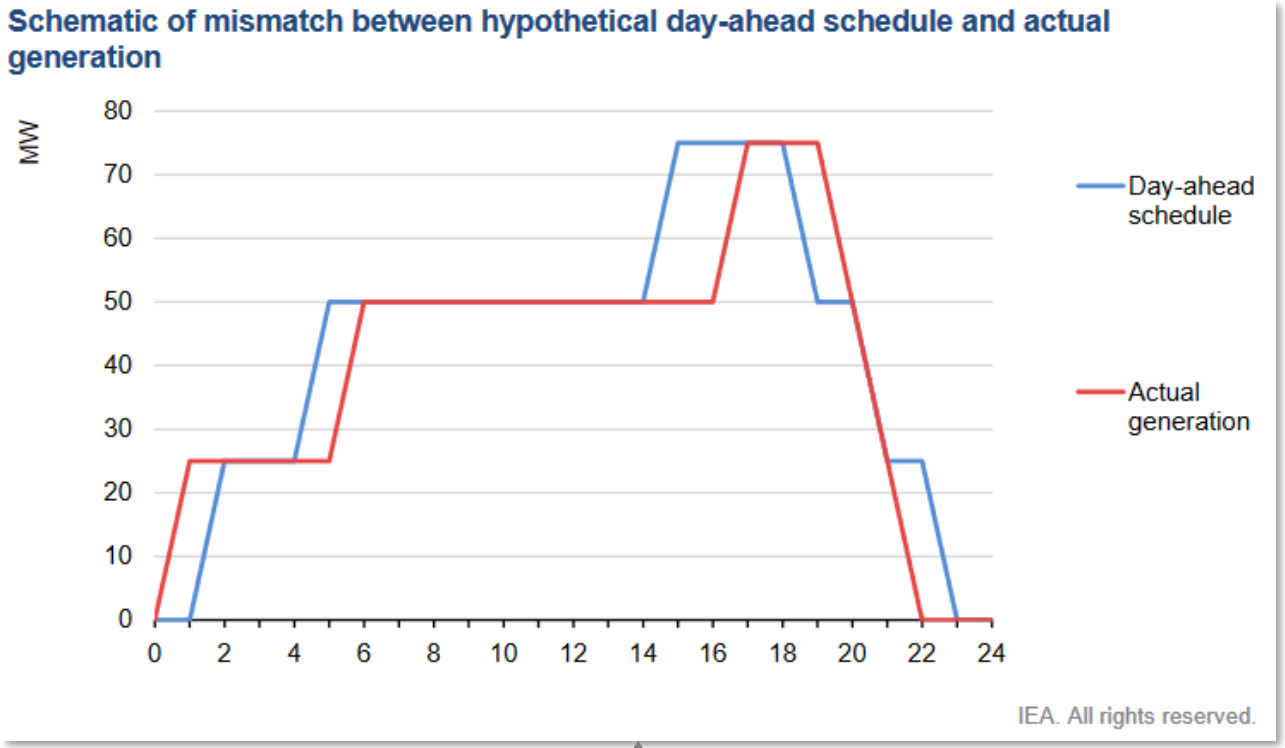
Evaluating the Impact of Weather Forecast Uncertainty in Power Systems Management

Hauke Bents, Lüder von Bremen, Bruno Schyska, Clara Buller

German Aerospace Center (DLR), Institute of Networked Energy Systems, Oldenburg, Germany

Motivation



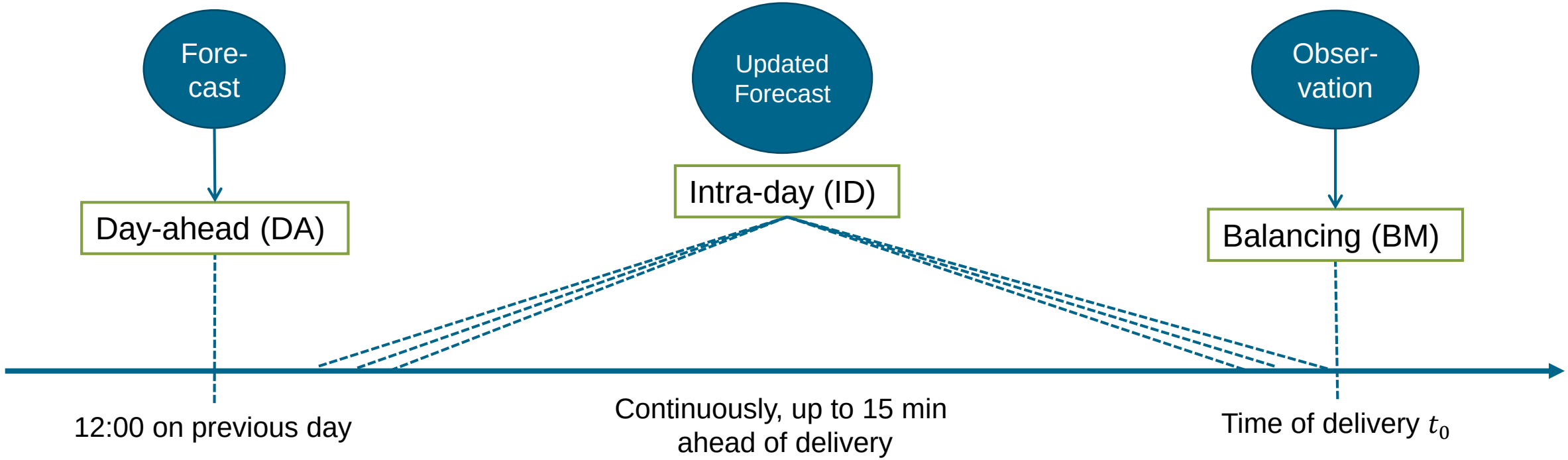
Flexibility to correct for errors
→ **What is the best way to schedule?**

(1) IEA, “Electricity security matters more than ever”, in *Power Systems in Transition*, Paris: IEA, 2020. https://www.iea.org/reports/power-systems-in-transition
(2) R. J. Bessa et al., “Towards Improved Understanding of the Applicability of Uncertainty Forecasts in the Electric Power Industry”, *Energies*, vol. 10, 1402, 2017. doi.org/10.3390/en10091402

Structure

- 1. Power Dispatch Clearing & Toy Network
- 2a. Sensitivity of power dispatch to the share of flexible generators
- 2b. Benefit of including short-term forecast updates
- 3. Conclusion

