Recommended Practices for wind/solar integration studies

IEA Wind TCP Task 25: Design and Operation of Energy Systems with Large amounts of Variable generation in collaboration with IEA PVPS TCP Task 14

Review webinar 3rd July, 2024

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Nicolaos Cutululis, DTU, Denmark
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Contents / Agenda

IEA Wind TCP

16:00 Introduction. Input data, Scenario build up. Hannele Holttinen, OA Task 25

16:20 Recommendations for studying operational impacts. Damian Flynn, UCD (Task 25 WP Balancing lead)

16:40 Recommendations for assessing Adequacy impacts. Hannele Holttinen, OA Task 25

- Adequacy of Transmission network. Damian Flynn, UCD
- Adequacy of Distribution network. Denis Mende, Fraunhofer IEE

17:00 Recommendations for studying impacts on power system stability. Nicolaos Cutululis, DTU (Task 25 WP Stability lead)

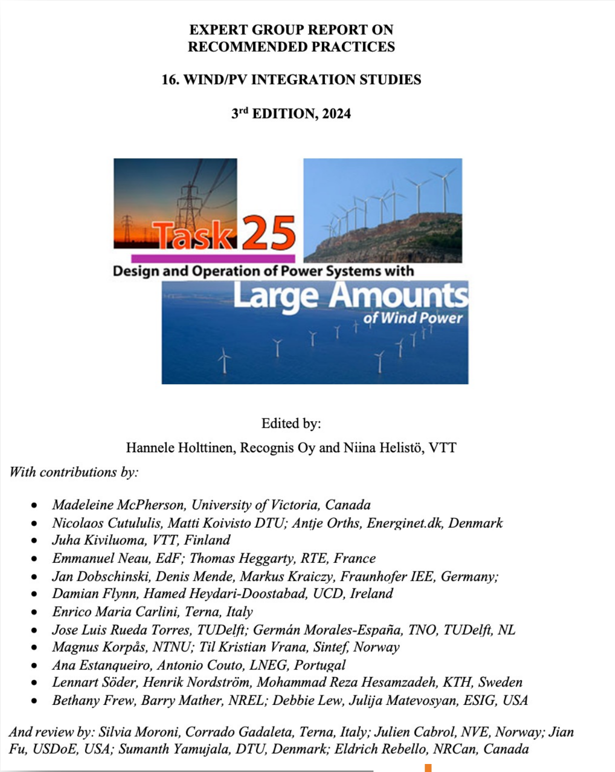
17:10 Recommendations for analysing and presenting results. Summary. Hannele Holttinen, OA Task 25

17:20 Q&A and discussion. 17:30 end of webinar

Recommended Practices – what, why and for whom

IEA Wind TCP

- 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 existing grid integration study - what is taken into account and what is not
- Recommendations on how to perform studies: methodologies, assumptions, and inputs needed for system impact studies
  - No results (refer to our summary report for results)



EXPERT GROUP REPORT ON
RECOMMENDED PRACTICES

16. WIND/PV INTEGRATION STUDIES

3rd EDITION, 2024

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

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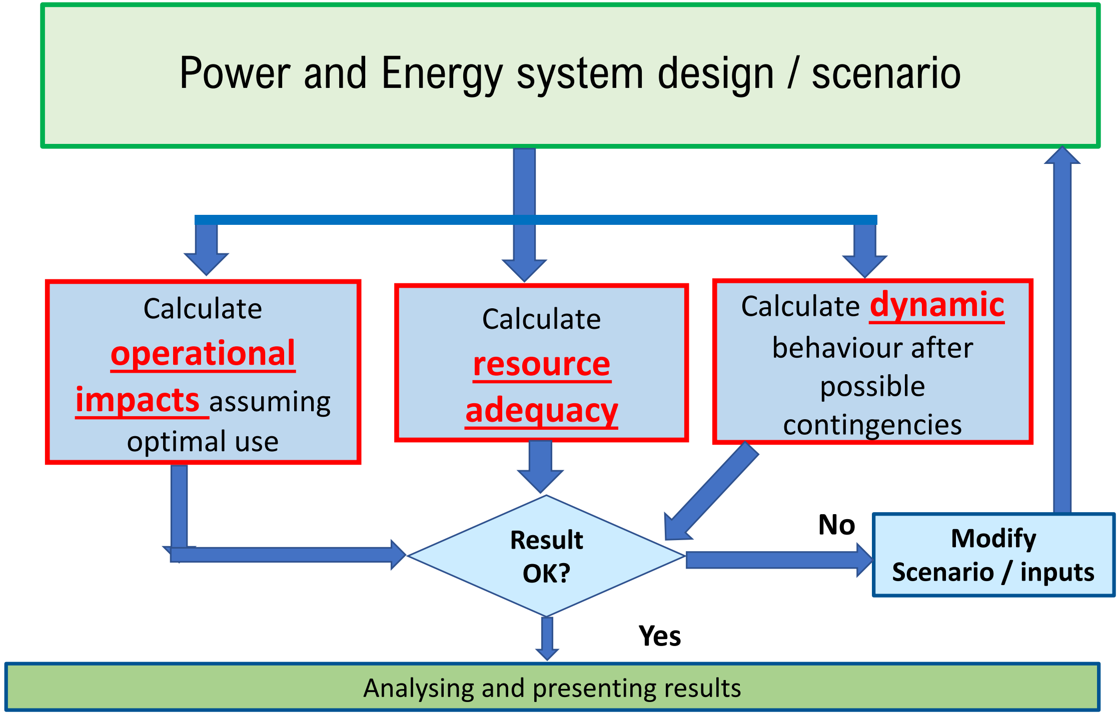
Edition 3 of RP16

IEA Wind TCP

Builds on Edition 2 from year 2018 that added solar, and distributed grid (PVPS TCP)

→ a new flow chart and a lot of revisions in the text

Review process ongoing, comments welcomed

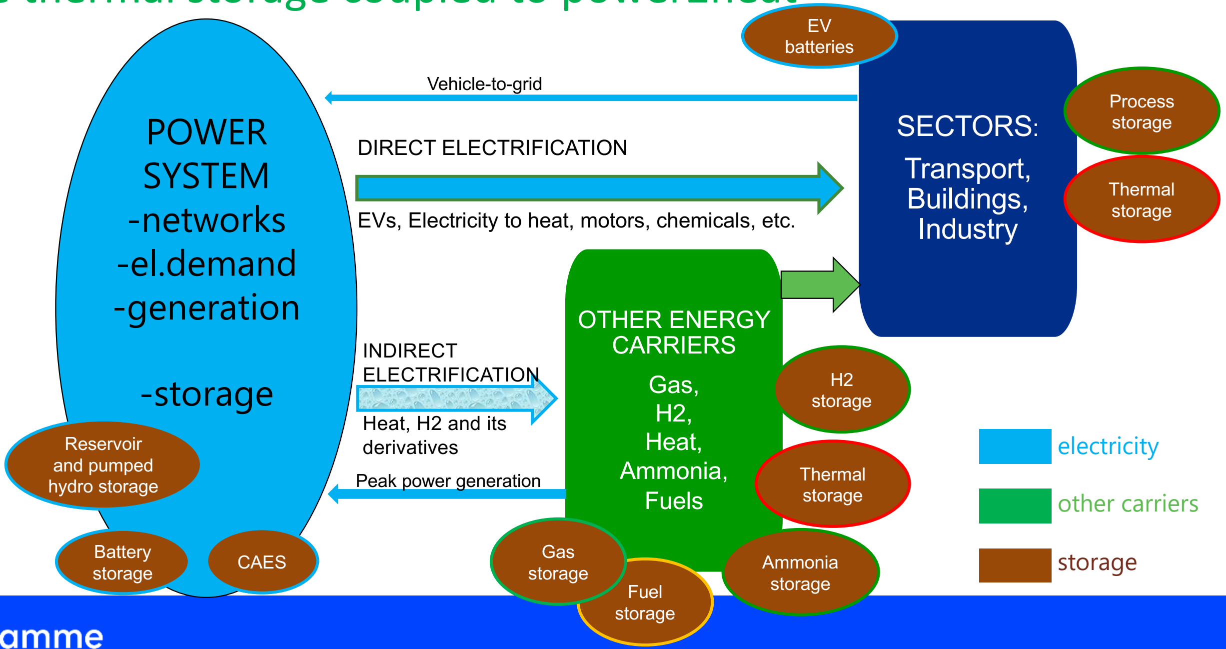


Edition 3 of RP16

IEA Wind TCP

Energy system coupling becoming more important for future power systems

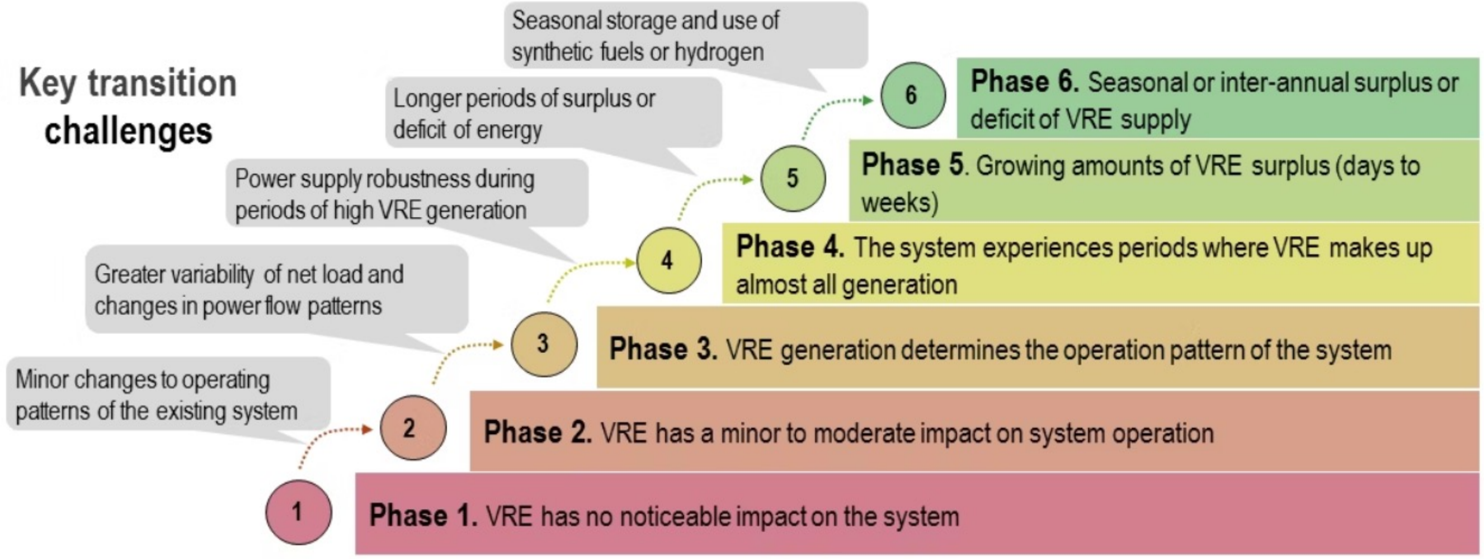
→ Future load scenarios, demand response from new types of loads from power2X, storage components like thermal storage coupled to power2heat



Edition 3 of RP16

IEA Wind TCP

Previous edition had most recommendations for small, and medium shares of wind/solar → Added a third layer, for wind/solar dominated systems



