Evaluating the benefit of probabilistic Lidar-based wind power forecasts in power systems management

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Presenting: Marion Schroedter-Homscheidt[1]

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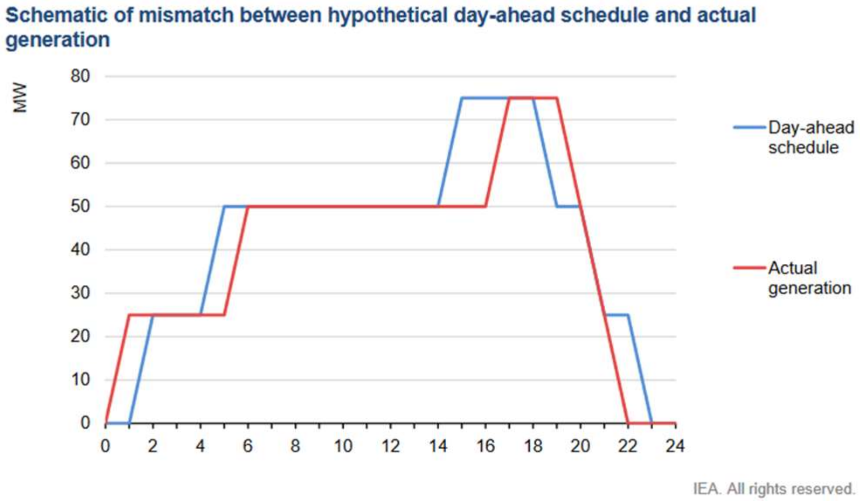
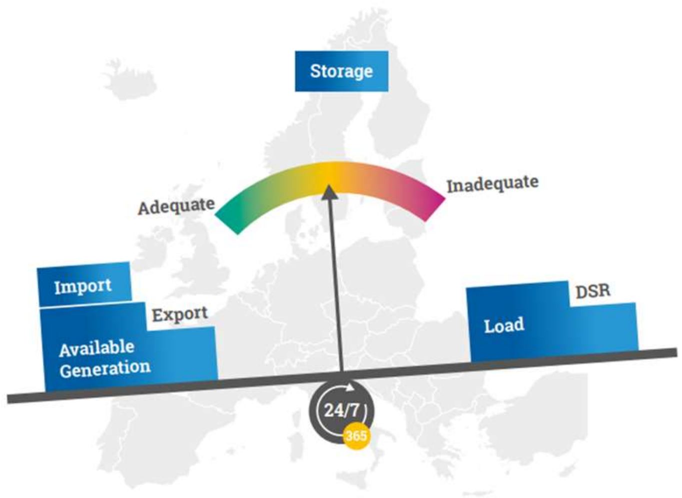
Uncertainty is inherent to the management of power systems