Power Dispatch Clearing



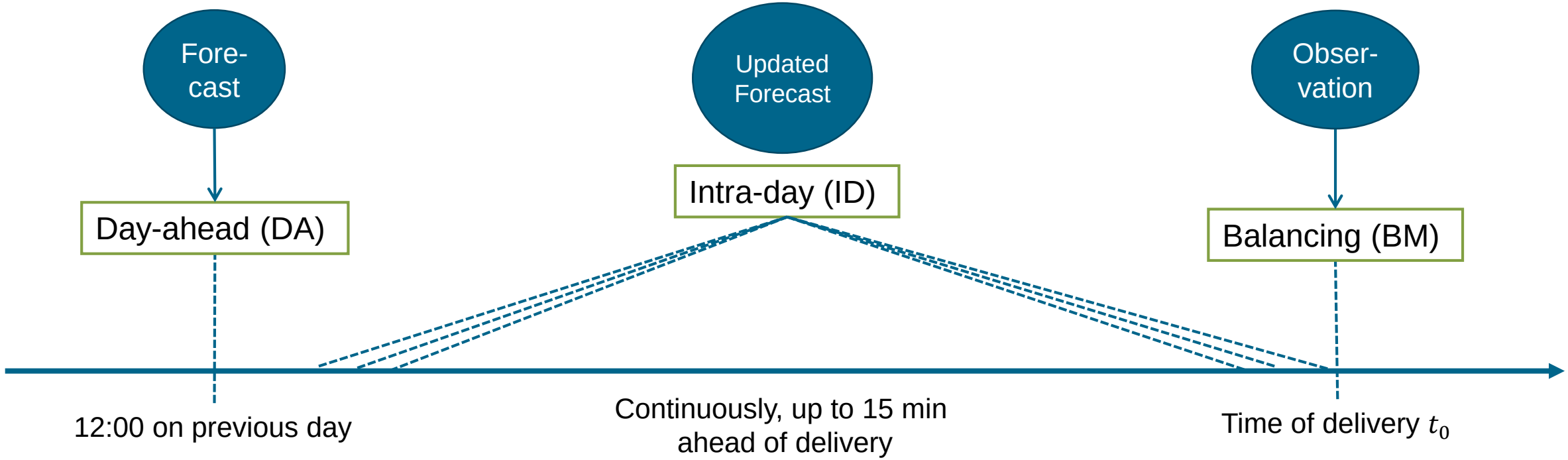
Determine **initial schedules/dispatch** of generation

Refine schedules with updated forecasts

Balance deviation between scheduled generation and demand

(3) J. M. Morales et al., “Electricity market clearing with improved scheduling of stochastic production”, *European Journal of Operational Research*, vol. 235, pp. 765-774, 2014. doi.org/10.1016/j.ejor.2013.11.013

Power Dispatch Clearing



min Day-ahead Dispatch Costs

$$C_{Day-ahead} = c_{Fuel} \cdot P_{DA}$$

min Intra-day Correction Costs

$$C_{Intra-day} = 1.\mathbf{11} \cdot c_{\mathrm{Fuel}} \cdot P_{\mathrm{add}} + 0.\mathbf{98} \cdot c_{\mathrm{Fuel}} \cdot P_{\mathrm{reduce}}$$

min Balancing Costs

$$C_{Balancing} = 1.14 \cdot c_{\mathrm{Fuel}} \cdot P_{\mathrm{add}} + 0.97 \cdot c_{\mathrm{Fuel}} \cdot P_{\mathrm{reduce}} + \boldsymbol{c_{\mathrm{Shed}} \cdot P_{\mathrm{Shed}}}$$

(3) J. M. Morales et al., “Electricity market clearing with improved scheduling of stochastic production”, *European Journal of Operational Research*, vol. 235, pp. 765-774, 2014. doi.org/10.1016/j.ejor.2013.11.013

Five-bus toy network

- Network designed to capture **impact of high wind feed-in** onto transmission network
- Share of flexible generation capacity is changed per bus
  - Total conventional generator capacity constant
  - 22 GW conventional generators
  - 25 GW windfarms
  - 140 TWh of electricity demand per year
- Simulation in hourly resolution
- Evaluation of yearly aggregated values

Carrier		C (€/MW h)
conventional	OCGT	4.5
	Nuclear	2.6

Flexible generator

Table 1: Costs of conventional generators

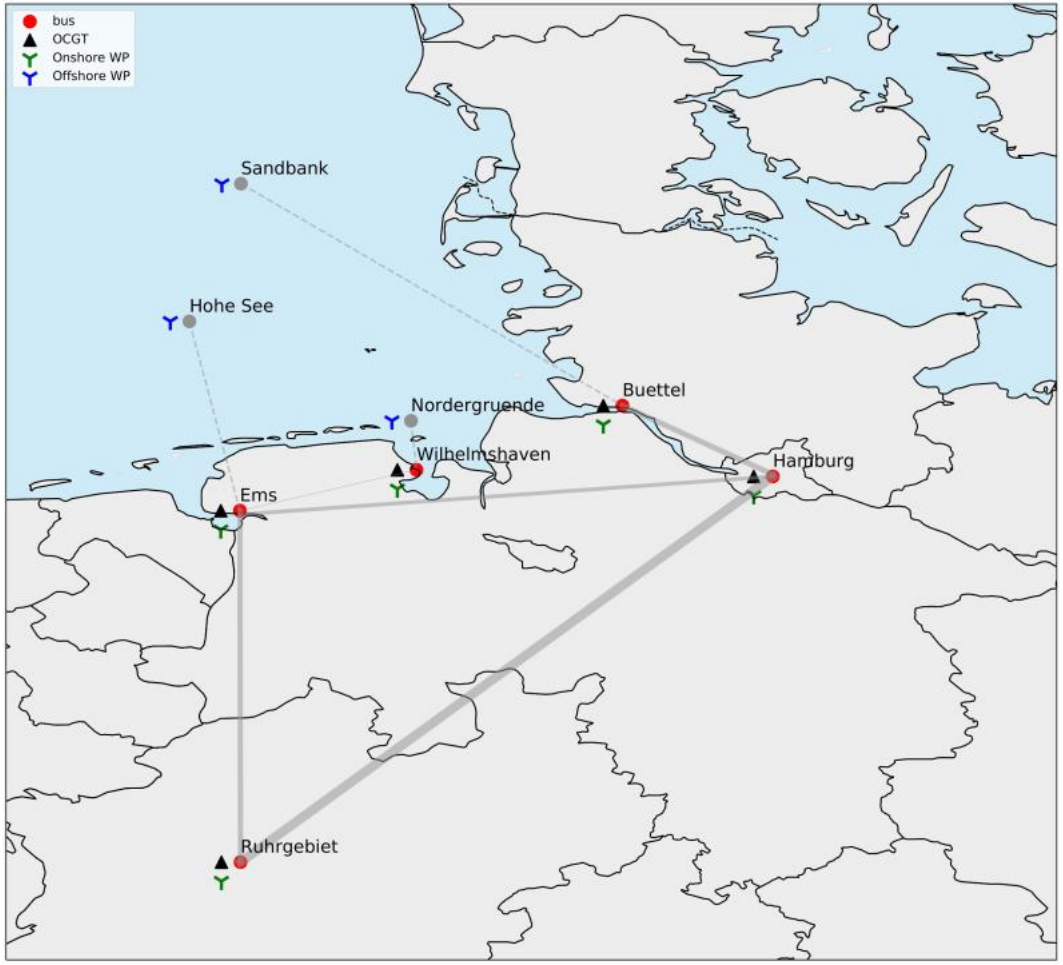
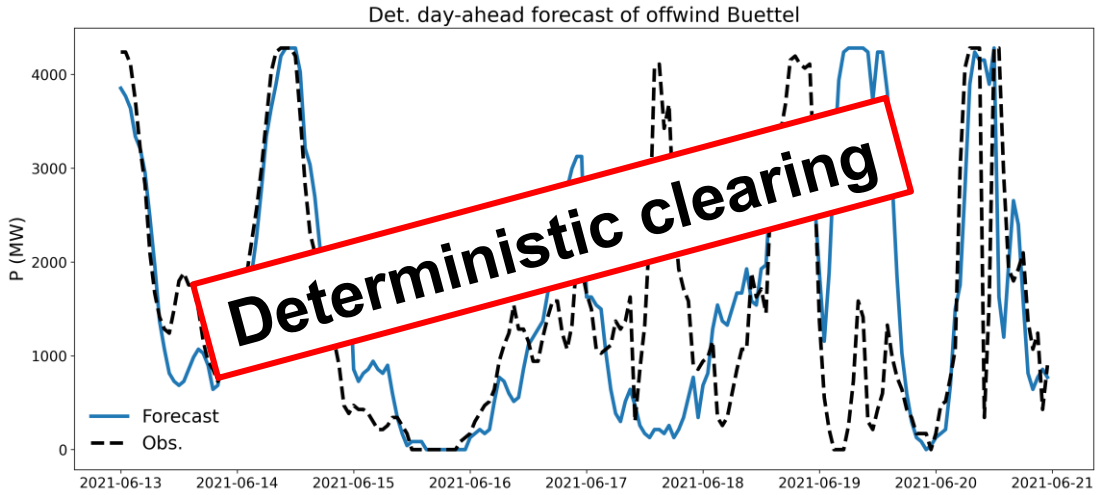


