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

The Planning Challenge

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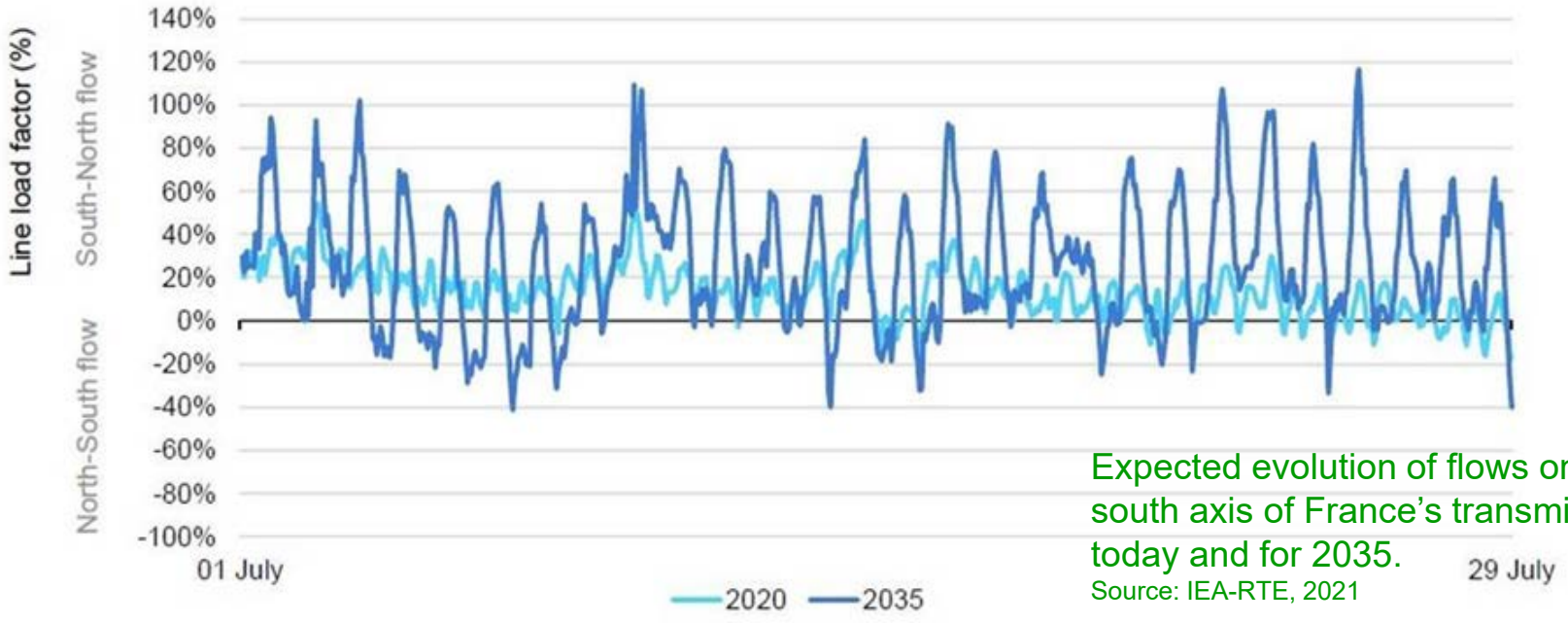
Transmission planning