Planning the operation

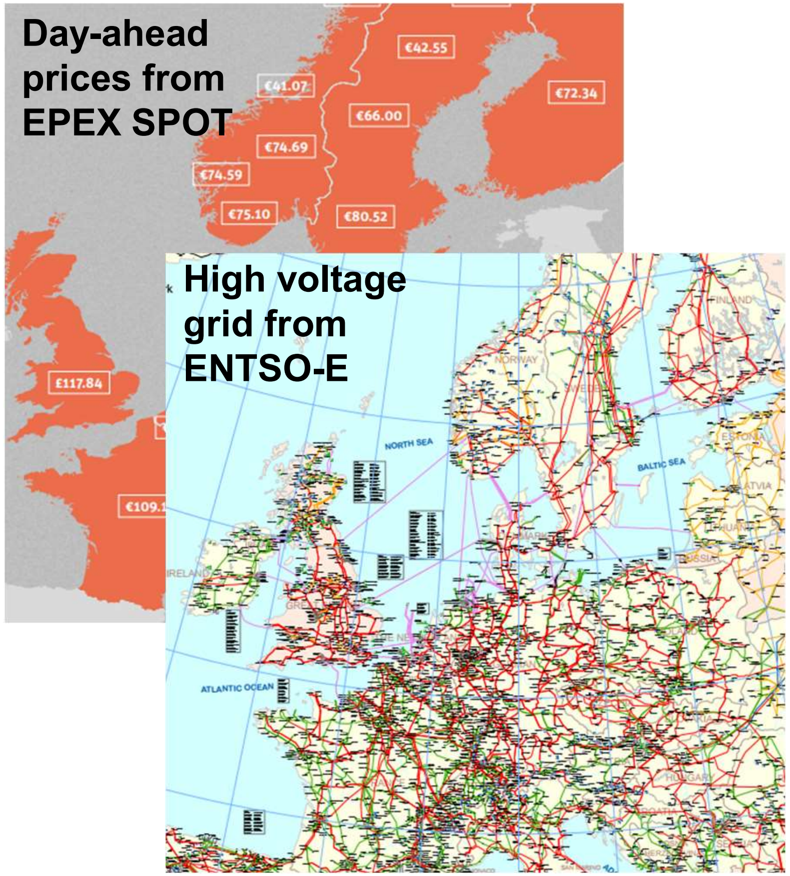


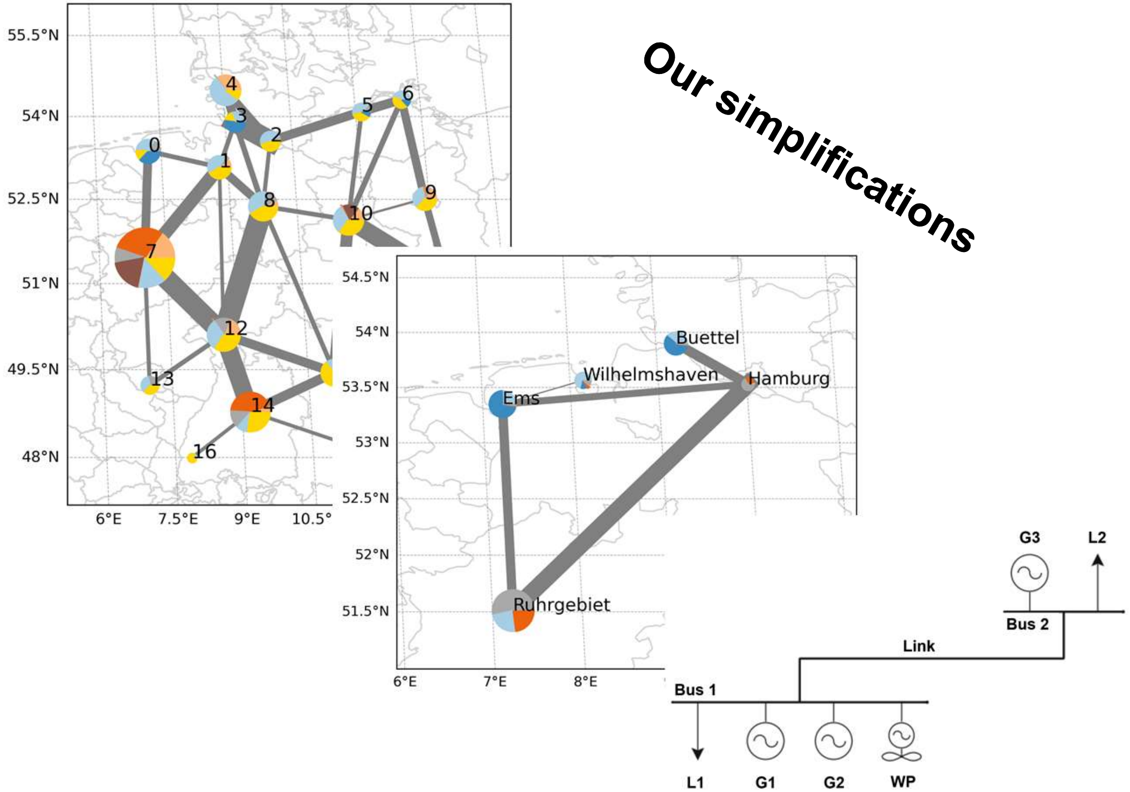
Operating the system



(1) IEA (2020), Electricity security matters more than ever, in *Power Systems in Transition*, Paris: IEA. https://www.iea.org/reports/power-systems-in-transition
(2) ENTSO-E (2023), *European Resource Adequacy Assessment*, Brussels: ENTSO-E. https://www.entsoe.eu/outlooks/eraa/2023/eraa-downloads/

Power system management and its simplification



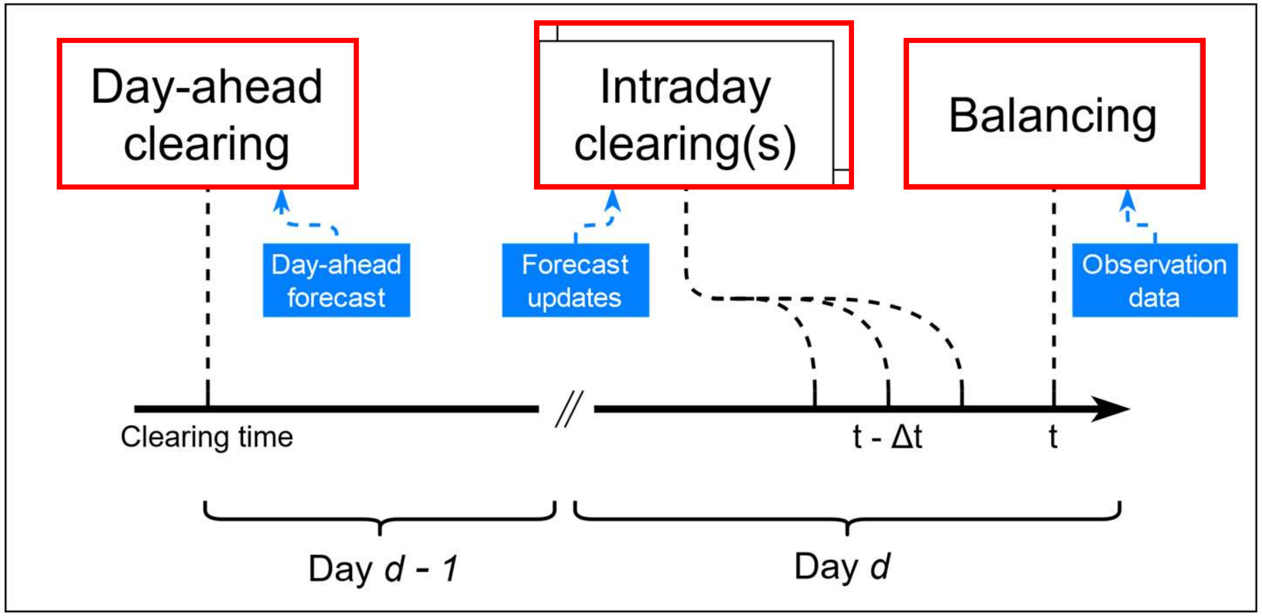


(3) EPEX SPOT (2022), How Do Electricity Prices Come About?, in *Fundamentals of European Electricity Markets*, Paris. https://www.epexspot.com/en/downloads#publications

(4) ENTSO-E (2024), *Interconnected Network of ENTSO-E*, Brussels: ENTSO-E. https://www.entsoe.eu/data/map/downloads/

Workflow in ProPower (Probabilistic power forecast evaluation tool)
Deterministic Use Case

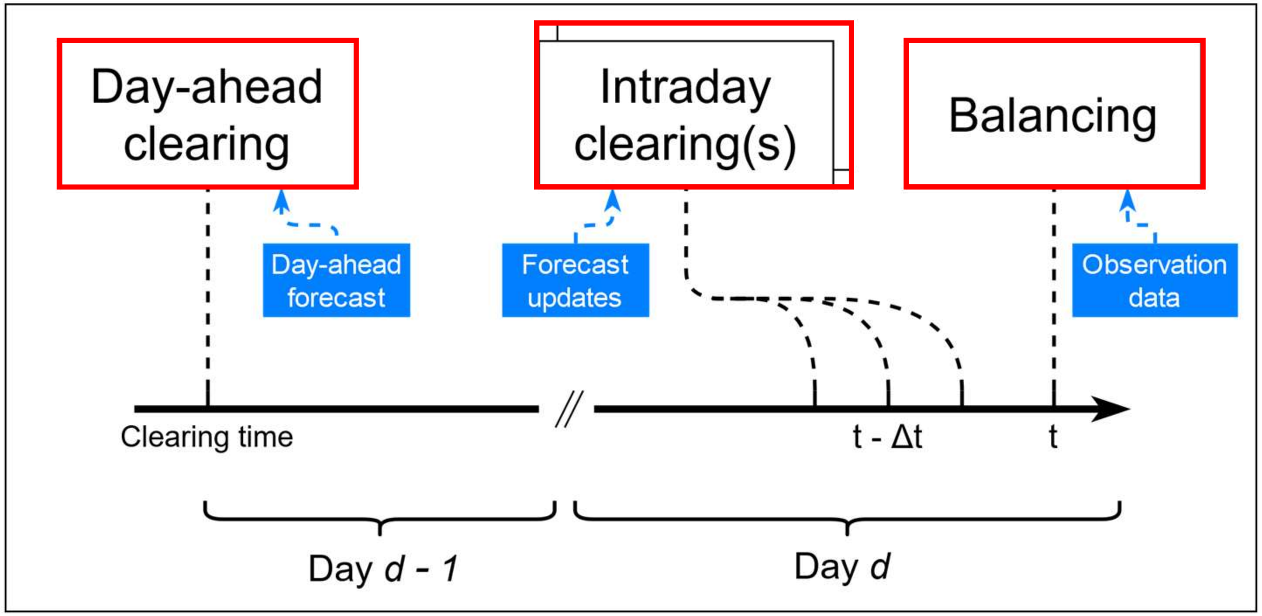
Management of the power system



Determine **preliminary schedule of generation** (=Dispatch)	**Adjusting the dispatch** using forecast updates at lower costs than balancing	**Balancing the difference** of dispatch and observed feed-in

