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Welfare benefits of co-optimising energy and reserves

ICEBERG interim workshop

14 June 2024

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Introduction

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The study: Goal and team composition

- **Goal**: Quantify the **potential welfare gains**, relative to the status quo, of a move towards **co-optimisation** and estimate what fraction of these benefits can be reaped by the **market-based** approach, to support the ongoing R&D activities on the implementation of co-optimisation in Single Day-Ahead Coupling (SDAC)
- Team composition:
  - **Anthony Papavasiliou** (National Technical University of Athens, Greece) and **Daniel Avila** (Université Catholique de Louvain, Belgium)
  - ACER internal project team: Marco Pavesi, Martin Viehhauser, Mathieu Fransen

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Status quo: Sequential clearing with national balancing capacity markets

- With the fast-paced penetration of renewable energy sources, **balancing capacity markets are set to play an even more important role** in the future electricity market design
- **Energy and balancing capacity are inherently interdependent**: generating units providing these services should be started up and running to be able to provide energy and/or balancing capacity
- Despite this interdependency, **the status quo** in European market design is based on clearing balancing capacity separately from energy. **Balancing capacity is typically cleared first** and is followed by the day-ahead clearing of energy
- Following the clearing of the day-ahead balancing capacity and energy markets, **asset owners are required to nominate individual units** that can deliver on the traded energy and balancing capacity
- **Resources that are cleared for balancing capacity effectively commit to submit offers into the balancing market**, i.e. the real-time energy market, that are greater than or equal to the amount of balancing capacity that has been traded in the balancing capacity market

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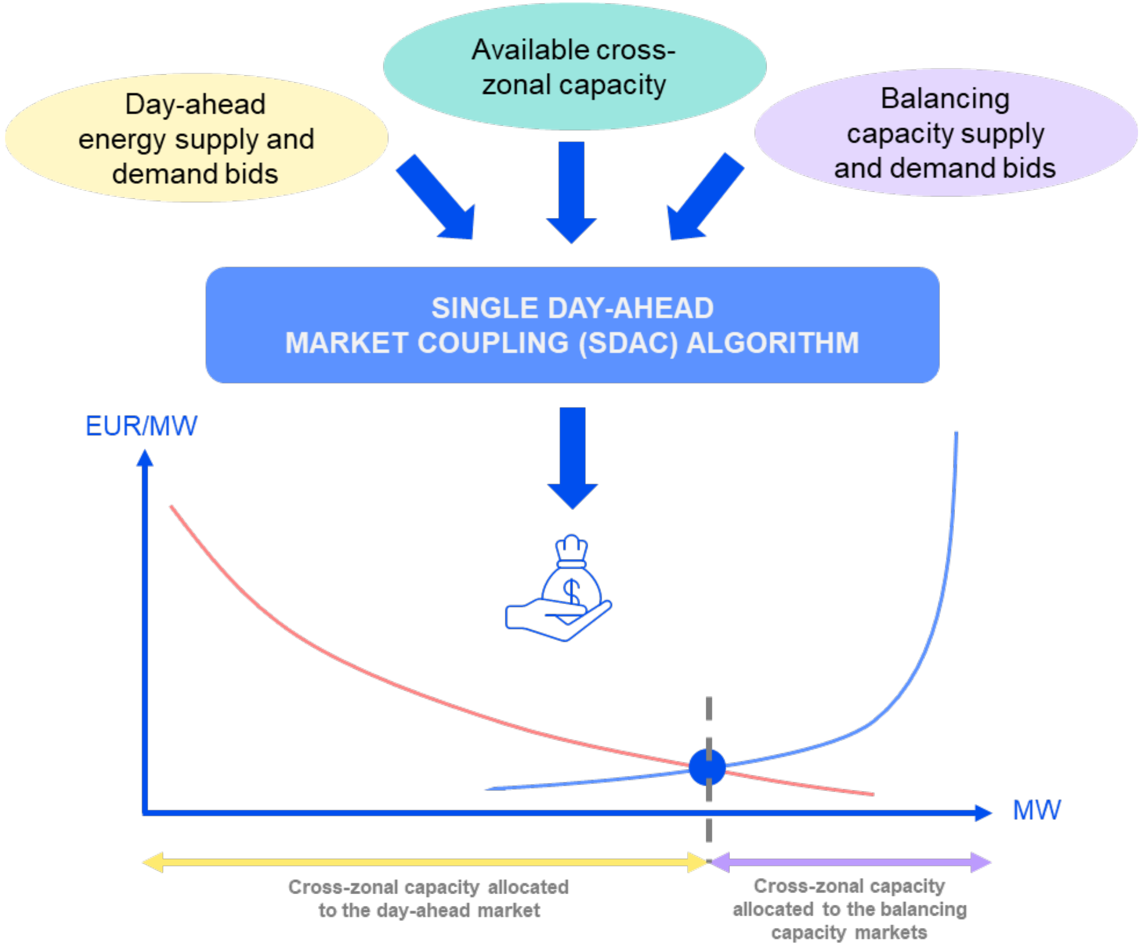
Market-based: Sequential clearing with integrated day-ahead balancing capacity markets