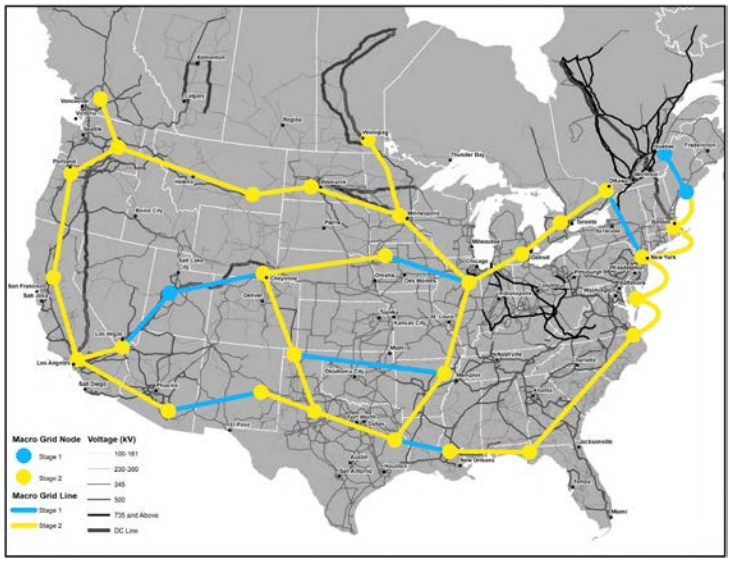
- Greater deployment of wind (and solar) yields higher line utilization, indicating greater benefit and additional need for transmission
- Investments can be partly integrated into renewals of ageing assets
- Public engagement with citizens is key for social acceptance
  - In Ireland and Germany, a stepwise process has been developed to increase transparency



Expected evolution of flows on a north-south axis of France's transmission grid, today and for 2035.
Source: IEA-RTE, 2021

Transmission planning

- Regional transmission planning
  - Macro-grid discussions in US
  - Enhance existing corridors in Europe



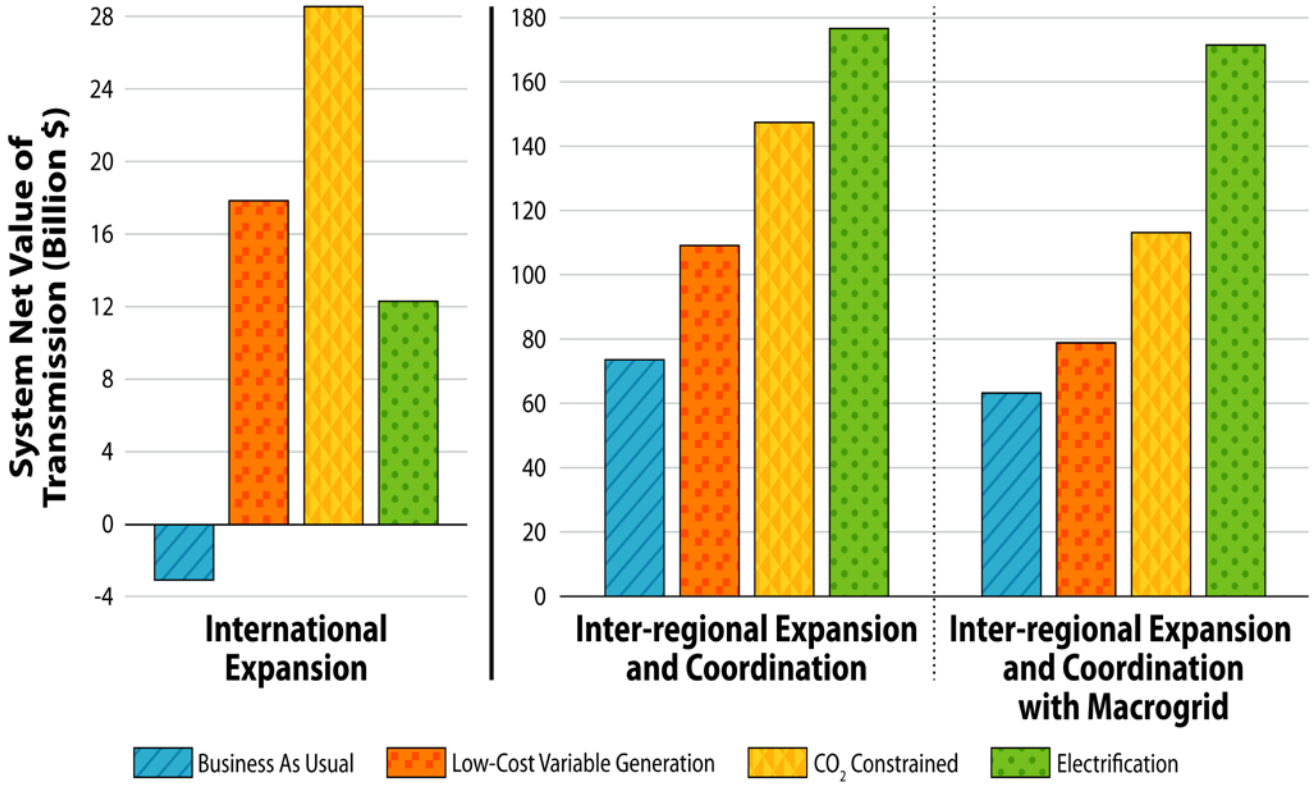
Conceptual macro-grid to unite the US power systems.