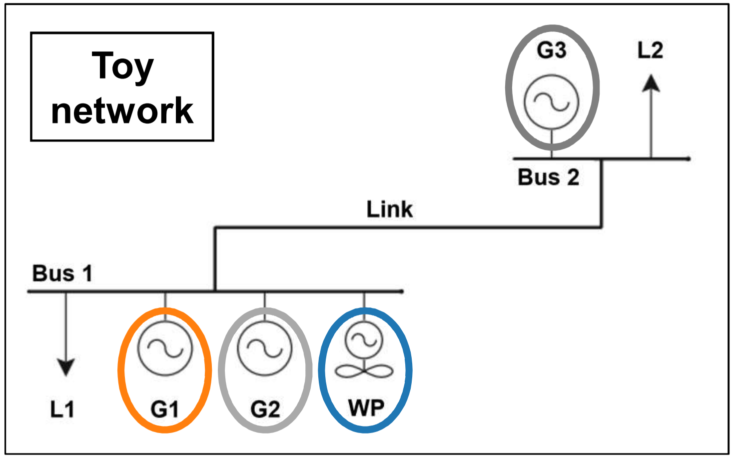
Workflow in ProPower (Probabilistic power forecast evaluation tool)
Deterministic Use Case

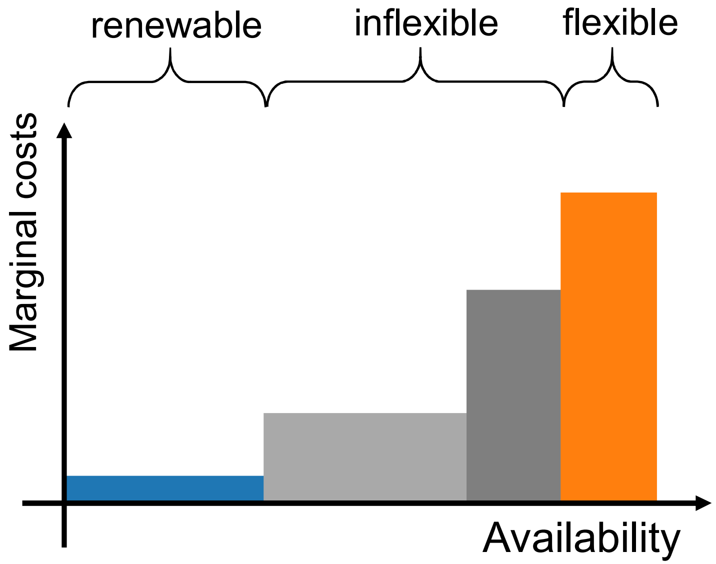
Management of the power system



min Day-ahead dispatch costs	*min* Intraday correction costs	*min* Balancing costs

A simple network topology for ProPower modelling

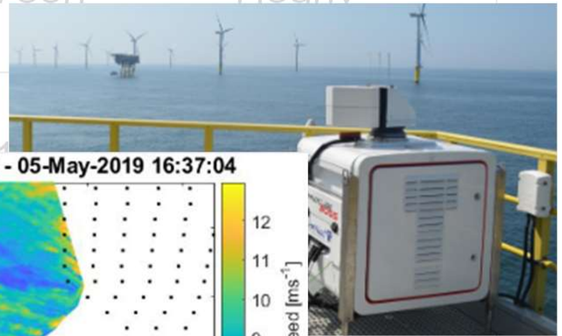


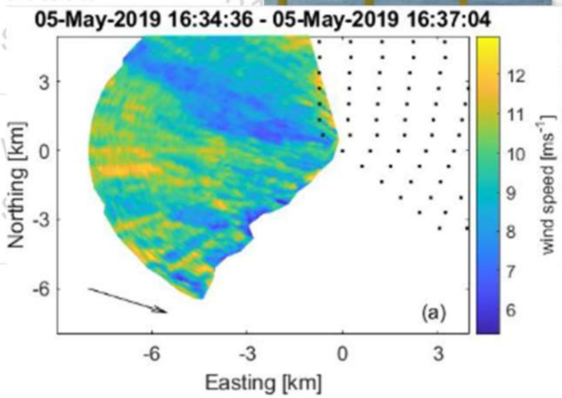


- Constant load profile (170 MW) for simplicity
- WP is 50 MW large
- G1 is 100 MW large
- G1 can ramp to balance forecast errors
- Load shedding occurs if errors are too large (➢ very costly)

Description of ProPower meteo input

ProPower input	short	Leadtime (init. time)	Data source	Forecast products	Availability in 2022	Used Resolution
Day-ahead forecast	EPS-Day2 MEAN and ENS	+24h to +47h (00 UTC)	ECMWF EPS*	100U, 100V	8760h	Hourly
Intraday forecast 1	EPS-Day1 MEAN and ENS	+0h to +23h (00 UTC)	ECMWF EPS*	100U, 100V	8760h	Hourly
Intraday forecast 2	Lidar+5min	+5min	Long-range single-Doppler Lidar[3]	Wind		
Observation	Lidar-obs.	–	Long range single-Doppler Lidar[3]			





Wind farm „Nordergründe“ (111 MW)
53° 50‘ 6“ N, 8° 10‘ 5“ E

(5) F. Theuer et al., “Minute-scale power forecast of offshore wind turbines using long-range single-Doppler lidar measurements”, *Wind Energy Science*, 5, 1449-1468, 2020. doi.org/10.5194/wes-5-1449-2020

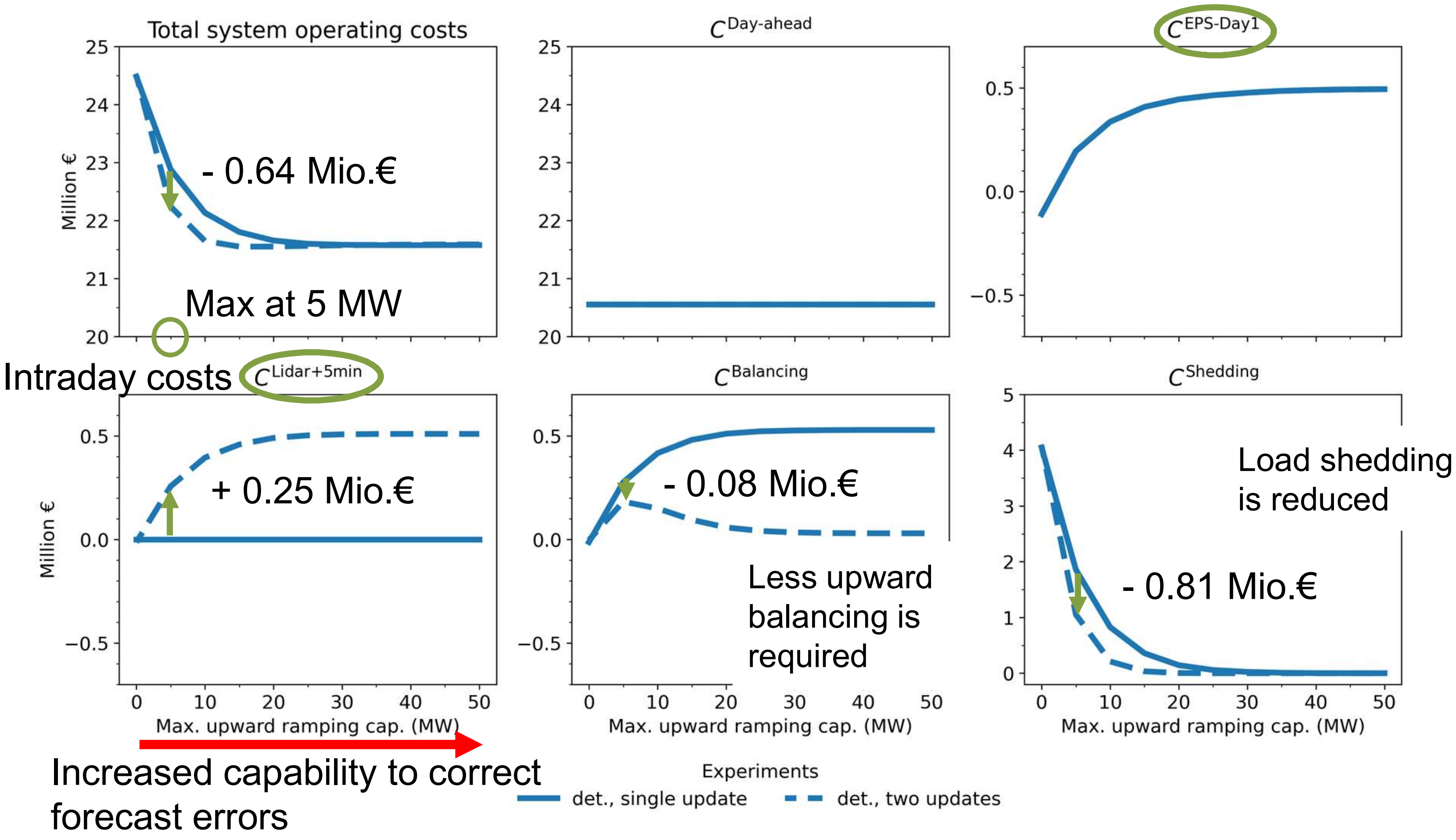
*ECMWF EPS = European Center for Medium-Range Weather Forecasts Ensemble Prediction System used without calibration

