

DTU



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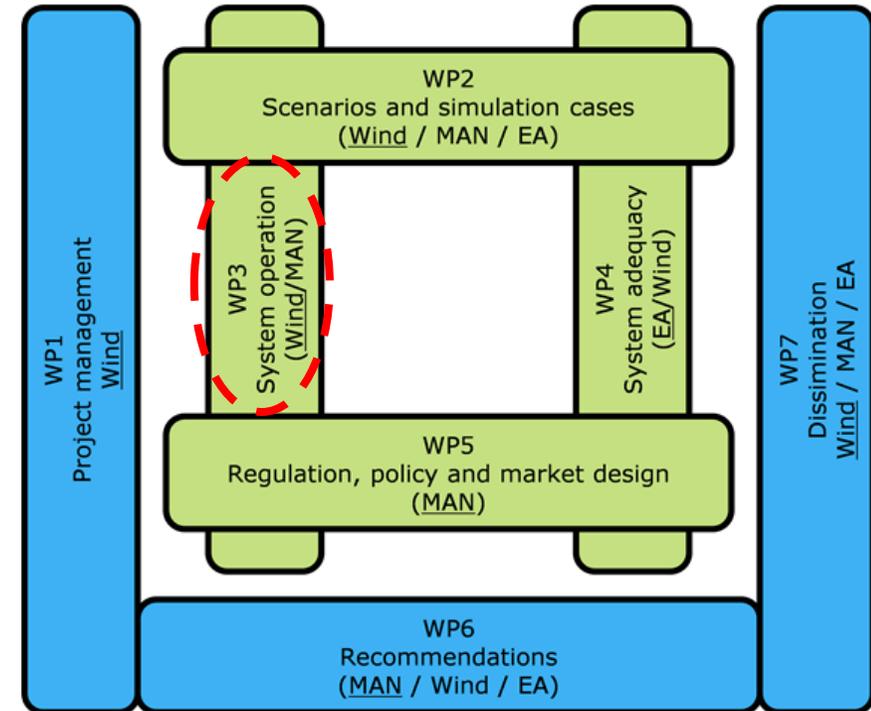
¹DTU Wind Energy

²DTU Management

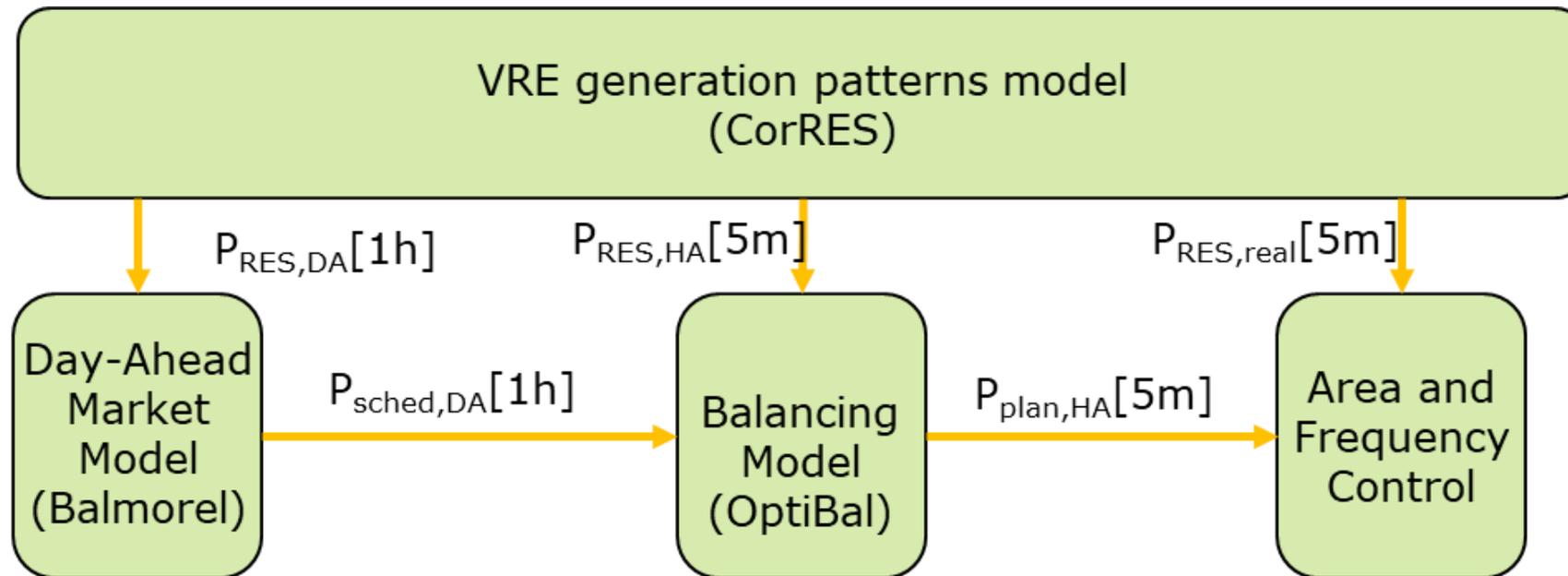
Market operation and balancing with future massive offshore wind power

