studies:

- changes in the assumed remaining system become increasingly necessary, and beneficial: generation portfolio and network infrastructure, taking into account potential flexibility and technical capabilities of power plants. Additional scenarios for operating practices recommended

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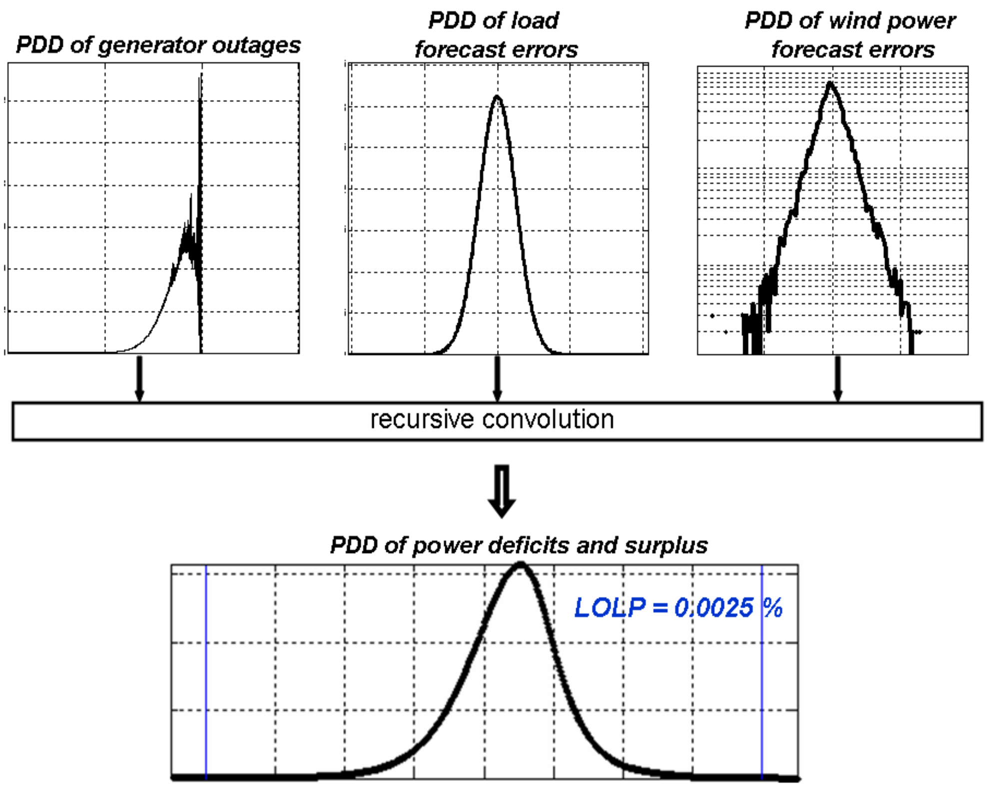
Operating reserve allocation with wind/PV

1. Synchronous wind/PV and load time series + forecast error distributions + generation outage distribution
2. Calculate for appropriate time scales, f.ex. automatically responding (secs-mins) and manually activated (mins-hour). Split data for categories with care not to double-count
3. Combine uncertainty keeping the same risk level before and after wind/PV
4. With increasing shares, use dynamic, not static reserves



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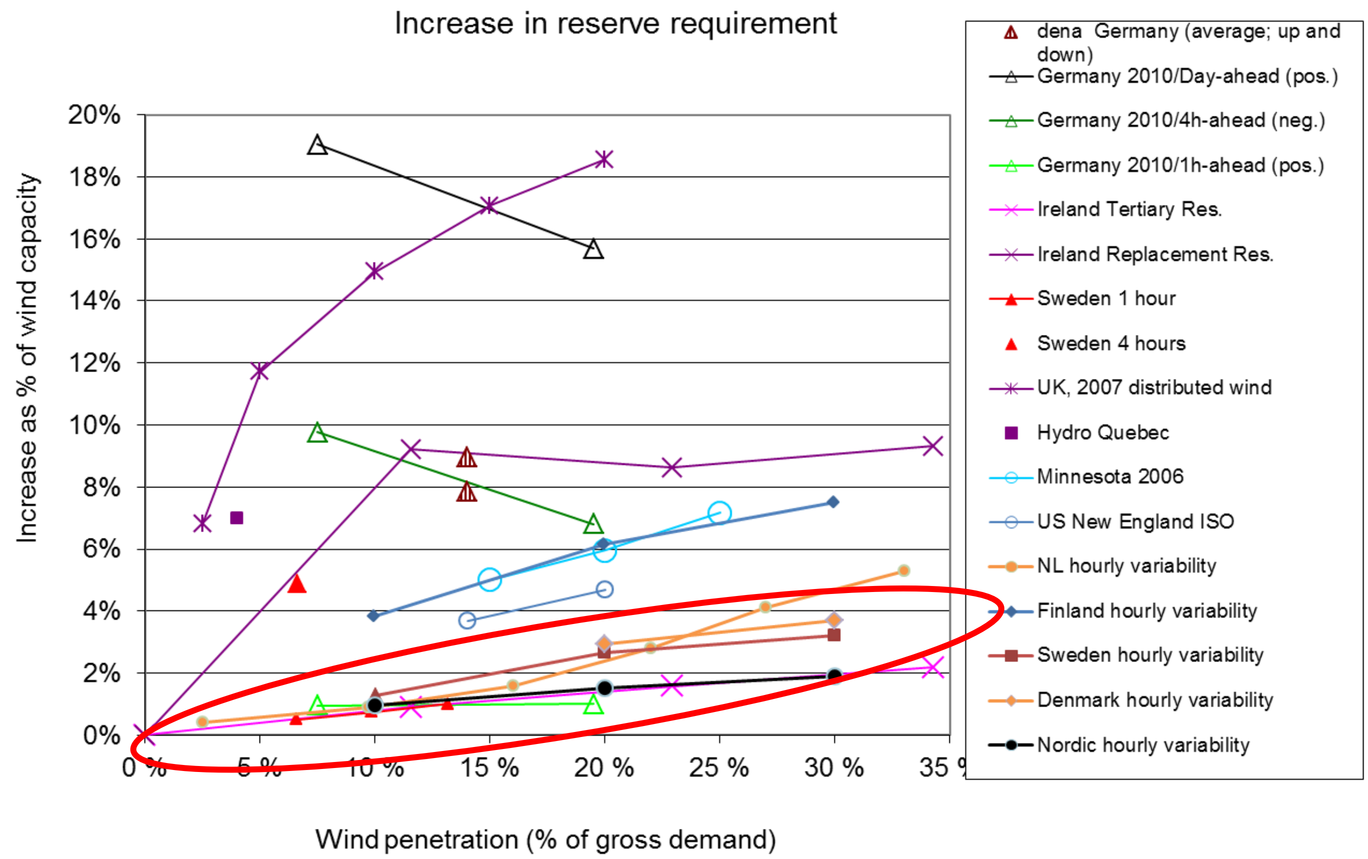
Results of studies for increase in operating reserves

- 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 with neighbouring system operators in Germany has resulted in reduction of use of frequency control, while wind and solar have increased

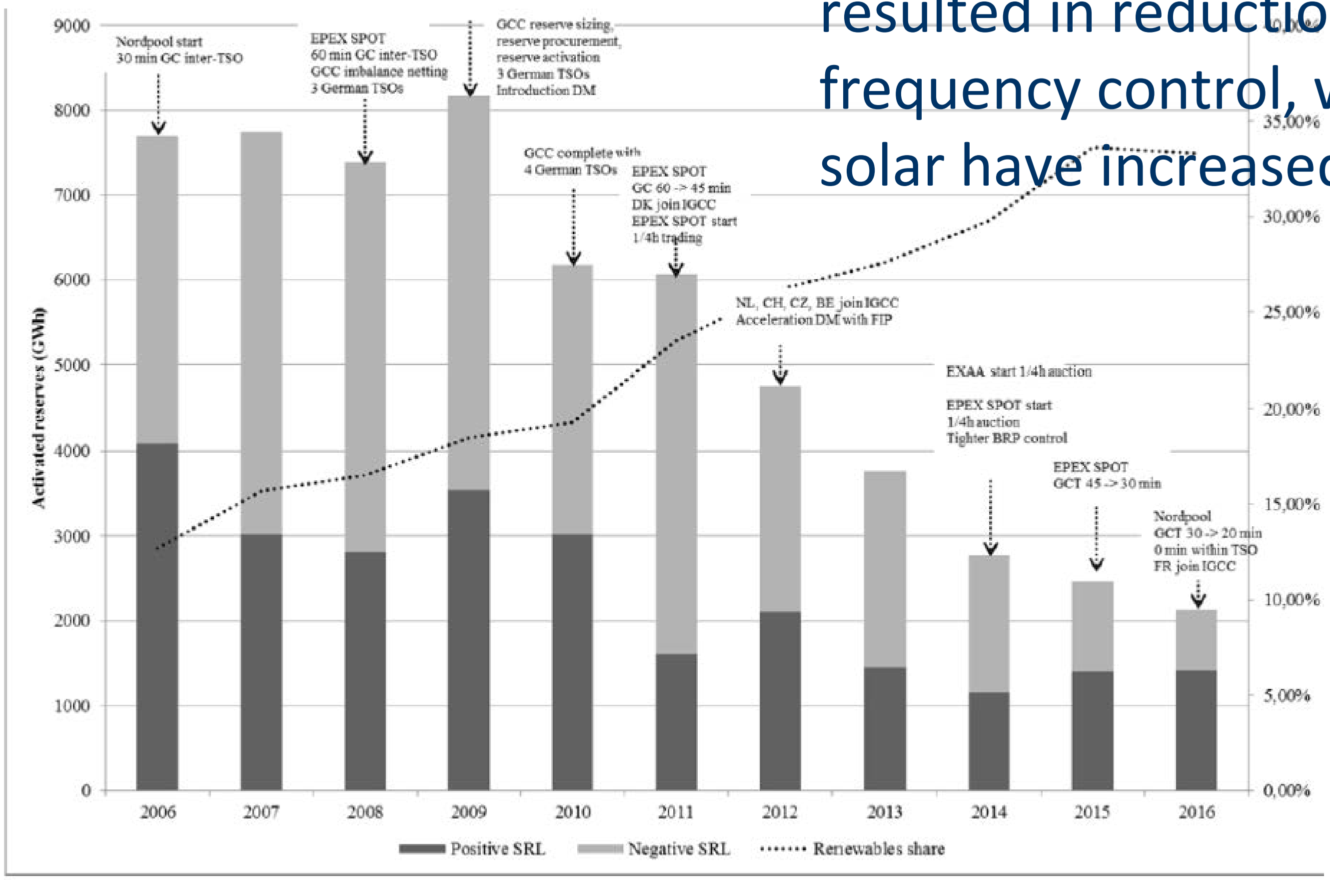
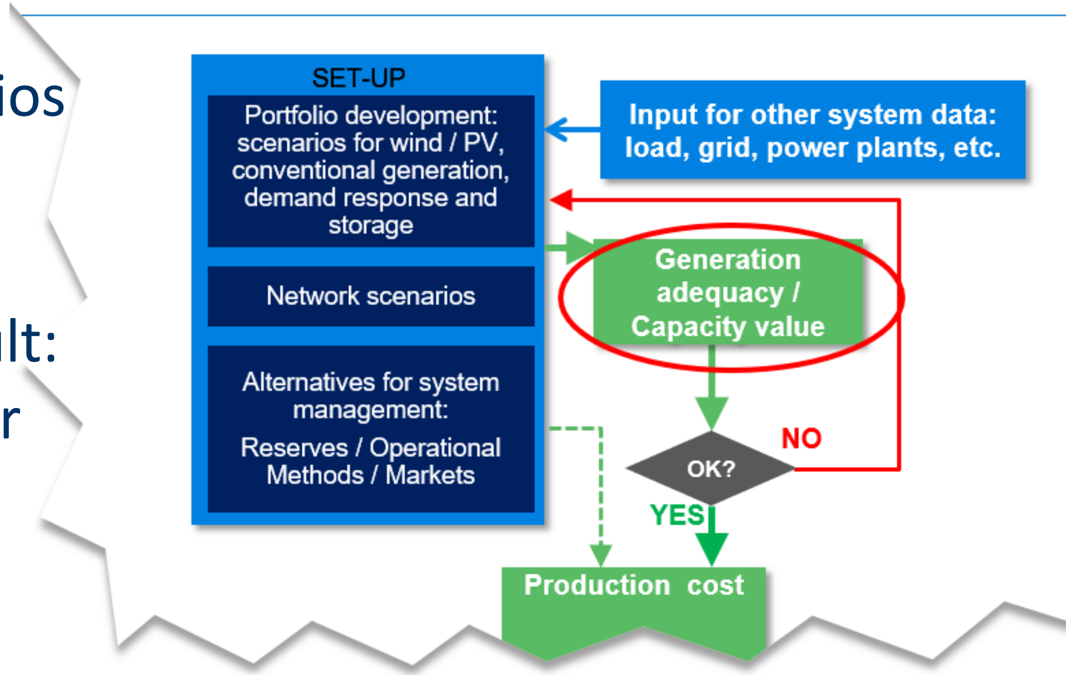


Figure 13: Total activated German Secondary Reserves (or aFRR) per year marked with events considered in this paper.