- Laid down under **Article 41 of Electricity Balancing Regulation (EBGL)**. The idea is to maintain the current paradigm of sequential clearing, but allowing the **exchange of balancing capacity and/or sharing of reserves between bidding zones**
- For this to be possible, network capacity needs to be reserved on transmission lines at the stage of the day-ahead market; **the opportunity cost of booking balancing capacity which could have been allocated to the energy market** is a necessary input for this process
- Once the day-ahead balancing capacity market is cleared, **the amount of transmission capacity that is used for trading balancing capacity between bidding zones is removed from the day-ahead market model**, which is run in the final step of the market-based approach

Anticipated day-ahead energy prices → opportunity costs for balancing capacity offers → Day-ahead balancing capacity market → (Remaining cross-zonal capacity) → Day-ahead energy market

Co-optimisation: Joint day-ahead clearing of balancing capacity and energy

- Co-optimisation covers two aspects: i) allocation of **cross-zonal capacity**; ii) optimisation of **reserve and energy** markets
- Co-optimisation overcomes the drawbacks of market-based allocation regarding **forecast errors** and **coordination inefficiencies**
- Co-optimisation allows the **liquidity** of the day-ahead market to also be directly accessible to balancing capacity markets
- The allocation of cross-zonal capacity for balancing aims to **facilitate the cross-border trade of balancing energy in PICASSO, MARI and TERRE**



Methodology and assumptions

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Sequential modelling

Forecast of day-ahead energy prices

Status quo

Day-ahead balancing capacity market

Fix balancing capacity allocation

Day-ahead energy market

Market-based (Article 41 EBGL)

Day-ahead balancing capacity market with trading of BC

Fix balancing capacity allocation

Day-ahead energy market

Fix nuclear setpoints*

Units committed for BC remain on

Balancing energy

Realisation of real-time conditions

Why a two-step (day-ahead to real-time) modeling approach?

Co-optimisation (Article 40 EBGL)

Interplay between market design and irrevocable physical decisions ⇒ **short-term economic inefficiencies**