Figure 1: Topology of network. Demand hubs in Hamburg and Ruhrgebiet. Windparks in the North Sea. Congestion in the North.

Five-bus toy network



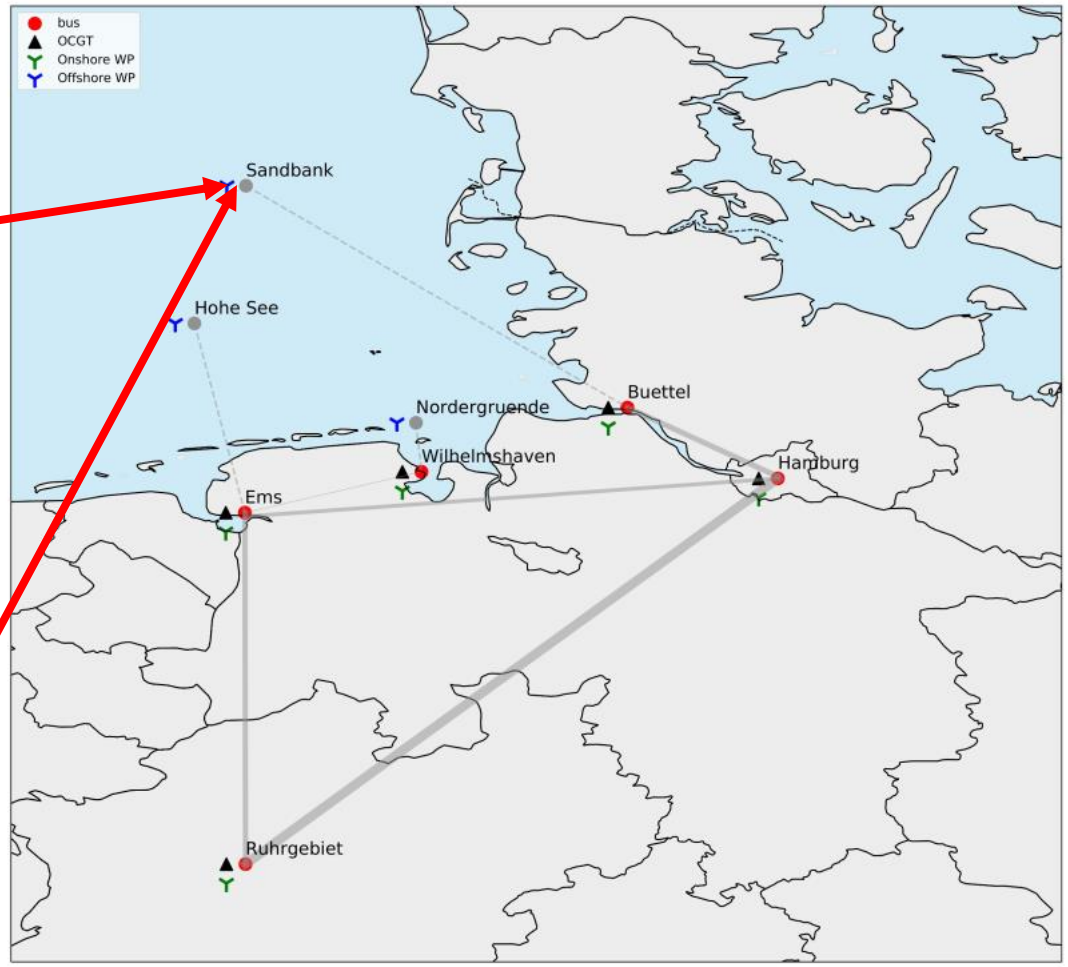
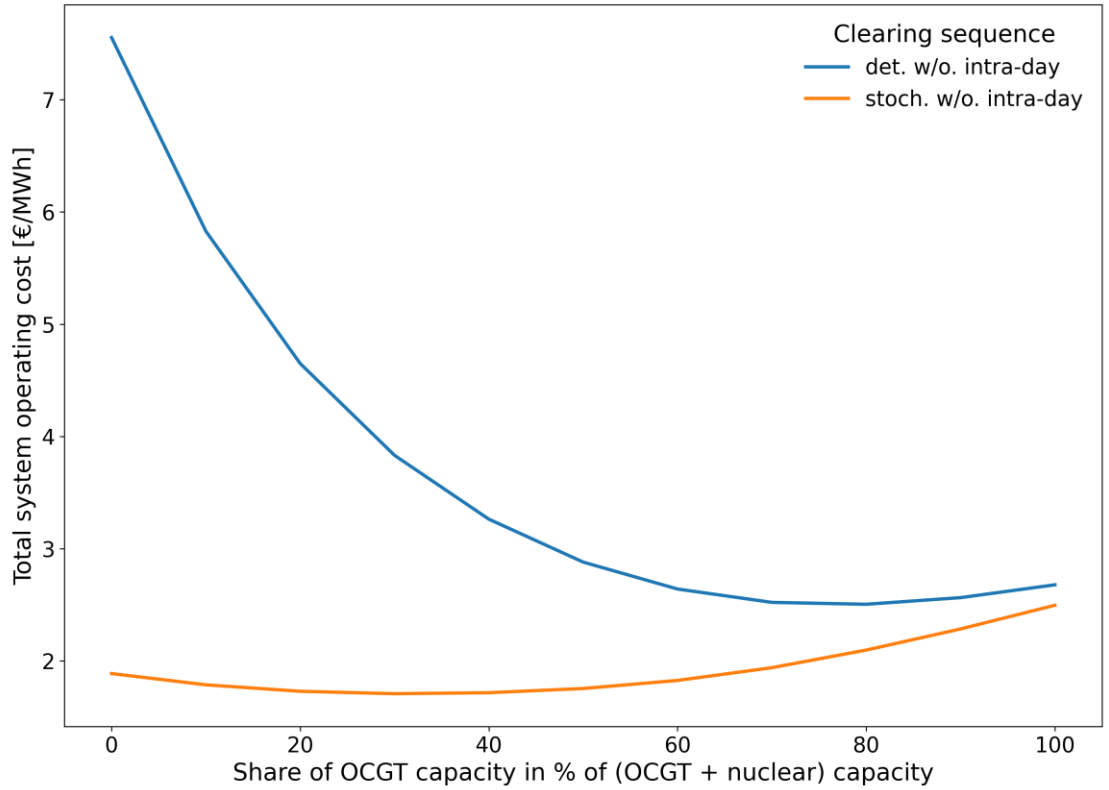