Source: ESIG. 2021. Transmission Planning for 100% Clean Electricity. https://www.esig.energy/wp-content/uploads/2021/02/Transmission-Planning-White-Paper.pdf

Europe-wide grid architecture for a low-carbon future, as identified by a recent ENTSO-E ten year network development plan (TYNDP).

Source: “Completing the Map 2020 – Power System Needs in 2030 and 2040; ENTSO-E, Nov 2020).

With more wind (and solar) deployment, inter-regional coordination and expansion are more beneficial

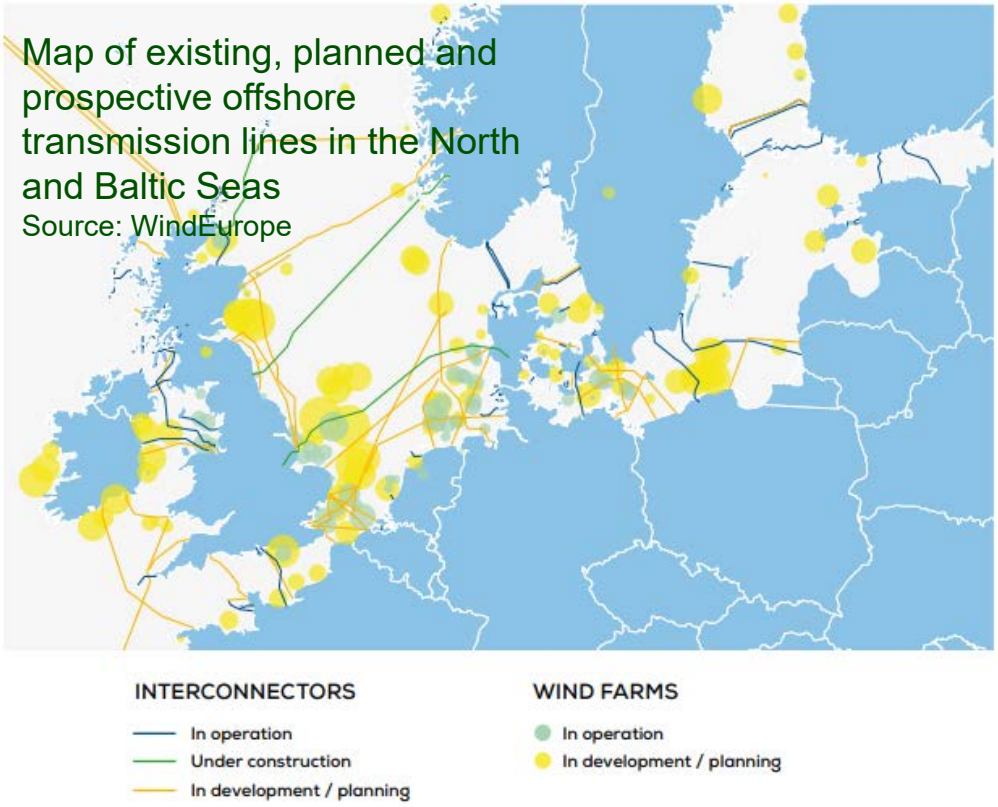


Continent-wide net value of transmission expansion for the four scenarios in the NARIS study.

Source: Brinkman et al., 2021. The North American Renewable Integration Study: A U.S. Perspective. Golden, CO: National Renewable Energy Laboratory. NREL/TP-6A20-79224. https://www.nrel.gov/docs/fy21osti/79224.pdf.