Source: Rena Kuwahata, Peter Merk, WIW17

Generation capacity adequacy

- Needed for making consistent future scenarios (how much capacity will wind/PV replace),
- as integration study result: **capacity value** of wind or solar PV

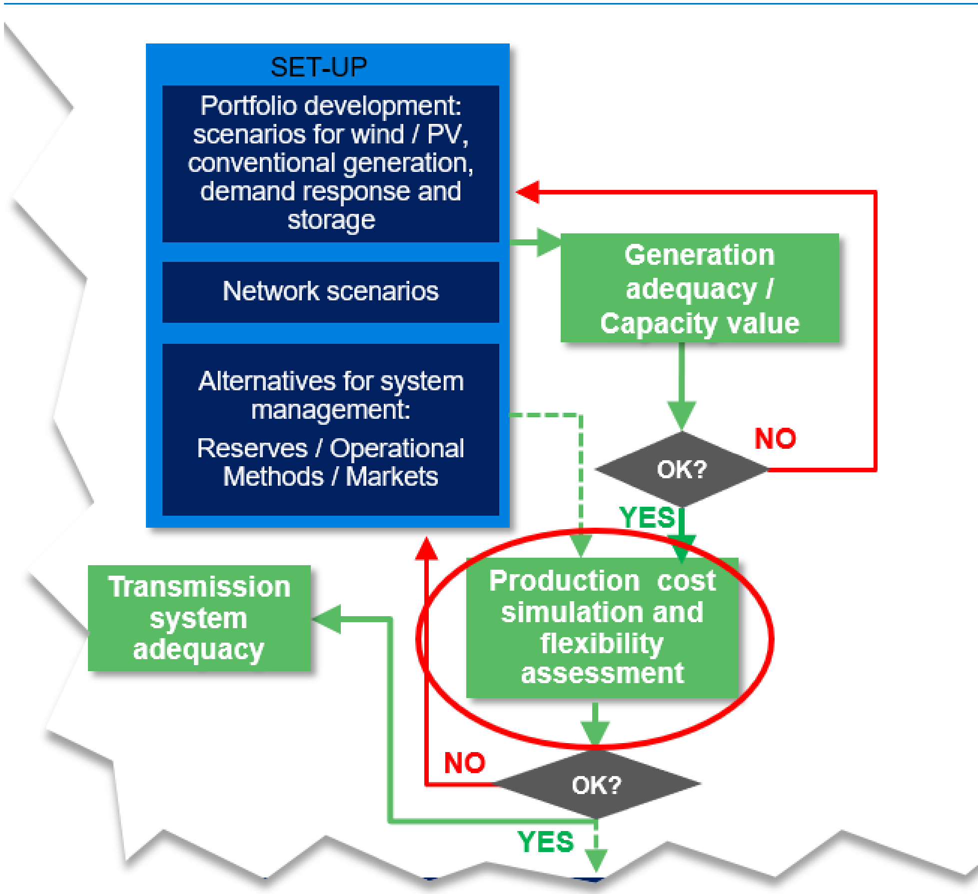


Recommendations:

- Assess how much increase in load will bring same reliability/LOLP in the system when adding wind or solar (ELCC method)
- Input data – synchronous wind/PV/load data. Number of years critical for robust results, more than 10 years

Production cost simulation – flexibility assessment

- Impact of wind/PV on other power plants' operation. Simulated with Unit Commitment and Economic Dispatch (UCED)
- Iteration loops /sensitivies often needed: results sensitive to base case selection (non-wind/PV case of comparison)
- Input data: hourly wind/PV data synchronous with load (and hydro), smoothing impact and forecast accuracy



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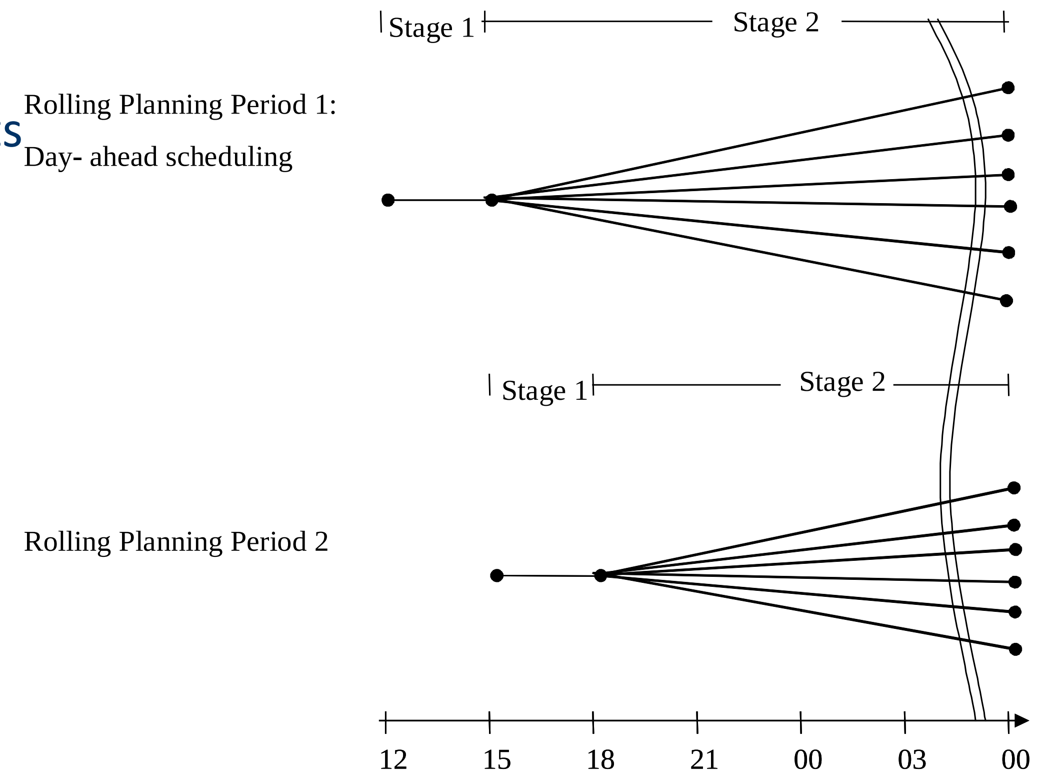
Task 25
Design and Operation of Power Systems with Large Amounts of Wind Power

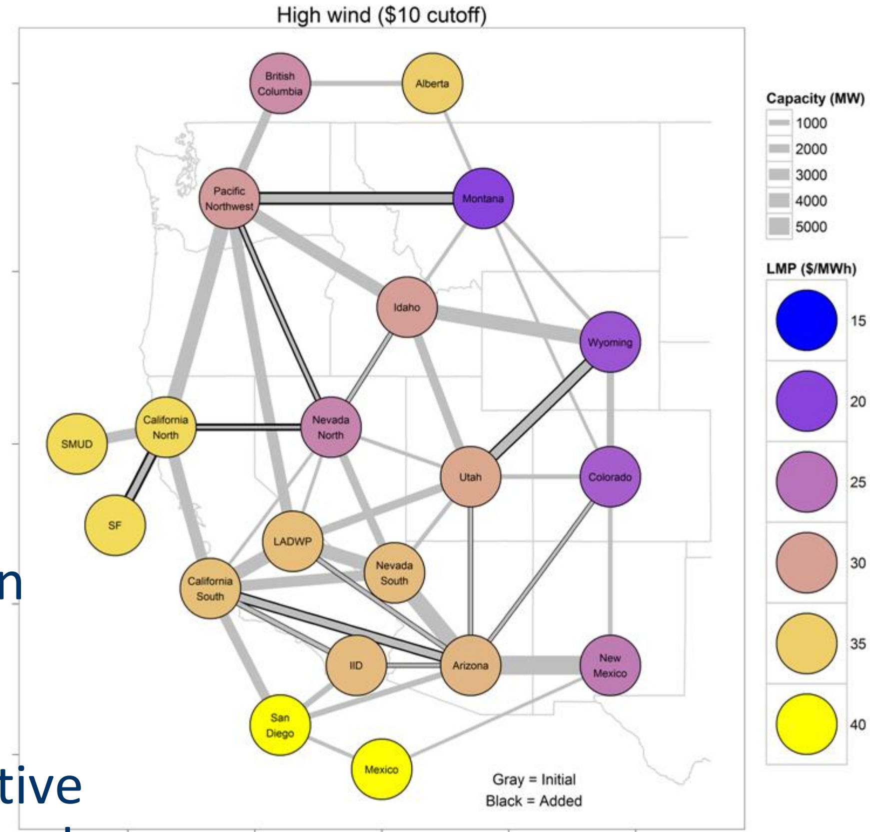
Recommendations for Unit Commitment and Economic Dispatch (UCED)

1. Impact of uncertainty on commitment decisions with possibilities to update forecasts (rolling planning)
2. Increased operating reserve targets
3. Flexibility limitations and constraints: min.generation levels, ramp rates, part load efficiency,..
4. Possible new flexibilities (power2heat, EVs, storages, demand response, dynamic line rating)



Recommendations for Unit Commitment and Economic Dispatch (UCED)

5. Possibilities and limitations of interconnections
   - model neighbouring system or mention assumption (over- or underestimating transfer possibilities)
6. Limitations from the transmission network require modeling of congestion and N-1 security
   - Net transfer capacity, or iterative methods can be used. Additional stability constraints for very high wind/PV shares.