How much system costs can be reduced by using Lidar forecasts additionally?
Deterministic Use Case

	Experiment 1: „Single update“	Experiment 2: „Two updates“
Simulation steps	1. Day-ahead clearing with EPS-Day2-MEAN lead time to 48h **2. Intraday clearing with EPS-Day1-MEAN (shorter lead time to 24h, higher accuracy)** 3. Balancing with Lidar-obs. (as truth)	1. Day-ahead clearing with EPS-Day2-MEAN (48h) 2. Intraday clearing with EPS-Day1-MEAN (24h) **3. Intraday clearing with Lidar-FC-MEAN (5 min FC lead time)** 4. Balancing with Lidar-obs. (as truth)
Output data	➢ Day-ahead dispatch ➢ **1x** Intraday corrections ➢ Balancing corrections, Load shedding	➢ Day-ahead dispatch ➢ **2x** Intraday corrections ➢ Balancing corrections, Load shedding

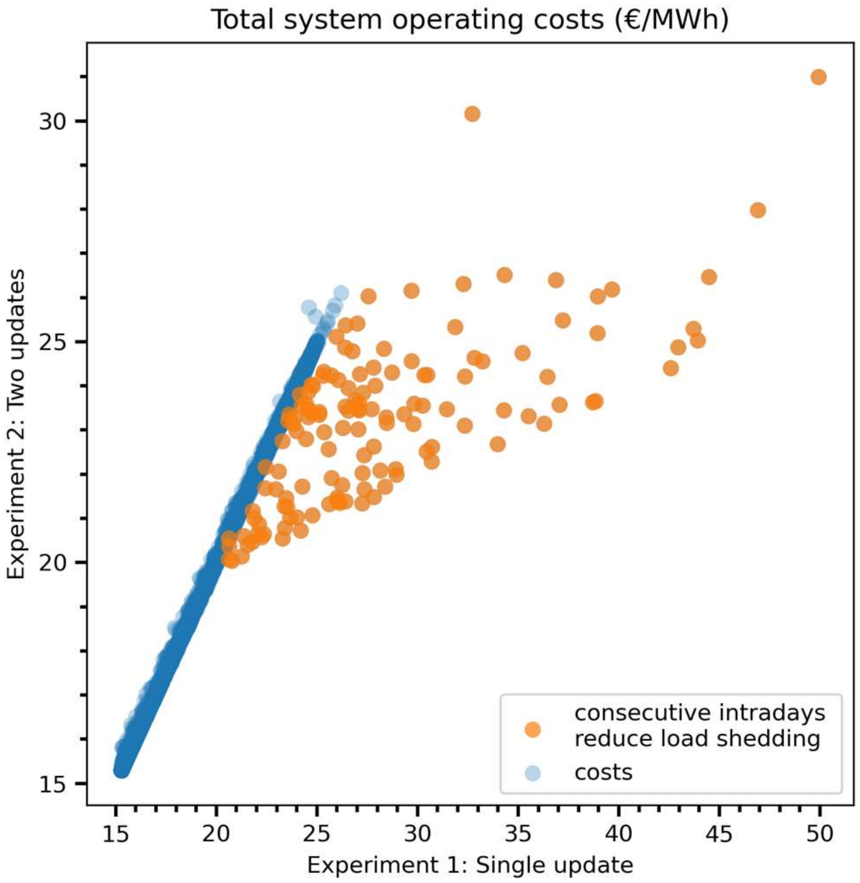
The cost reduction by Lidar forecasts is largest if G1 flexibility is low

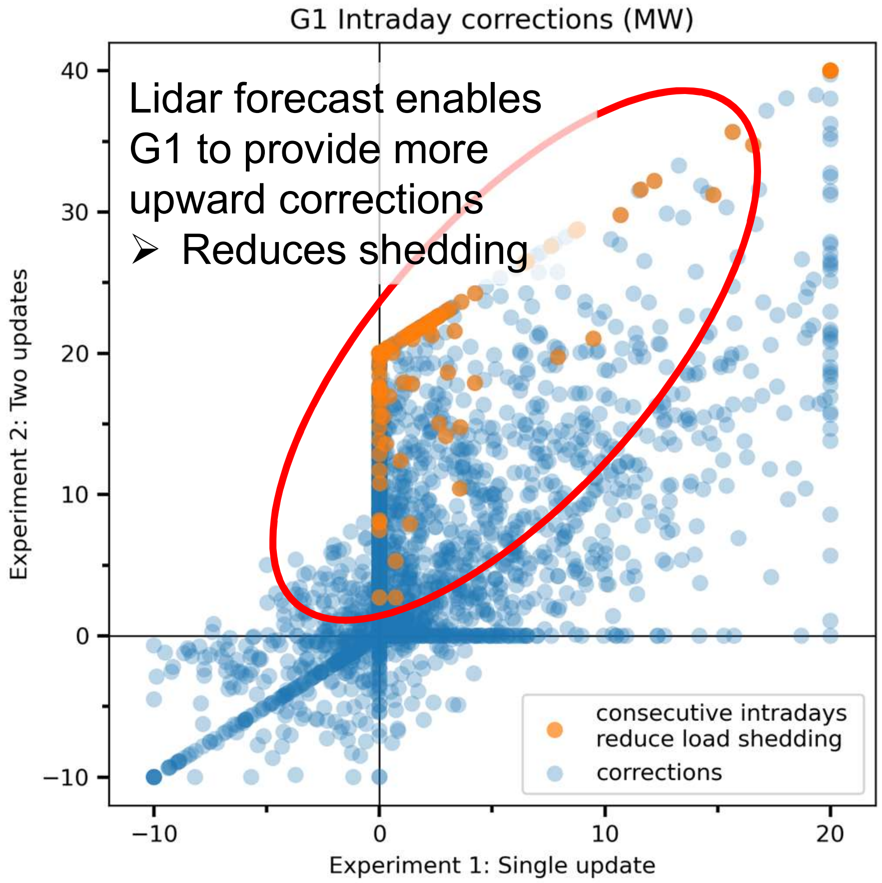
Total system operating costs are reduced