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Overview of model features

Features in **bold** likely to bias analysis in favour of sequential designs

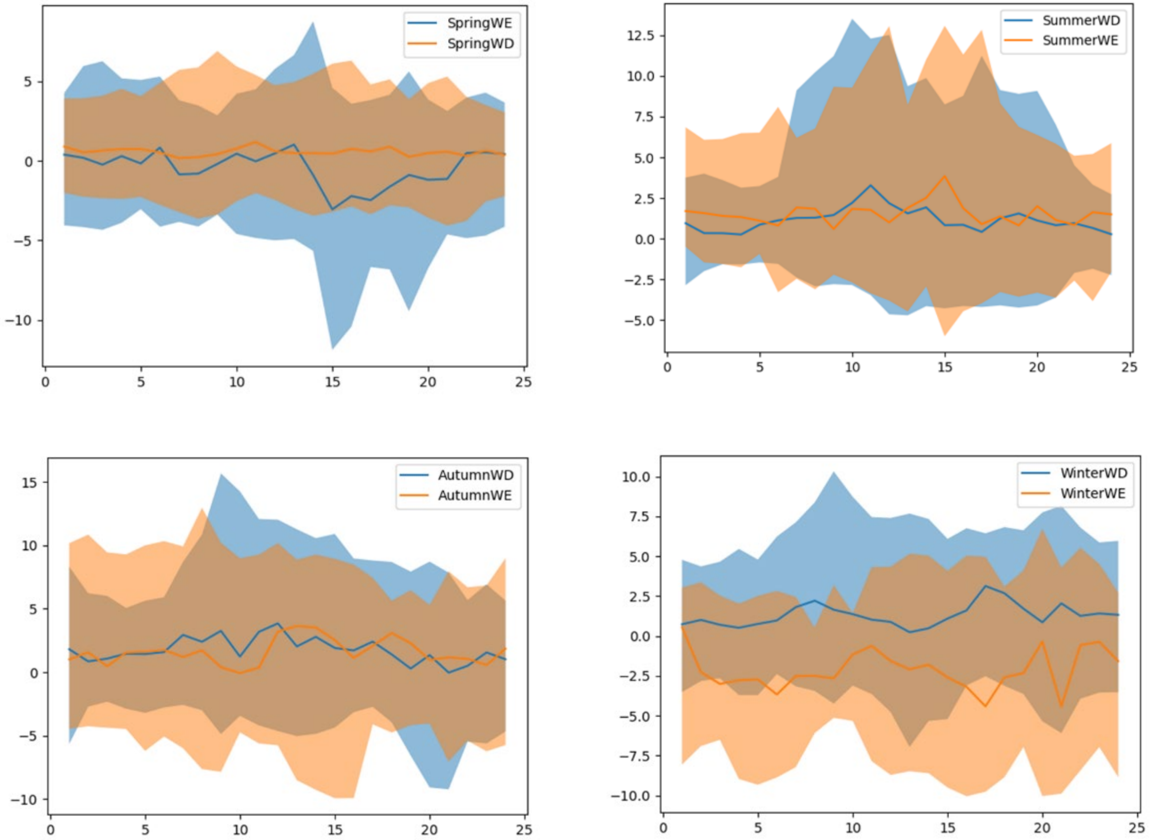
* Subject to sensitivity analysis

	Status quo	Market-based	Co-optimisation	Balancing
Unit commitment (fixed cost, ramp rates, min up/down times, …)	☑	☑	☑	N/A
Fast/slow units	☑	☑	☑	N/A
Upward/downward aFRR/mFRR	☑	☑	☑	N/A
15-minute market time unit	☑	☑	☑	☑
Flow-based network model	☑	☑	☑	☑
Deterministic requirement	N/A	☑	☑	N/A
CZC available in balancing capacity module	☒	☑	☑	N/A
Up to 10% of RAM allocated for trade of BC*	N/A	☑	☒	N/A
Bidding zone cannot import more than 50% of its BC from other bidding zones	N/A	☑	☑	N/A
Energy price forecasts of co-optimisation used for BC market clearing	☑	☑	N/A	N/A
Explicit interaction between energy and BC	☒	☒	☑	N/A

Price forecast errors

- The sequential designs (status quo and market-based) require an energy price forecast for bidding in day-ahead balancing capacity market
- Forecast error model:
  - **Base error**: Historical difference of energy price of period t of day d and day $d-1$ (of same type)
  - **Agent-specific additional error**: normal (zero mean, standard deviation = 3% of DA energy price)
- Based on 2020 historical energy price data (2021 and 2022 dropped due to energy crisis)

* Subject to sensitivity analysis



Mean, 25 percentile and 75 percentile of price forecast error for the Belgian bidding zone

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Caveats

- Unit-based unit commitment model as opposed to portfolio bidding
  - Methodological necessity (no available data for portfolios in all studied designs)
  - But we do account for coordination benefits of portfolios*
  - Offers favourable bias for sequential models due to greater expressiveness of unit commitment relative to existing EU bidding language
- Ignore “no paradoxically accepted bids” (no PAB) pricing rule
- Joint clearing of aFRR and mFRR
  - Offers favourable bias for sequential models due to coordination benefits of aFRR/mFRR interaction
- Perfect competition and truthful bidding

* Subject to sensitivity analysis

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Case study

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Input data

- **Detailed technical and economic information** about networks, generators, loads, and renewable supply
- An operational year is described by **eight representative days** (day types), which affect load, renewable supply, and hydrology. There are eight day types, one for each season and weekday versus weekend
- For each day type we have **145 profiles of renewable supply data available,** provided as input to the real-time module. The day-ahead simulations are run using the average renewable supply data
- Network represented with **flow-based polytopes** derived from JAO
- **Reserve requirements per bidding zone** are derived from ENTSO-E TP, TSOs website or information provided by individual TSOs/NRAs