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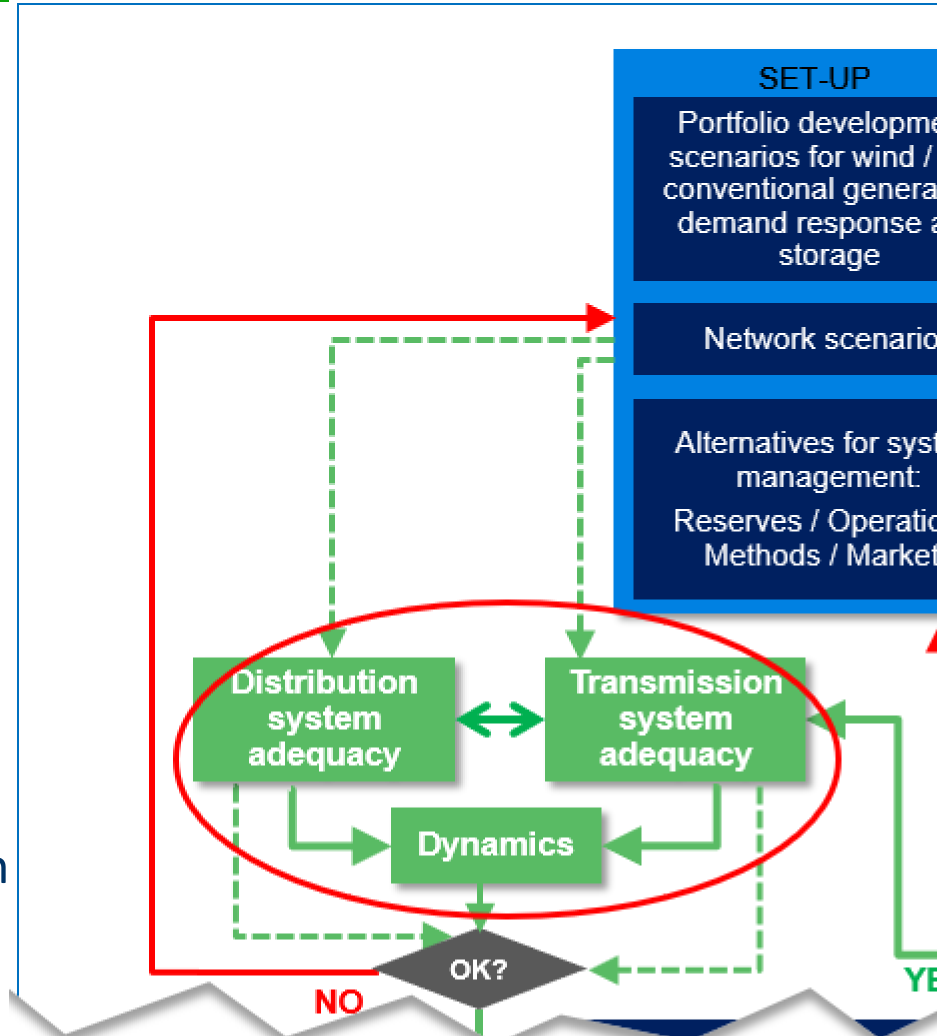
Task 25
Design and Operation of Power Systems with Large Amounts of Wind Power

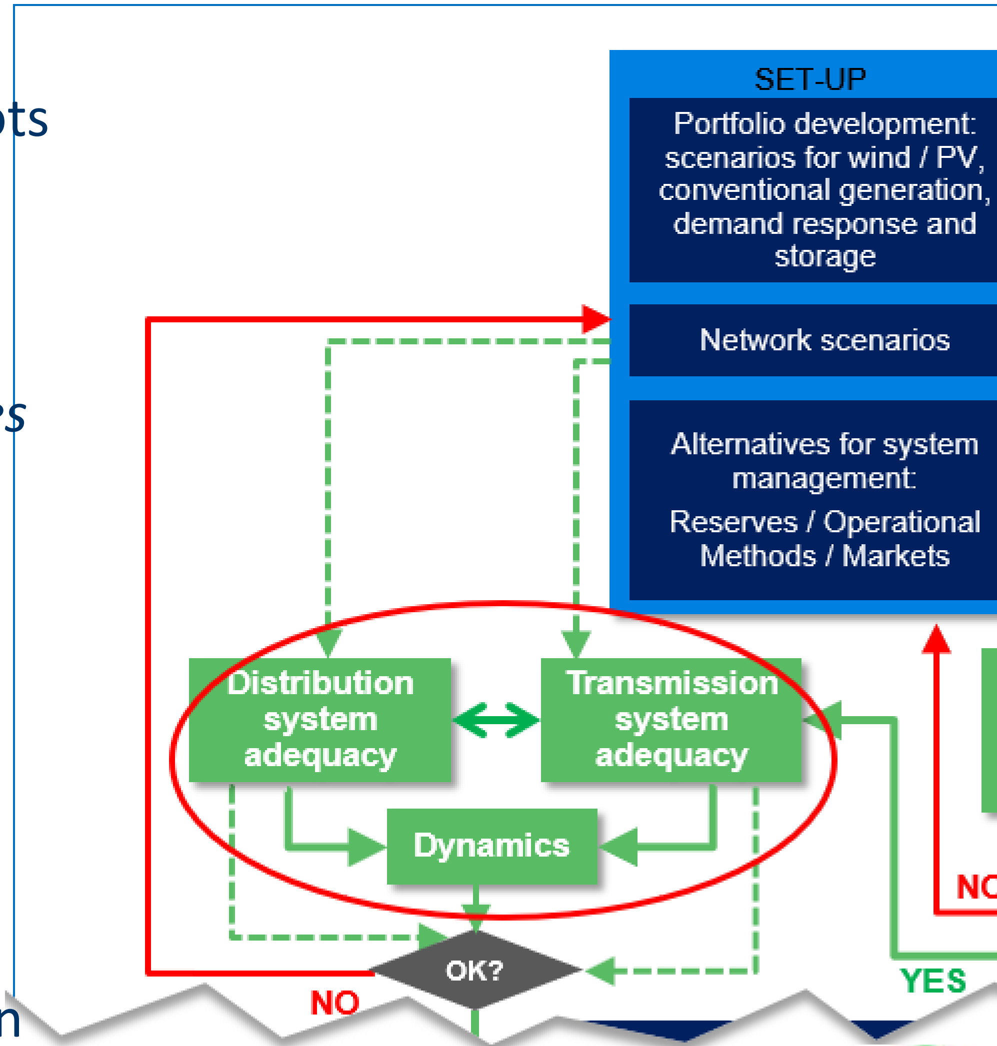
Distribution network

- *Distribution Grid Reinforcement Analysis:* grid optimization, before grid reinforcement, before grid expansion
- *Grid Losses Analysis*: a detailed study of the grid losses for a certain number of reference grids, which represent other distribution grids, combined with statistical analysis or data-driven methods is recommended
- Stronger coordination of transmission and distribution grid studies will be required with higher shares of wind/PV



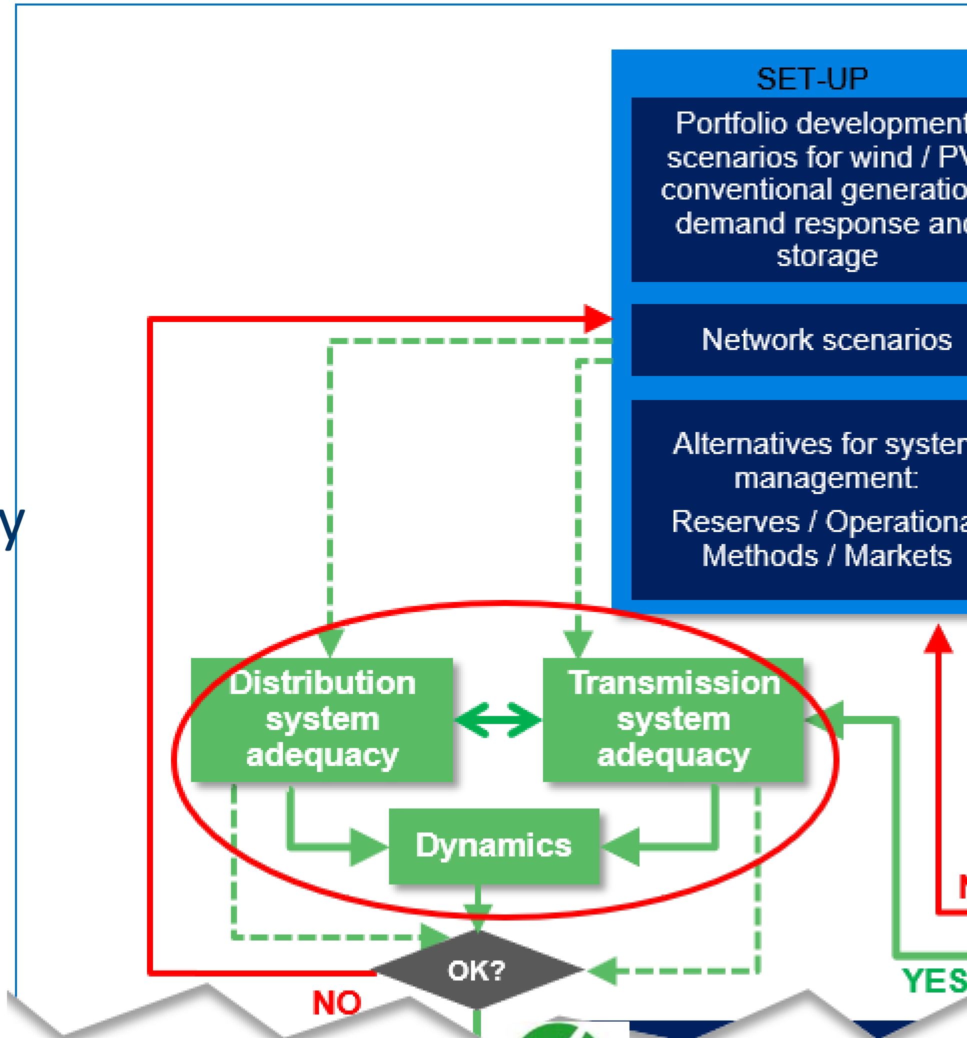
Transmission network

- *Creating a number of credible power flow cases*: more snapshots than peak and low load: critical situations regarding wind and solar power
- *Steady-state power flow analyses with N-1 security criteria:*
- Voltage profiles and network loading (congestion) assessment (probabilistic)
- Time series power flows for operation of discrete controllers and cross border flows
- Short circuit levels and protection



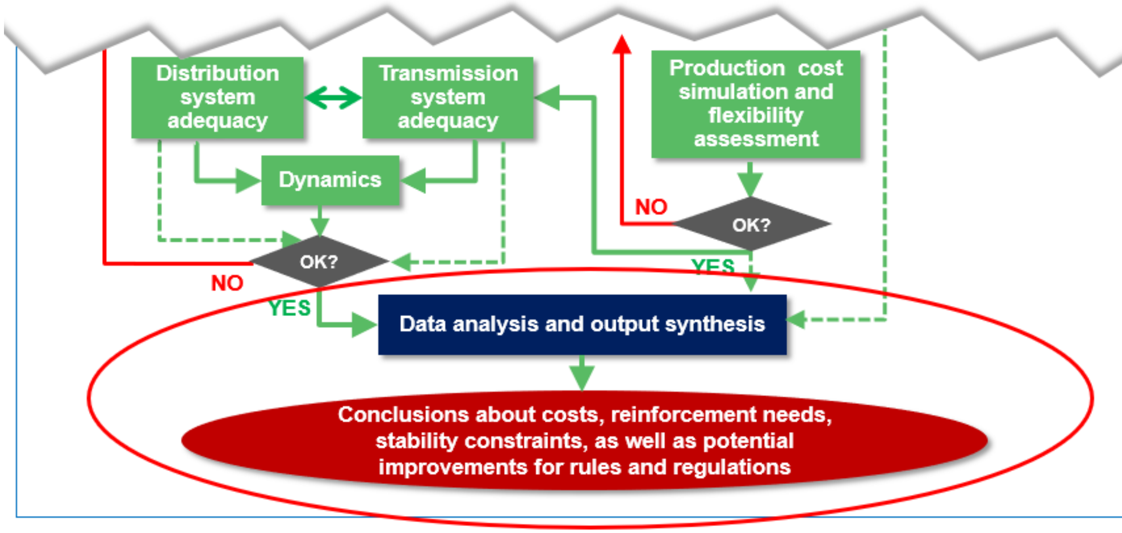
Power system dynamics

- Wind/PV models important, validation also for other generators and load needed
- Transient stability: include protection. Many mitigation options exist.
- Voltage and frequency stability at higher shares of wind/PV
- Small-signal stability, Sub-synchronous oscillations also when wind/PV displacing a lot of conventional generators, also transient events might become more severe (common-mode fault events)



Analysing and Presenting the Results

- Iterations provide significant insights
- Comparisons to base case selected may impact results. Integration cost contradictory issue – so far no accurate methods found to extract system cost for a single technology
- Present the share of wind/PV for easier comparison with other studies