Impact of second intraday update

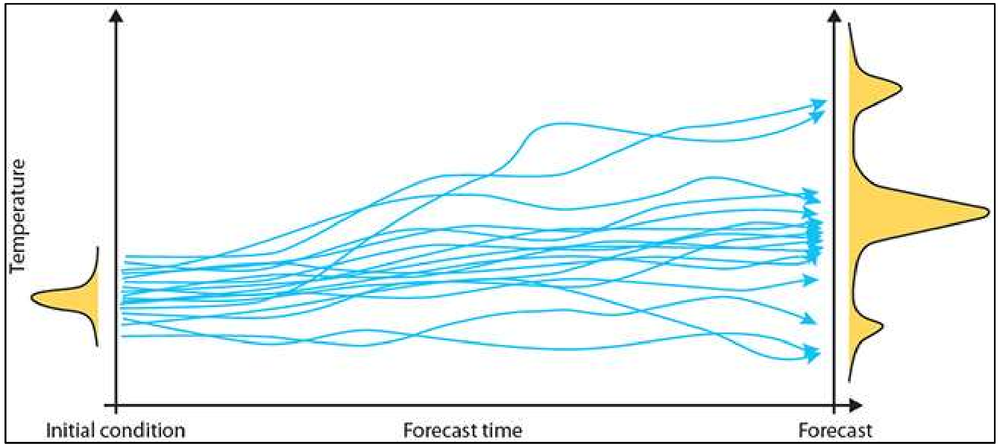
Case: 20 MW upward ramping capacity

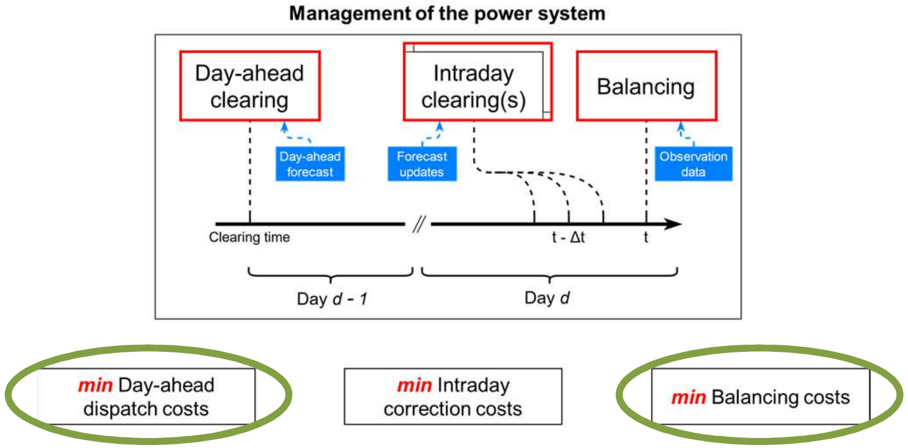




Ensemble predictions allow stochastic optimisation

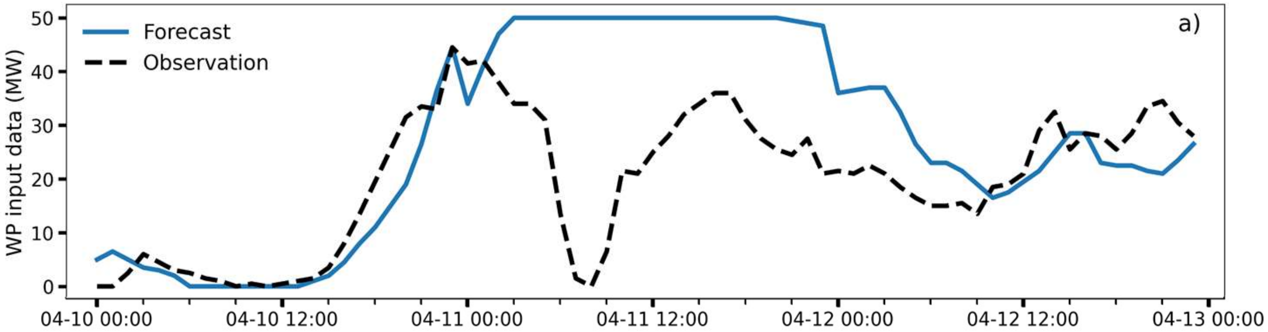
- How can we make use that we already have an estimate of the upcoming forecast error?
- We are dealing with balancing costs…





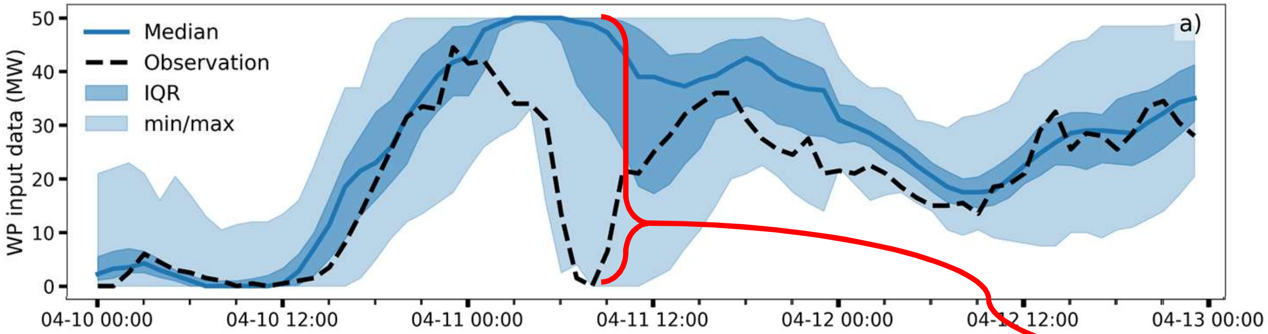
(6) ECMWF (2017), Twenty-five year of ensemble forecasting, online. https://www.ecmwf.int/en/about/media-centre/news/2017/twenty-five-years-ensemble-forecasting

Workflow in ProPower (Probabilistic power forecast evaluation tool)
Probabilistic Use Case