Figure 1: Topology of network. Demand hubs in Hamburg and Ruhrgebiet. Windparks in the North Sea. Congestion in the North.

Sensitivity of power dispatch to the share of balancing providers

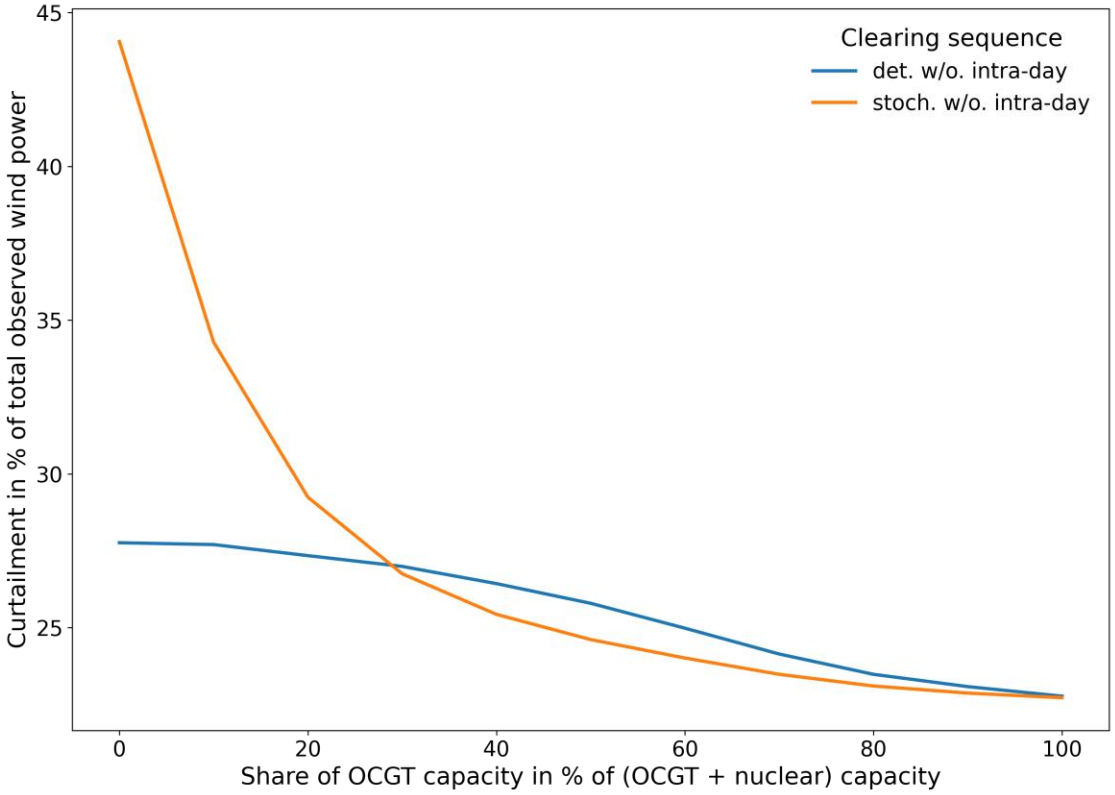
- Anticipating balancing actions reduces total system operating costs
  - Dispatch includes forecast uncertainty
- Cost-optimal system operation not under 100% flexible generators

$$C_{Total} = C_{Day-ahead} + C_{Balancing}$$



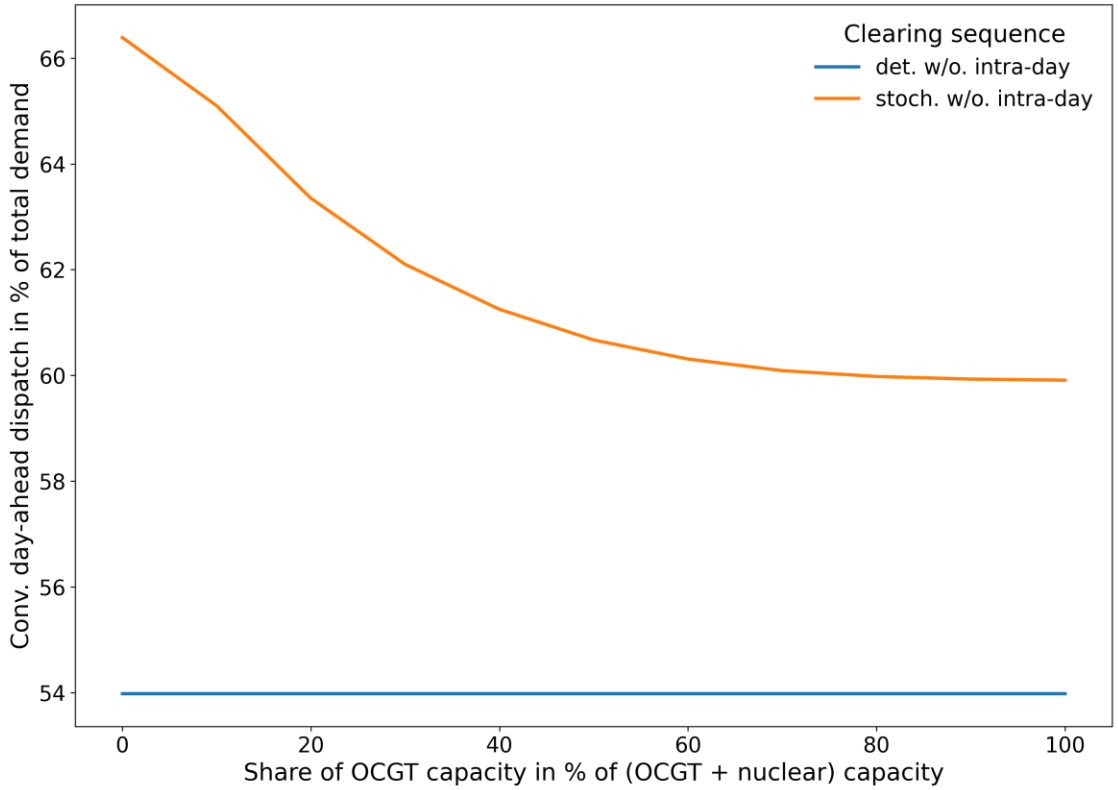
Sensitivity of power dispatch to the share of flexible generators