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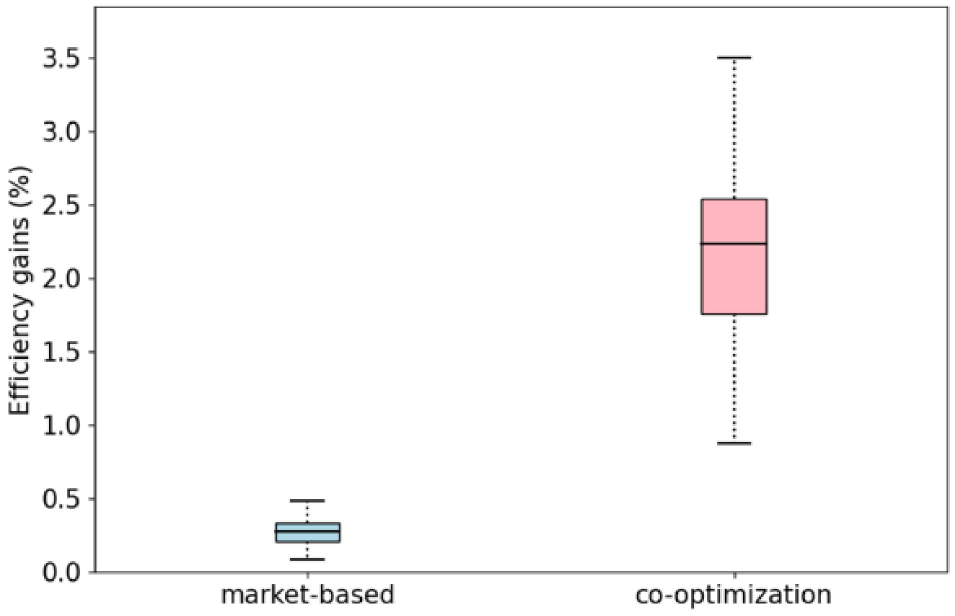
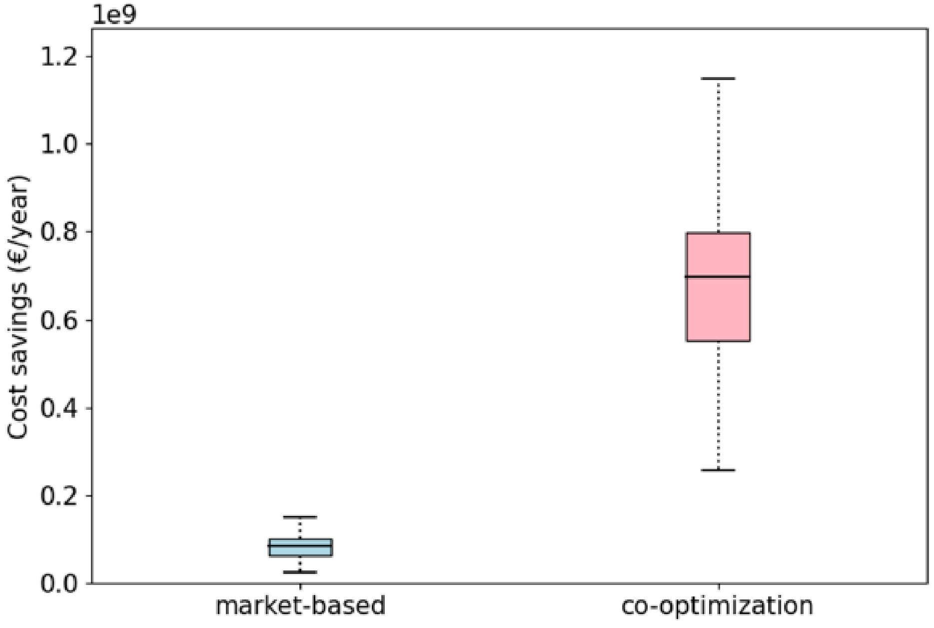
Cost comparison of alternative designs

Costs are assessed in the **real-time balancing** module, not in day-ahead





2.1% welfare gains with **co-optimisation** (678 MEUR/year for Core → **~1.3 BEUR/year for the EU**)
0.3% welfare gains with **market-based** (84 MEUR/year for Core → 159 MEUR/year for the EU)

