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Wind Power Offshore: System Aspects and Grid Integration

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Contents

- System Integration of Wind Power
- Power System Operation with Wind Power
- Conclusions and Outlook

- Grid Integration of Offshore Wind Power
- Overview of Issues and Technologies
- Outlook

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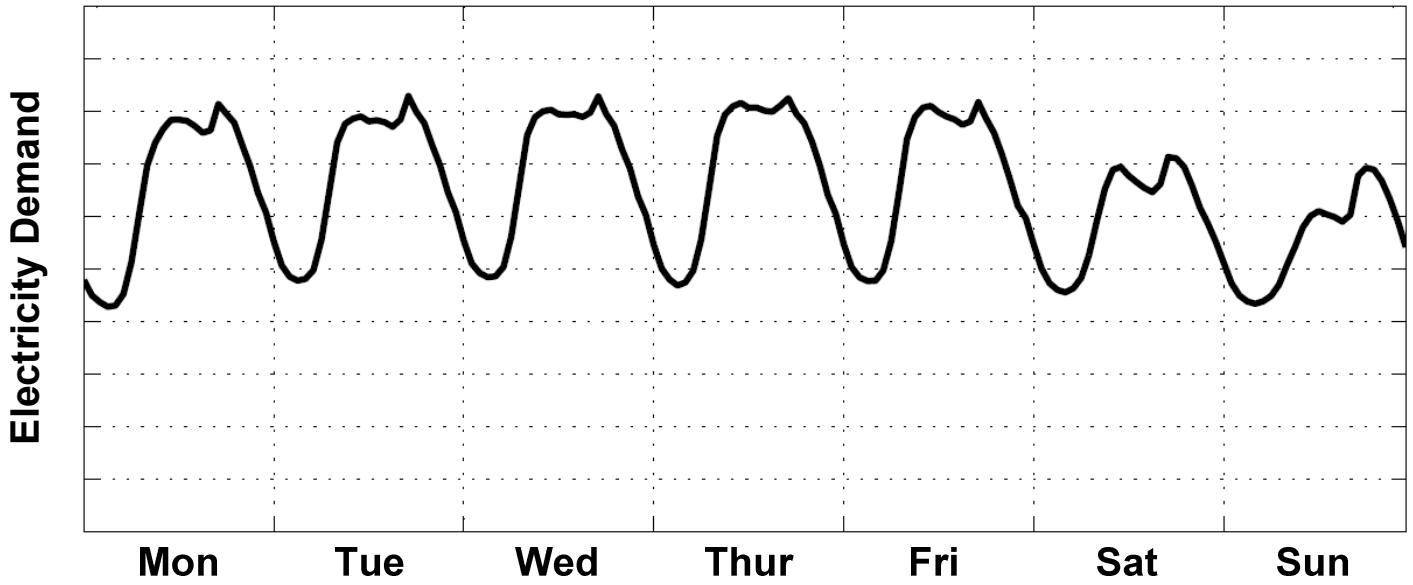
System Integration of Wind Power

- Power balance between generation and consumption
- Consumption varies during the day, week and year
- Operation of conventional units follows consumption

System Integration of Wind Power



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System Integration of Wind Power

- Power balance between generation and consumption
- Consumption varies during the day
- Operation of conventional units follows consumption

- Wind power introduces additional power variations and uncertainty into the system, and may reduce conventional capacity available for power balancing
- **How much wind power can the system handle?**
- Investigate consumption, wind power and aggregated variability
- Simulate power system operation with wind power
- Investigate possible solutions for power balancing