Source: https://www.iea.org/reports/status-of-power-system-transformation-2019

Model tools to assess future energy systems

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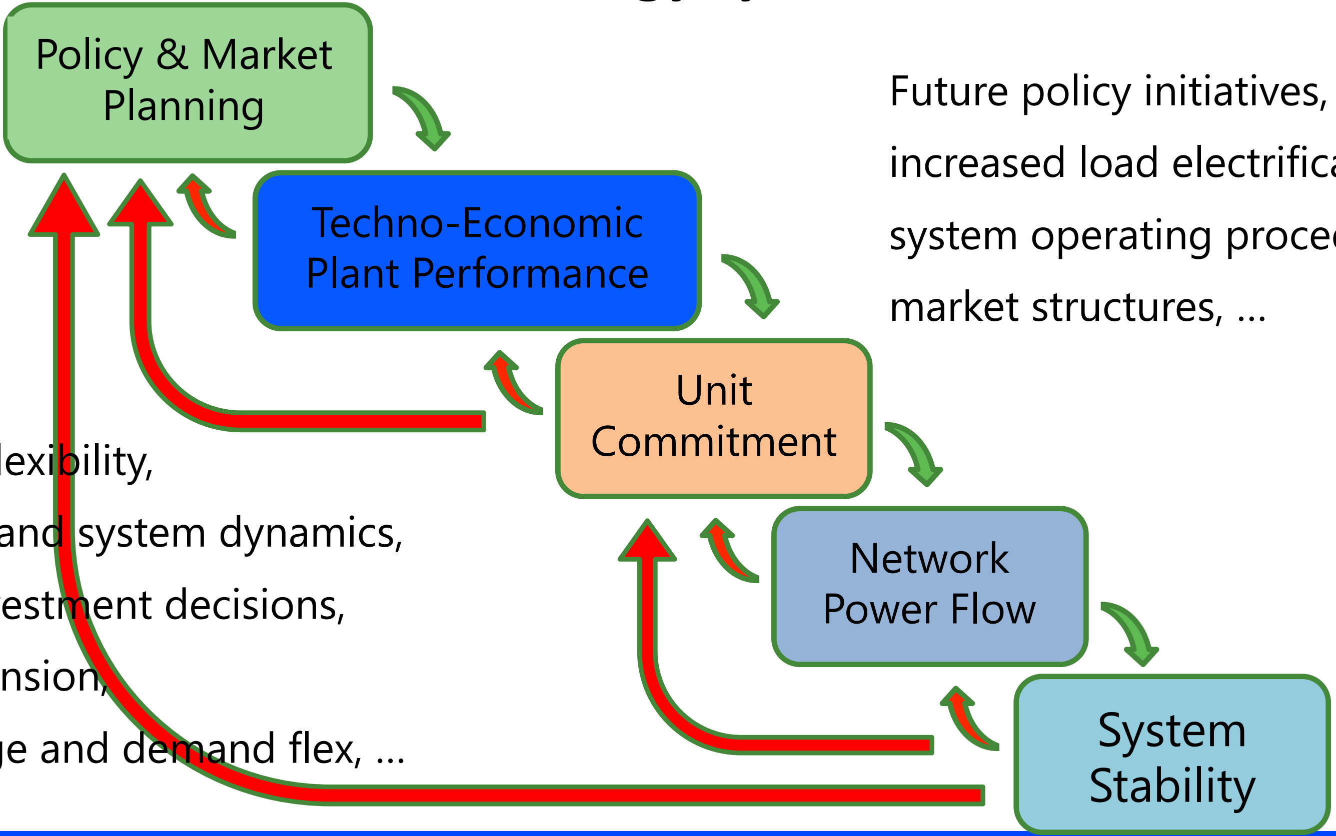
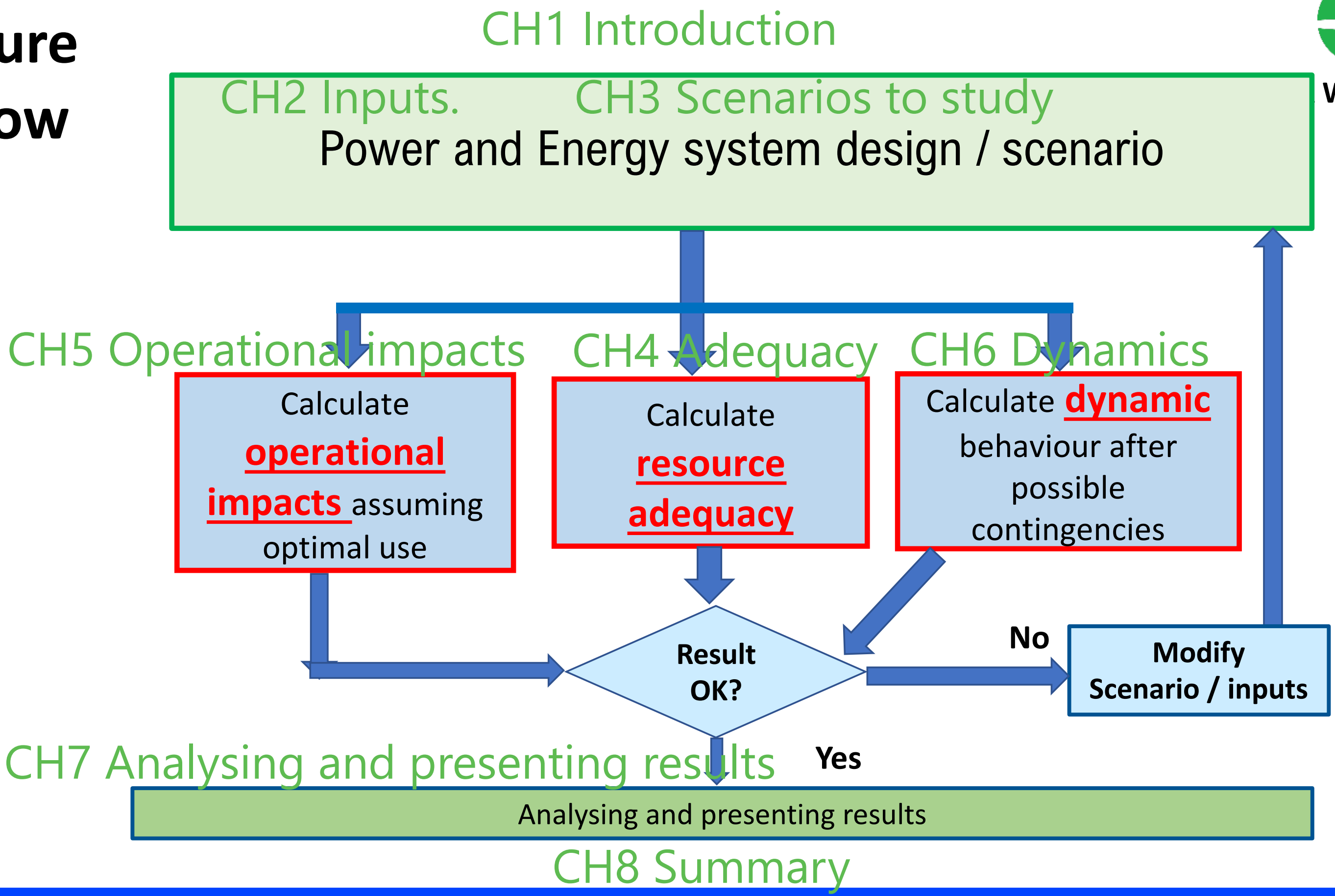


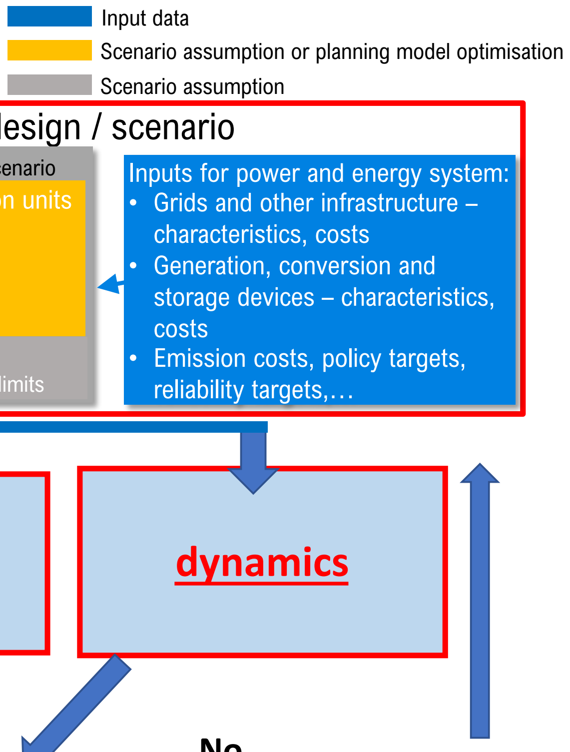
Future policy initiatives,
increased load electrification,
system operating procedures,
market structures, …

Operational flexibility,
plant cycling and system dynamics,
impact on investment decisions,
network expansion,
energy storage and demand flex, …

Report structure follows the flow chart



Input data (Chapter 2)



IEA Wind TCP

Input data: wind/solar generation time series

- System wide area
- Long data set for resource adequacy
- Minute/hourly with correct smoothing impact for variability for UCED
- Sync with other weather dependent time series
- Climate change impact

	Resource Adequacy and Capacity Value	Unit Commitment and Economic Dispatch (UCED) Including Reserve Requirements	Capacity Expansion Models CEM (for determining the basic generation and storage mix)
Temporal resolution	Typically, hourly data is enough	Dependent on the resolution of the dispatch, typically 5 minutes to 1 hour	Hourly. Preferably full-year but representative days may be applied for large systems and studies with multiple energy carriers
Spatial resolution	System-wide time series. It is more important to catch the levels of wind/PV output during peak load situations than to incorporate spatial smoothing effect of short term variability.	System-wide time series, incorporating spatial smoothing effects. If a load flow calculation is required, wind and PV time series aggregated on transformer station level are needed.	System-wide time series, incorporating spatial smoothing effects.
Length of investigation period	Long time series especially for wind power, more than 30 years improves the assessment catching extreme low winds during peak loads. For longer term studies incorporate climate change impacts to resource.	UCED: One year of data is usually enough, but more years are better, especially include high-wind year to capture possible variability. Reserve requirements: longer time series including extreme events improve the assessment.	Snap-shot years for optimization of capacity expansion - most consistent use of CEM spans over several decades
Time synchronization	Coincident wind, PV and load time series, and if applicable, also of other weather-dependent generation (data based on time-synchronised wind, solar irradiation, temperature and rain)	Coincident wind, PV and load time series, and if applicable, also of other weather-dependent generation (data based on time-synchronised wind, solar irradiation, temperature and rain)	As for Resource Adequacy. DLR models should also rely on the same weather data as used for generation and load
Technology characteristics	Offshore and land-based wind; low wind technology; solar tracking technology and different orientation; wind and solar PV mix, to capture the generation characteristics especially when scarcity of resource	Offshore and land-based wind; low wind technology; solar tracking technology and different orientation; wind and solar PV mix, to capture the generation characteristics	Offshore and land-based wind; low wind technology; solar tracking technology and different orientation; wind and solar PV mix, to capture the generation characteristics