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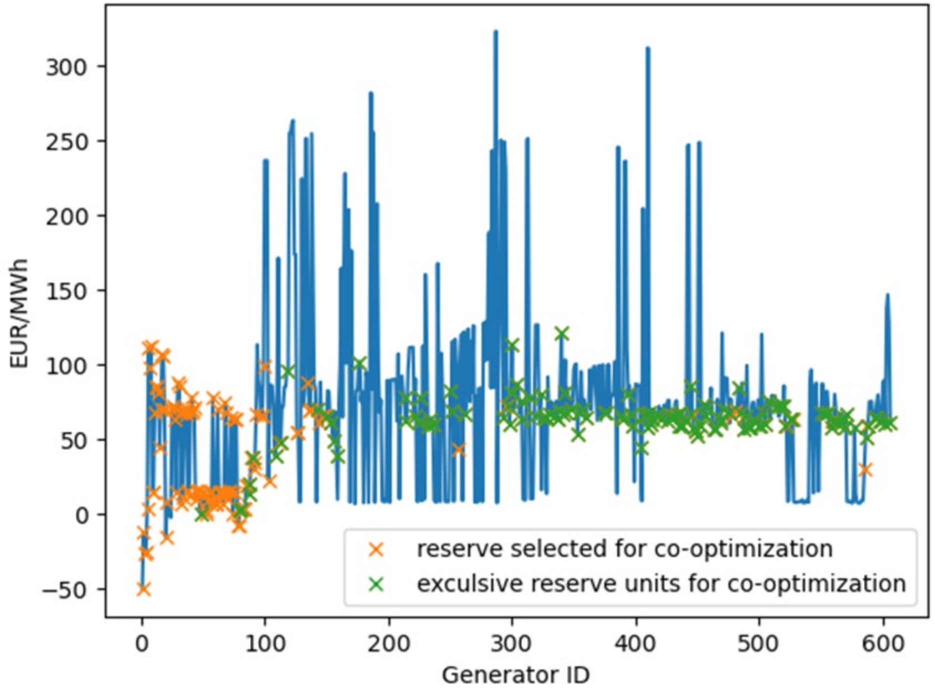
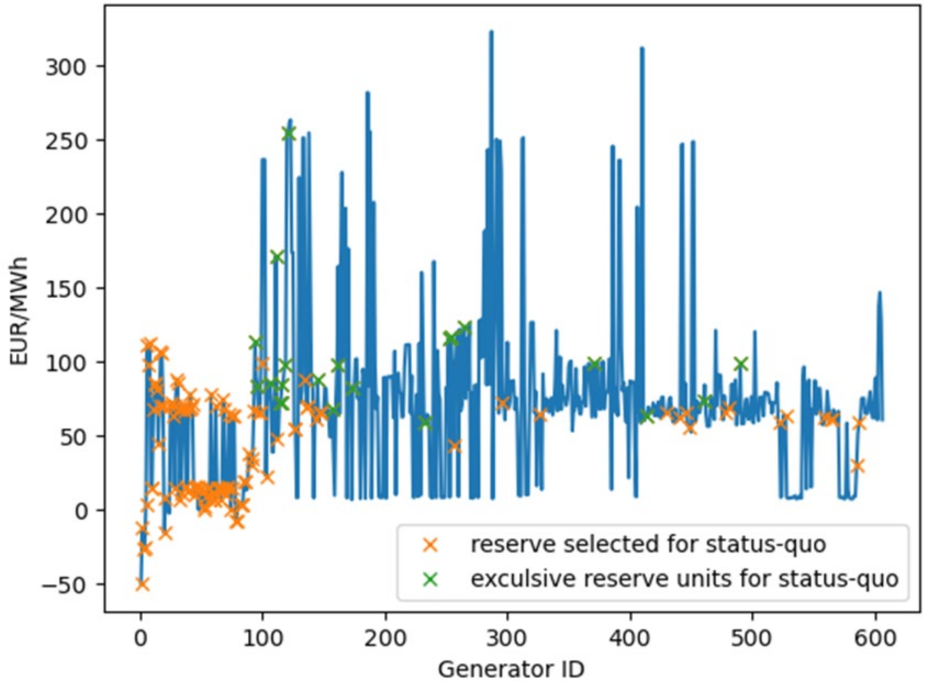
Categorisation of units