Research Questions in WP3

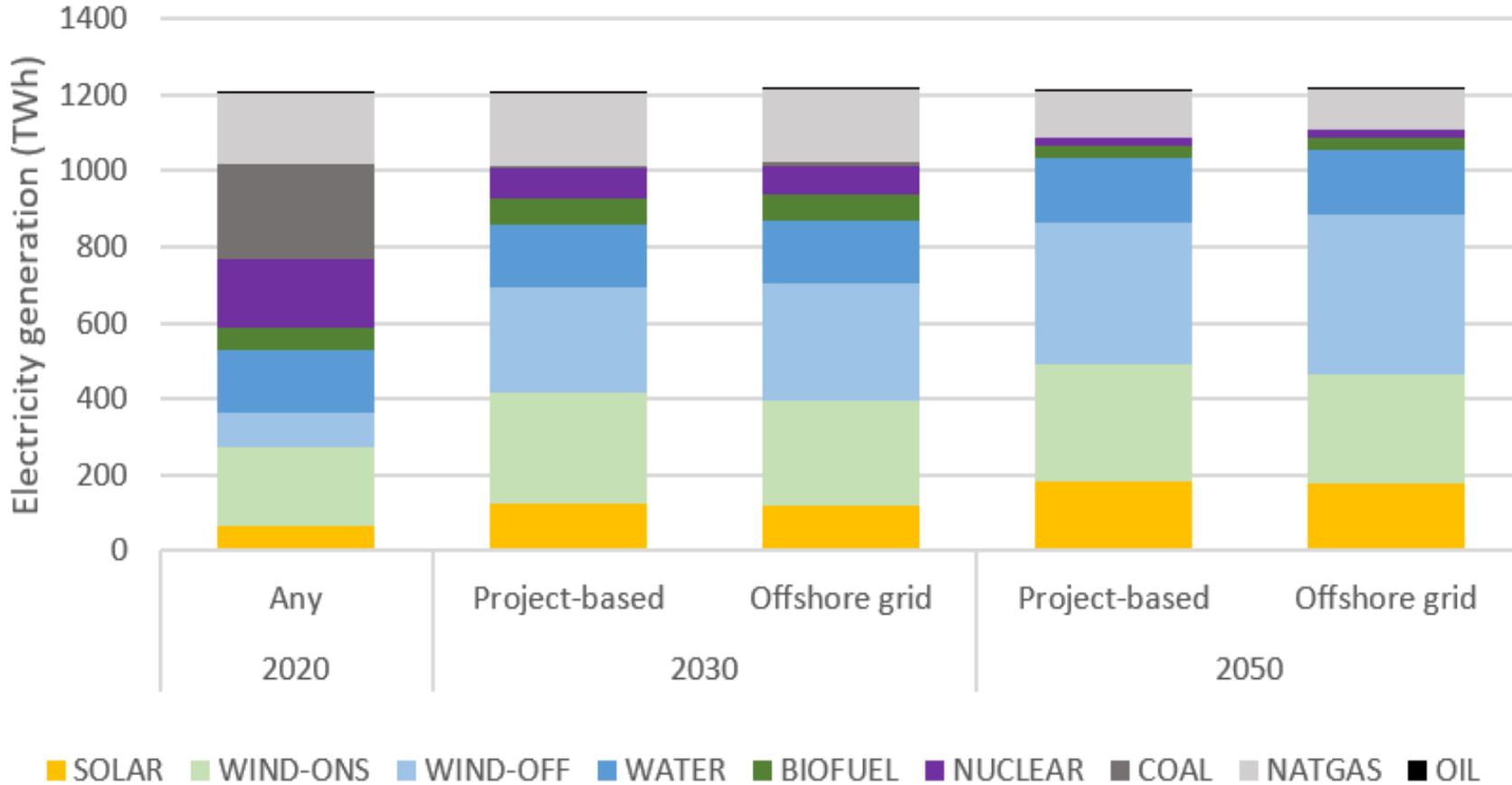
- What is the **value of offshore grid** on balancing of forecast errors?
- What is the **impact** of forecast errors **on automatic reserves**?
- How to **quantify** the automatic reserve requirements in 2030 and 2050 scenario for balancing wind power forecast errors?
- What are the **sensitivities of frequency control parameters** (delay, ramp rates, volume of reserve) on frequency quality?