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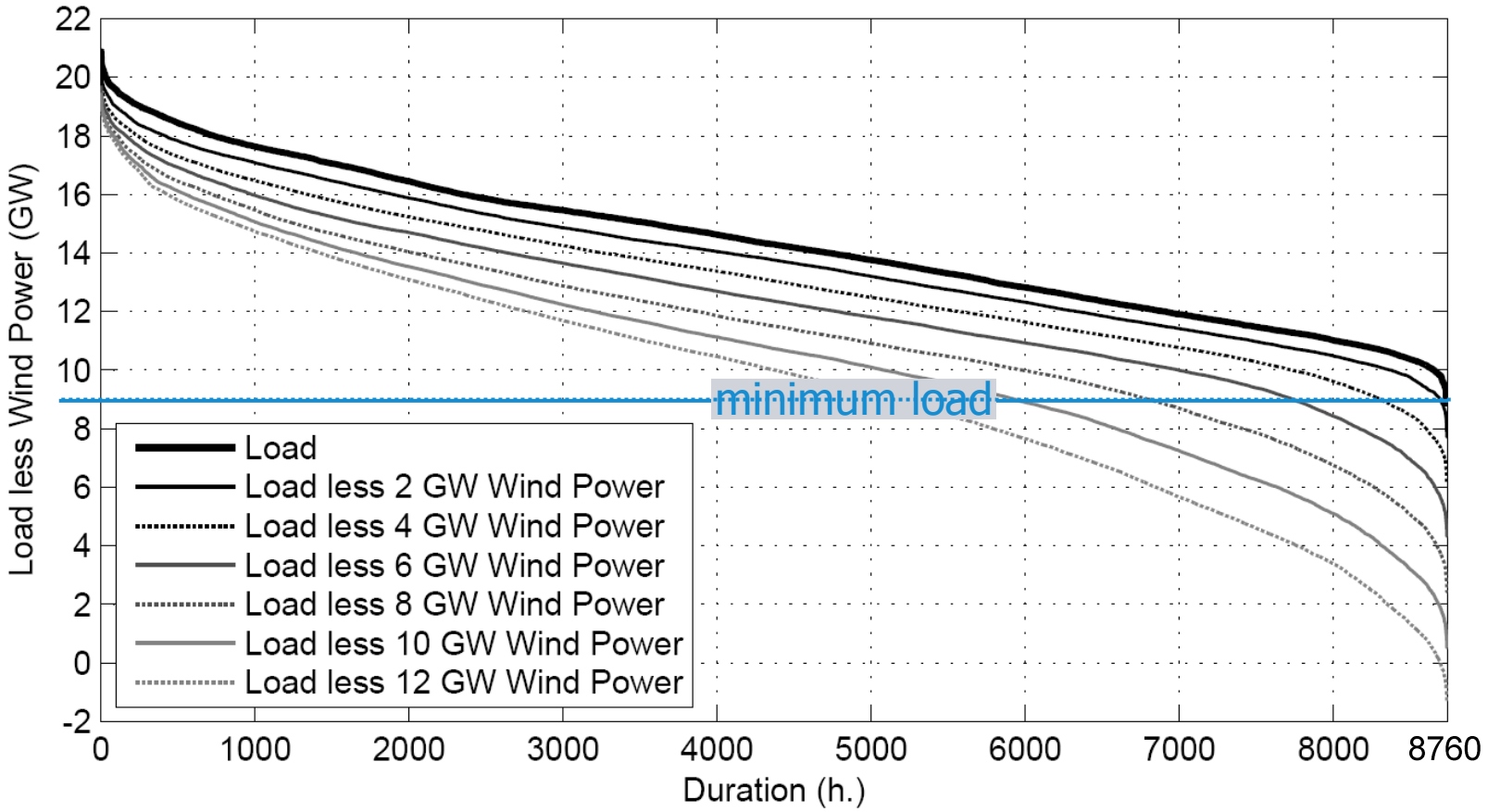
Annual Load Duration Curves