Technology	Fast (MW)	Slow (MW)	Non-dispatchable (MW)	Total (MW)	Marginal cost	Fixed costs
Biomass	10892	1142	0	12034	Medium	Medium
Gas	72402	13344	0	85746	High	Medium
Hard coal	0	46511	0	46511	High	High
Waste	729	845	0	1574	Medium	Low
Nuclear	0	0	82087	82087	Low	High
Brown coal/lignite	0	38281	0	38281	High	High
Oil	5934	752	0	6685	High	Medium
Coal-derived gas	2331	0	0	2331	High	Medium
Pumped storage	0	0	22960	22960	NA	Low
Wind	0	0	119084	119084	Low	Low
Hydraulic	0	0	46170	46170	Low	Low
Solar	0	0	128553	128553	Low	Low
Other	1800	0	0	1800	Low	Low

The role of fixed costs

Units are ordered on the x-axis by increasing fixed cost



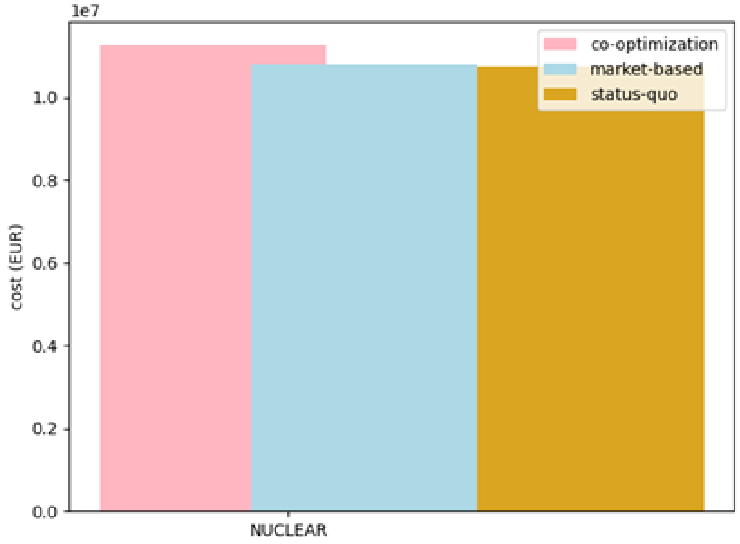


Co-optimisation allows an allocation of balancing capacity for units with relatively **high fixed** costs by **considering them only once and allowing those units to cover both needs**

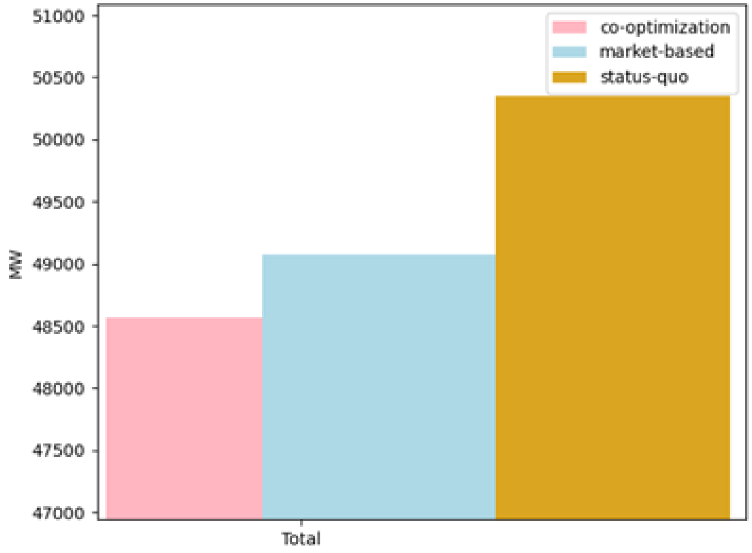
The role of technical minima

Co-optimisation operates with resources that have a **lower accumulated technical minimum**, thus increasing the space for dispatching energy from generation resources with **lower variable cost**

Day-ahead dispatch of nuclear



Day-ahead sum of the technical minimum power of all committed units



Co-optimisation achieves an **optimised usage of nuclear power resources**, compared to the sequential clearing designs, by **limiting the commitment of gas units for balancing capacity**