- Low flexibility leads to increased curtailment
  - Higher shares of conventional generators
- Deterministic clearing outperforms stochastic clearing for below 30% of OCGT
  - Stochastic clearing procures additional security in form of conventional generation

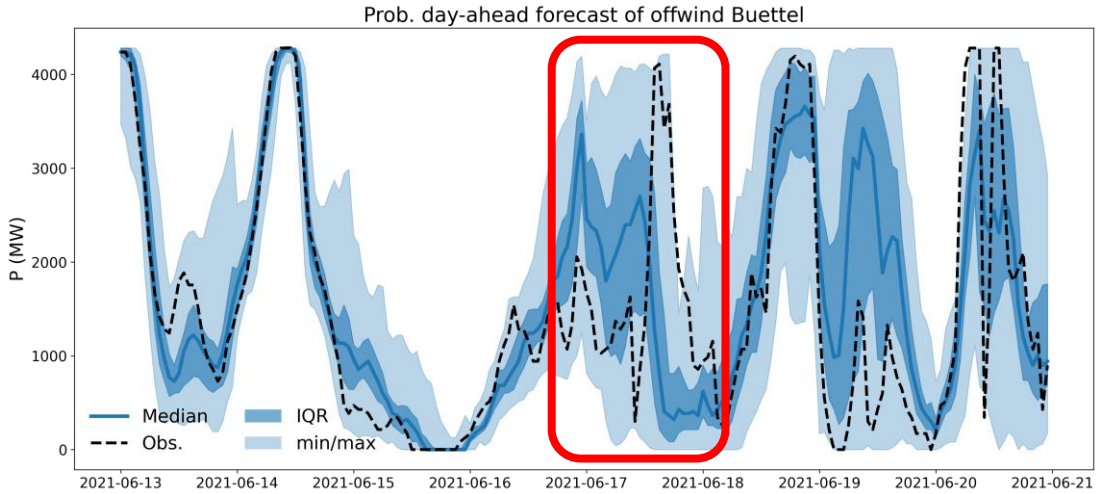


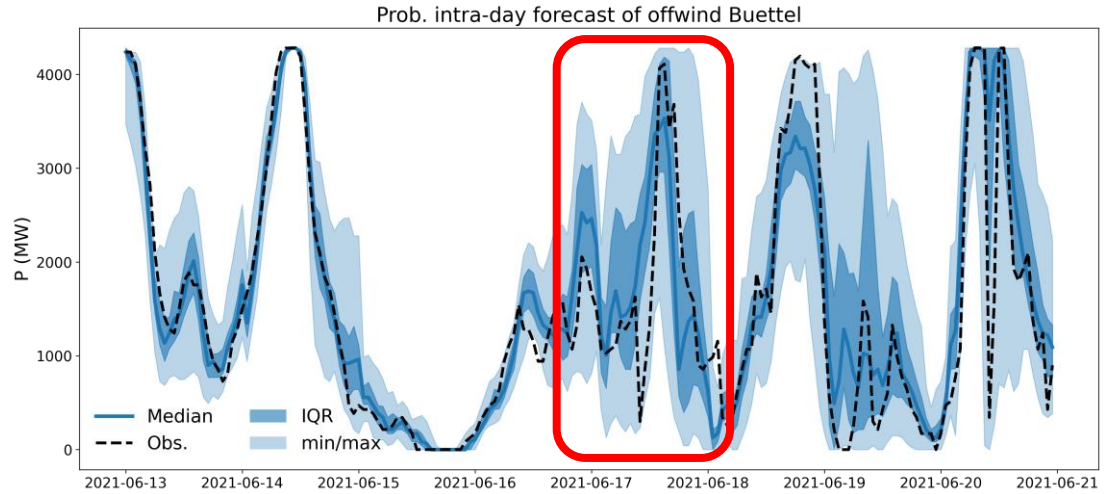
Sensitivity of power dispatch to the share of flexible generators

- Stochastic dispatch procures higher levels of conventional generator capacities
  - Low flexibility leads to additional scheduling of conv. generation
  - Increases flexibility at balancing stage where capacity is repurchased