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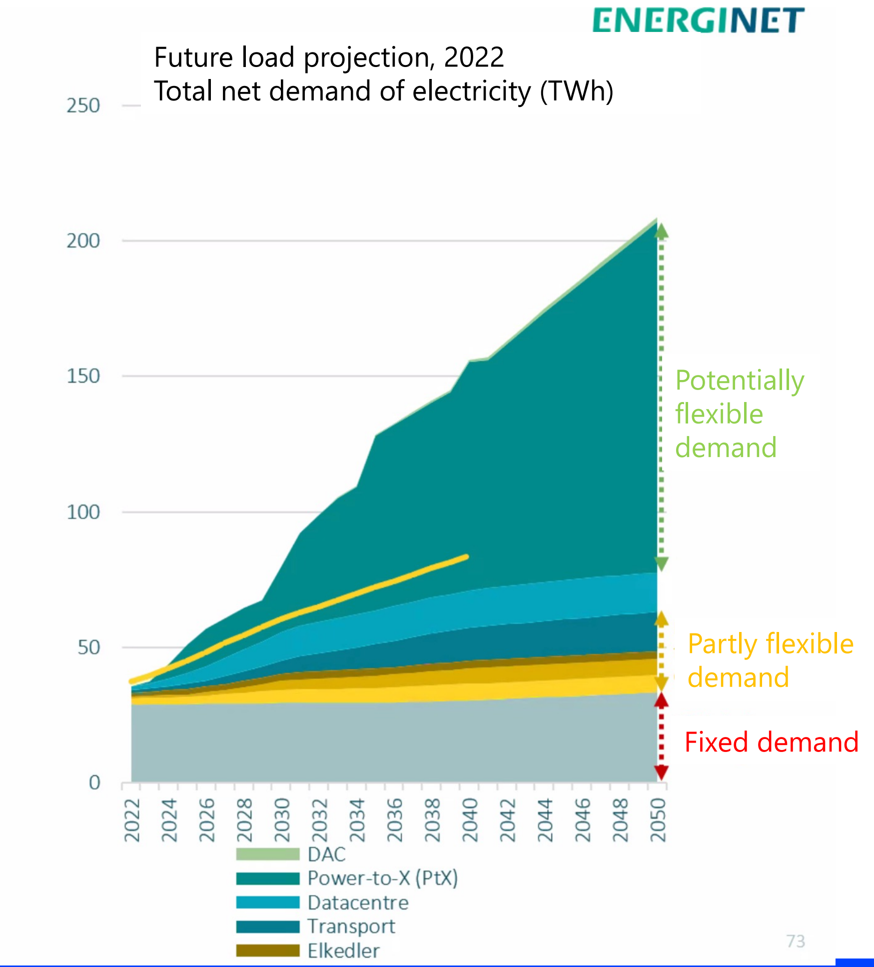
Input data - load

- Load growth projections to future years, due to electrification – can be double the current electricity demand
- Load flexibility important to capture



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Input data - recommendations

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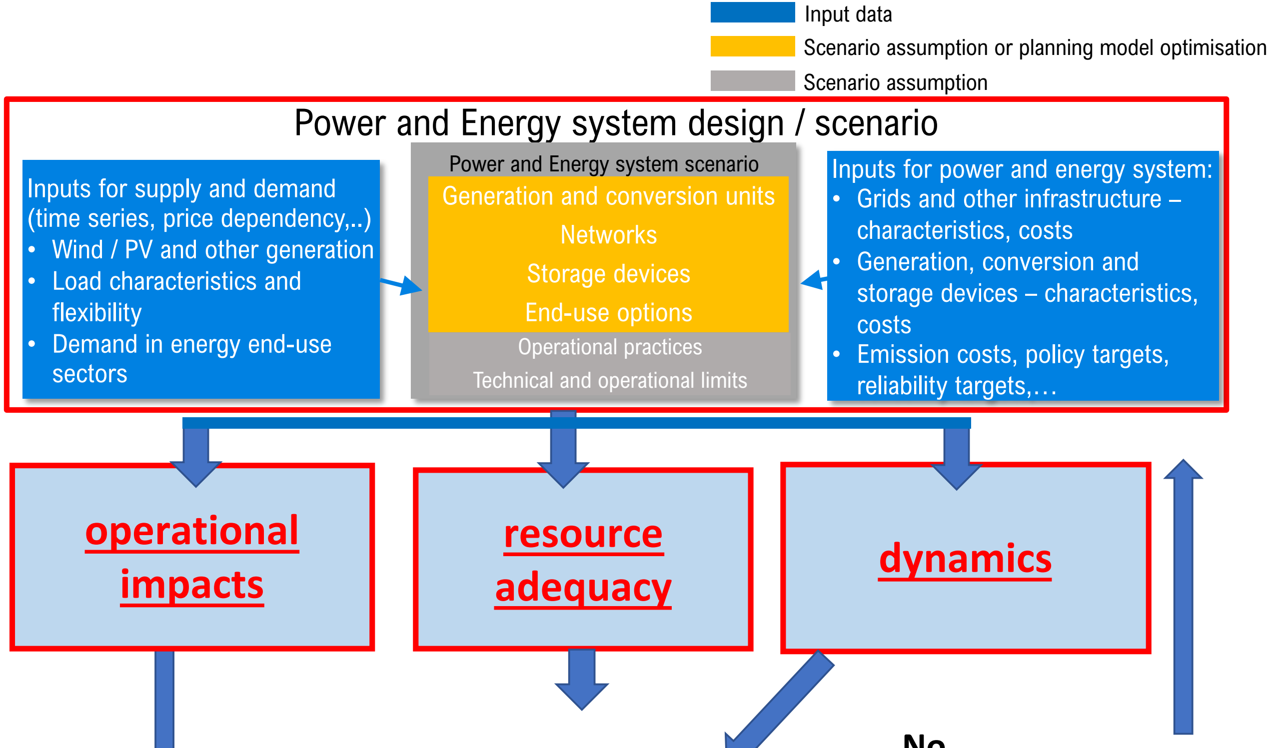
	Resource Adequacy/ Capacity Value	Capacity Expansion Model	Unit Commitment and Economic Dispatch (UCED) including Reserve requirements	Power Flow	Dynamics
Wind/PV	At least hourly generation time series for distributed wind/PV energy covering the area, time-synchronised with load data, preferably with climate change impacts. For wind, more than 10 years of data.	Hourly generation time series for distributed wind/PV energy covering the area, time-synchronised with load data, preferably with climate change impacts.	5-minute to hourly generation time series of at least 1 year for distributed wind/PV power covering the area, for relevant mix of technologies and time-synchronised with load data, preferably with climate change impacts.	Wind/PV capacity at nodes, generation and load snapshots relevant for wind/PV integration, active and reactive power capabilities.	Wind/PV capacity at nodes, high and low generation and load snapshots, dynamic models, operational strategies.
Wind/PV Short-term Forecasts	Not needed for traditional resource adequacy tools.	No, but measure of uncertainty from short-term forecasts (reserve requirements)	Forecast time series, or forecast error distribution for time frames of UCED, and reserve requirements	May be needed in future	Not needed
Load	Hourly time series coincident with wind/PV data, at least 10 years of data, preferably with climate change impacts.	Hourly time series based on historic data and predictions, for the full analysis period, preferably with climate change impacts.	5-minute to hourly time series coincident with wind/PV, for at least 1 year. Load flexibility incorporated (flexible loads separately). Include climate change impacts for 2050 and beyond.	Load at nodes, snapshots relevant for wind/PV integration	Load at nodes, high and low load snapshots. Dynamic models with capabilities and characteristics.
Load Forecasts	Not needed for traditional resource adequacy tools.	Not needed	Forecast time series, or forecast error distribution for time frames of UCED and reserve requirements	May be needed in future	Not needed
Network	Cross border capacity, if relevant. Forced outage rates and mean time to repair, for main transmission corridors affecting resource adequacy.	Transmission line capacity between neighbouring areas	Transmission line capacity between neighbouring areas and/or circuit passive parameters	Network configuration, circuit passive and active parameters	Network configuration, circuit parameters, control structures
Other Power Plants	Rated capacities, forced outage rates (ideally as a time series), mean time to repair. Hydro power resource limitations (dry/wet/normal year), preferably with climate change impacts.	Investment cost, efficiency, fuel costs, emission factors. Ideally also operational characteristics from UCED.	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

Scenarios (Chapter 3)



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Scenarios to study – main decisions to make

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- The current system (with slight foreseeable changes) or a future power system?
  - Higher shares of wind/PV power will be relevant for a future system, 2030–2050 timeframe. Adding wind/PV will replace conventional generation capacity changing remaining system.
- Area studied: one balancing area or the whole synchronous power system? How to take into account the neighbouring areas in the study?
- Future generation portfolio: assumptions of emission policy to reach targets, (relative) prices for different fuels used in the generation mix
- Future demand: traditionally simple growth rate for known demand profile. For future systems electrification with different demand profiles and flexibilities important.
- Degree of coupling of energy sectors: relevance (and costs) of new energy vectors, e.g. (green) hydrogen, or (green) hydrogen-based fuels.

Future scenarios should be optimised

Scenarios by assumptions -->

- Generation mix and fuel prices
- Load projection
- Transmission expansion and reinforcements
- Flexibility assumptions – generation, load, storage

Scenarios by capacity expansion tool

- Optimised, based on technology costs and assumptions on life-time of assets
- Emission targets can be included
- Also transmission lines btw areas can be optimised
- Energy system coupling taken into account
- Flexibility inputs important – including operational practices

Recommendations for Power and energy system scenarios

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Small amounts of wind/PV, short term

- Add wind/PV to an existing or foreseen system, with existing operational practices

Larger shares of wind/PV, longer term

- changes in the assumed remaining system become increasingly necessary and beneficial
- Capacity expansion tools recommended

Wind/PV dominated systems in future

- Changes will be so important that the system to study becomes completely different: new electrification loads, integration of IBR, reduction of synchronous machines, interaction with other energy sectors/carriers
- Capacity expansion models should be used, and all the feasibility checks for Operational impacts, Adequacy and Dynamics become more crucial to perform

Recommendations for Capacity Expansion Tools

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Demand and storage

- Improve representation of demand flexibility, energy storage and sector coupling including access to other than electrical storage