Offshore grids

- TSOs are planning offshore grids as well
  - Meshed grids, hubs, and energy islands
  - HVDC technology improvements to increase cost effectiveness, reliability, and land-based grid support



Map of existing, planned and prospective offshore transmission lines in the North and Baltic Seas
Source: WindEurope

North Sea Wind Power Hub joint initiative started by system operators TenneT TSO B.V. (Netherlands), Energinet (Denmark), and TenneT TSO GmbH (Germany), with transmission interconnectors (left), Energy Island concept (middle) and the option of increased regional interconnection (right).

Capacity value of wind

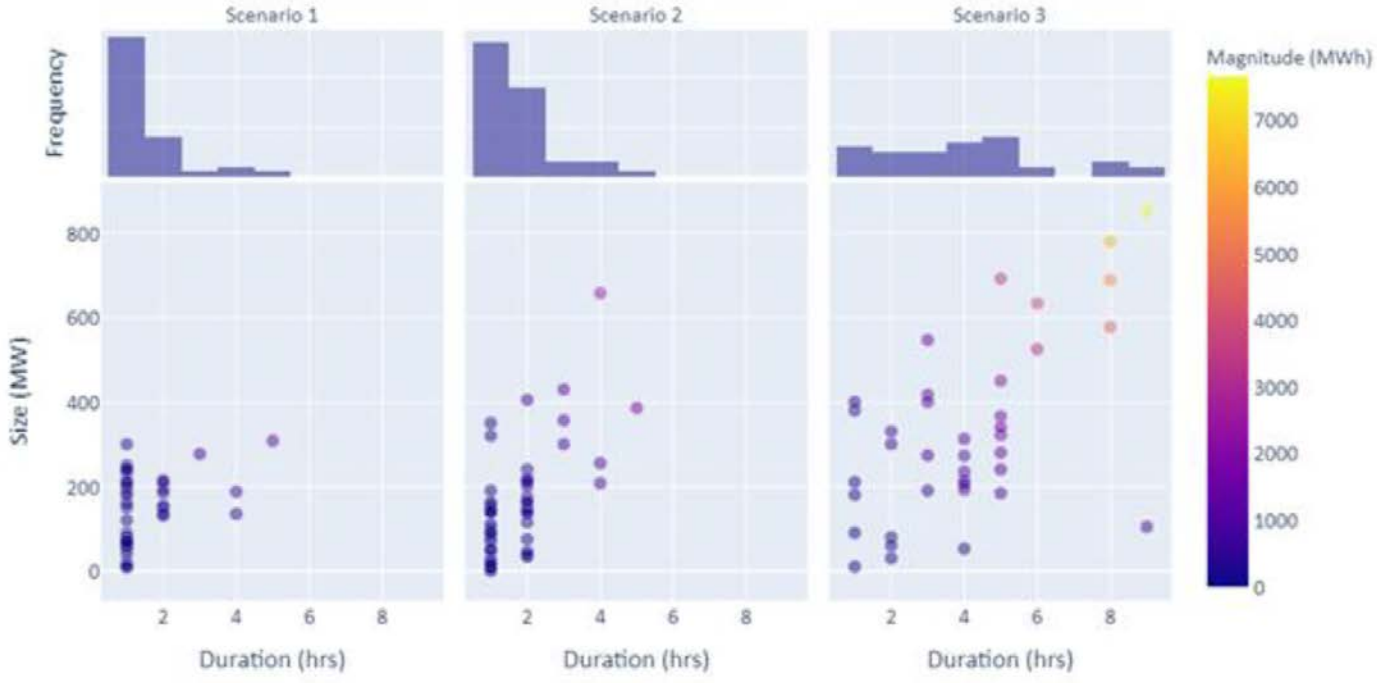
- Generally decreases with increasing share of wind
  - This trend is less pronounced across larger geographic areas
- More years of data are needed for robust results
- Ideally calculated with probabilistic methods
  - LOLP, EFC, etc.
- Also often used as inputs into planning models and capacity markets

Capacity credit of wind in the Western United States. The average capacity credit is16% for land-based turbines and 41 % for offshore turbines.