Benefit of including short-term forecast updates





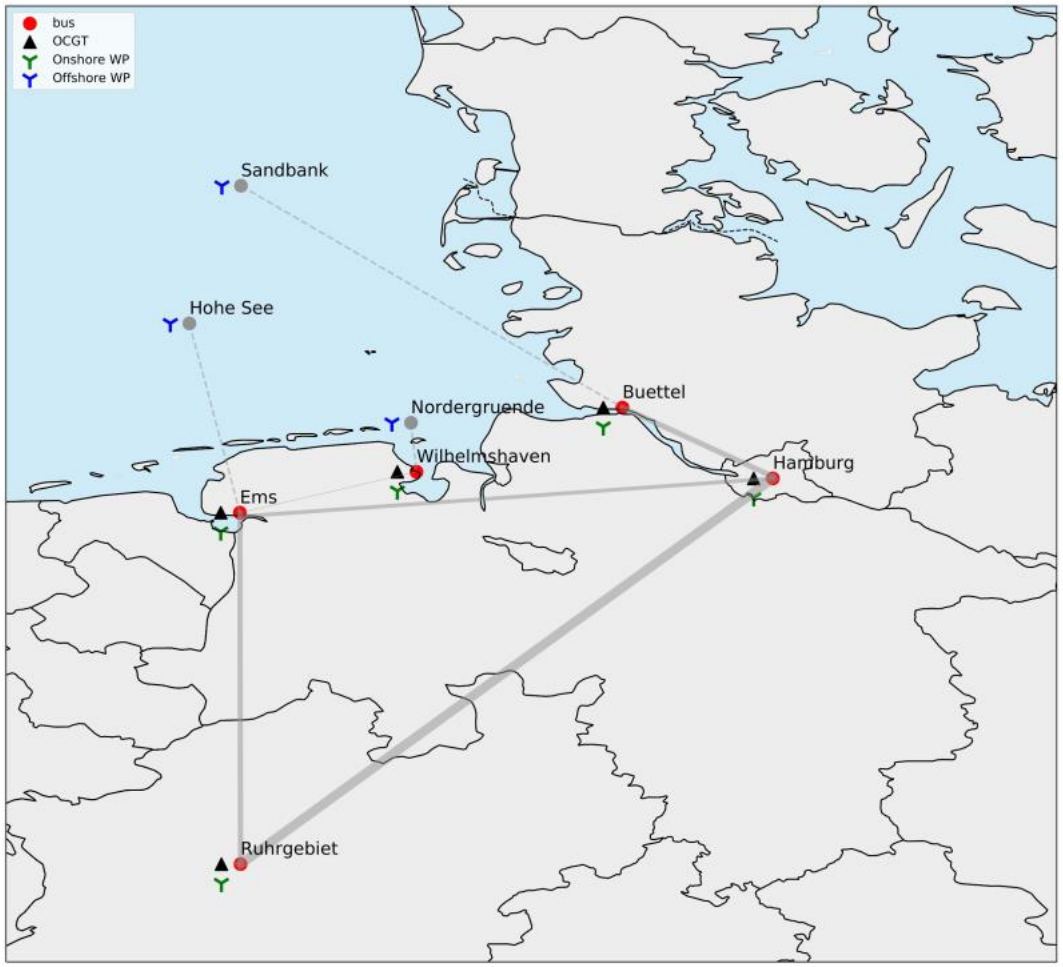
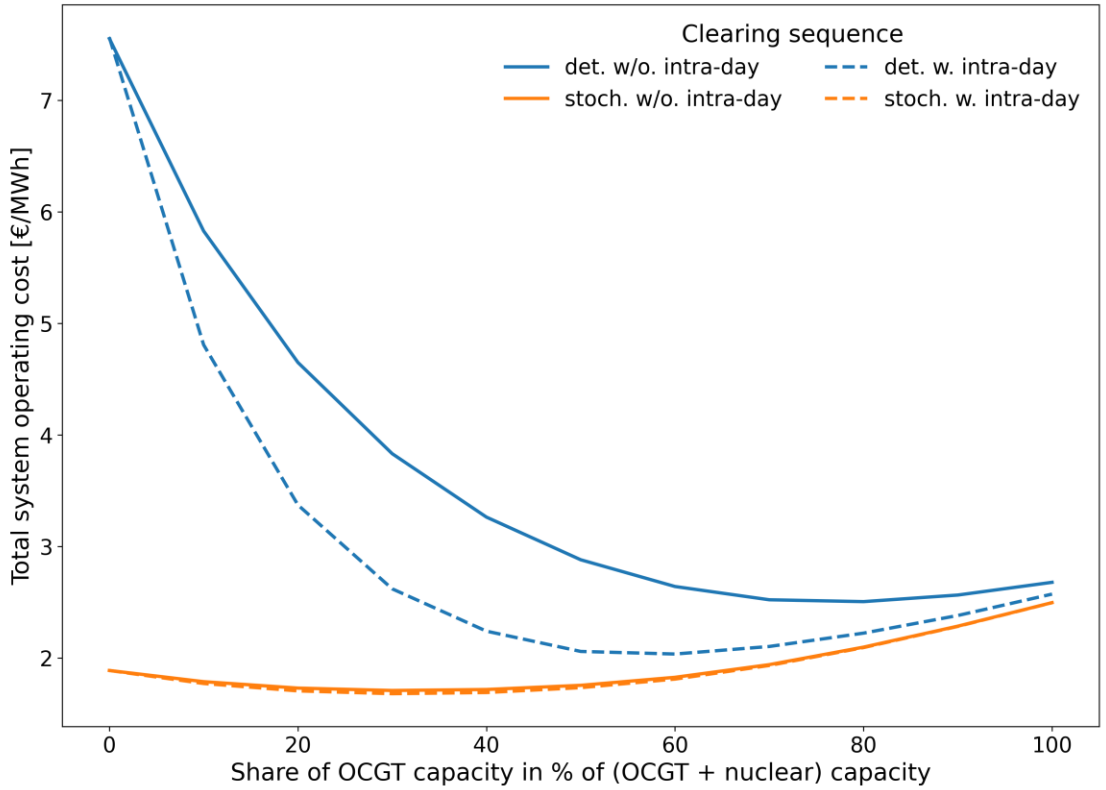


Figure 1: Topology of network. Demand hubs in Hamburg and Ruhrgebiet. Windparks in the North Sea. Congestion in the North.

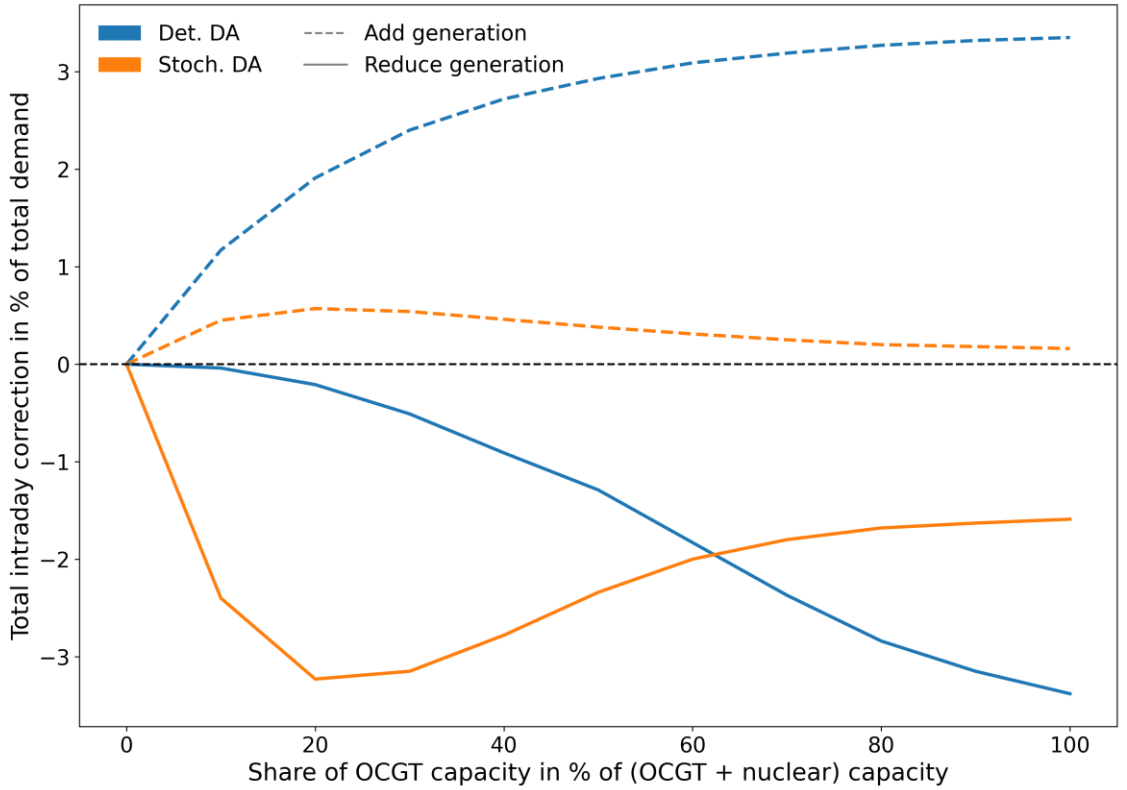
Benefit of including short-term forecast updates