Short-term balancing

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

Grid

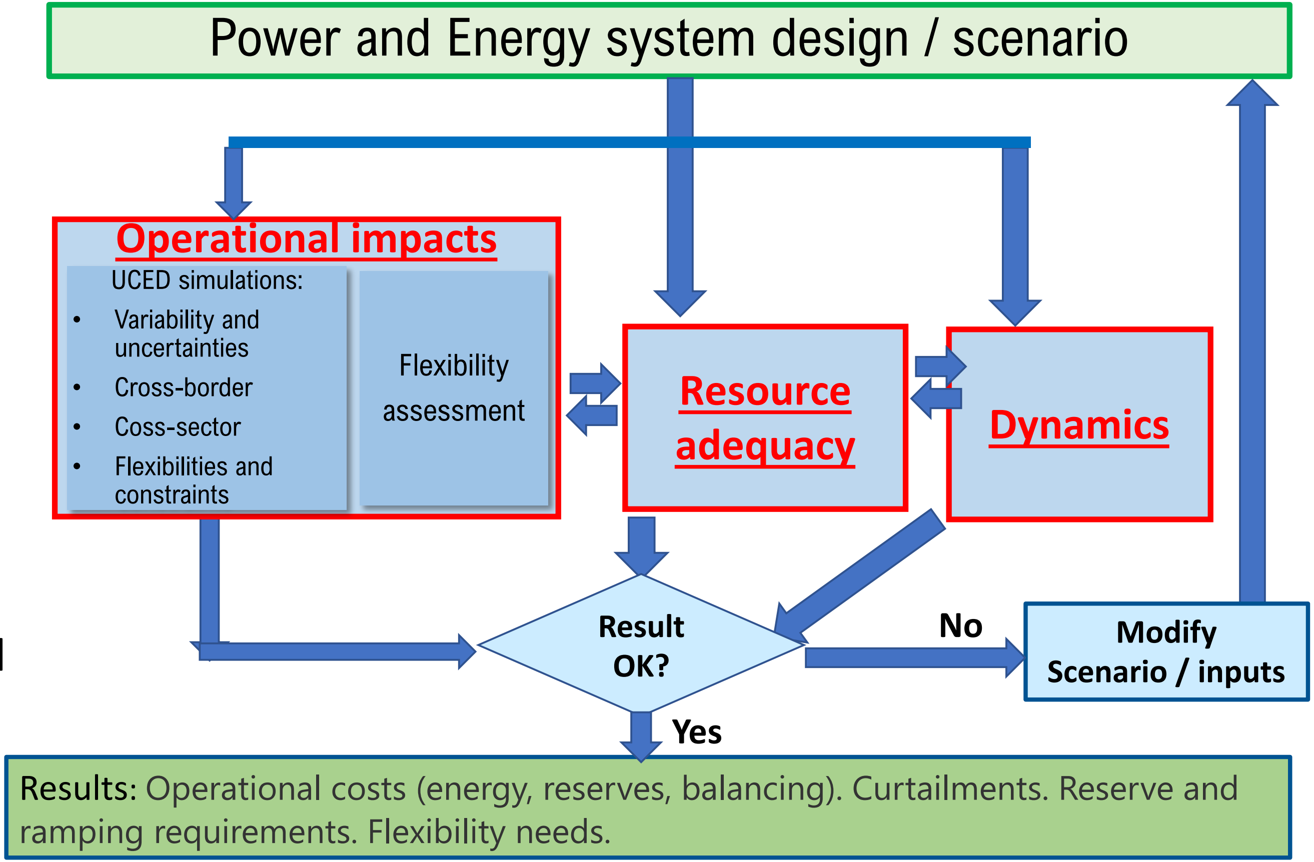
- grid limitations and stability constraints, including grid expansion costs: network capacity is very important when determining optimal wind and solar capacity in different areas

Markets

- operational practices reflecting future system needs and services

Operational impacts (Chapter 5)

Damian Flynn, UCD
Task 25 WP Balancing lead



Ensuring that the studied scenario is operable

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- Ensuring sufficient flexibility to cope with demand variability and uncertainty, renewable generation variability and uncertainty, profitability and unforeseen (dimensioning) events
- Simulated with Unit Commitment and Economic Dispatch (UCED) tools, to evaluate the impact of wind/PV on the operation of other power plants
- Iteration loops /sensitivies often needed; results sensitive to base case selection (non-wind/PV case of comparison)
- Input data: at least one year of at least hourly wind/PV data – synchronous with load (and hydro) and capturing smoothing impact and forecast accuracy

UCED model tools to capture wind, solar and flexibility

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- Time resolution
- Component model details
- Stability aspects
- Network representation
- Deterministic vs. stochastic
- New technology options
- …

Table 5.1. Evolution of short-term energy balancing with increasing shares of wind/solar energy (updated from Kiviluoma et al., 2012)

		Scheduling Frequency	
	Explanation	**Once per Day**	**More Regular Scheduling**
Dynamic Reserve Procurement	Reserve requirement is based on dynamic forecast error estimates for different time horizons	Wind/PV power increases tertiary reserve requirement significantly, but the impact is more limited when forecast uncertainty is accounted for dynamically	Combined impact of more frequent UC intervals and dynamic reserve procurement enables the tertiary reserve requirement to be kept at a low value, most of the time
Stochastic Unit Commitment	Optimisation of UC decisions across several scenarios for possible wind/PV and demand outcomes	Improves reliability and yields more optimal UC outcomes	Reduces tertiary reserve procurement and improves UC optimality
Scheduling Resolution	Scheduling period is shortened (e.g. from hourly to 5 minute resolution)	Ramps within the scheduling period are reduced, which lowers the regulating reserve requirement; scheduling accuracy is improved	

Operating reserve allocation with wind/PV - recommendations

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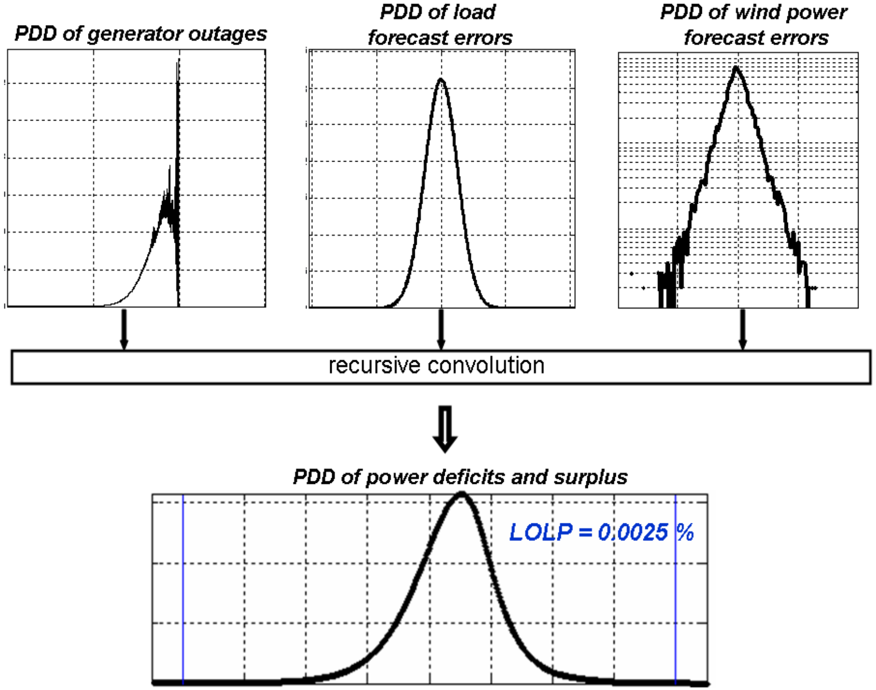
1. Synchronous wind/PV and load time series + forecast error distributions + generation outage distribution
2. Calculate for appropriate time scales, e.g. automatically responding (secs-mins) and manually activated (mins-hour). Split data for categories with care taken not to double-count
3. Combine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



Managing variability and uncertainty – reserves and scheduling

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- Closer to real-time gate closure
- Stochastic or robust scheduling
- Increased scheduling frequency
- Multi-period unit scheduling
- Shorter scheduling intervals

Figure 5.3. Management of operational flexibility through scheduling strategy or reserve product design (Source: EPRI, 2019).

Cause	Type	Resolve in Scheduling	Approximating Reserve Examples
Variability	Between Intervals		Flexible ramping reserve
Variability	Within Interval		Frequency control reserves – regulation
Uncertainty	Between Intervals		Flexible ramping reserve
Uncertainty	Within Interval		Frequency control reserves – contingency
Uncertainty	Before First Interval		None currently proposed

Flexibility assessment recommendations

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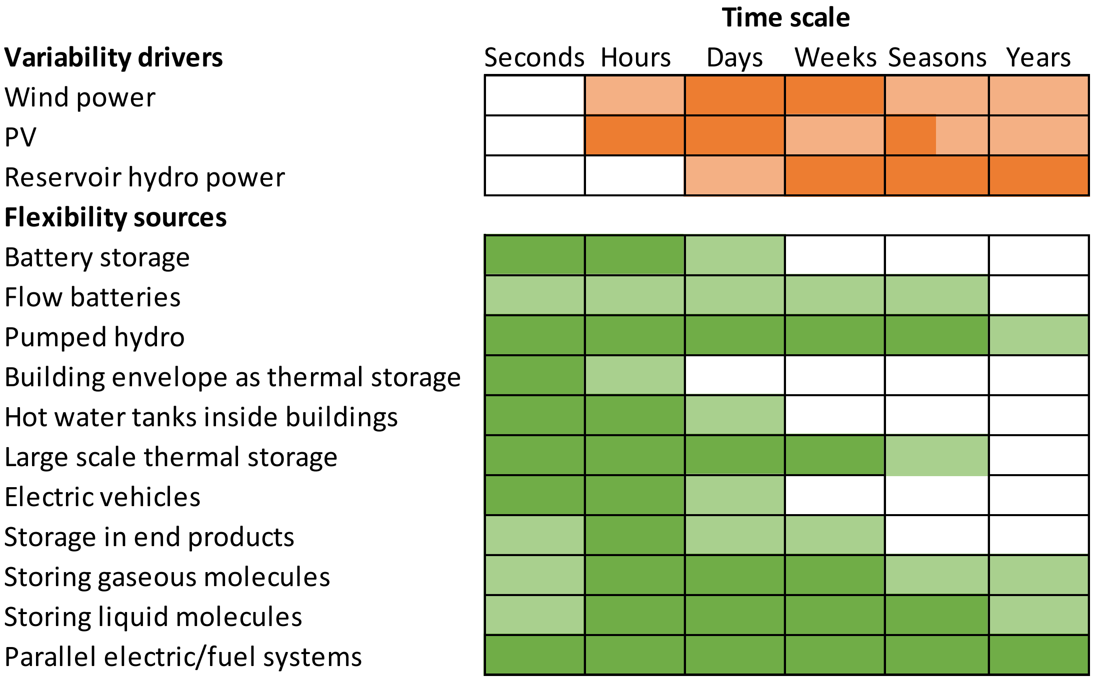
- Assess available flexibility for the existing power system
- Apply metrics to determine if additional flexibility options are sufficiently economically justified
- Cost–benefit analysis to determine required response characteristics of existing (and new) flexibility sources



... and wind, solar seconds to hours ... and reservoir hydro for all time scales

Operational impacts – recommendations

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- *Co-incident time series of wind/PV and load (for at least one year)*
  - At least hourly temporal resolution, synchronised with other weather dependent sources
  - High temporal and spatial resolution, long duration dataset, paired with forecast uncertainty
  - For hydropower, consider different hydrological scenarios (wet/dry years)
- *Results from high wind/solar scenarios can be sensitive to choice of base case (low wind/solar) scenario*
  - Utilising capacity expansion models help to ensure internally consistent scenarios
- *Capture all relevant system characteristics and generator/load responses through operational simulations and UCED modelling*
  - At high wind/solar shares, model impact of uncertainty on dispatch decisions, using stochastic optimisation and rolling planning

Operational impacts – recommendations

IEA Wind TCP

- *Model capabilities and limitations of flexibility* sources
  - Generation (up/down ramping, minimum up/down times, minimum stable levels, ...)
  - Explicitly represent neighbouring systems in sufficient detail
  - Operational practices (which may limit accessible flexibility over different timeframes)
- *Base operating reserve targets on wind, solar, load forecast uncertainty*
  - Take care not to double-count uncertainty impacts
  - At high RES shares, include dynamic reserves, faster markets and increased market resolution
- *Represent grid, N-1 security and stability constraints in sufficient detail*
  - Additional UCED constraints or separate analysis using power system analysis tools
  - Power flow analyses and grid enhancing technologies for grid bottlenecks
  - Stability constraints, linking to contingency reserves, and locational reactive/inertia/etc. capability