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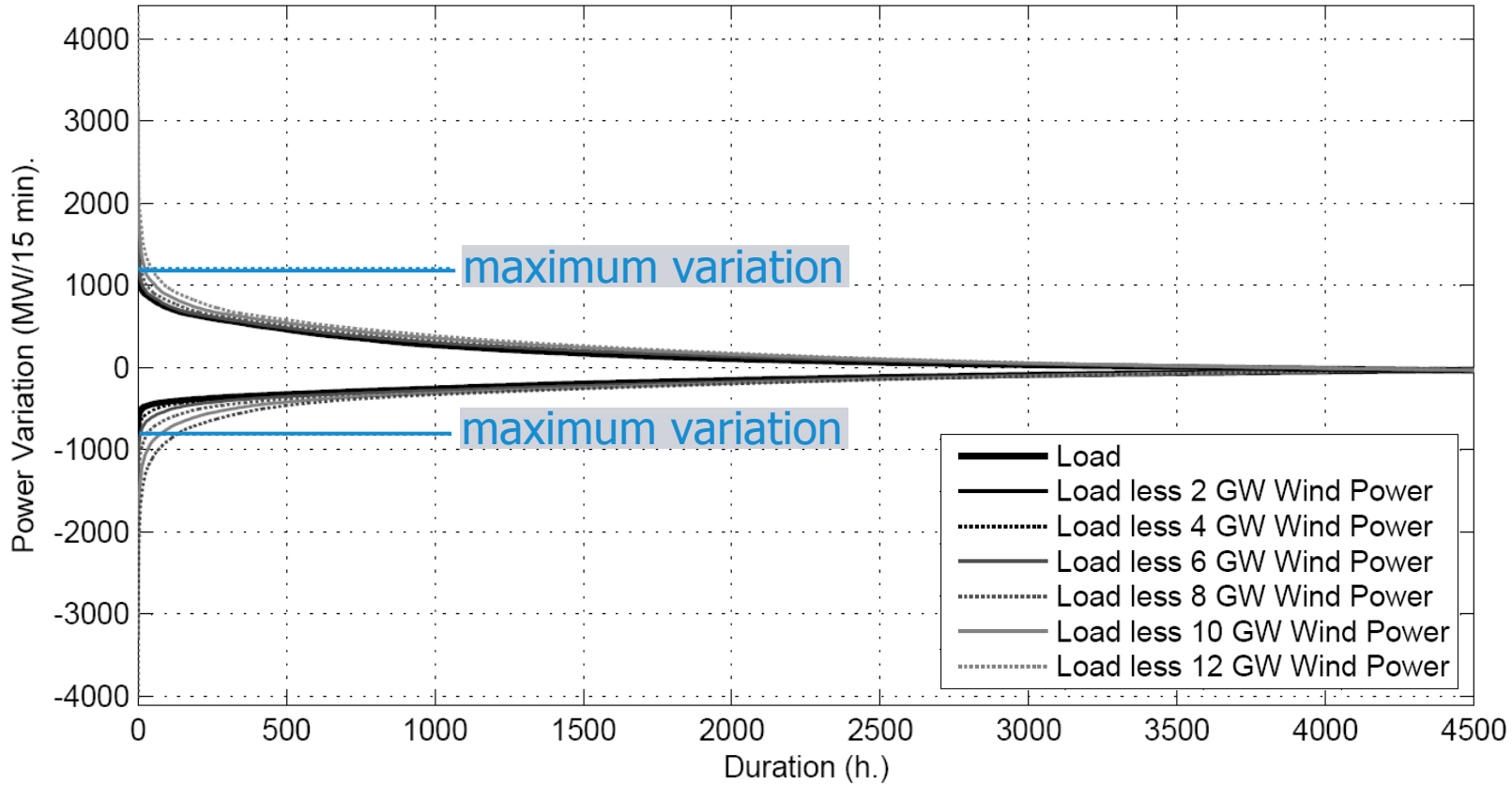
Annual Load Variability Curves



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Power System Operation with Wind Power

- Chronological simulation of power system operation
- 0-12 GW in the Netherlands, up to 1/3 of total consumption
- International exchange with B, D, F, UK and NOR
- 32 GW of wind power in Germany taken into account
- Consumption and wind power forecasts integrated into scheduling of conventional power plants
- Hourly updates of wind power forecasts
- International market gate-closure times
- Assessment of reliability, economic cost and CO_2-emissions of power system operation with and without wind power