Modelling Tool Chain

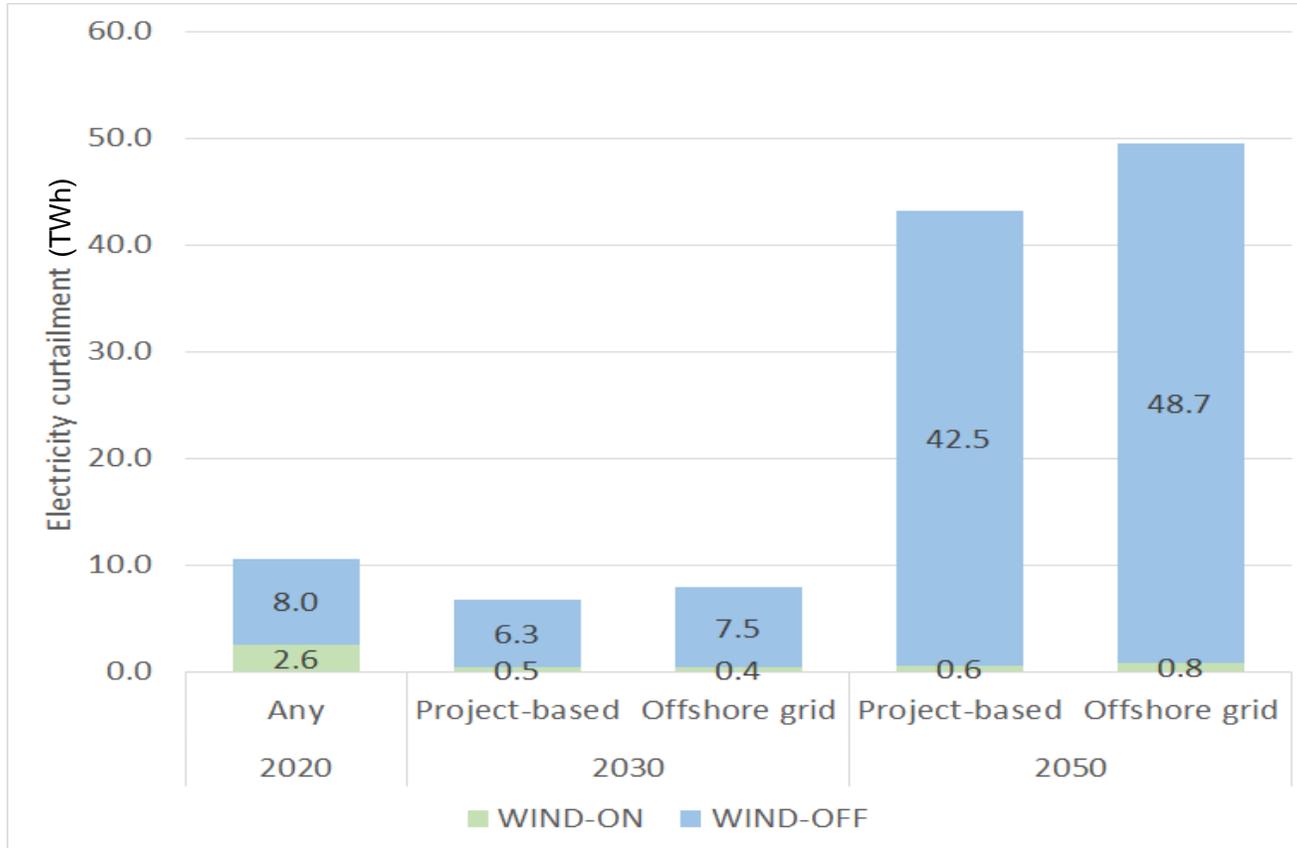


Day-Ahead market: TWh



- **Penetration of Wind and Solar replaces most fossil generation towards 2050, but not completely**
- More Wind Offshore production in Offshore Grid scenario, but less wind onshore and solar