Recommendations – wind/PV dominated systems

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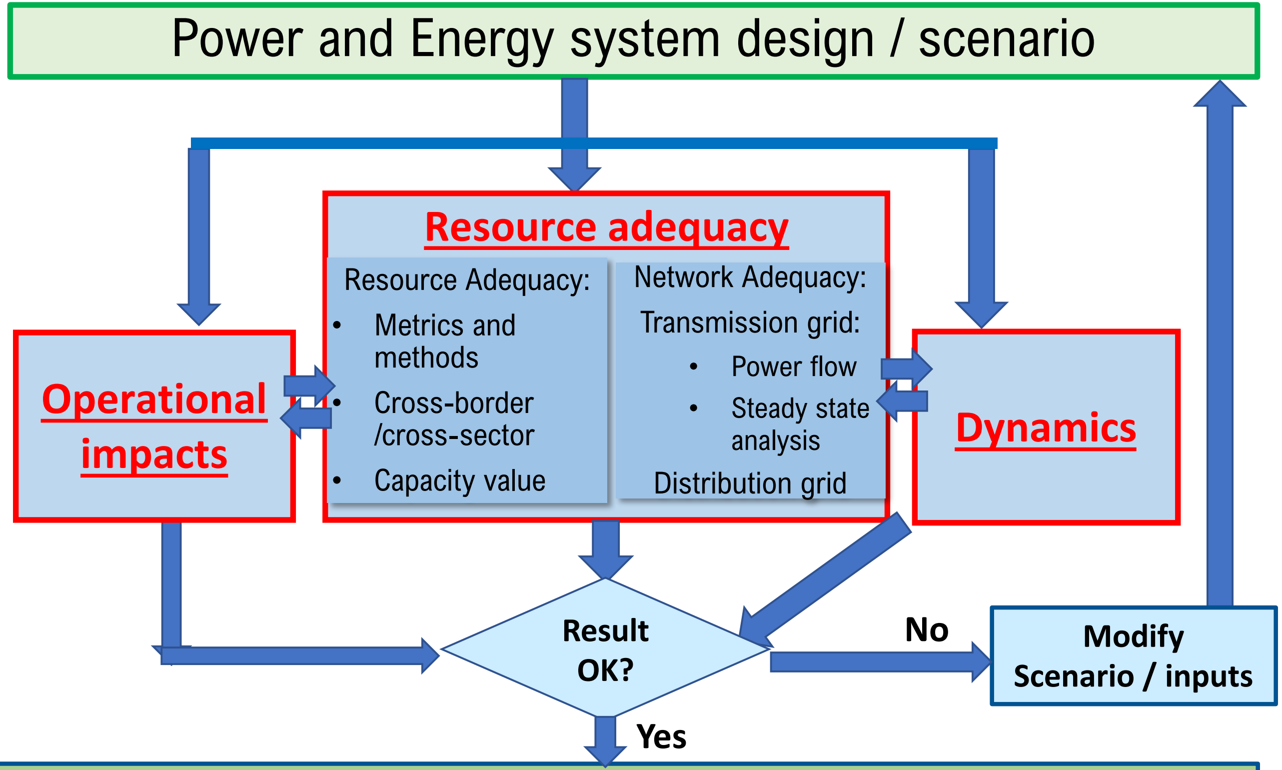
- *Use probabilistic models and risk assessment tools*
  - Apply deterministic and probabilistic assessment approaches for risk-based operation, and appropriate modelling approximations
  - Consider wind/PV forecasting best practices, and update forecasts closer to the delivery hour
- *Represent other relevant energy sectors*
  - Heating, cooling, transport and P2X, incorporating flexibility and process constraints
- *Represent energy storage and price-responsive loads within system services*
  - Incorporate (complex) constraints relating to service availability
  - Represent regional aggregation of distributed resources for bulk systems
- *Expand market options/products for flexibility trading*
  - Include market options for system/area/nodal/individual imbalances at different timescales

Adequacy impacts (Chapter 4) Resource Adequacy

Hannele Holttinen,
Task 25 OA



Results: LOLE, LOLP, EENS, capacity value of wind/solar. Efficient use of existing network or requirements for new network investments

Ensuring that the scenario studied has adequacy

- Resource adequacy – loss of load probability checks, enough generation capacity/storage/energy available to cover the (fixed) load
  - needs for more back up generation/storage?

- Network adequacy – steady state checks to transmission and distribution networks
  - needs for reinforcing the grid?

Resource adequacy – new metrics

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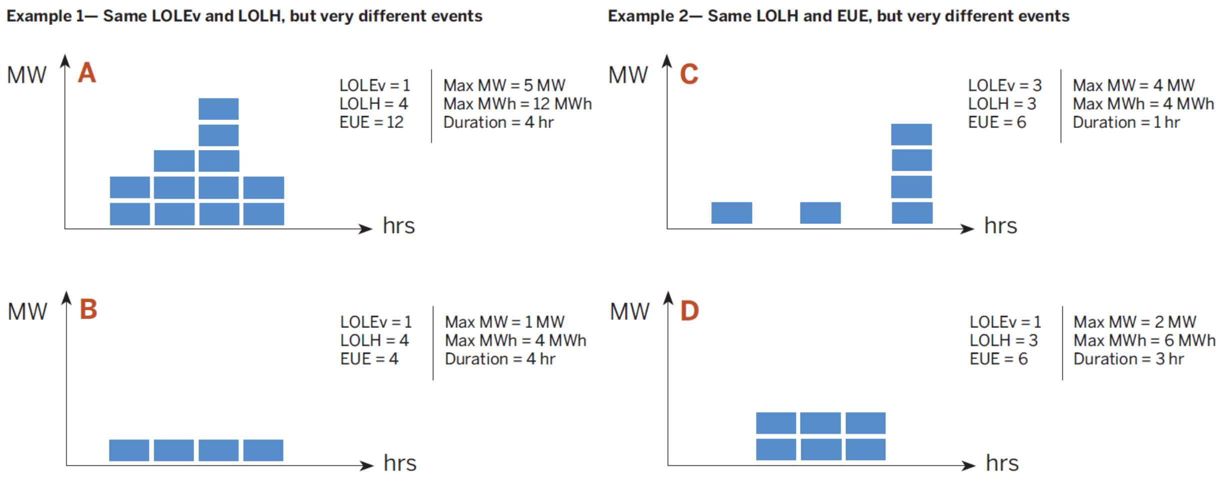
- Traditionally Loss of load probability (LOLP) or loss of load expectation (LOLE) like allowing max one event in 10 years
- For severity of events (duration, magnitude), also loss of load hours (LOLH) and Expected unserved energy (EUE)



Each block represents a one-hour duration of capacity shortfall, and the height of the stacks of blocks depicts the MW of unserved energy for each hour. A: a single, continuous four-hour shortfall with 12 MWh of unserved energy; B: a single, continuous four-hour shortfall with 4 MWh of unserved energy; C: three discrete one-hour shortfall events with 6 MWh of unserved energy; D: a single, continuous three-hour shortfall with 6 MWh of unserved energy.

Source: Energy Systems Integration Group.

Resource adequacy - methodology

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- Traditional methods exist taking into account wind and solar (as net load)
- For higher shares, and future energy coupled systems, combined effect of numerous system stresses – extreme weather, equipment failures, fuel limitations – on top of an evolving resource and supply mix is requiring more granular and detailed resource adequacy modelling
  - Increasing importance of energy-limited resources (wind, solar, storage and demand response) - full year of chronological operation of the grid
  - multiple, correlated events caused by common weather patterns
  - multi-area assessments – neighbouring areas simulated
  - frequency, magnitude, duration, and timing, as well as other aspects that capture economics or tail risks (extreme events)

Resource adequacy - recommendations

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Neighbouring areas	• Import possibilities (including forced outage rates) during times of generation scarcity • Recent model developments using Monte Carlo
Inter-annual resource variability	• Enough data to capture extreme events (10+ years) • Energy adequacy • Climate change impacts on resource availability and demand profiles
Chronological models	• To include load and storage flexibility at times of scarcity of energy • Difference of electrification loads to existing loads, and climate change impacts on demand profiles
New adequacy metrics	• Use LOLH (Loss-of-load Hours) and LOLE (Expectation), and EUE (unserved energy), assess tail risks • Reliability target - which critical loads must be served

Capacity value of wind/solar

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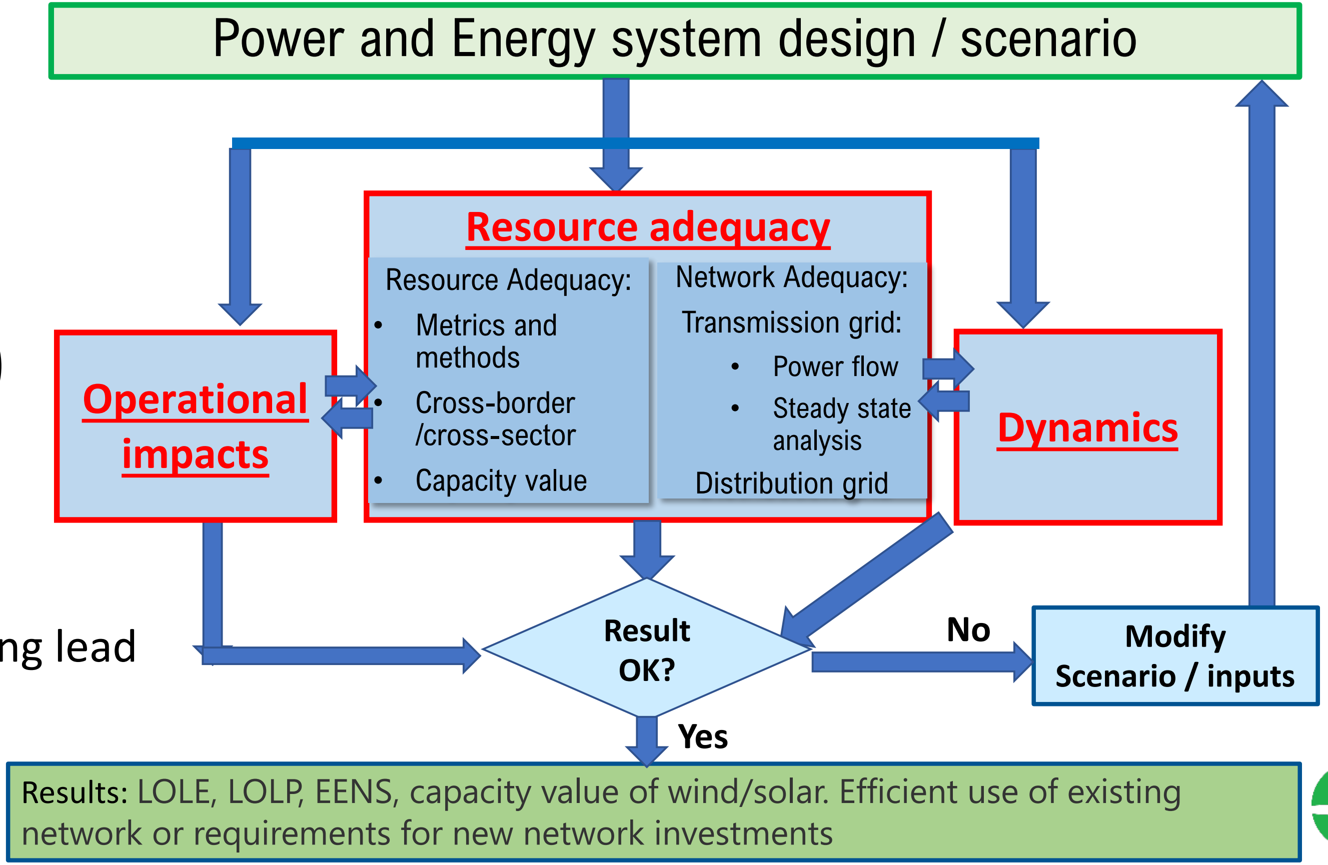
- Capacity value is heavily system-dependent and need to be updated to reflect the changing system buildout, configuration, and operations
- ELCC method recommended to assess the capacity value of a certain asset
  - How much increase in load will bring same reliability/LOLP in the system when adding wind or solar (or combined): Effective Load Carrying Capability ELCC
- Input data – synchronous wind/PV/load data. Number of years critical for robust results, more than 10 years
- For wind and solar dominated systems, the calculation of capacity value for separate technologies will no longer be meaningful - integrated planning approach where resource adequacy is embedded recommended