Source: Jorgenson, J., Awara, S., Stephen, G., Mai, T., 2021. A systematic evaluation of wind's capacity credit in the Western United States. *Wind Energy* 24, 1107–1121. https://doi.org/10.1002/we.2620

Resource adequacy in future systems

- Improvements to metrics, methods, and/or tools are needed to:
  - Include coordination with neighbouring areas
  - Reflect extreme events, including correlated outages and multiple years of data
  - Capture magnitude, duration, frequency, and timing of potential loss of load
  - Model chronology, which is essential for resources like load participation and storage



Plots of size, duration, frequency of shortfall events. Each scenario has a different resource mix but the same LOLE (i.e., number of dots).

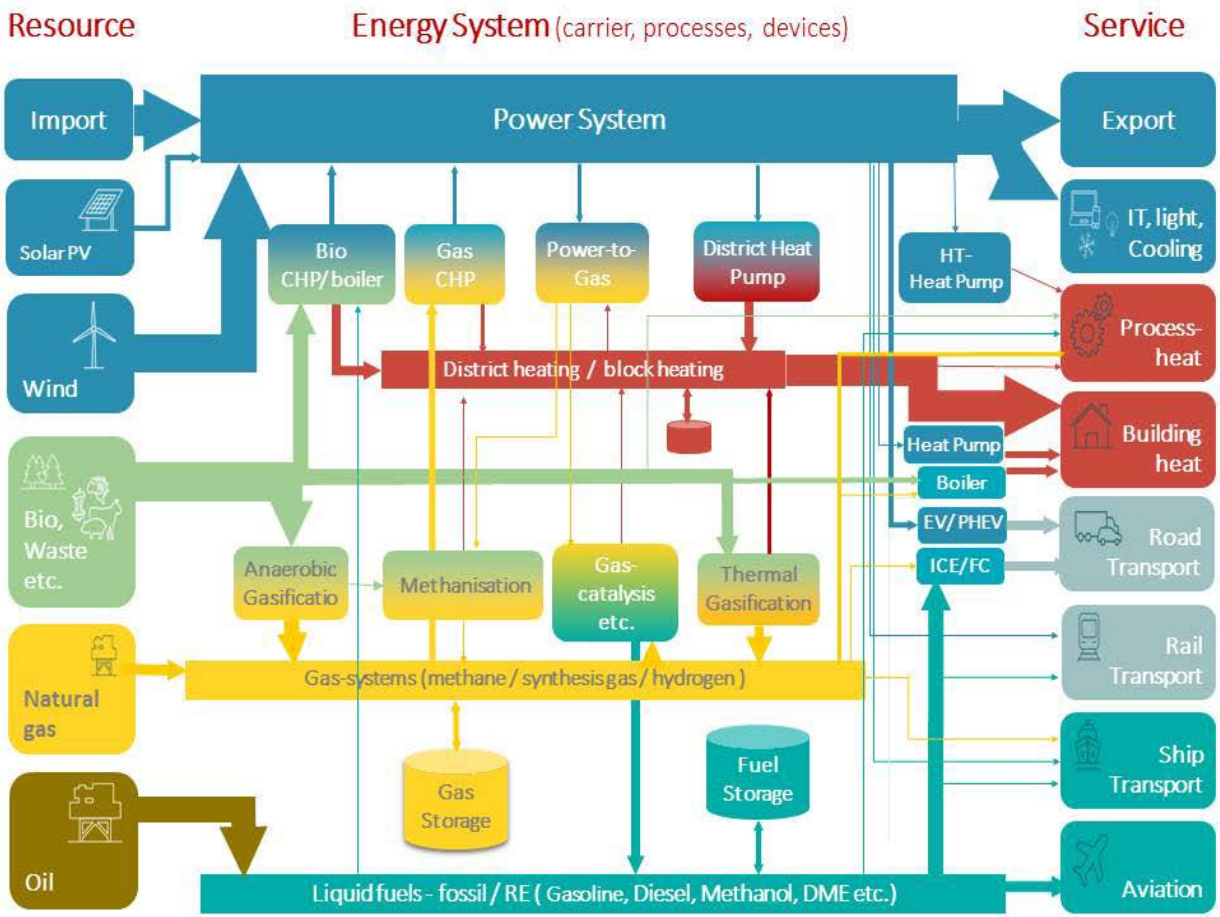
Source: ESIG. 2021. Redefining Resource Adequacy. https://www.esig.energy/resource-adequacy-for-modern-power-systems/