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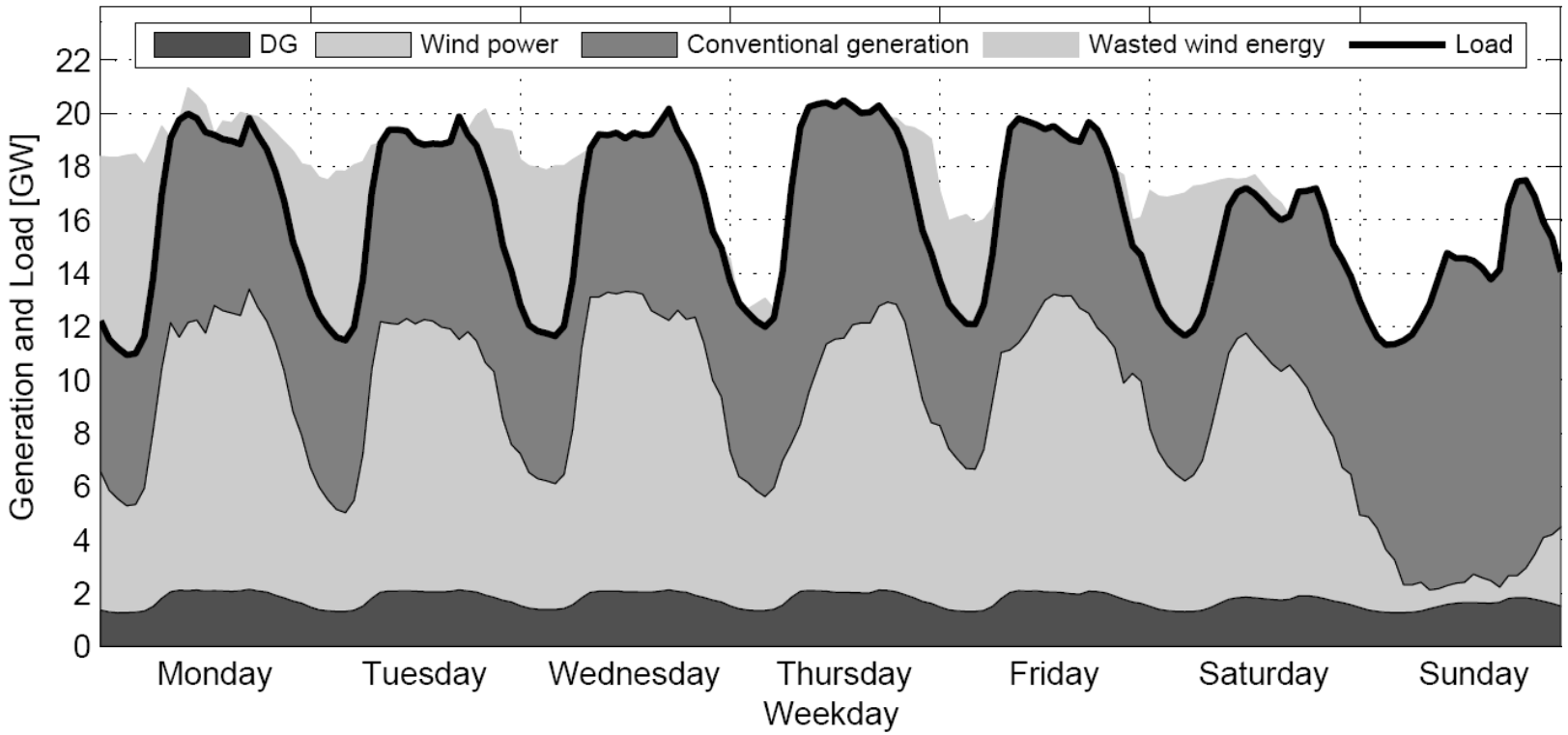
Power System Operation with Wind Power



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Conclusions and Outlook

- Wind power decreases operating costs and CO_2
- Variability and limited predictability of wind power present no technical barriers for integration
  - Conventional units provide sufficient flexibility
  - Updated wind power forecasts are important
- First integration bottleneck is minimum load problem (high-wind, low-load periods) due to must-run power plants
- Interconnection capacity, international markets and flexibility of existing conventional generating units (coal, CHP) are possible solutions, and are largely available
- Large-scale energy storage is technically unnecessary and economically unfeasible