Network Adequacy (Chapter 4)



Damian Flynn, UCD
Task 25 WP Balancing lead

Transmission planning - adequacy of the network

IEA Wind TCP

- Recommendations report addresses network adequacy, involving steady-state feasibility checks in Chapter 4 and stability checks in Chapter 6, while transmission scenarios form part of power system scenarios in Chapter 3
  - System operators define a transmission planning process, covering many phases of integration studies in the Recommended Practices report
  - Many more RES scenarios required than previously evaluated (probabilistic weighting)
- If steady-state and/or dynamic feasibility checks are failed then transmission network enhancement options must be investigated
  - Reinforce transmission lines, or invest in grid enhancing technologies
  - Combined power flow analyses and UCED required to fairly analyse dynamic line rating, and other grid-enhancing technologies, as an alternative to network upgrades

Network adequacy – Transmission power flow

IEA Wind TCP

- Modified unit commitment / economic dispatch
  - ❖ Incorporate must run and locational plant constraints?
  - ❖ Still fit for purpose for future high wind/solar scenarios?
  - ❖ Include DC network representation + assessment of N-1 security?
- Network expansion / reinforcement options
  - ❖ Dynamic line rating + high temperature low sag conductors
  - ❖ Power flow controllers / line compensation
  - ❖ SVC / STATCOM / FACTS devices / BESS ...
- Probabilistic assessment of event occurrence vs. severity of outcomes
  - ❖ Time series power flow – switching operations

Steady state checks for adequacy of network

IEA Wind TCP

- Identify transmission network bottlenecks (congestion) for intact network, and all possible N-1 cases considering all critical network elements
  - ❖ Can overload risk and severity be solved by operational measures?
  - ❖ Line thermal induced bottlenecks addressable by power flow analysis (with re-dispatch), otherwise dynamic studies are needed
- Assess ability to maintain an acceptable voltage profile
  - ❖ Reactive power absorption/production and controllability should be simulated to determine the need for reactive compensation
  - ❖ Some solution options, e.g. synchronous condensers, may have stability impacts
- Mitigation measures using grid enhancing technologies should be simulated

Short circuit levels/weak grids

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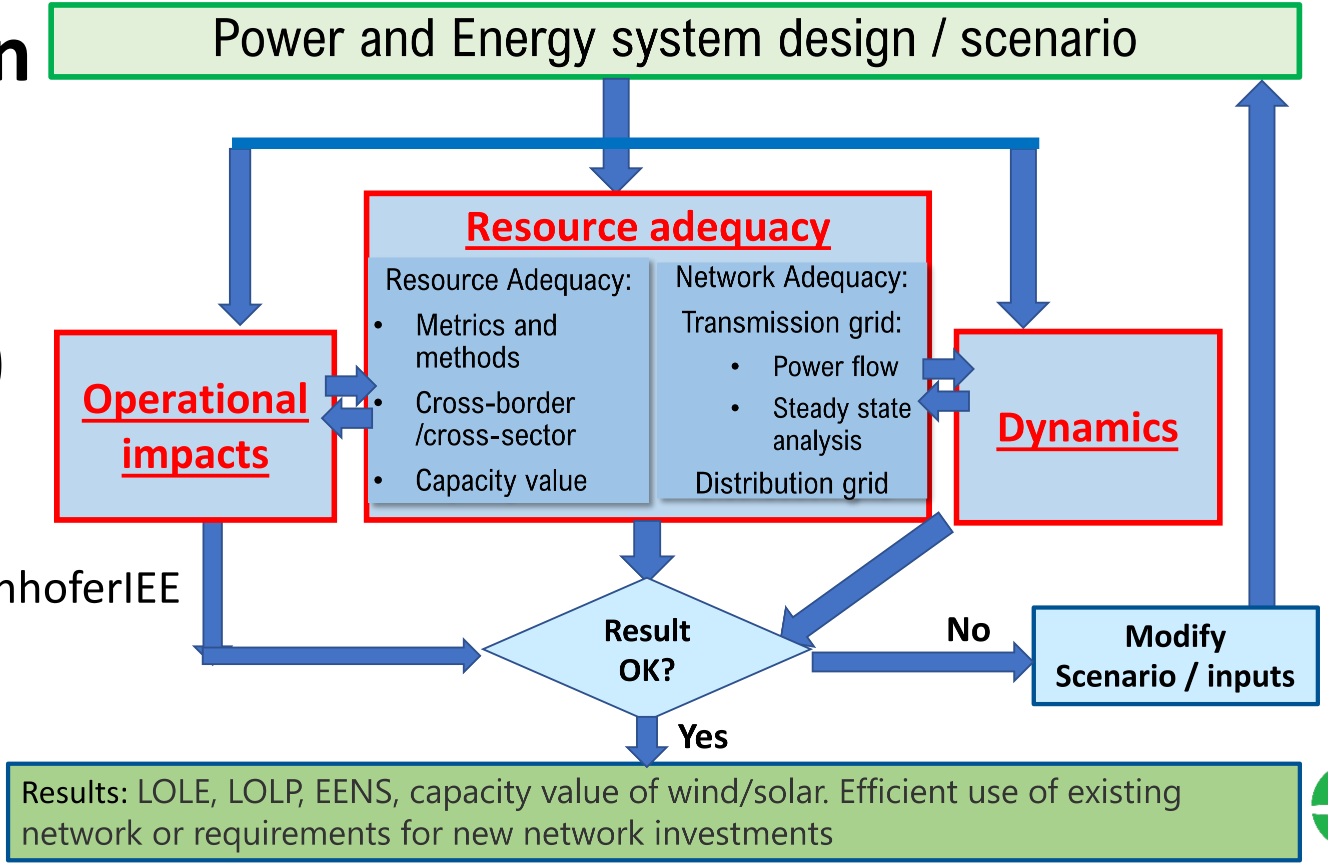
- When synchronous generation is not dispatched, there can be a reduction in the minimum short circuit level in some locations
  - ❖ May affect power quality, such as voltage step changes after shunt switching, correct operation of line commutated HVDC converters, operation of protection systems, ...
  - ❖ Presence of wind/solar generation in non-traditional locations can improve the fault level in those areas
- Harmonic distortion not traditionally seen as an issue at transmission level
  - ❖ Increased utilisation of power electronic converters, perhaps grid connected using underground cable connections, can alter such assumptions
  - ❖ New harmonic injections, and resonance amplification effects induced by HV/EHV cables, can drive harmonic distortion at point of connection outside planning levels

Distribution Network Adequacy (Chapter 4)



Denis Mende, FraunhoferIEE
PVPS TCP Task 14

Adequacy of distribution network

- Best-practice of distribution grid modelling depends on detailed study objective and available input data.
- Power flow / Time series analysis:
  - Hosting capacity (section 4.3.1)
  - Contingency, congestion management and grid reinforcement (section 4.3.2)
  - Voltage variability and reactive power control algorithms (section 4.3.3)
  - (Active power) Flexibility assessment of distributed energy resources (section 4.3.4)
  - Grid losses analysis (section 4.3.5)
- Additionally: Short circuit analysis (Protection studies); Dynamic stability analysis (Fault-ride through and anti-islanding detection studies)

Distribution grid reinforcement analysis - recommendation

- Comprehensive options for grid planning measures should be considered, i.e. grid optimization before grid reinforcement before grid expansion
- Analyses can either be performed using representative or actual grid data.
- Presentation of results: wind/PV integration driven reinforcement costs in contrast with generally necessary reinforcements, such as replacing outdated grid assets.

Grid losses analyses - recommendations

- For information on the effects on the distribution system wind/PV are connected to
- Consider both the location and generation pattern of wind/PV when representing distribution grids, as they both have a significant impact on the grid losses.
- In order to partially validate the implemented model of the grid area, the energy flow in the studied grid area can be investigated in comparison with real measurement data available at transmission level bulk supply points.