Day-Ahead market: Curtailment

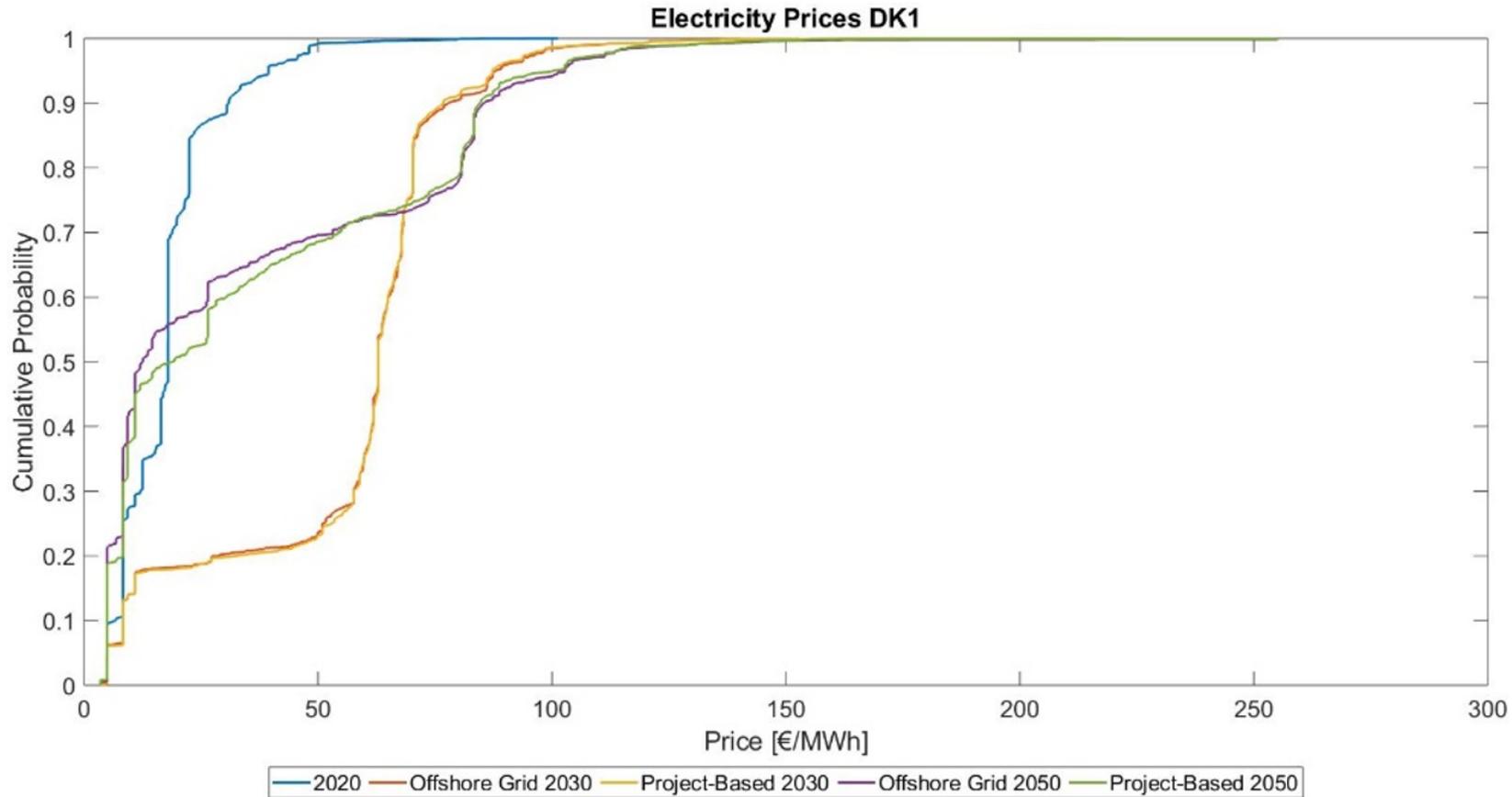


Year	Scenario	curtailment wr.t wind production (%)
2020	Any	3.5%
2030	Project-based	1.2%
2030	Offshore grid	1.3%
2050	Project-based	6.0%
2050	Offshore grid	6.5%