Deterministic day-ahead clearing

min	Day-ahead dispatch costs



Stochastic day-ahead clearing

min	Day-ahead dispatch costs
	+ expected balancing costs

Stochastic intraday clearing

min	Intraday correction costs
	+ expected balancing costs

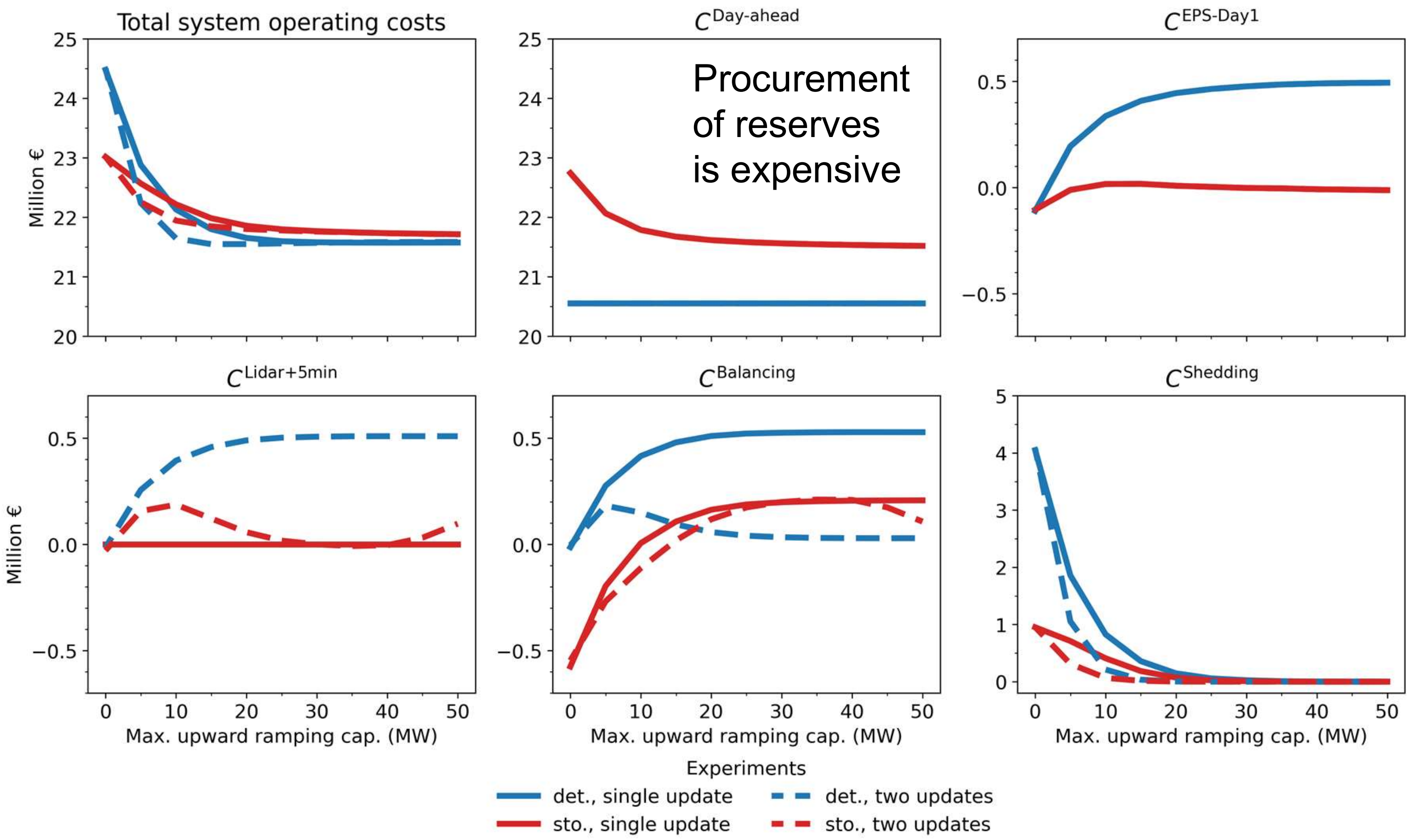
Ensemble members

Large spread leads to increased dispatch of G1, G2 and G3
- ➢Enough reserve left when observation falls short

(7) 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

Comparing deterministic and stochastic clearing

Stochastic clearing reduces costs for small flexibility



Stochastic clearing reduces shedding strongly

Conclusion & Outlook

- Power system management without Lidar forecasts vs management with deterministic Lidar forecasts
  - Less balancing energy is required
  - Less expensive load shedding occurs
- Use of lidar forecasts is most beneficial when available flexibility is low
- The advantage of lidar forecasts persists but is smaller if probabilistic forecasts are used for day-ahead clearing (i.e. stochastic clearing)
- Next step: Extend analysis to more complex grid topology
  - VRE portfolio to be extended to include onshore, offshore and solar power plants
  - Include battery management
- Outlook: up to now grid operator viewpoint shown,
  add focus on a revenue based analysis of forecasts
  - Operator perspective in analysis (➢ what are the payments to the operator?)
  - Use nodal electricity prices

THANK YOU!
ANY QUESTIONS?