Input data summary

	Capacity Value/ Power (resource) Adequacy	Unit Commitment and Economic Dispatch (UCED)	Power Flow	Dynamics
Wind/PV	Hourly generation time series for distributed wind/PV energy covering the area. Especially for wind, more than 10 years recommended	5-minute to hourly generation time series of at least 1 year for distributed wind/PV power covering the area	Wind/PV capacity at nodes, high and low generation and load snapshots, active and reactive power capabilities	Wind/PV capacity at nodes, high and low generation and load snapshots, dynamic models, operational strategies
Wind/PV Forecasts	Not needed	Forecast time series, or forecast error distribution for time frames of UCED	May be needed in future	Not needed
Load	Hourly time series coincident with wind/PV data, at least 10 years recommended	5-minute to hourly time series coincident with wind/PV, of at least 1 year	Load at nodes, snapshots relevant for wind/PV integration	Load at nodes, high and low load snapshots, dynamic capabilities
Load Forecasts	Not needed	Forecast time series, or forecast error distribution for time frames of UCED	May be needed in future	Not needed
Network	Cross border capacity, if relevant	Transmission line capacity between neighboring areas and/or circuit passive parameters	Network configuration, circuit passive and active parameters	Network configuration, circuit parameters, control structures
Other Power Plants	Rated capacities and forced outage rates	Min, max on-line capacity, start-up time/cost, ramp rates, min up/down times. efficiency curve, fuel prices	Active and reactive power capabilities, system dispatch	Dynamic models of power plants

Based on

- Recommended Practices for wind/PV integration studies, IEA WIND RP16 Ed.2

  https://community.ieawind.org/publications/rp

- IEA WIND Task 25 summary report

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

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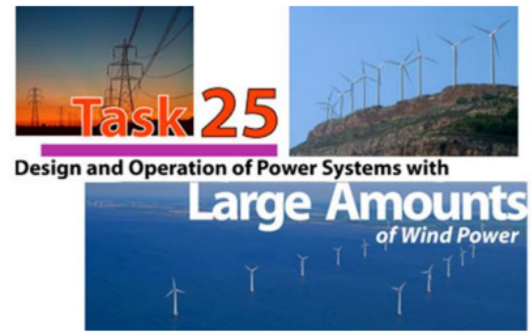
New web site:

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

EXPERT GROUP REPORT ON RECOMMENDED PRACTICES

16. WIND/PV INTEGRATION STUDIES

2nd EDITION, 2018



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Integration/system impact studies are still evolving, towards 100% renewables

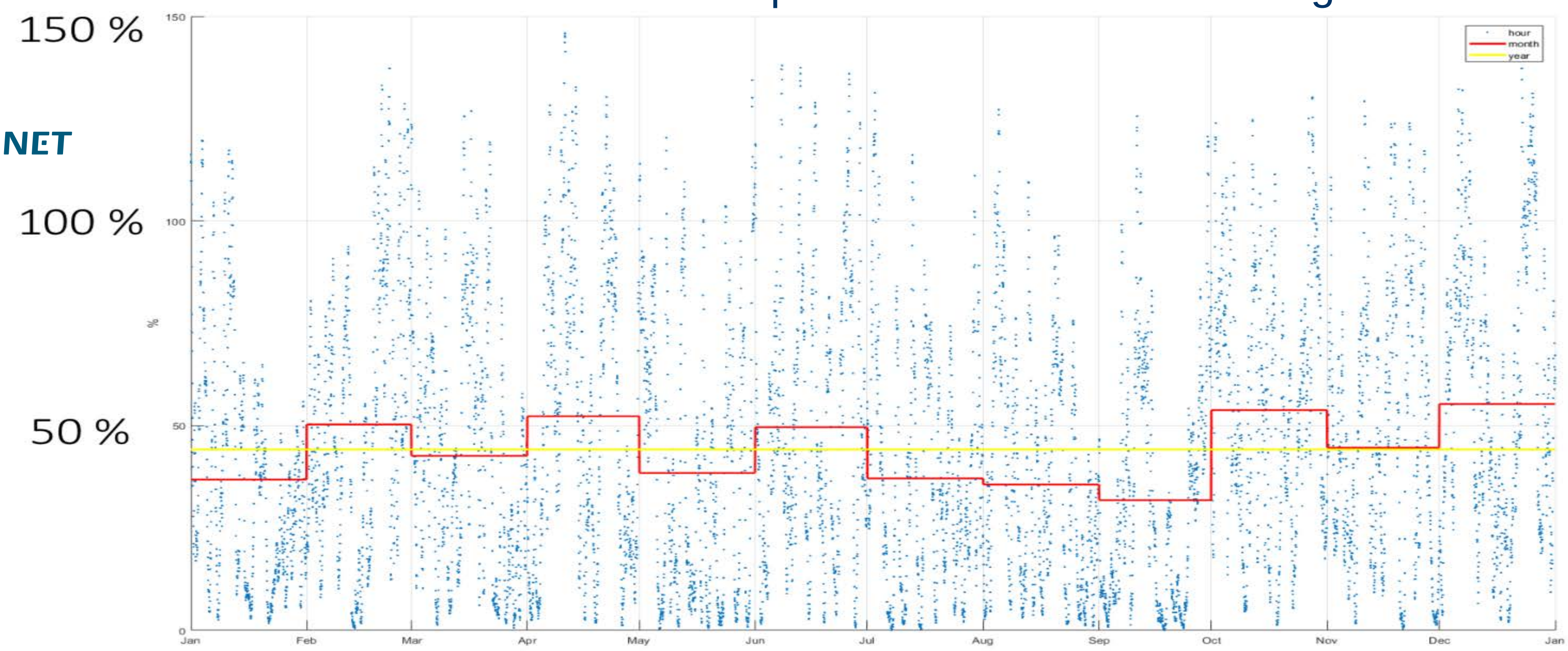
- **Metrics and tools for flexibility needs** of the power system, and ways for more flexibility
- **Simulation tools that consider uncertainty** of wind in different time scales, and combine **network constraints with UCED constraints**
- **Stability assessment with high VIBRES**
- Ways to set up simulation cases to efficiently extract impacts and system costs – **from cost of integration to cost of inflexibility**

Towards 100% RES, and VIBRES

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

Example DK 2017 43 % on average

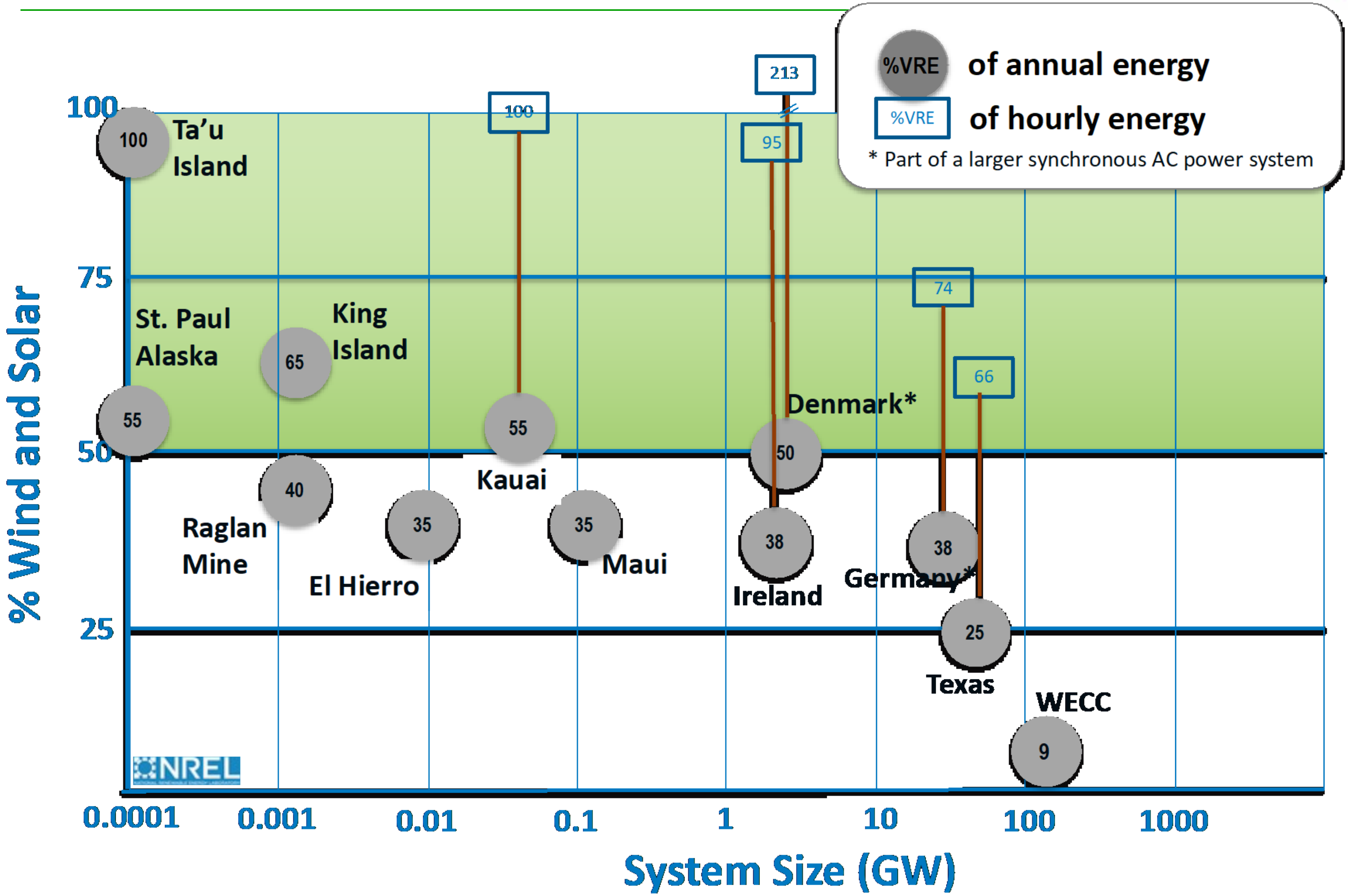
ENERGINET



Towards 100% RES, and VIBRES

1. 100% VIBRES region that is part of a larger non-100% VIBRES synchronous power system
   – challenges are about balancing, local aspects of stability and efficient sharing of electricity and reserves with neighbouring areas. Highlights importance of how the neighbouring regions are presented in studies
2. A synchronous system getting closer to 100% VIBRES for short periods of time
   – a challenge on top of these: system-wide stability issues
3. 100% yearly energy from VIBRES
   – a challenge on top of these: the adequacy issue, to meet high demand at low VIBRES contribution

Experience is growing

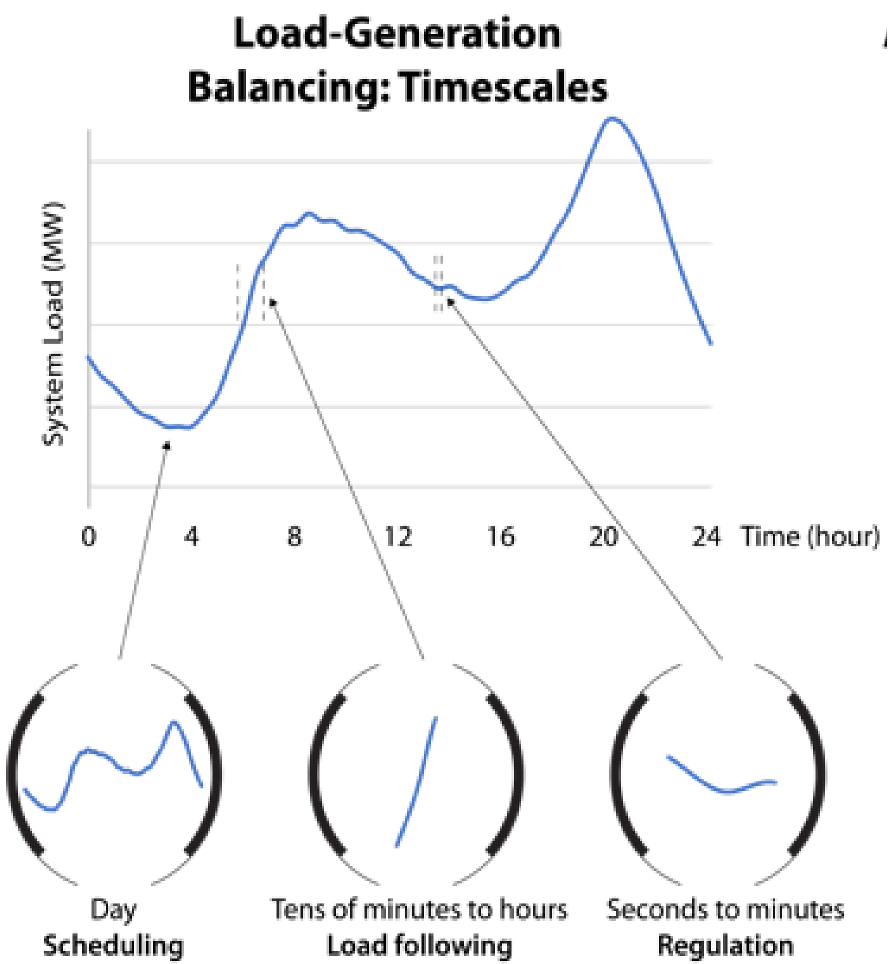


Transition to a (nearly) 100% annual VIBRES system gradually during the next decades