Scenario	Year	Wind curtailment difference (TWh)	Wind generation difference (TWh)
Offshore grid	2030	1.1	16.5
	2050	6.4	27.7

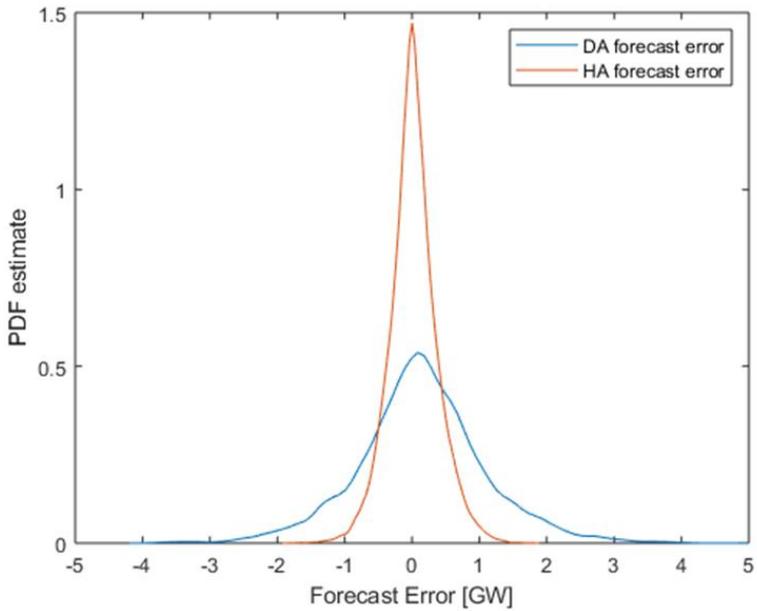
Comparison w.r.t Project-based

Day-Ahead market: Electricity Prices

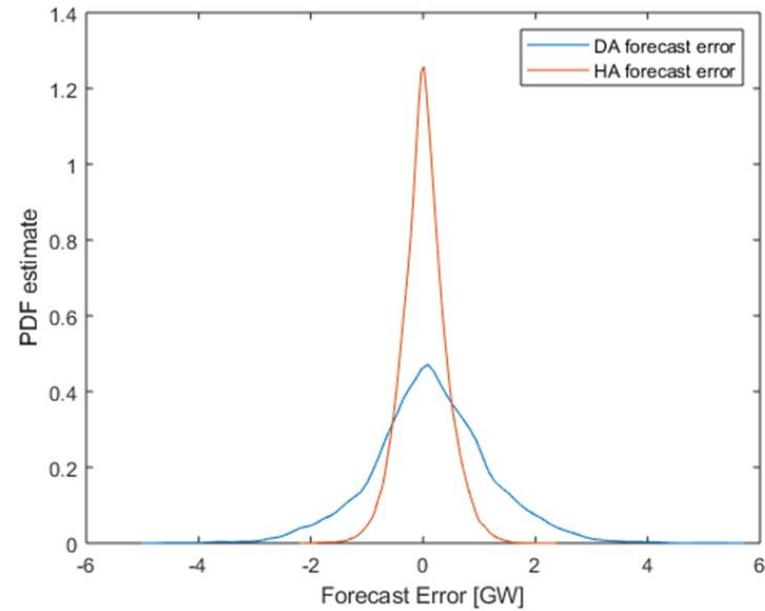


- Average prices increase from 2020 to 2030 and decrease from 2030 to 2050
- Volatility of prices increases towards 2050
- Prices depend largely on the assumptions of CO₂ prices