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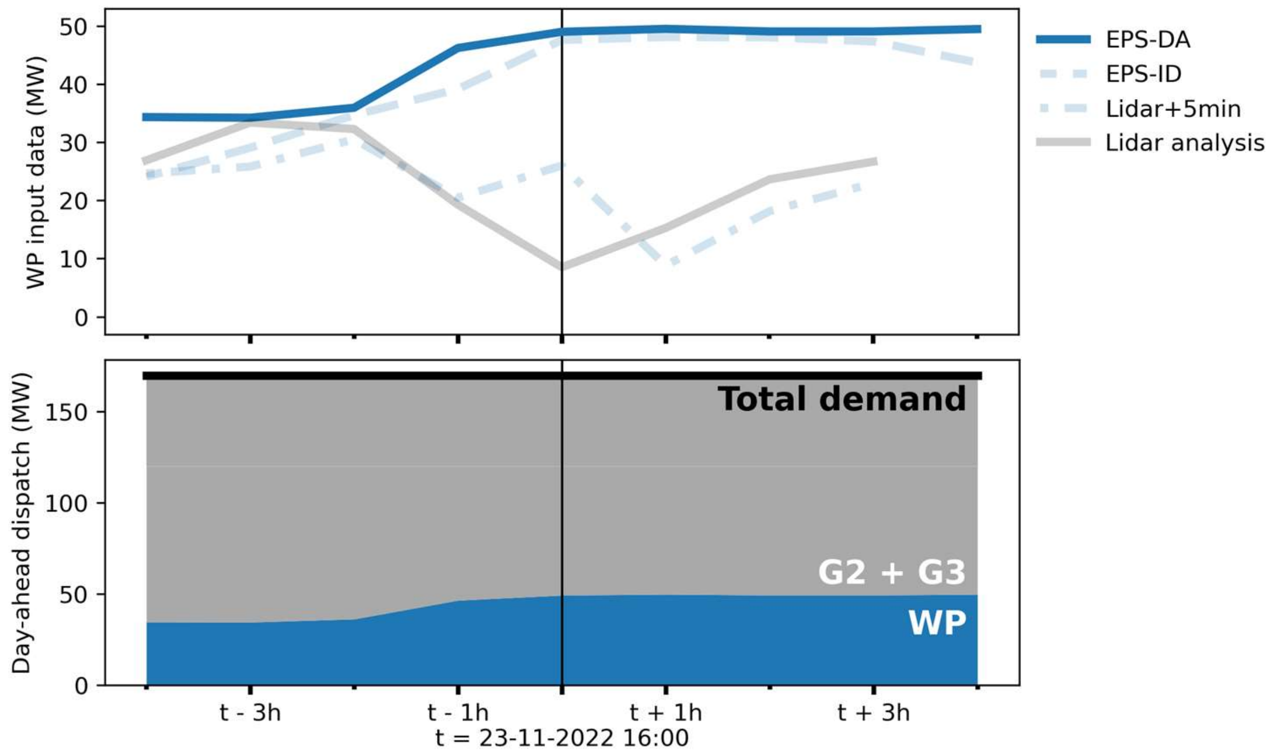
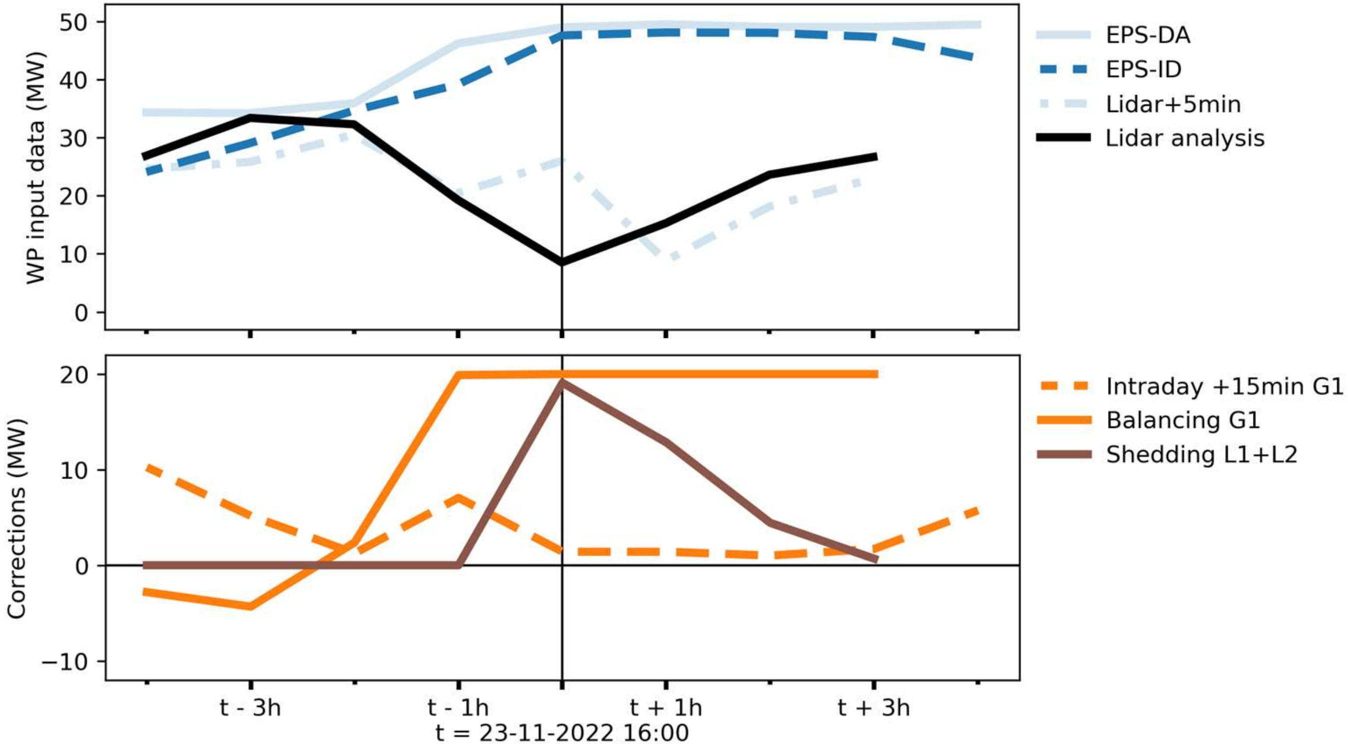
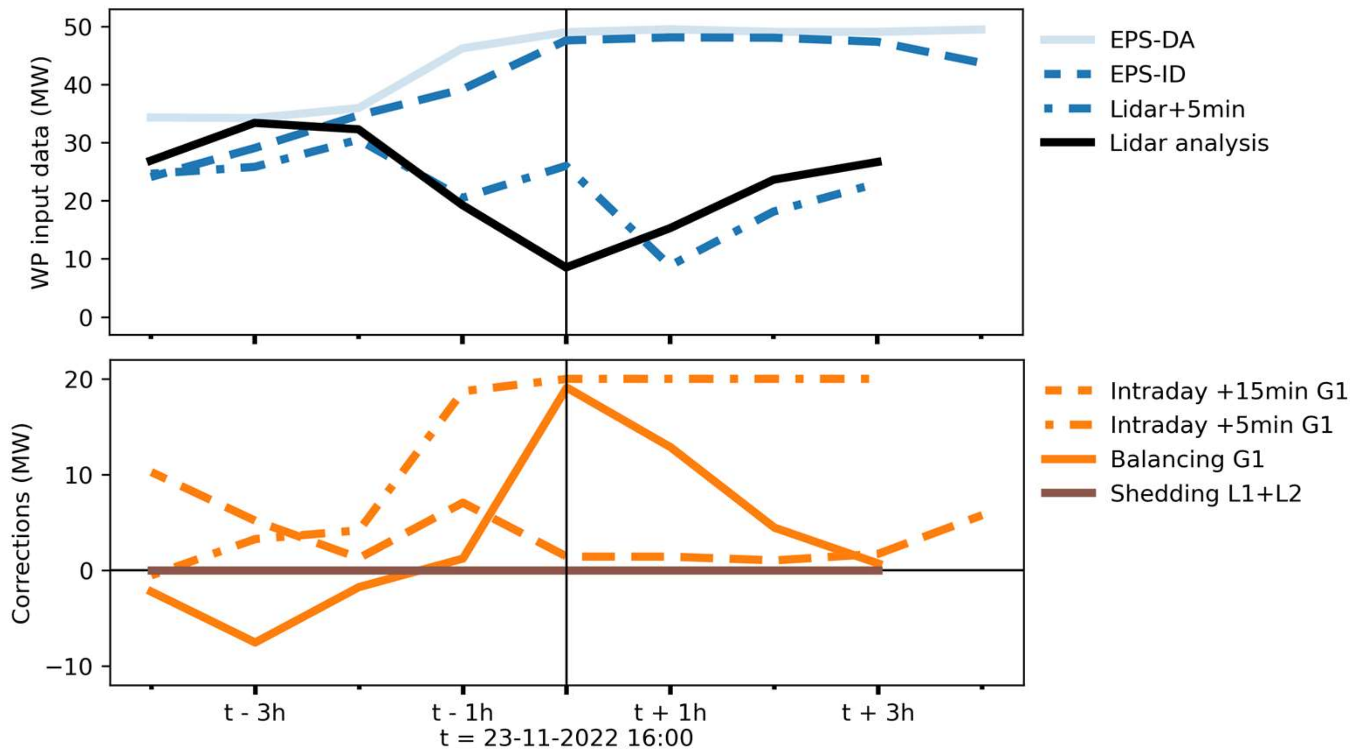
Backup: Clearing of deterministic day-ahead