Grid Integration of Wind Power

Previous research does not consider grid connection aspects

Generation moving away from load centers
- The need for long distance transmission

Gradual replacement of conventional generation
- Ensuring stable operation of the grid

Variability and partial predictability influences grid operation
- Changing power flows may unveil network bottlenecks

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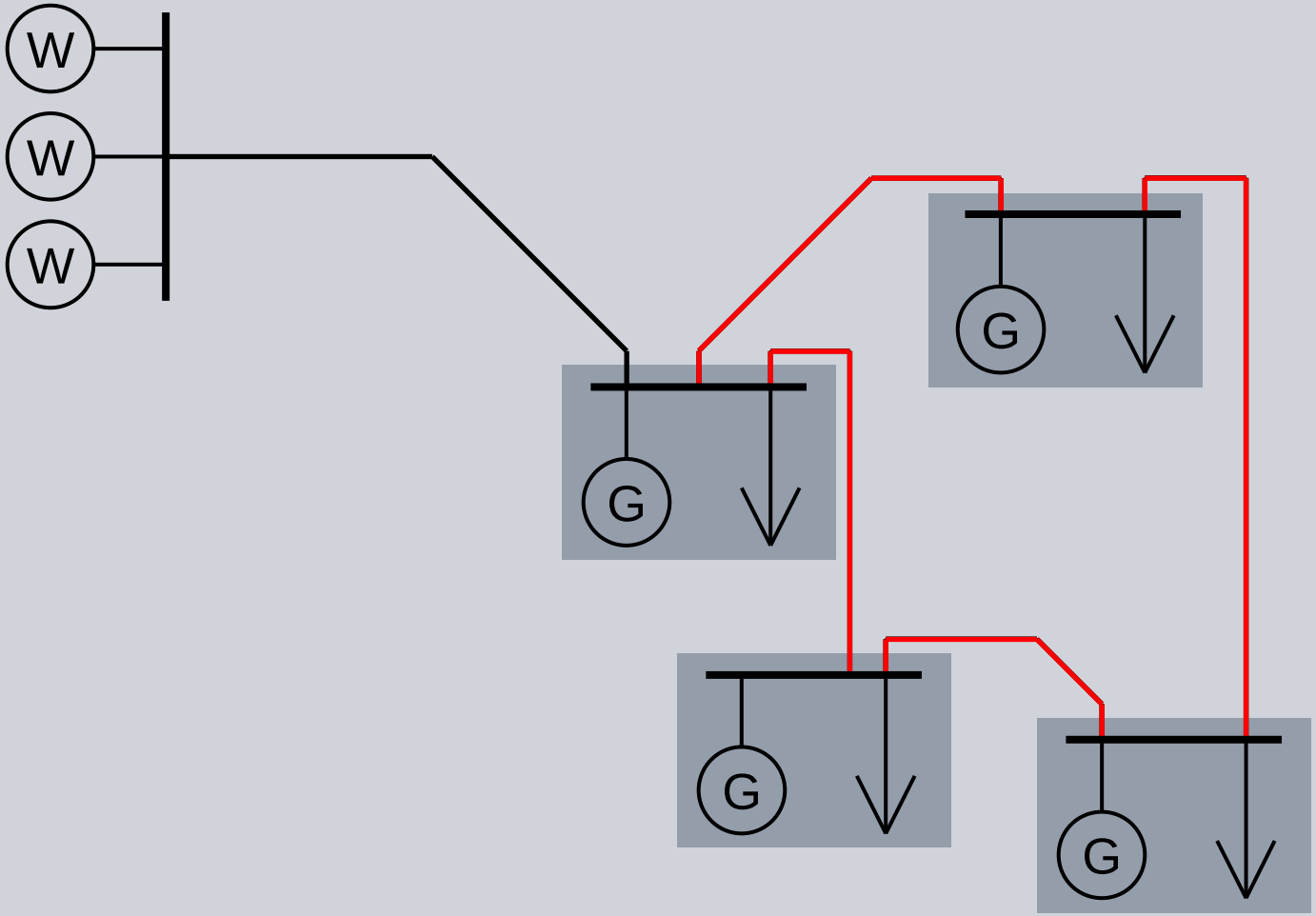
Development of Power Systems



Generation Moving Away from Load Centers
The Need for Long Distance Transmission

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Generation is moving from where the load is to where the resources are best → **offshore wind power**

Conventional AC cable transmission is limited both in transmission distance and power rating

HVDC transmission
- Current source converter
- Voltage source converter

Succes of wind integration depends on reducing €/MW!