Distribution networks - future

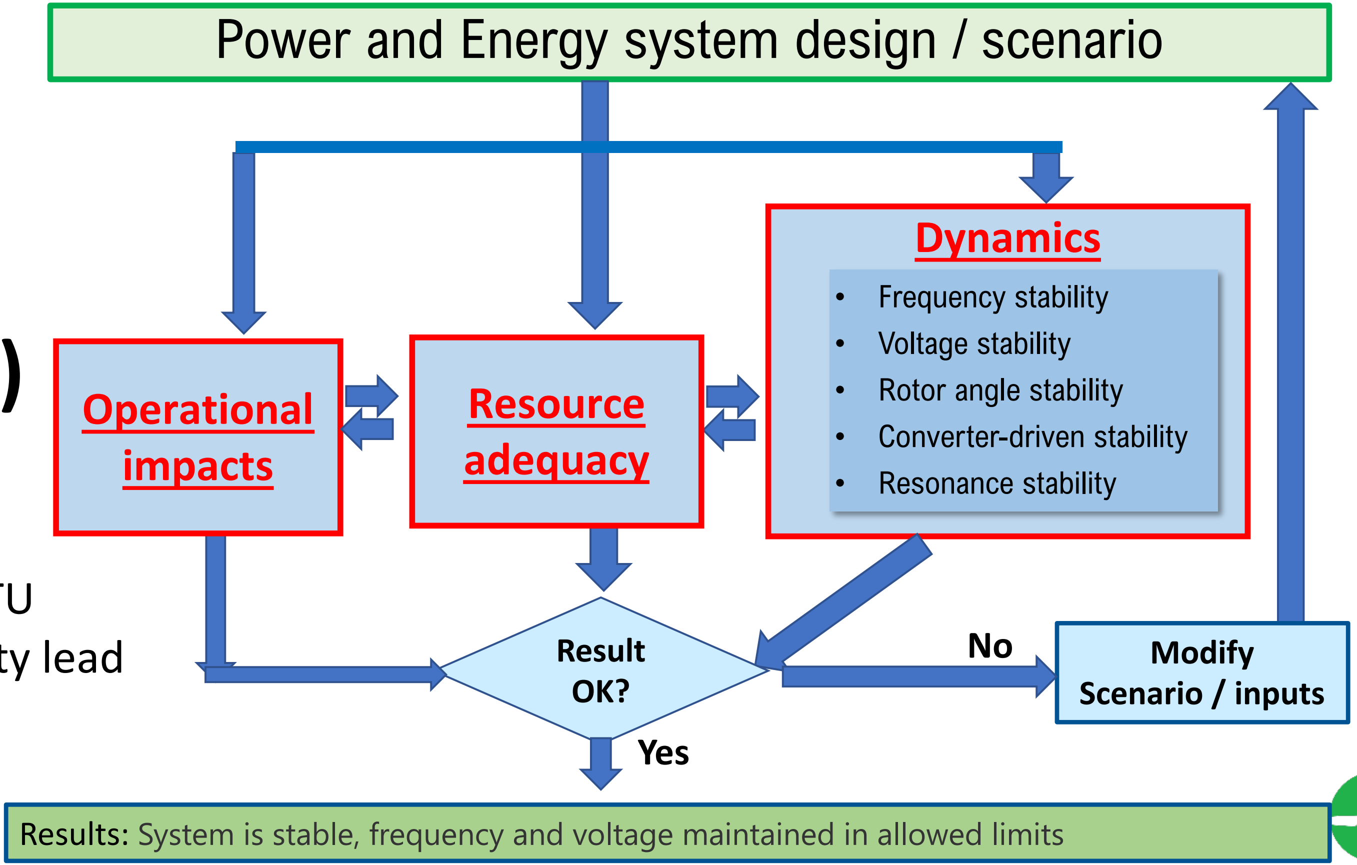
IEA PVPS

- Well established best-practice examples and advanced planning procedures for distributed Wind/PV integration studies partly still required.

- With higher shares of wind/PV: stronger coordination of transmission and distribution grid studies to access the full capabilities and flexibilities of distributed resources for the overall bulk power system.
    - The methods that so far have been only used for analysing transmission grids will also become relevant for distribution grid analyses
    - Distribution grid representations in transmission system studies increasingly needed

Dynamics (Chapter 6)

Nicos Cutululis, DTU
Task 25 WP Stability lead



Ensure to keep power system stable

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- Frequency stability is the ability to maintain the system frequency under normal operating conditions and following a major imbalance between generation and load, e.g., tripping of the most heavily loaded lines or the largest generator infeed.

- Voltage stability is the ability to maintain an acceptable voltage profile under normal operating conditions and after being subjected to a disturbance.

- Rotor angle stability is the ability of the interconnected synchronous machines in a power system to remain in synchronism under normal operating conditions and to regain synchronism after being subjected to a small or large disturbance.

Ensure to keep power system stable

- Converter driven stability can be classified into two parts: fast and slow interaction. Fast converter-driven interactions occur between the control systems of power-electronic-based systems and fast-response components of the power system or other power electronic-based devices. Slow converter-driven interactions occur between the control systems of power electronic-based devices and slow-response components of the power system.

- Resonance stability is characterized by oscillations that occur in the sub-synchronous frequency range of 5–45 Hz. Depending on where these oscillations occur, they can be classified into various types, such as sub-synchronous resonance (SSR), sub-synchronous torsional interaction (SSTI), and sub-synchronous control interaction (SSCI). Resonance stability covers the effect of HVDC and FACTS on torsional and of DFIG controls on electrical resonance stability.

What to study: depending on particular system concerns

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- Determine if the grid is sufficiently robust to sustain disturbances (temporary and and dimensioning contingencies), and capable of recovering satisfactorily
- Evaluate dynamic impacts from newly connecting generation or load to the power system – and deployment against grid code requirements
- Investigate impact of different distributed generation locational distributions
- Assess transmission limits when these are set by a combination of transient stability, small-signal stability and/or voltage stability concerns.
- Assess impact of sub-synchronous interactions as part of small signal stability analysis
- Determine optimal measures to avoid generation curtailment due to dynamic constraints.

Wind / PV Models

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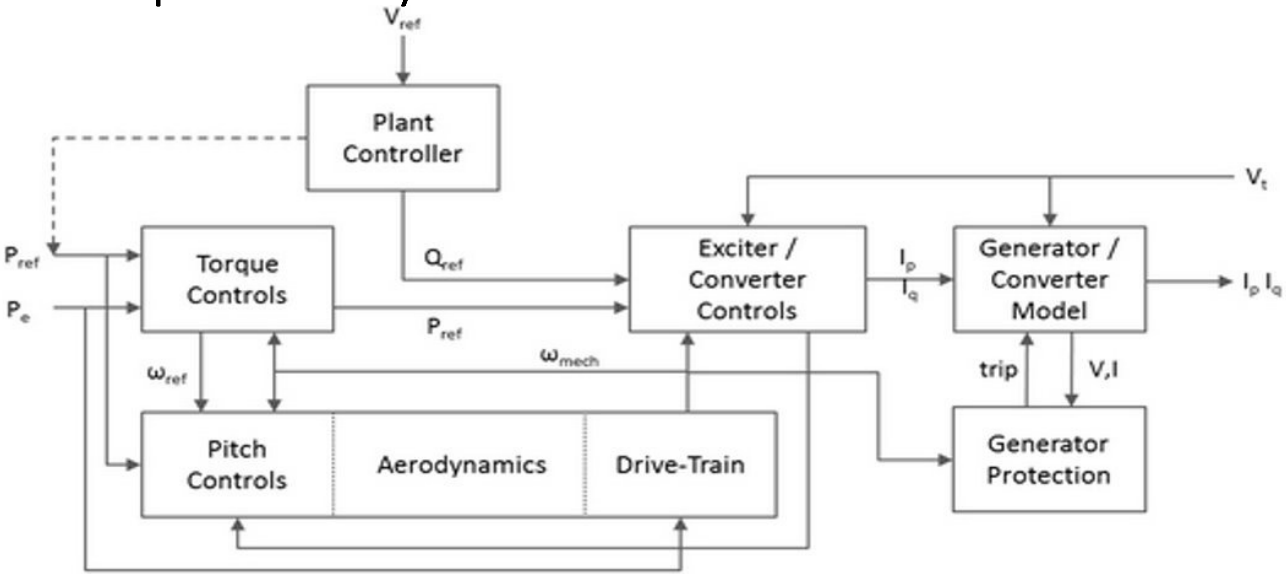
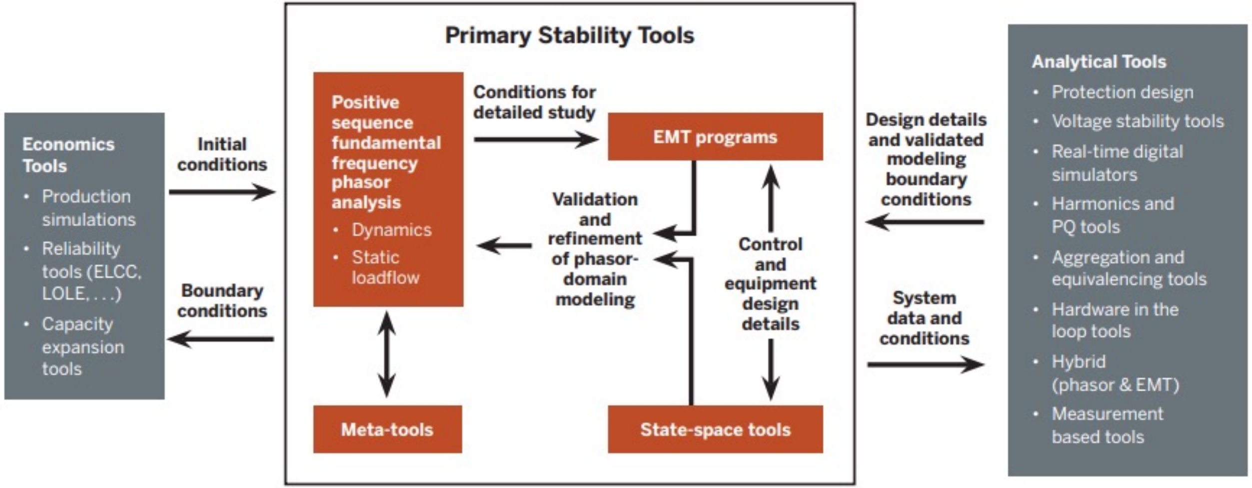
- Linked with evolving wind / PV capabilities and grid codes. Validated.
- Variety of control options that modern power electronics offer, can be adapted to the particular systems studied



Simulation tools

- Need to move to more detailed electro-magnetic simulations (EMT)
- Models for components needed for evolving wind/solar technology, and new loads

FIGURE 27
Stability Simulation Environment



Source: HickoryLedge.

Dynamics - recommendations

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Selecting cases (snapshots)

- Worst case scenarios
- Foreseen operational conditions
- Based on UCED

Wind/PV/BESS/Load models

- suitable for studying each particular stability phenomena
- ensure correctly parametrized (validation)
- consider variety of control options that modern power electronics offer, adapted to the particular systems studied.

Stability cases relevant for the system

- Frequency / voltage stability
- Rotor angle stability
- Resonance and converter stability
- Common mode failures

Recommendations: Frequency and Voltage stability

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- *Frequency stability studies:*
  - The inertia, droop and governor settings of all synchronous units, and frequency control block models and settings of all IBRs providing frequency control are needed
  - Model any protective functions in IBRs or synchronous generators that may respond to frequency or rate of change of frequency exceeding certain thresholds.
  - A reduced network representation may be sufficient.
- *Voltage stability studies:*
  - At low wind/solar/BESS shares: stability is likely to be unaffected or even enhanced by the presence of wind turbines/PV panels if the reactive power control capabilities deployed
  - At higher shares of wind and solar: voltage security levels may be affected in certain locations with high concentration of wind/solar/BESS or system-wide as conventional generation is displaced.

Recommendations: Rotor angle stability

- ***Transient stability studies:***
  - Include effect of protection devices for both network and converter-interfaced generating equipment; however, boiler/steam turbine models are not required. Protection relay settings should recognize changes in the dynamic response of the system, as adopted by the local TSO. The ability of generation to ride through multiple voltage dips within a certain period may also need to be addressed.
  - Wind, BESS and solar generation can provide system support during voltage dips, and help to dampen oscillations. Proper representation of the impedance connecting the plants is crucial.
  - To mitigate, fast acting reactive power response devices during and following disturbances can be applied (e.g. FACTS, synchronous compensators, and/or requiring generation/storage for that specific capability)
- ***Small-disturbance stability studies:***
  - Small-disturbance stability may be impacted if conventional generation (and associated power system stabilizers) are displaced and magnitude and direction of transmission line power flows are altered.