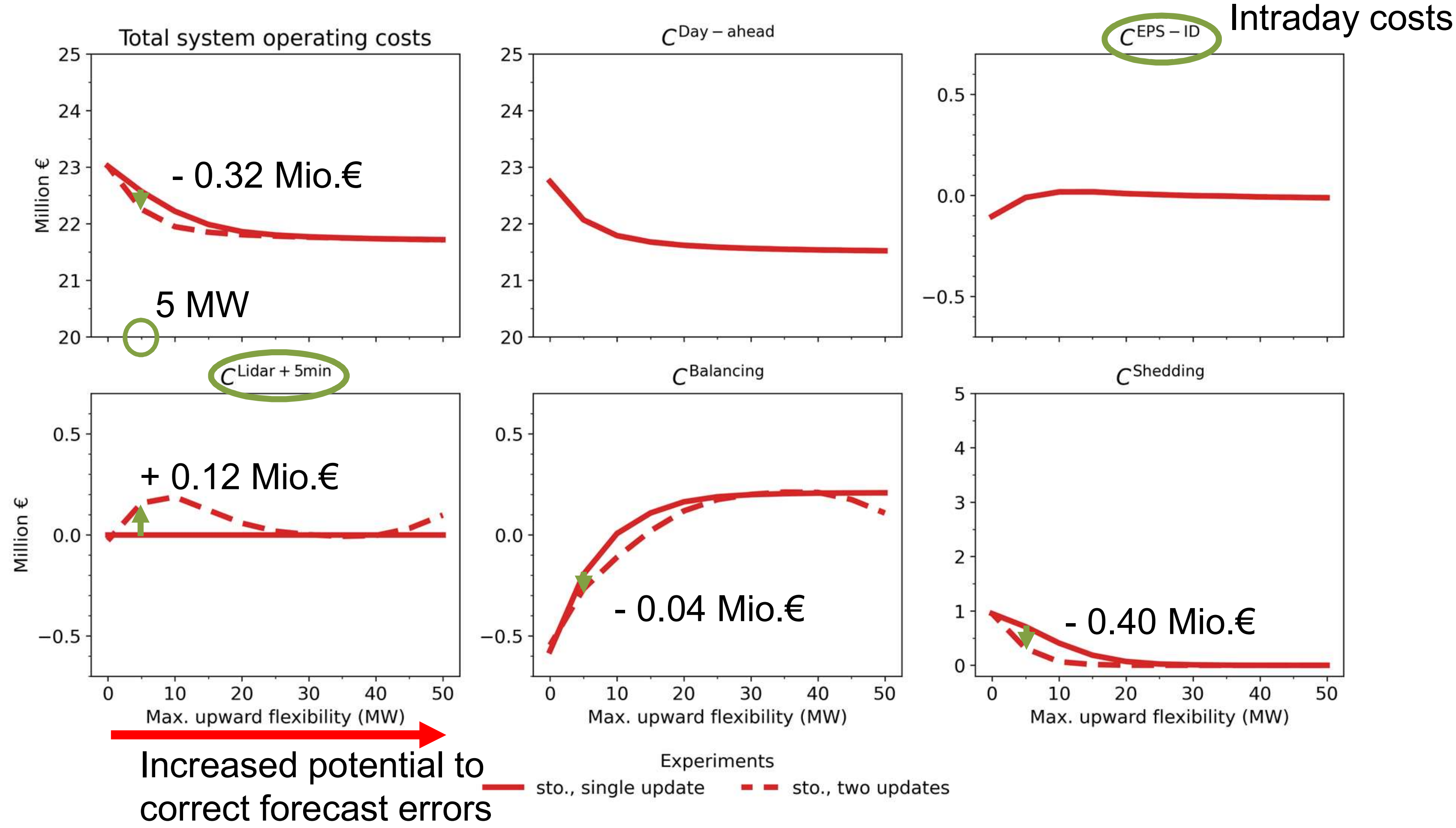
Backup: Intraday corrections from EPS-ID forecast and resulting balancing corrections



Backup: Consecutive Intraday corrections from EPS-ID forecast and Lidar+5min forecast and resulting balancing corrections

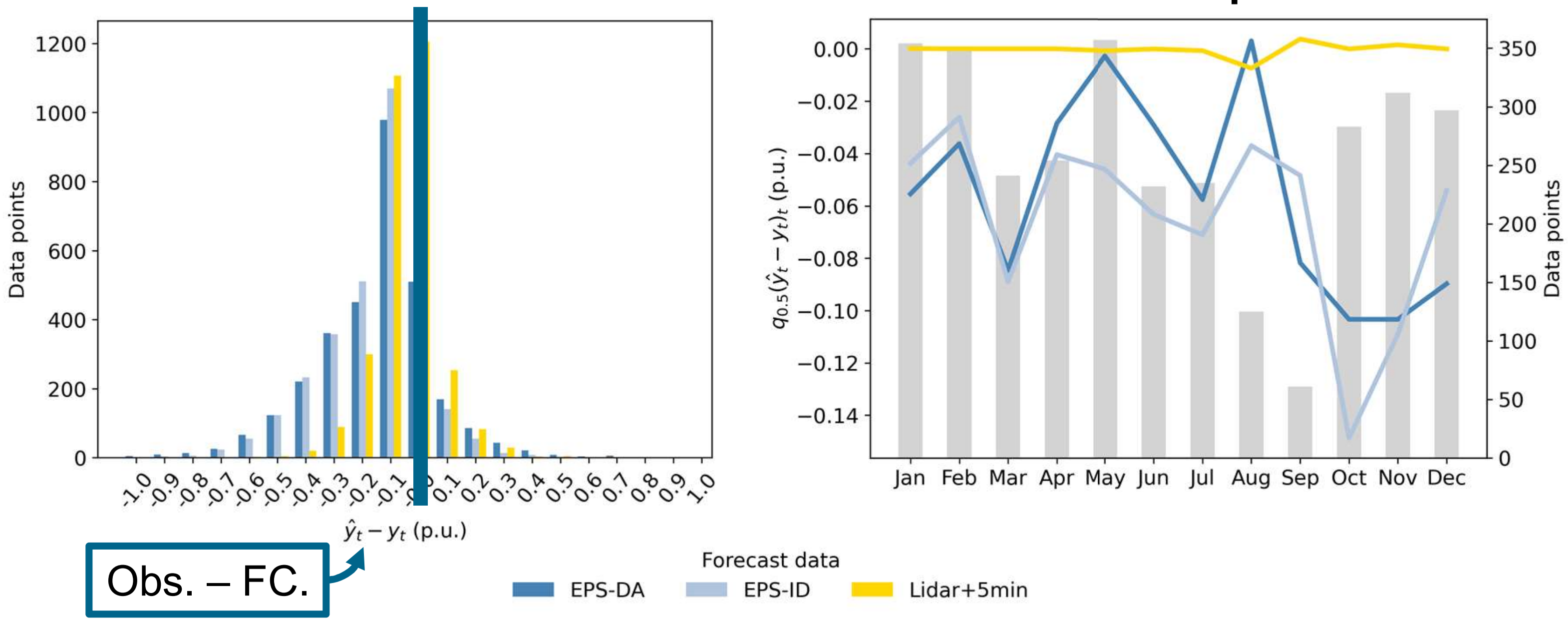


Probabilistic Lidar forecast reduces costs in probabilistic use case (stochastic clearing)



Backup: Lidar forecast has lower bias than NWP forecast

Distribution of biases | **Median biases per month**



- 3102 hours from 2022 available for analysis
- EPS-DA and -ID forecasts overestimate feed-in
  - Lidar +5min forecast provides additional, valuable information