- Intra-day corrections cheaper than balancing measures
- Strong impact on deterministic clearing due to …
  - Reduction of balancing actions
- Stochastic clearing already efficient



Benefit of including short-term forecast updates into clearing chain

- Deterministic clearing strongly adds generation
  - More flexible generation in the balancing stage
- Stochastic generation reduces generation at 30% of flexible generators
  - High amount of flexible generation is not required



Summary

- Studied a **novel clearing approach including forecast uncertainty** into unit commitment process
  - Based on a **probabilistic weather forecast** by ECMWF
  - Including **uncertainty reduces total system costs**
  - Deterministic clearing prone to forecast errors

- **Intra-day clearing** for short-term updates was included
  - Strongest cost reduction in deterministic clearing at medium flexibility shares
  - Cost reduction on stochastic clearing small

THANK YOU!

Backup: Linear optimized power flow

	Conventional:	Stochastic:
Day-ahead (DA) Market	***min*** Day-ahead Dispatch Costs	***min*** Day-ahead Dispatch Costs + Expected Balancing Costs
	$\min_{g,g^{+/-}} \sum_{n,s} (C_{n,s} g_{n,s,t})$	
Intra-day (ID) Market		***min*** Intra-day Correction Costs + Expected Balancing Costs
		$\min_{g^{+/-},s} \varrho \cdot \left(\sum_{n,s} \left(C^{+}_{n,s} g^{+}_{n,s,t} + C^{-}_{n,s} g^{-}_{n,s,t} \right) \right) + \mathbb{E}_{\omega} \left[C^{\mathrm{BM}}_{\omega} \right]_t$
Balancing (BM) Measures		***min*** Balancing Costs
		$\min_{g^{+/-}} \sum_{n,s} \left(C^{+}_{n,s} g^{+}_{n,s,t} + C^{-}_{n,s} g^{-}_{n,s,t} \right) + \sum_{n,i} \left(C^{shed}_{n,i} s_{n,i,t} \right)$

(6) J. M. Morales et al., “Electricity market clearing with improved scheduling of stochastic production”, *European Journal of Operational Research*, vol. 235, pp. 765-774, 2014. doi.org/10.1016/j.ejor.2013.11.013

(7) T. Brown, J. Hörsch and D. Schlachtberger, “PyPSA: Python for Power System Analysis”, *Journal of Open Research Software*, Jan. 2018.

Backup: Conventional vs. stochastic limits

- Conventional day-ahead schedule **limits generation by deterministic forecast**

$$g_{n,s,t} \leq \tilde{G}_{n,s,t} \cdot \bar{G}_{n,s}$$

- Stochastic day-ahead clearing limits generation through **anticipating balancing scenarios** from probabilistic forecast

$$g^{+}_{n,s,t,\omega} - g^{-}_{n,s,t,\omega} \leq \tilde{O}_{n,s,t,\omega} \bar{G}_{n,s} - g_{n,s,t}$$

Backup: Linear optimized power flow

- **Nodal balancing** (i.e. Kirchhoff's current law) in conventional day-ahead

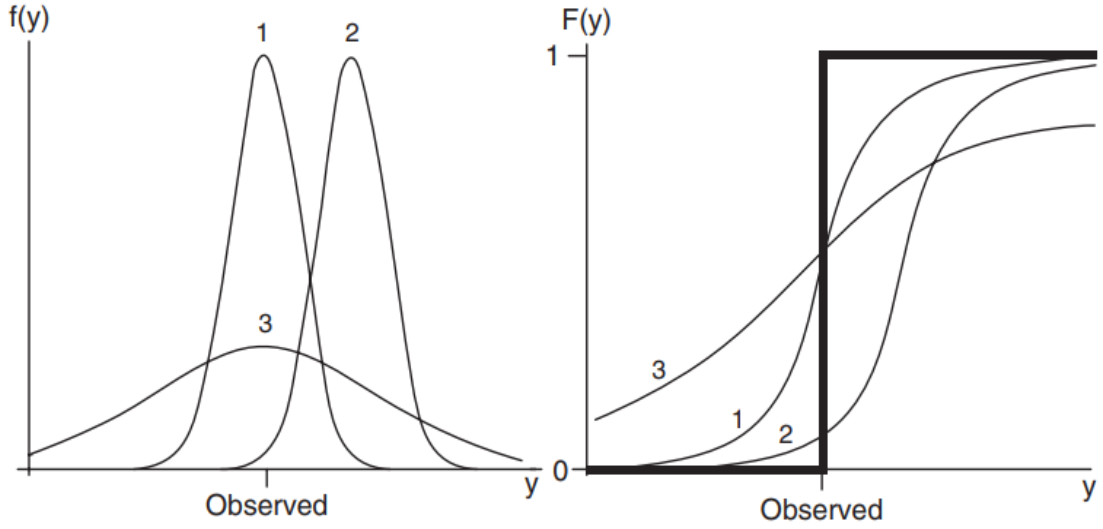
$$\sum_{s} g_{n,s,t} - \sum_{l} K_{n,l} f_{l,t} = \sum_{i} D_{n,i,t}, \ \forall n, t$$

- Nodal balancing in balancing stage

$$\sum_{s} \underbrace{\left(g^{+}_{n,s,t} - g^{-}_{n,s,t}\right)}_{\text{Balancing}} - \underbrace{\sum_{l} K_{n,l} f_{l,t}}_{\text{Power flow}} + \underbrace{\sum_{i} s_{n,i,t}}_{\text{Shedding}} = \underbrace{\sum_{i} D_{n,i,t}}_{\text{Demand}} - \underbrace{\sum_{s} G_{n,s,t}}_{\text{Generation}}, \ \forall n, t$$

Backup: Continuous ranked probability score

- The continuous ranked probability score (CRPS) measures how well an observation fits into a probability distribution (PDF or CDF)