Recommendations – Resonance and Converter

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- *Resonance stability studies:*

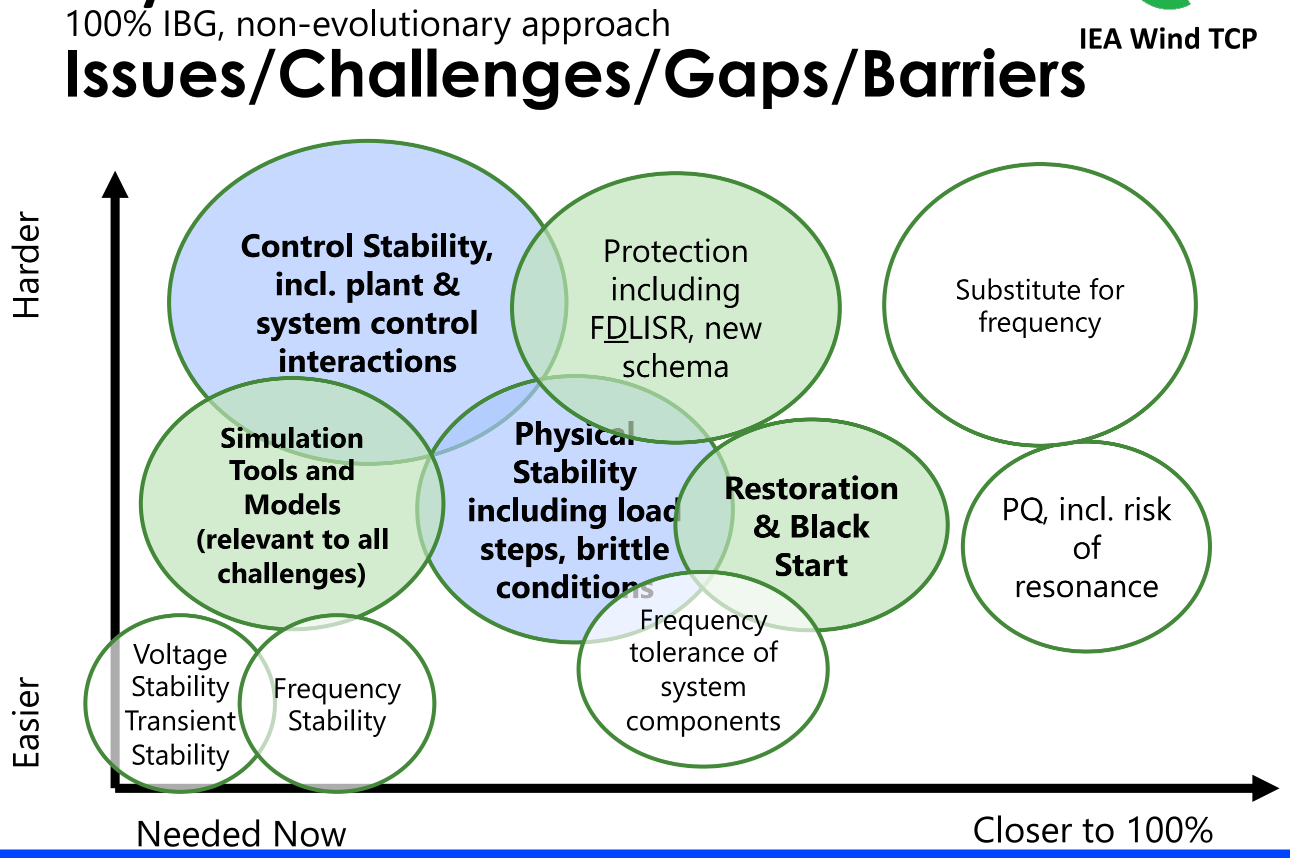
  - Sub-synchronous torsional interaction (SSTI) and sub-synchronous control interaction (SSCI) should be investigated as part of small-signal stability analysis, particularly in relation to doubly fed (type 3) wind turbines radially connected with series line compensation. SSCI studies may also be performed for all IBRs that may become radially connected with series compensation after a number of contingencies. A range of mitigation measures including bypass filters, FACTS devices, and auxiliary (damping) controls are available and should be considered

- *Converter-driven stability studies:*

  - Adequate models able of capturing the harmonic power dynamics, especially in multi-converter setups are crucial.

For future IBR dominated systems

- Moving towards 100% Inverter based resources (IBR), research on new paradigms of system operation



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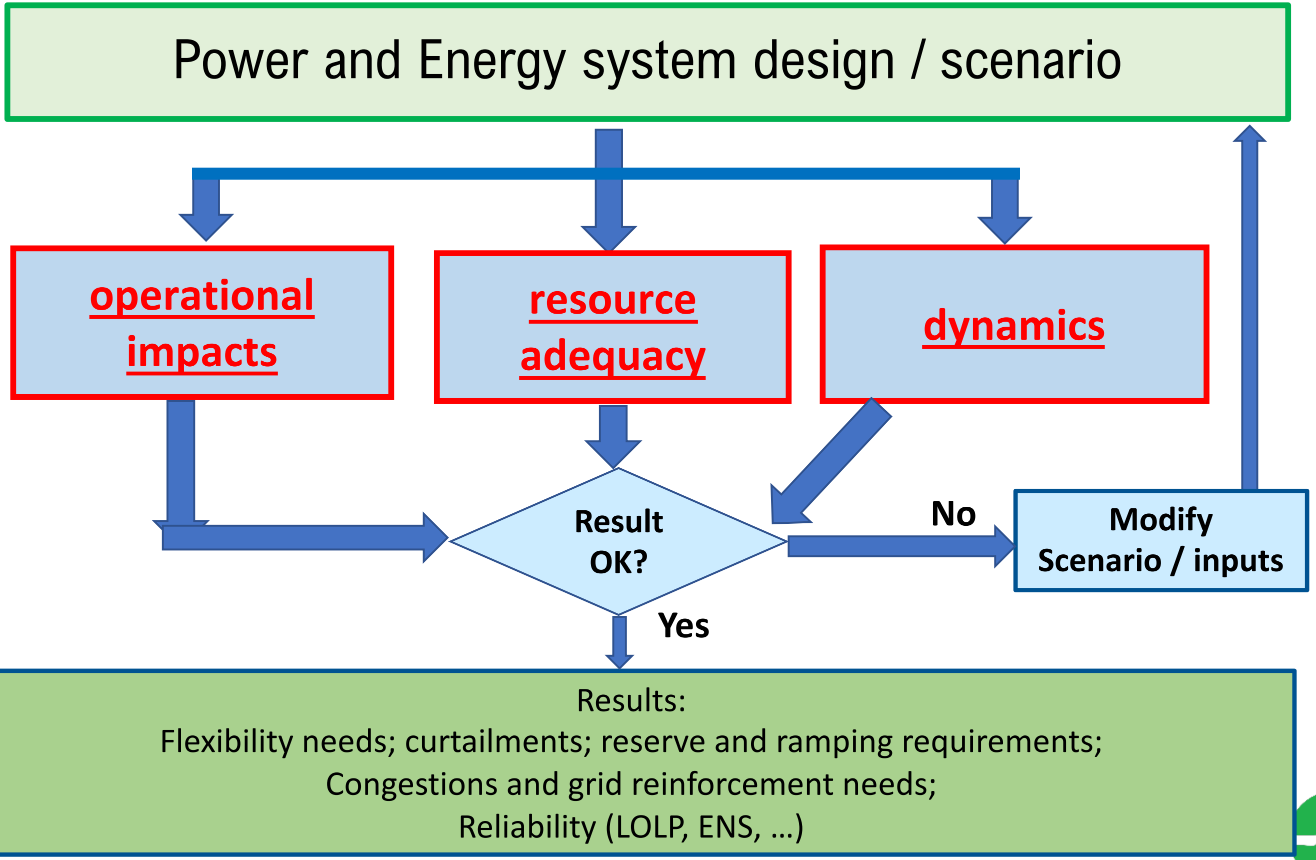
Analysing results (Chapter 7)



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Analysing and presenting the results

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- Iterations provide significant insights
  - importance of the main setup and scenario chosen as the basis for the results, as will have crucial impacts on the results.
- 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
- For easier comparison with other studies, present
  - Share of wind/PV, size of the power system; potential curtailments
  - all relevant assumptions and limitations of the methodology chosen: interconnections, flexibilities,

Use the recommended practices check-list for benchmarking your study!

Summary: Recommended Practices for wind/PV integration studies

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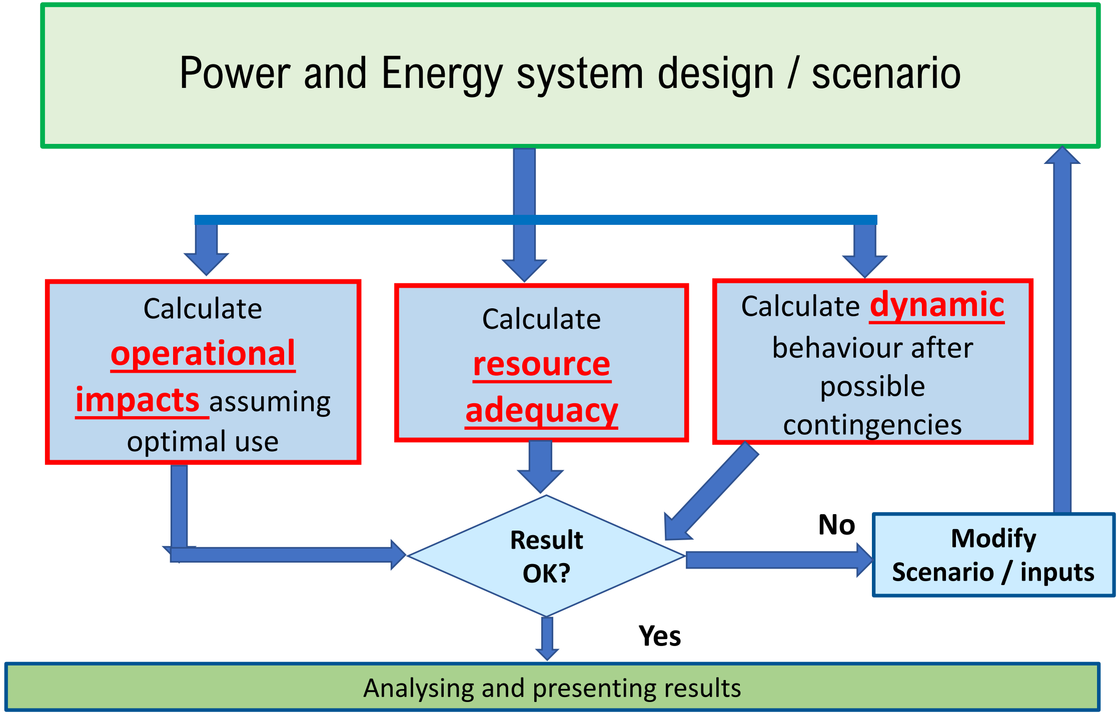
- Most studies analyse part of the impacts – goals and approaches differ
- Built on many inputs and assumptions that should be transparent
- A complete study with links between phases becomes more important at higher shares of wind/PV



Future work - evolution of methodologies

integration studies are becoming general system studies for energy transition

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Larger areas

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

Complexity

- increasing computational burden capturing 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: methods, tools and data, overlap btw operational models
- Flexibility needs and plant capabilities within adequacy, and stability concerns for network expansion and operational tools

Cost vs. risk

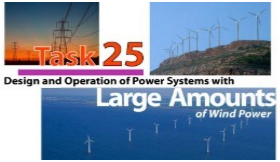
- reliability interface needs revisiting
- evolution of flexibility and price responsive loads

Task 25

- Design and operation of power systems with large amounts of wind power

Main authors of this report in red

- 17 countries + Wind Europe participate



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Review process ongoing, comments welcomed

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Report will be published at IEA Wind TCP web site https://iea-wind.org/iea-publications/ and as IEA PVPS TCP report

IEA PVPS