Offshore Transmission System Utilization

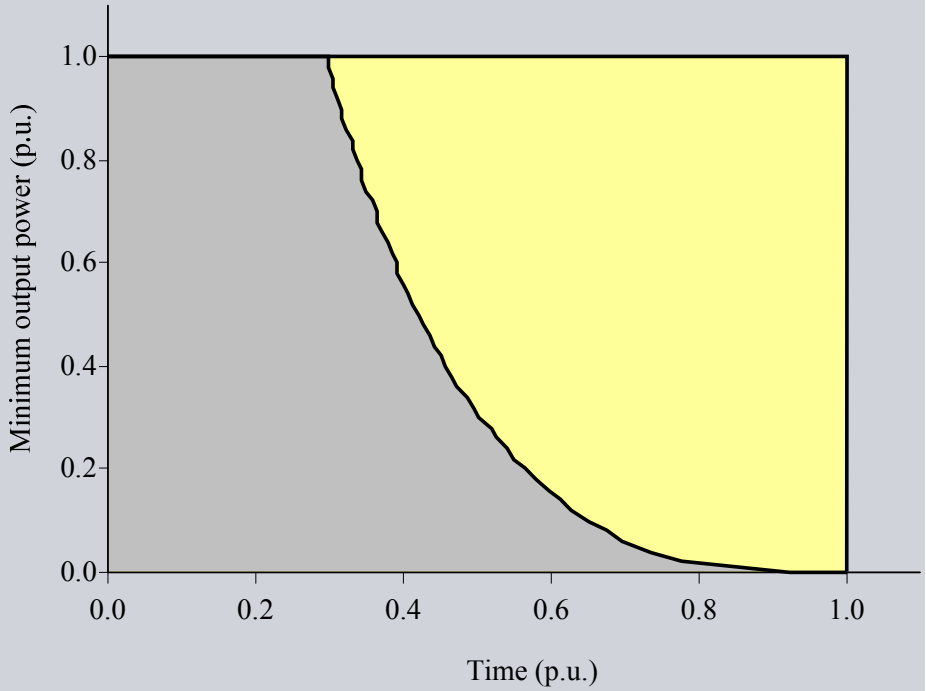
Capacity utilization is determined by wind stochastics and power curves

Dedicated transmission systems for wind experience 35–45% utilization

Increasing the utilizition of the transmission infrastructue reduces €/MW

Candidates:

- Trade (interconnection capacity)
- Oil & gas consumers
- Other RES



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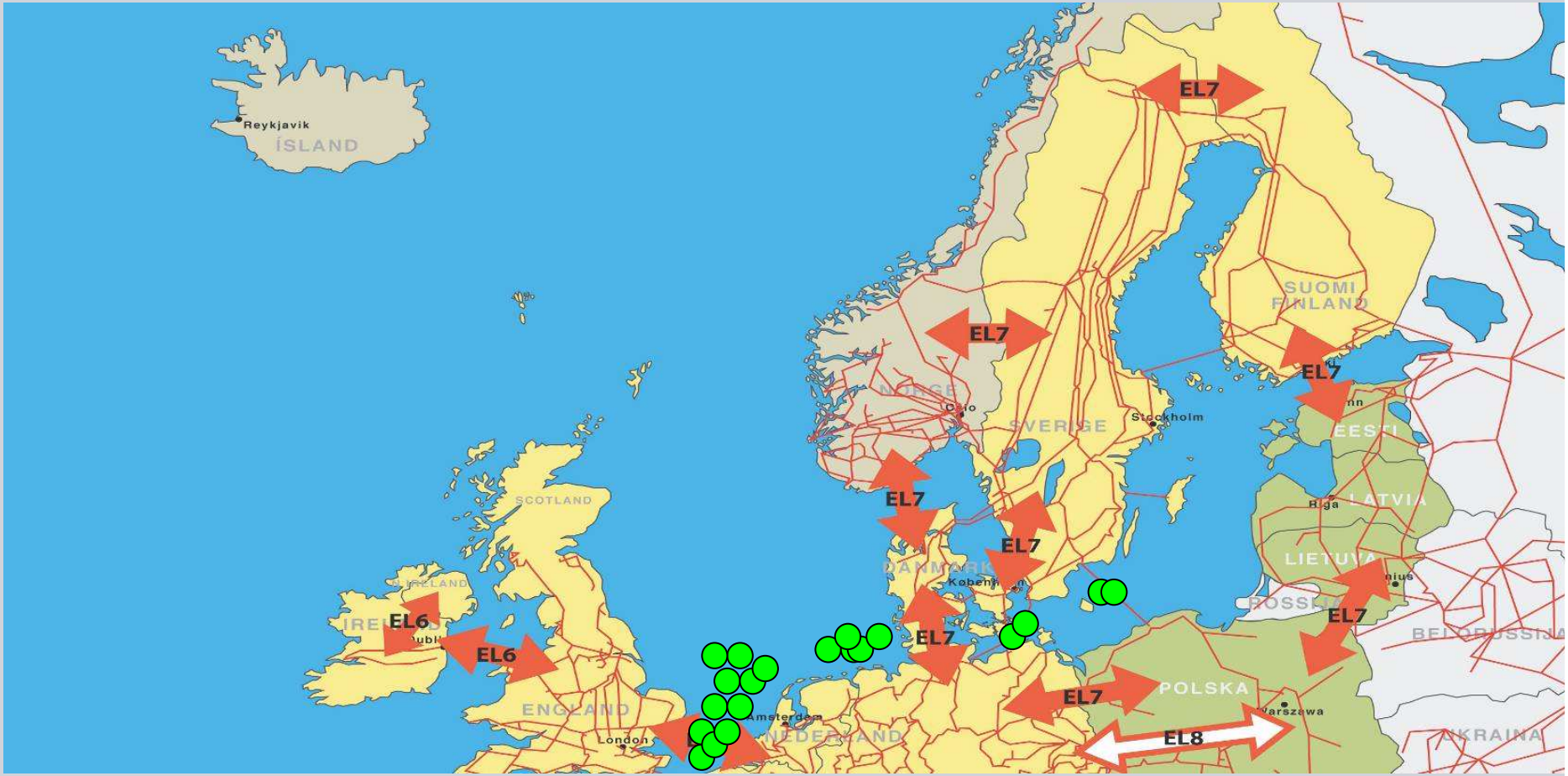
European Interconnection Capacity



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Operational aspects

When the share of wind in the system increases, we should carefully consider the effects on stable and secure operation:

- Generators with power electronics
  - inertial response
  - fault ride-through
  - reactive power support
- HVDC connections, fault ride through
- Power deficit caused by a single contingency (now 1300 MW)

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Variability and limited predictability

Besides the system integration aspects, variability and limited predictability will have influence on:

- Overloading of transmission lines
- Uncontrolled power flows (“Loop flows”)
- Stability

Mitigating measures:

- Power flow control (dispatch, phase-shifting transformers, FACTS)
- Market organization (gate-closure times)

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Conclusions and Outlook

From a system perspective, large-scale integration of wind power is well possible.