Planning – resource adequacy

- Resilience
  - More data to capture all weather related extreme events
  - integrated planning and operations tools and data. Greater overlap btw operational and planning time scale models
- Cost versus risk: reliability interface needs revisiting
- New metrics, not just LOLP as load not fixed
  - energy system coupling, flexible loads and storages: how to take to models to assess adequacy

Balancing - flexibility



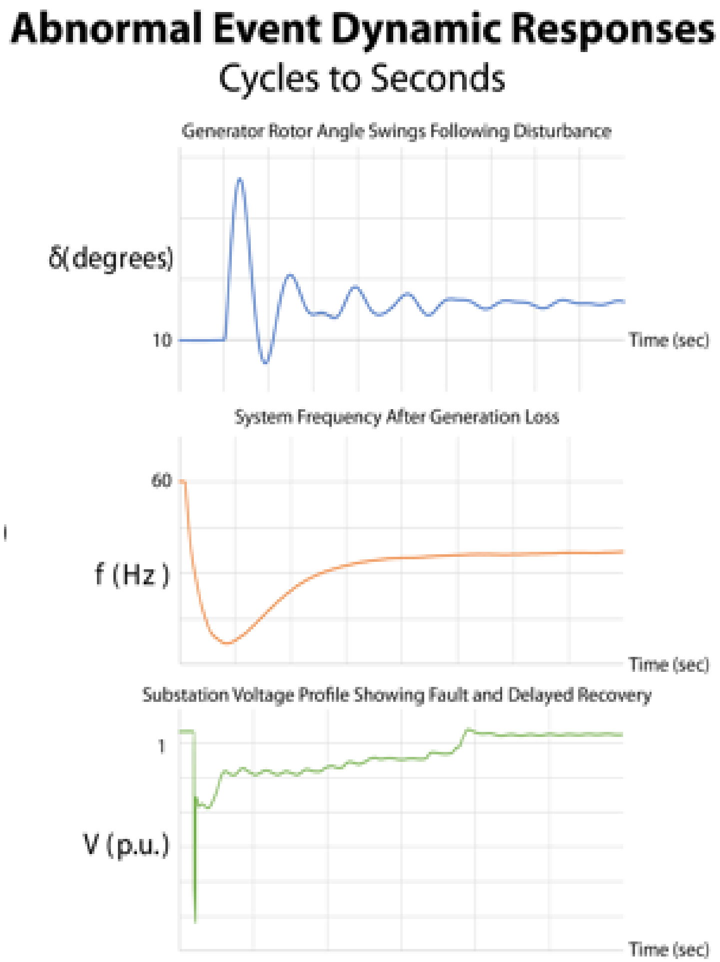
- Operational challenge: increased need for balancing in all time scales
- Also new flexibilities available, from VIBRES, from loads, from storages
- So far changes in operational practices have given more flexibility than VIBREs have increased

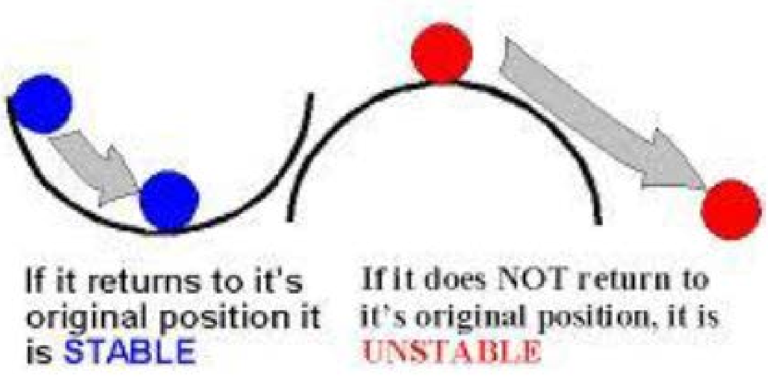
100% renewables studies so far look at days/hours time scale balancing

Stability challenges

In addition to energy produced, some power plants need to produce 'glue' to keep the power system resilient to disturbances – keeping it stable

- small signal stability
- frequency stability (inertia/fast responses)
- voltage stability





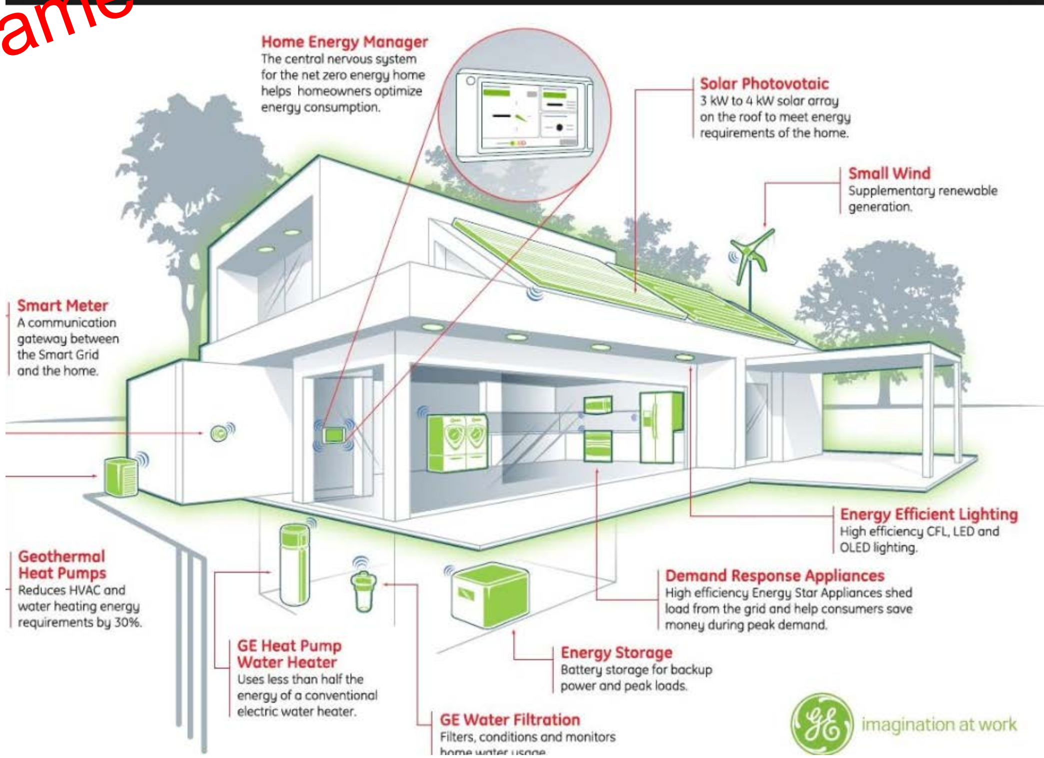
Opportunities: development happening at the same time

- Load transition:
  - changing the fixed load paradigm
- Smart grids, digitalization:
  - prosumers; DSO role
- Inverter controls:
  - rapid responses
  - synchronous machine characteristics but they don’t swing against each other (more stable)
  - grid forming inverters

The traditional load becomes active

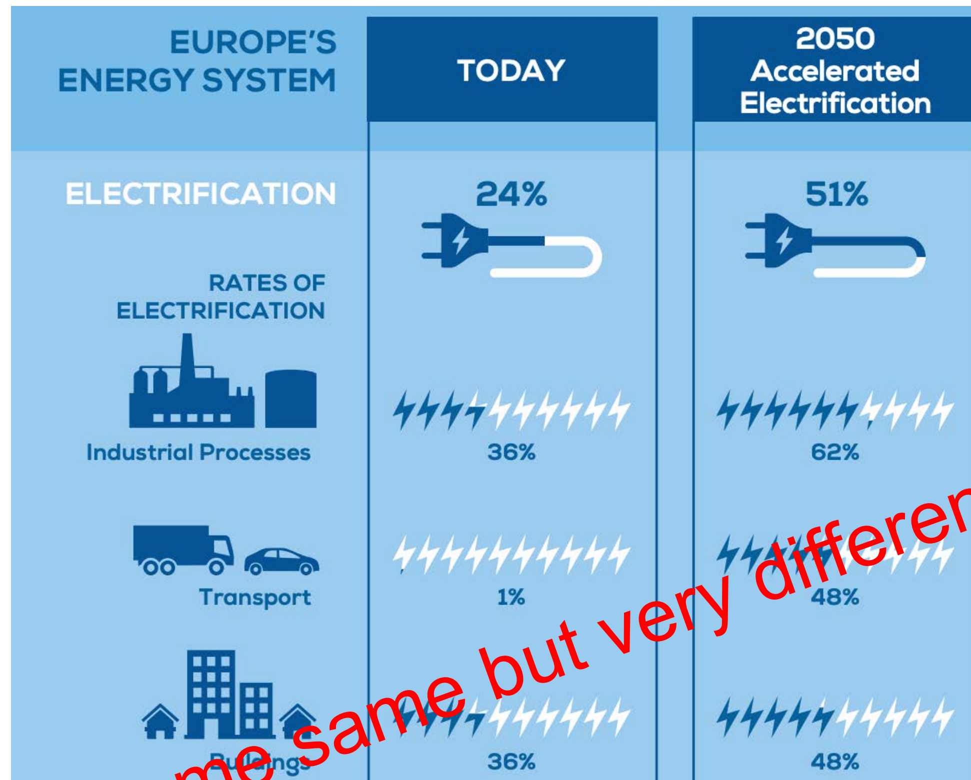
- Aggregators: offering same comfort/service and aggregating flexibility
- Prosumers: optimise use of (solar) generation. HEMS, BEMS, energy communities, local markets