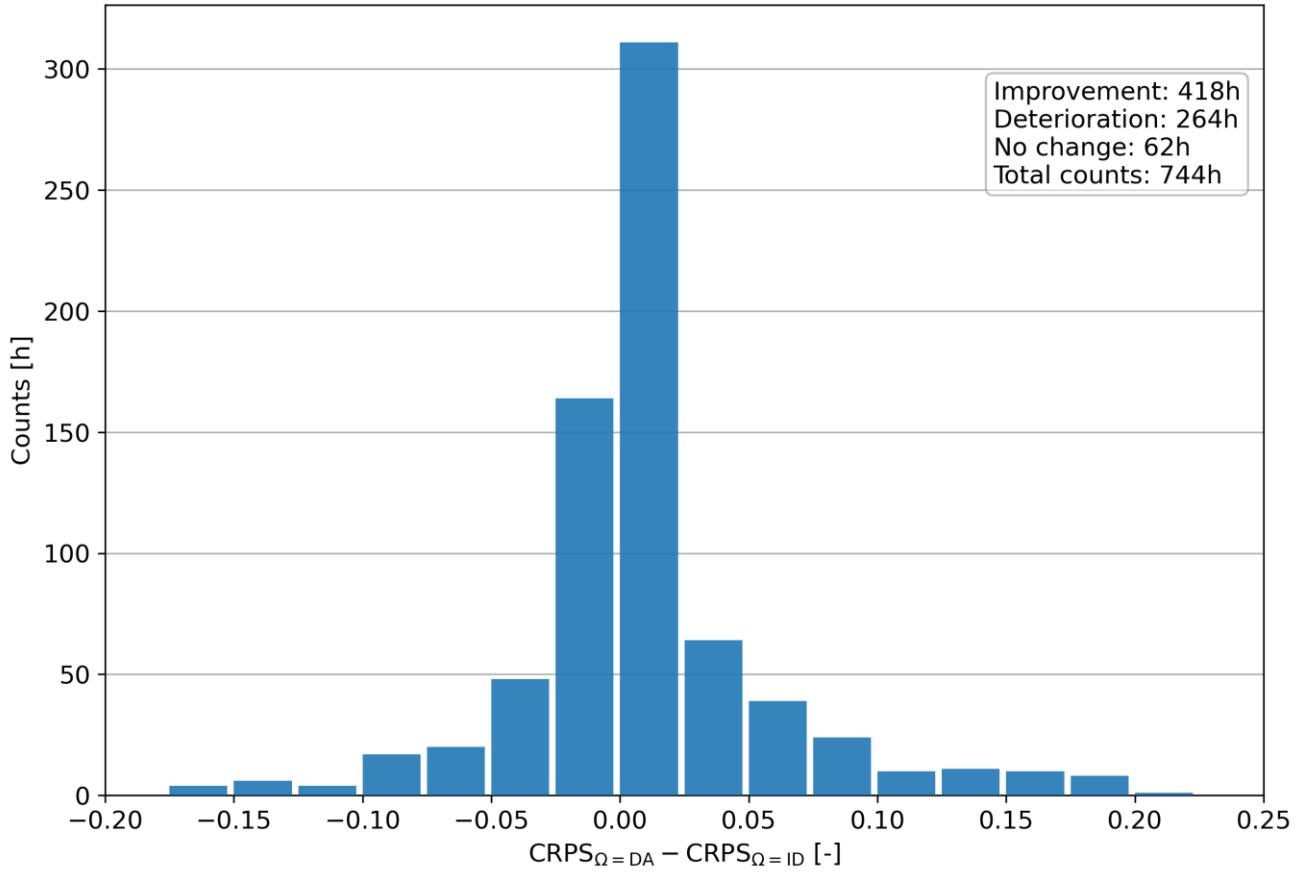


$$\mathrm{CRPS} = \int_{-\infty}^{\infty} [\mathrm{F}(y) - \mathrm{F}_O(y)]^2 \, \mathrm{d}y$$

(10) D. S. Wilks, “Forecast Verification”, in *Statistical Methods in Atmospheric Sciences*, 2nd ed., vol. 91, London: Academic Press, 2006, pp. 302f..

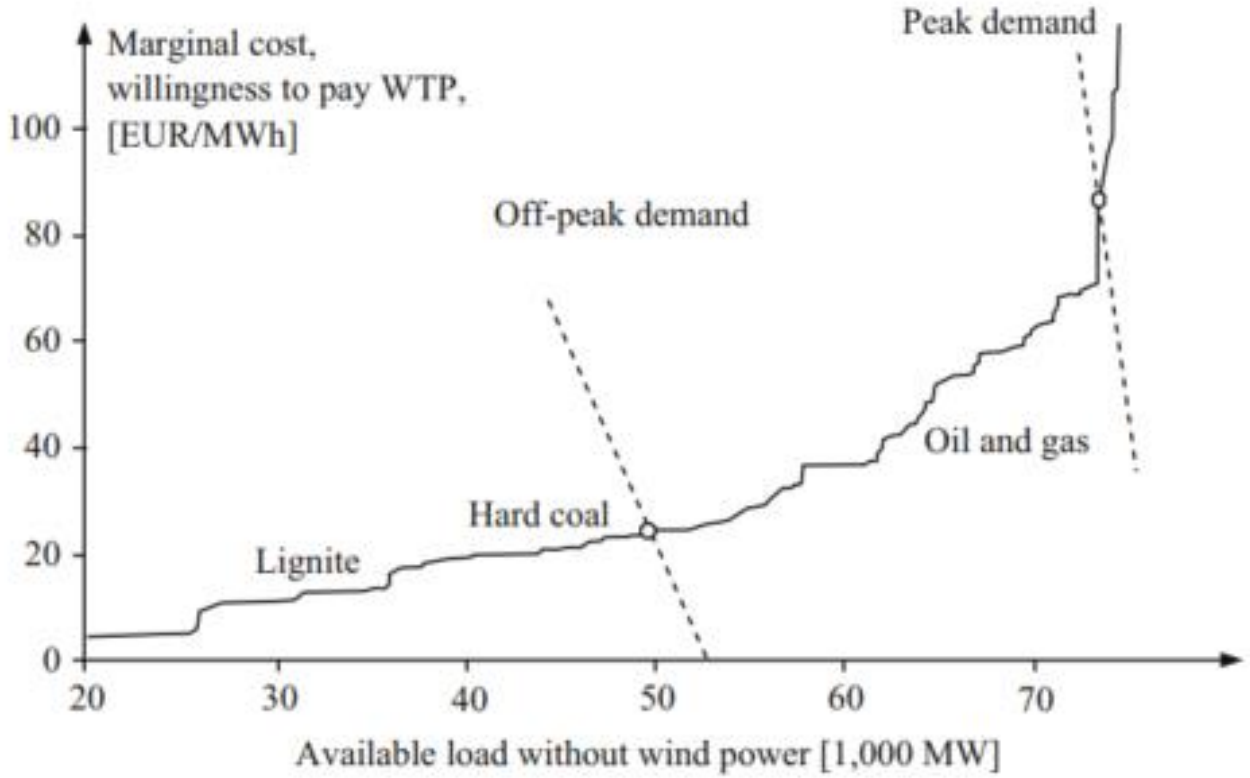
Backup: Distribution of Forecast Improvement

- ECMWF intra-day forecast deteriorated day-ahead forecast 35% of the time in March 2021



Backup: Merit Order

- **Merit order**: Expensive generators scheduled only when required



(14) P. Zweifel, A. Praktiknjo, G. Erdmann, “Markets for Electricity”, in *Energy Economics*, 1st ed., Berlin: Springer Nature, 2017, pp. 280.