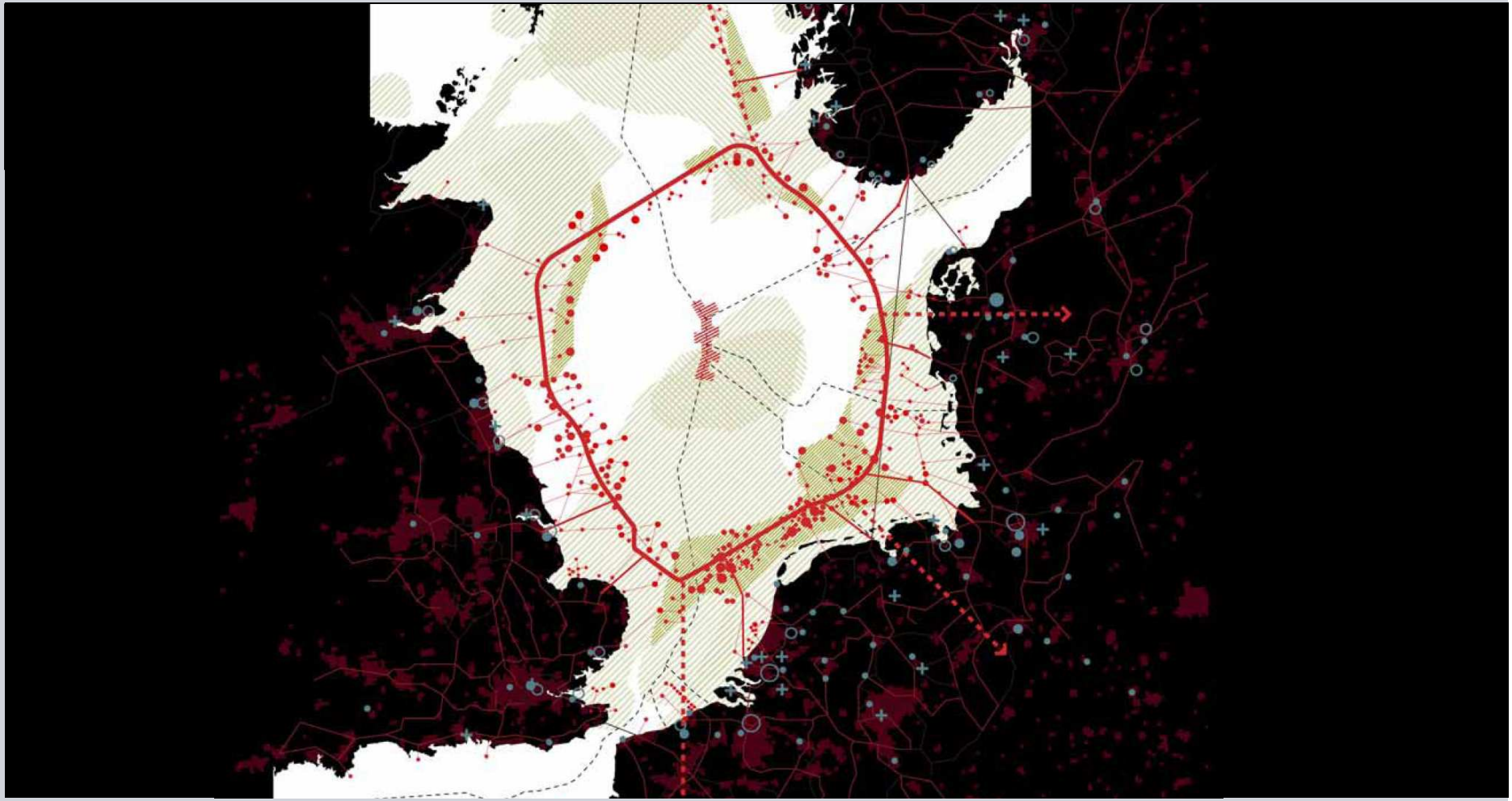
The transmission system puts constraints on the amount of wind that can be integrated:

- Limited capacity of transmission lines
- Influence on power flows
- Reduced inertia

Large-scale, remote (offshore) wind generation requires new transmission technologies (e.g. HVDC). These can be further developed to have similar behavior as conventional generation.

Reducing the €/MW ratio is the main driver.

May the future look like this?



Source: *Zeekracht: Deltaplan voor duurzame energie van de noordzee*, Natuur en Milieu, April 2008

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Thank you for your attention!

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