same same but different



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



not same but very different

Wind EUROPE

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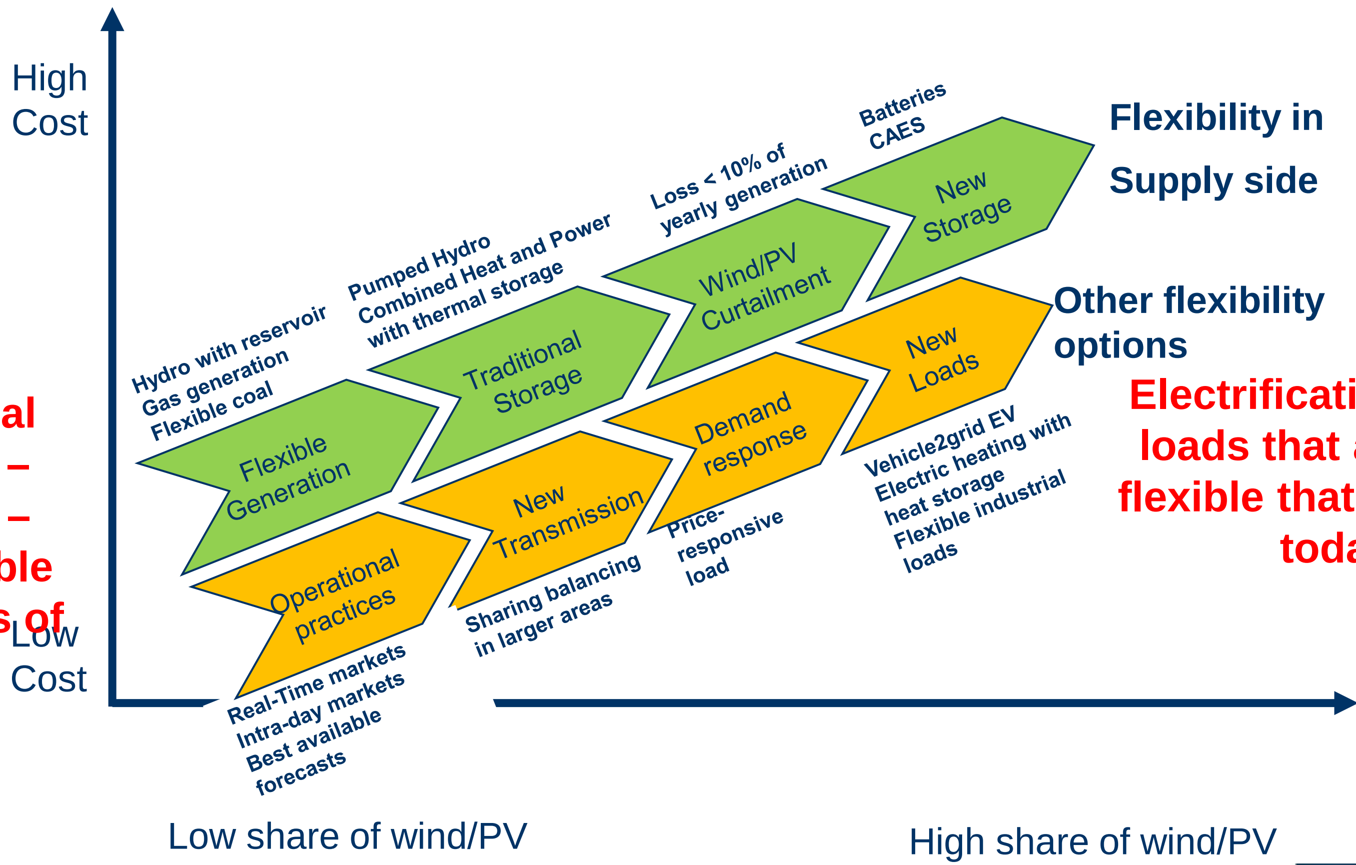
Balancing challenge: Using more of the flexibility solutions we know



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

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

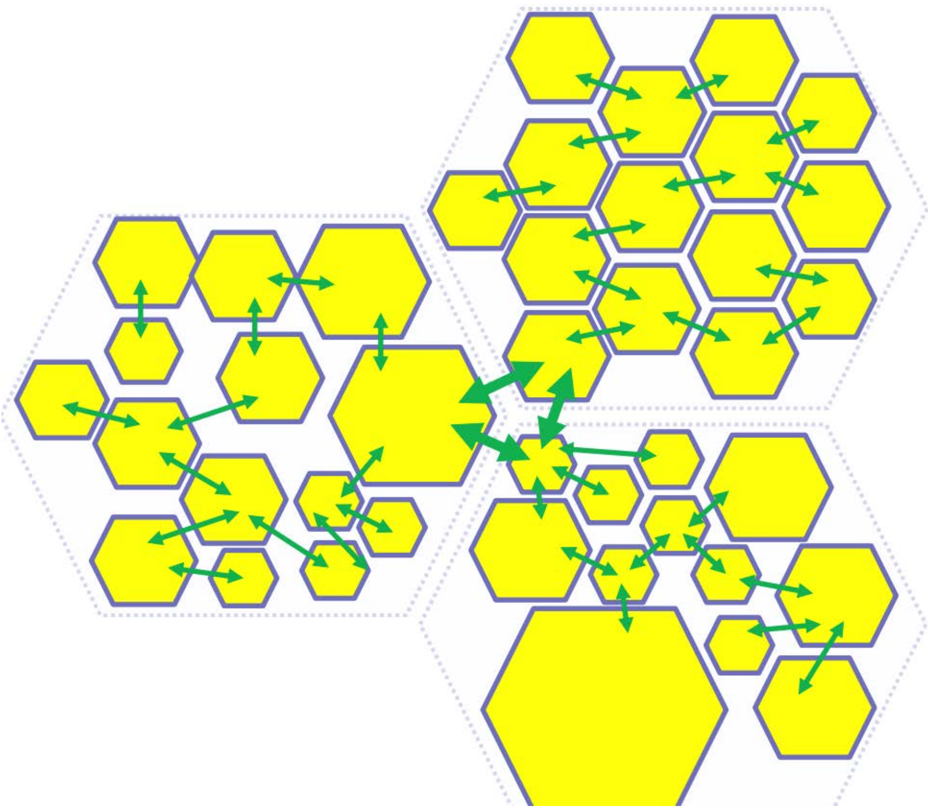
VIBREs – and loads and electrical storage can provide the system support services provided by generators today

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?

Using the local flexibility to system benefits

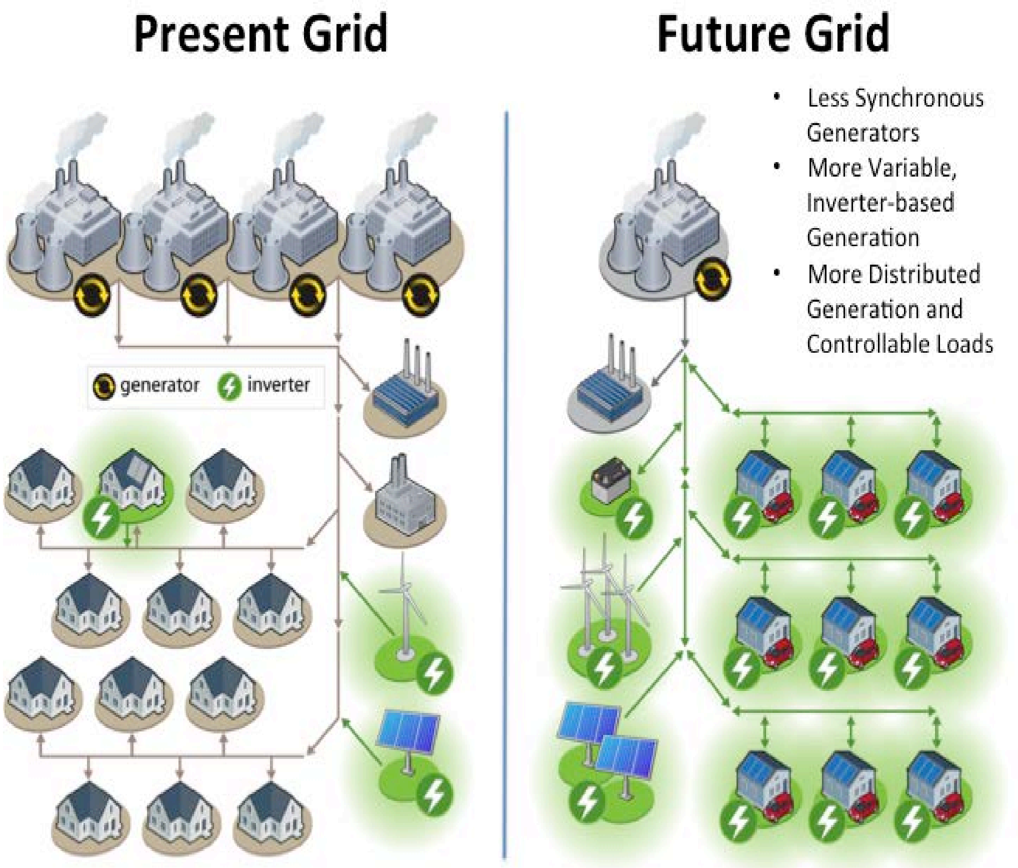
- Market based DSO/TSO collaboration through local flexibility markets
- Flexibility value as price signals to DER
- Vision: web of cells, with local smartness, utilising large system benefits when no grid bottlenecks



EERA
European Energy Research Alliance
Smart Grids Joint Programme

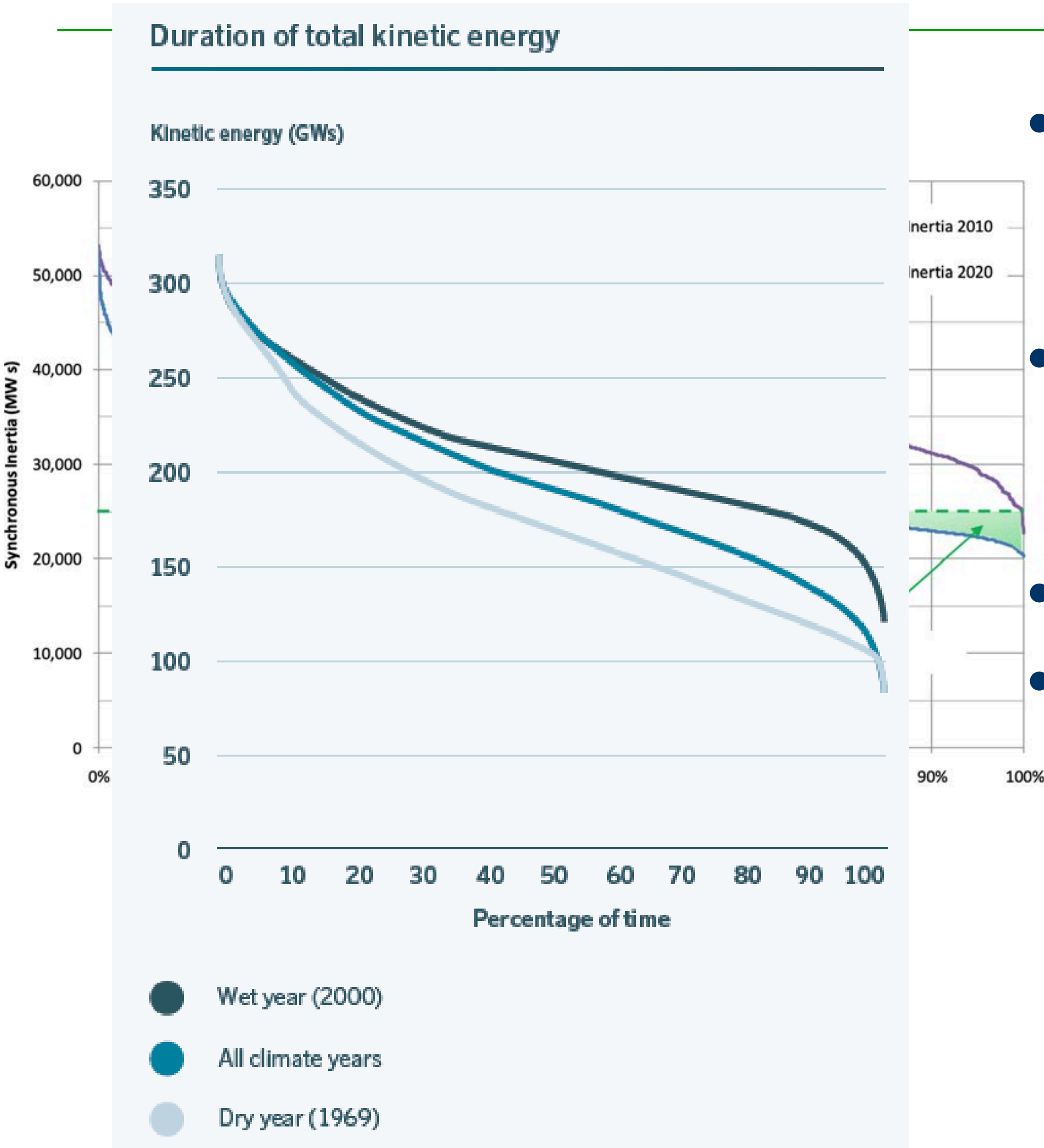
Task 25
Design and Operation of Power Systems with Large Amounts of Wind Power

Stability challenges



- Maintaining constant steady-state voltages and frequency
- Inertia—maintaining grid stability through physical response
- Short-circuit analysis and protection coordination
- Black start: Restoring power after outages