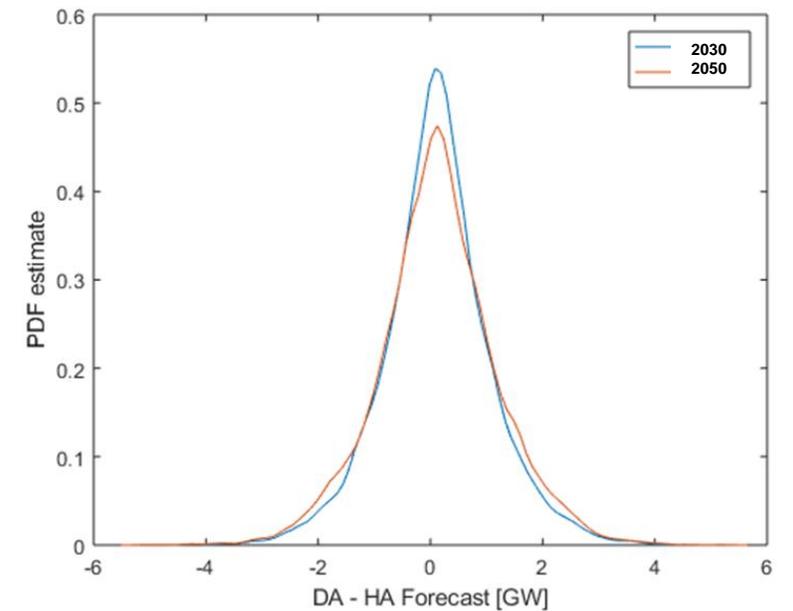
CorRES: Forecast Error Analysis



Denmark: 2030



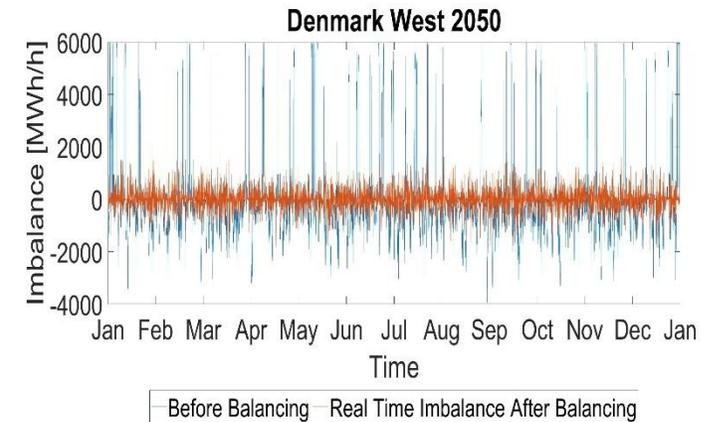
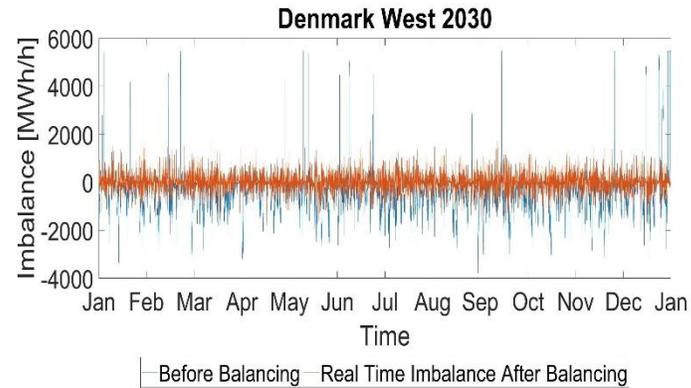
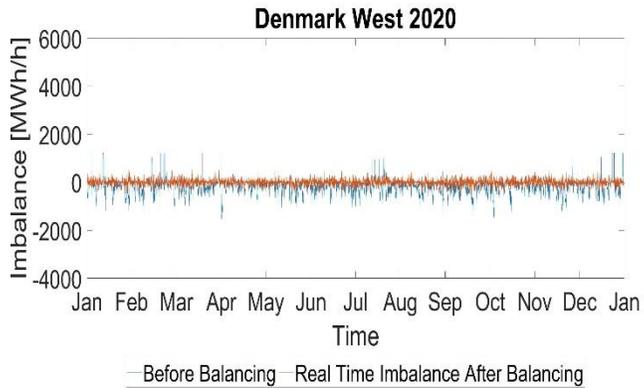
Denmark: 2050