Pushing the limits: 100% renewable power system studies

- Most look at hourly energy balances, and some include the increased electricity demand due to **electrification**, e.g., EU Fit for 55 study:
  - Electricity will cover 57% of final energy uses directly, plus 18% indirectly through H_2 and its derivatives
  - Electricity demand grows from 3,000 TWh to 6,800 TWh
  - Wind comprises 50% of the EU's electricity mix (total renewables 81%)
- **Transmission expansion** is common theme, e.g., U.S. MIT study:
  - Interstate coordination and transmission expansion reduce system cost from 135 $/MWh to 73 $/MWh
  - Cost reductions in solar, wind, and batteries lead to lowest electricity costs for systems with transmission expansion
  - Cost reductions for nuclear power or long-duration storage leads to greater electricity cost reductions for isolated systems

Pushing the limits: carbon neutrality

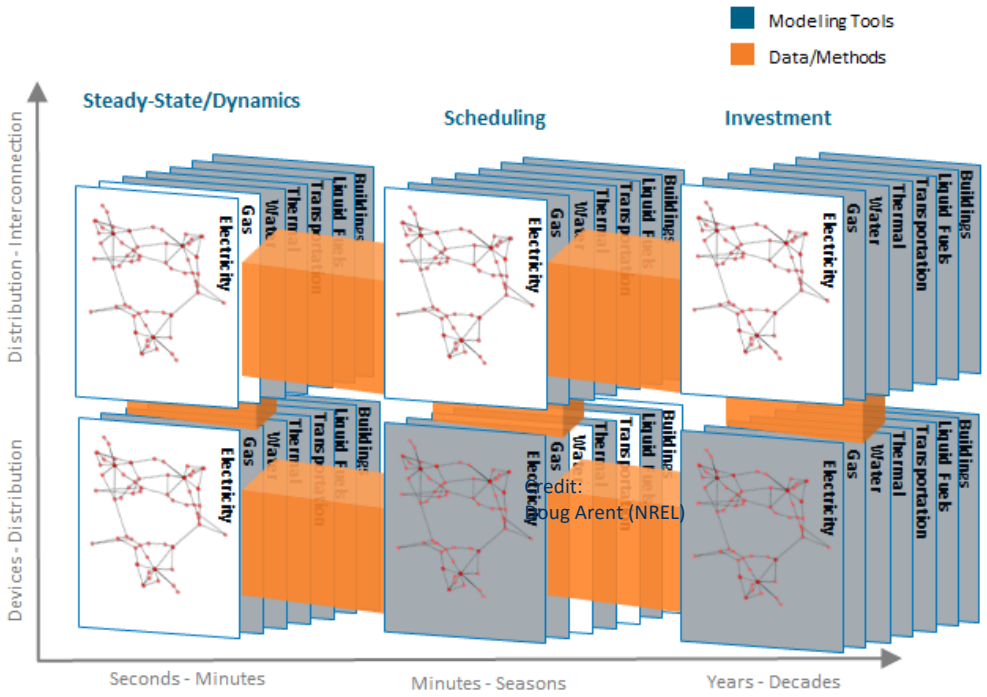
- Capture all energy sectors and their coupling
- Look at energy balances, not stability
- Some liquid fuels remain
  - Usually from biomass or electricity
  - Different applications, such as ammonia



Energy flow in the Danish energy system for 2035.
Source: Energinet

Pushing the limits: Tools

- Modelling complexity
  - VIBRES (variable inverter-based renewable energy source)
  - Need for higher resolution (temporal and spatial)
- Larger areas
  - Entire synchronous systems
- Integrated planning, operational, stability tools
- Cost versus risk
  - Price responsive demand
  - Differentiated reliability



NREL's Scalable Integrated Infrastructure Planning (SIIP) modeling framework.

Source: Doug Arent (NREL)

Thank You!!

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

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