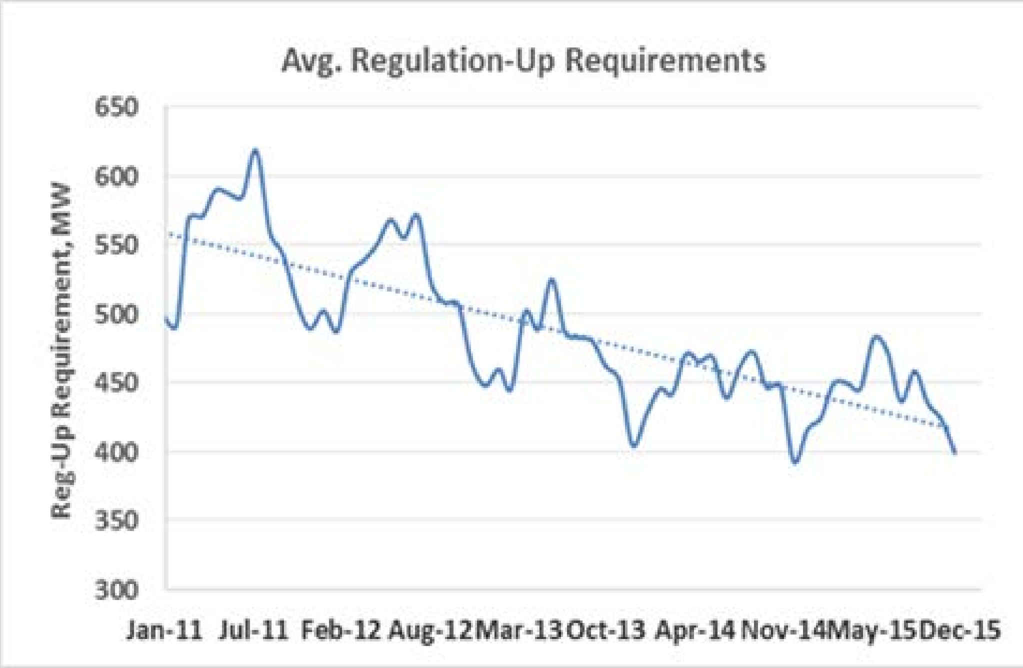
Frequency stability, inertia



- Inertia—maintaining grid stability through physical response
- Ireland: aiming for 40% share in 2020 – study 2010
- Nordic study for 2025
- Real-time (day-ahead) estimators for inertia in use in Ireland, GB, Nordic and Texas power systems

Faster response is more valuable

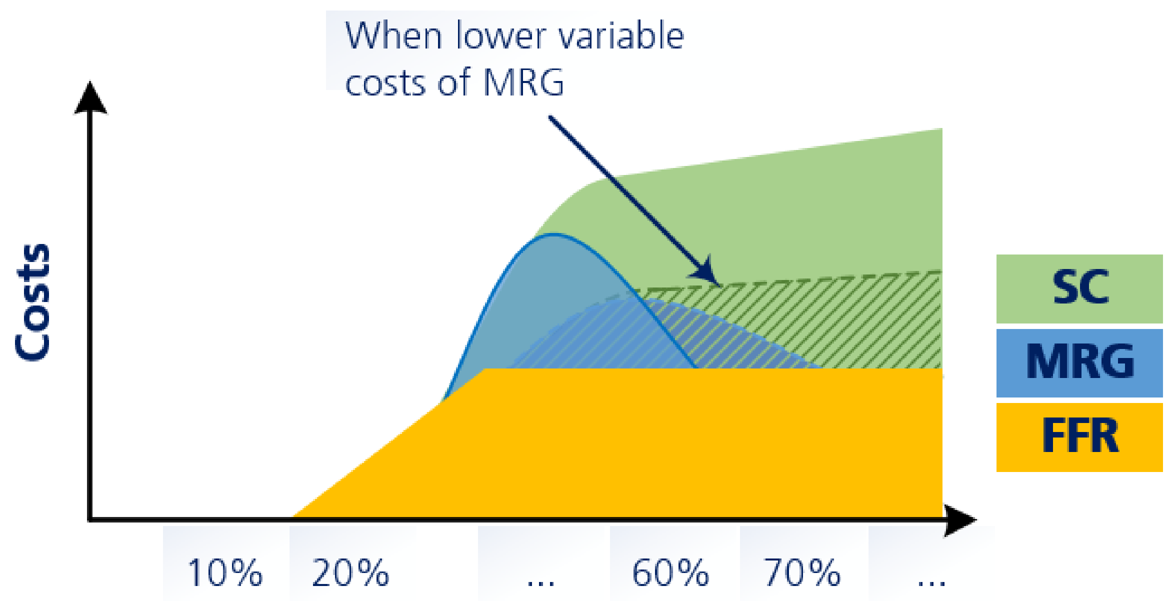
- ERCOT, Texas: FFR (0.5s) High wind, low load: 1,400 MW of FFR provides same response (and reliability impact) as 3,300 MW of PFR
- Hydro Quebec event 28 Dec, 2015, frequency nadir of 59.08 Hz, wind power plants response contributed to the recovery of the system frequency



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

Supporting frequency stability

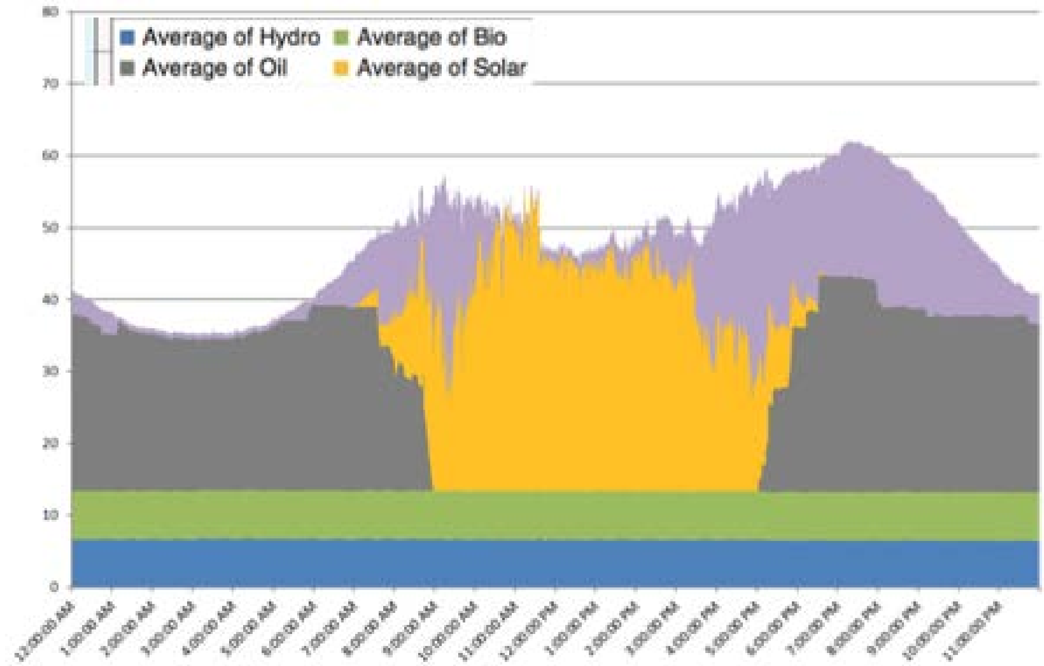
- Maintain inertia by keeping synchronous machines running (MRG) or other sources of synchronous inertia (SC, synchronous condensers)
- Speed up frequency response Faster primary frequency response (on synchronous machines), Fast frequency response (FFR)



Source: EdF (Primes et al 2019)

Small island power system: Kauai in Hawaii

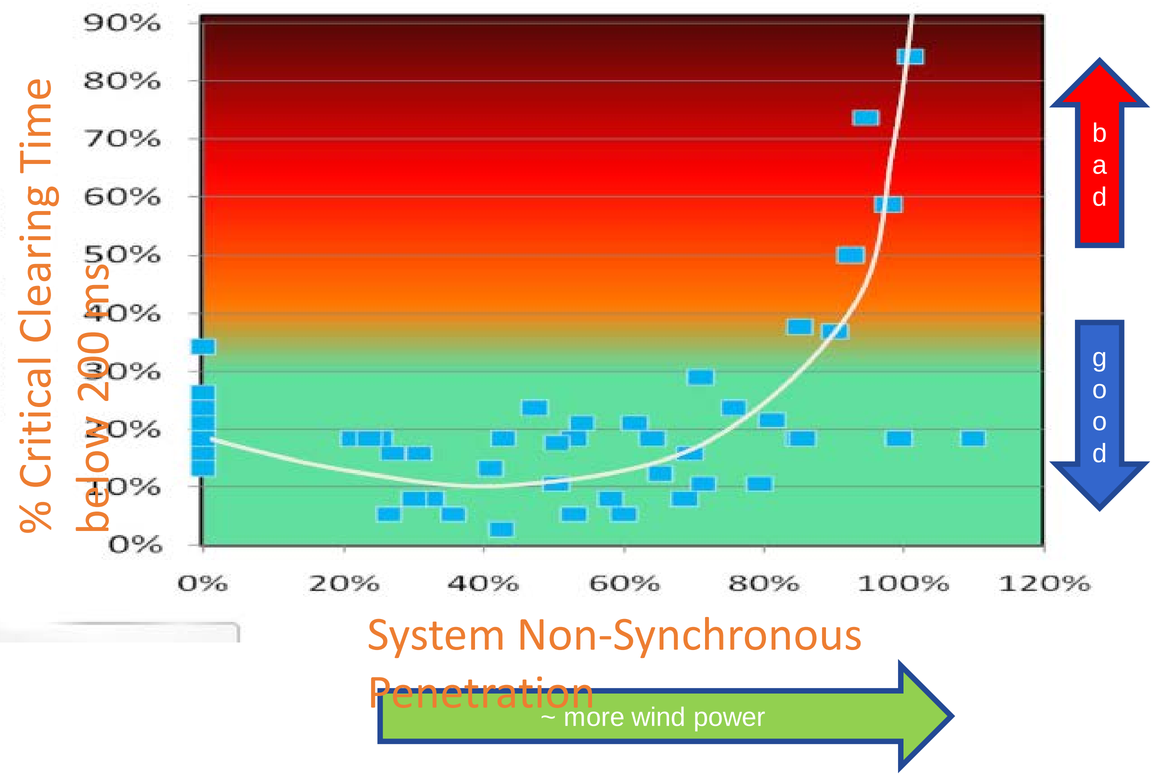
- quick-start diesel reciprocating engines
  - fast reserves (start up in minutes); one engine operating in synchronous condenser mode: inertia and system strength
- PV/battery hybrids for fast response
  - (cloud events on the order of seconds) hold 50% of the real-time output as spinning contingency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