Denmark: 2030, 2050

OptiBal: Imbalance reduced after Balancing

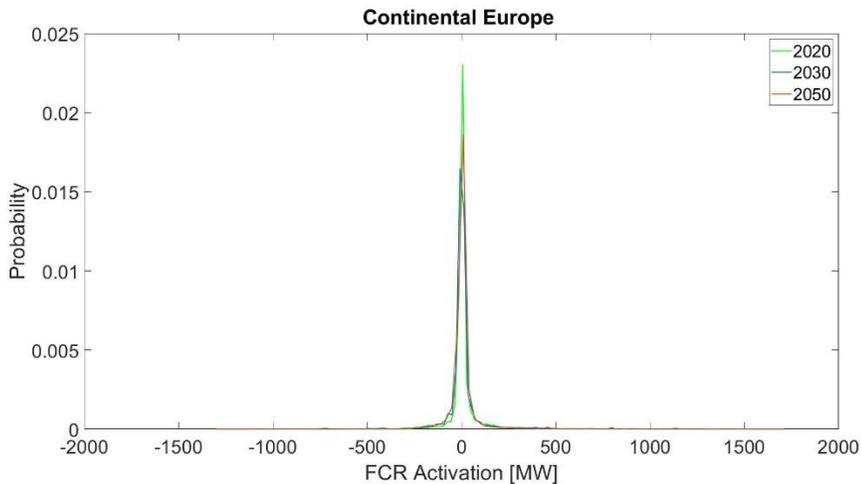
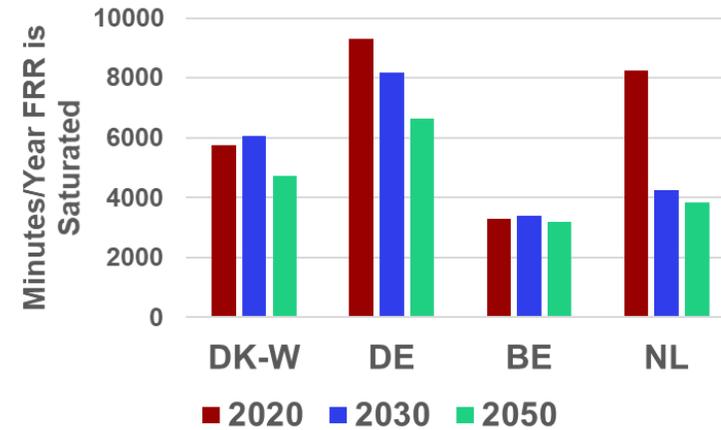
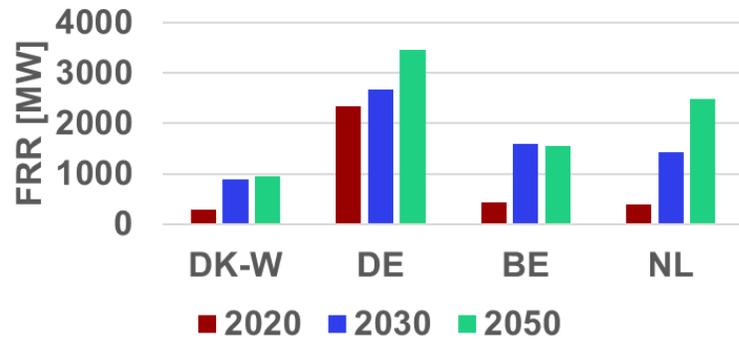
- Results for project based scenario



Frequency and Automatic Reserves

- Results for project based scenario

Probabilistic FRR Volume Quantification



	Minutes outside Nominal Freq. (± 50 mHz) / year
2020	2913
2030	3440
2050	7391

Discussion (based on Ongoing Work)

- Day-ahead market:
 - Prices become more volatile and increases from today's level
 - Curtailment increases because of higher penetration of renewables
 - Sector coupling have potential to impact price and curtailment
- Importance of the balancing market increases towards 2050
 - Higher volume of manual reserves required
- Frequency quality might deteriorate
 - Activation of FCR reduces the security of the power system
 - Higher volume of Automatic frequency restoration reserves required