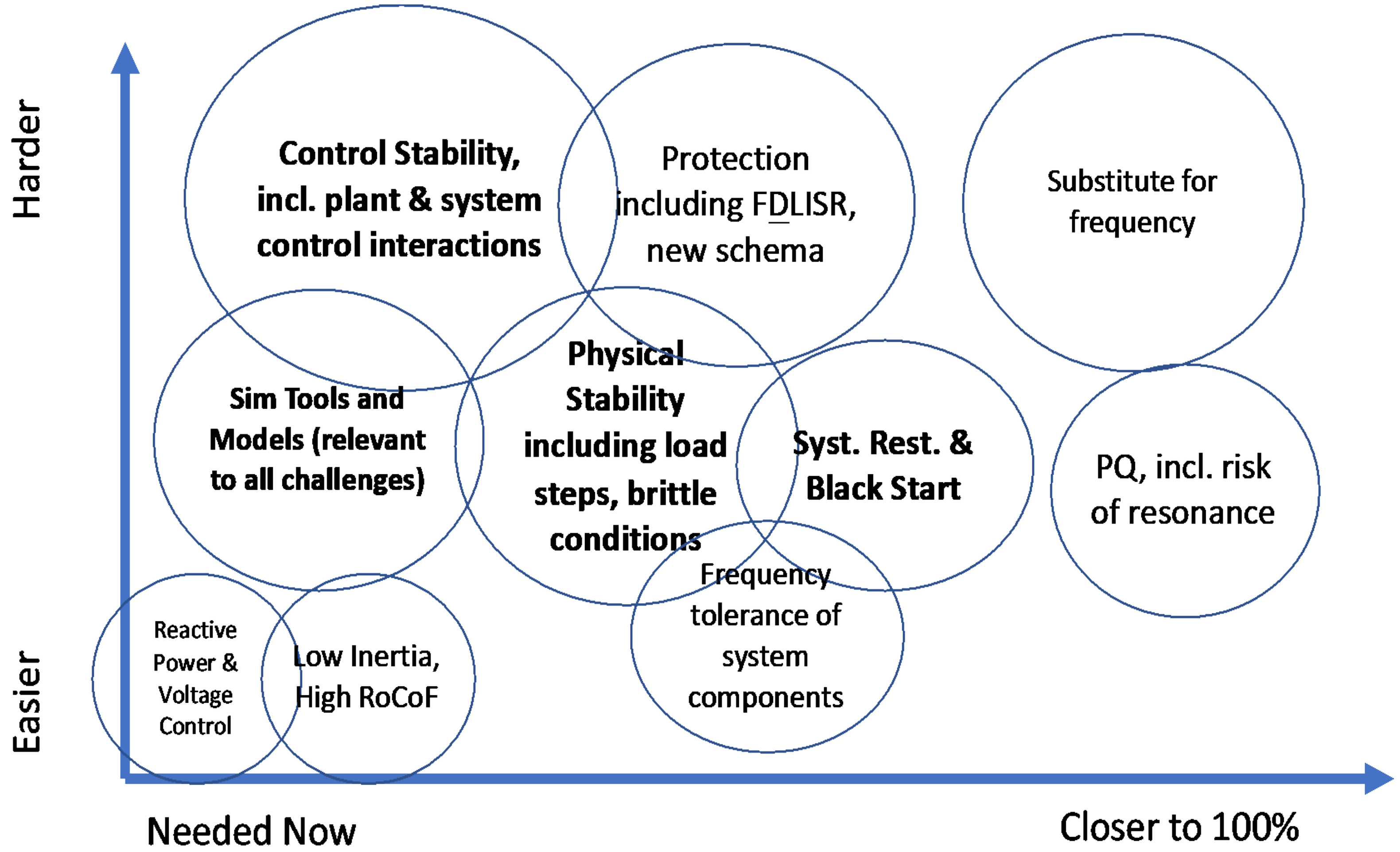
Ireland study: ok for 80-90%

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



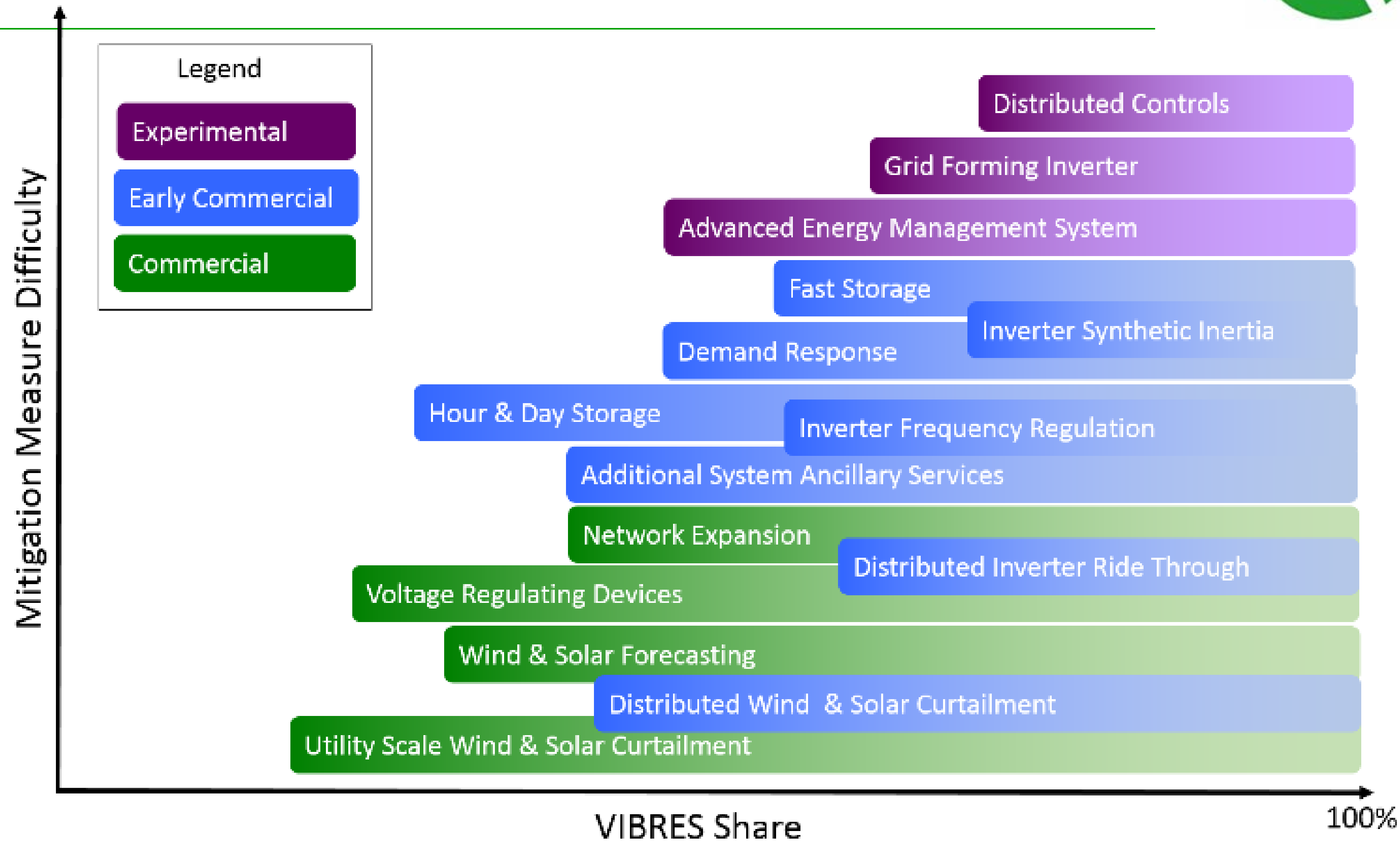
Ireland testing 75% SNSP since April 2021 and targeting 90% SNSP

Challenges map



FDLISR fault detection, location, isolation and recover;
RoCoF Rate of Change of Frequency
PQ Power Quality

Mitigation options



Tools are impacted by fundamental changes to maintaining frequency and voltages

- Paradigm change for greater detail and higher resolutions with new stability analysis tools development
- Control stability, inertialess power systems and grid-forming inverters are still evolving
- Existing protection systems require modification for large VIBRES shares with different fault characteristics
- Technical disparities between inverter technologies and synchronous generators requires the development of novel control schemes for interoperability, new approaches for black-start capability, and distributed control approaches for the larger volume of generating assets

Recommendations for Stability

- Ensure models are adapted to characteristics of inverted-based generators and loads. Complex, non-linear approaches for various load categories are increasingly required.
- Update existing positive-sequence fundamental frequency planning models for more advanced functionality (FFR, FCN). Identify limiting conditions to predict control stability and fast interactions, when EMT-based models are necessary. Represent PLL control structures accurately.
- Manufacturer-specific EMT models preferred, verified generic EMT models a necessary future development.
- Consider variety of control options available, with inverters potentially incorporating multiple operating modes.
- Study potential of advanced non-linear control approaches, such as virtual oscillator controls.

Gaps in planning and operational models

- Insufficient consideration of 3 sub-problems of reliability, flexibility and stability
  - New constraints in existing models or the ability to link models with more detailed analytical tools
  - No need to be complex, but must address costs and constraints that impact dispatch (or investment) decisions. Setting up approximations with offline studies
- Increasing need to consider energy sector coupling
  - requires that not only the 'production' side of a generator modeled, but also the fuel storage and consumption side, as the fuel might be delivered by, or have alternative uses in, a different sector
- Analysing energy adequacy
  - previously of interest to hydro dominated systems, but for near 100% renewable energy systems this will become more important
  - Scheduling models need to run for decades to capture this

Recommendations: UCED

Grid and stability constraints

- capturing bottlenecks and curtailments for locations
- Stability constraints: inertia by system non-synchronous share or rotational stored energy (MWs) limits; frequency control by sufficient frequency reserves, and voltage stability by sufficient equipment in relevant locations

Probabilistic models

- deterministic and probabilistic assessment approaches for risk-based operation, using new optimization methods and advances in computation

Wind and solar resource

- Temporal and spatial detail, long dataset
- forecast uncertainty integrating weather-dependent parts of the system in multiple decision cycles

Loads and storage

- Represent other relevant energy sectors
- Represent energy storage and price-responsive loads within system service. Potentially complex constraints relating to service availability, requiring more detailed models of distribution systems or aggregation of distributed resources for bulk systems

Markets

- Expand market options/products for flexibility trading

Recommendations: capacity expansion

Demand and storage

- Improve representation of demand flexibility, energy storage and sector coupling to obtain better future price predictions for systems with high VIBRES

Short-term balancing

- Include short-term balancing in order to see the impact of VIBRES forecast uncertainty on the optimal capacity mix

Grid

- Improve representation of grid limitations
- Include expansion costs
- for optimal VIBRES capacity in different areas

Markets

- Improve models to account for different market aspects, such as price signals for end-users, revenue sufficiency, TSO-DSO interaction and local markets.

Recommendations: adequacy

New adequacy metrics

- Reliability target - which critical loads must be served
- Use LOLH (Loss-of-load Hours) and LOLE (Expectation), and as a first proxy to price responsive demand how much EUE acceptable

Chronological models

- to ensure flexibility
- to include load and storage flexibility
- Flexibility metrics

Inter-annual resource variability

- Energy reliabilty
- Improve data, and sensitivity to capture extreme events.

Neighboring areas

- Recent model developments using Monte Carlo

Summary of recommendations

Larger areas

- the entire synchronous system for stability
- sharing of resources for balancing and adequacy purposes

Complexity

- increasing computational burden capturing VIBRES detail
- higher resolution for larger areas, with extended time series for weather dependent events

Demand and storage

- new types of (flexible) demand and storage,
- further links through energy system coupling

Model integration

- integrated planning and operations methodologies, tools and data. Greater overlap btw operational and planning time scale models
- Flexibility needs and plant capabilities within adequacy methods, and stability concerns for network expansion planning and operating

Cost vs. risk

- reliability interface needs revisiting
- evolution of flexibility and price responsive loads

Need for research

Use recommended practices check-list for benchmarking your study!

- **Stability**: better understanding, which requires improved simulation tools and generator models and better predictive tools and metrics. Future grids: DC transmission, grid forming converters.
- **System operation: agile market rules** to make revenue from solutions that are optimal for the system – also taking benefits from local trade. **energy system coupling, new demands**
- **Adequacy**: new methods to optimise the varying generation and flexible loads (from LOLP metrics)
- **New ways of modelling loads for all of these!**

Based on 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 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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IEA Wind Task 25

- Design and operation of energy systems with large amounts of variable generation
- Started in 2006, now 17 countries + WindEurope participate, international forum for exchange of knowledge

Country	Institution
Canada	NRCan (Thomas Levy); Hydro Quebec (Alain Forcione)
China	SGERI (Wang Yaohua, Liu Jun)
Denmark	DTU (Nicolaos Cutululis); Energinet.dk (Antje Orths)
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)
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 (Simon Watson)
Norway	NTNU (Magnus Korpås); SINTEF (John Olav Tande, Til Kristian Vrana)
Portugal	LNEG (Ana Estanquiero); INESC-TEC (Bernando Silva)
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 (B-M. Hodge, M. O'Malley); ESIG (J.C. Smith); DoE (J. Fu)
WindEurope	European Wind Energy Association (Daniel Fraile)

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