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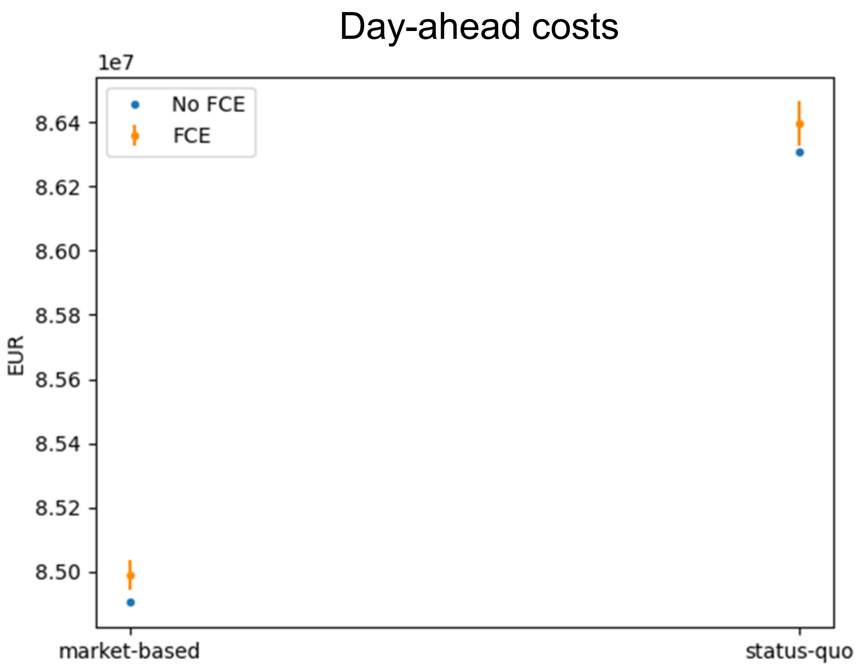
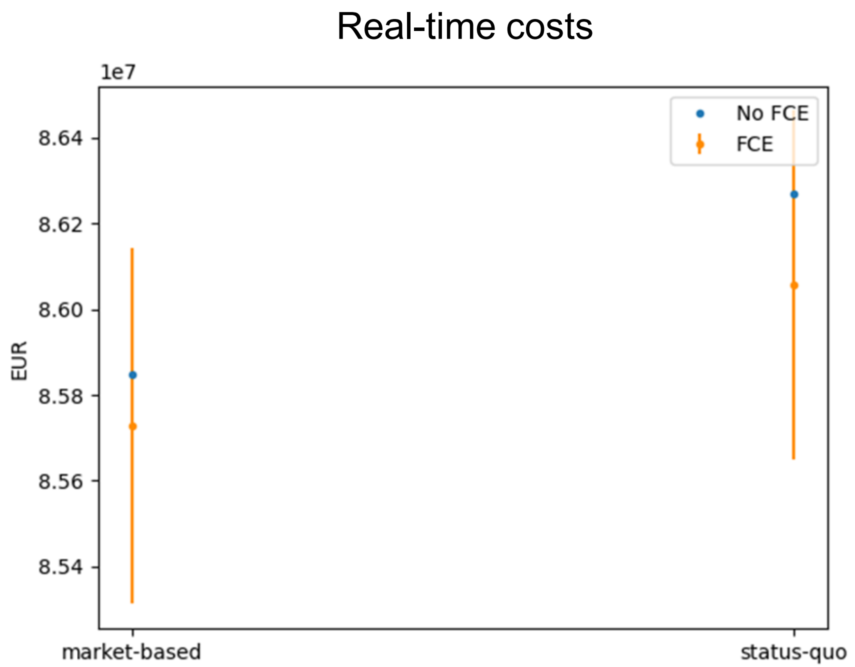
The role of intraday adjustments

- Our sequential clearing models benefit from a **significant reallocation of unit setpoints between day-ahead and real time**
- Major reshuffling of setpoints between day-ahead commercial positions and real-time physical positions places a **big burden on intraday adjustments** and may, to a certain extent, be over-optimistic
- **In day-ahead**, the **co-optimisation** model achieves efficiency gains of **~4%** relative to status-quo and **market-based** achieves **~1%** welfare gains compared to status quo
- This is equivalent to assuming an ideal scenario **without any imbalance** in real-time

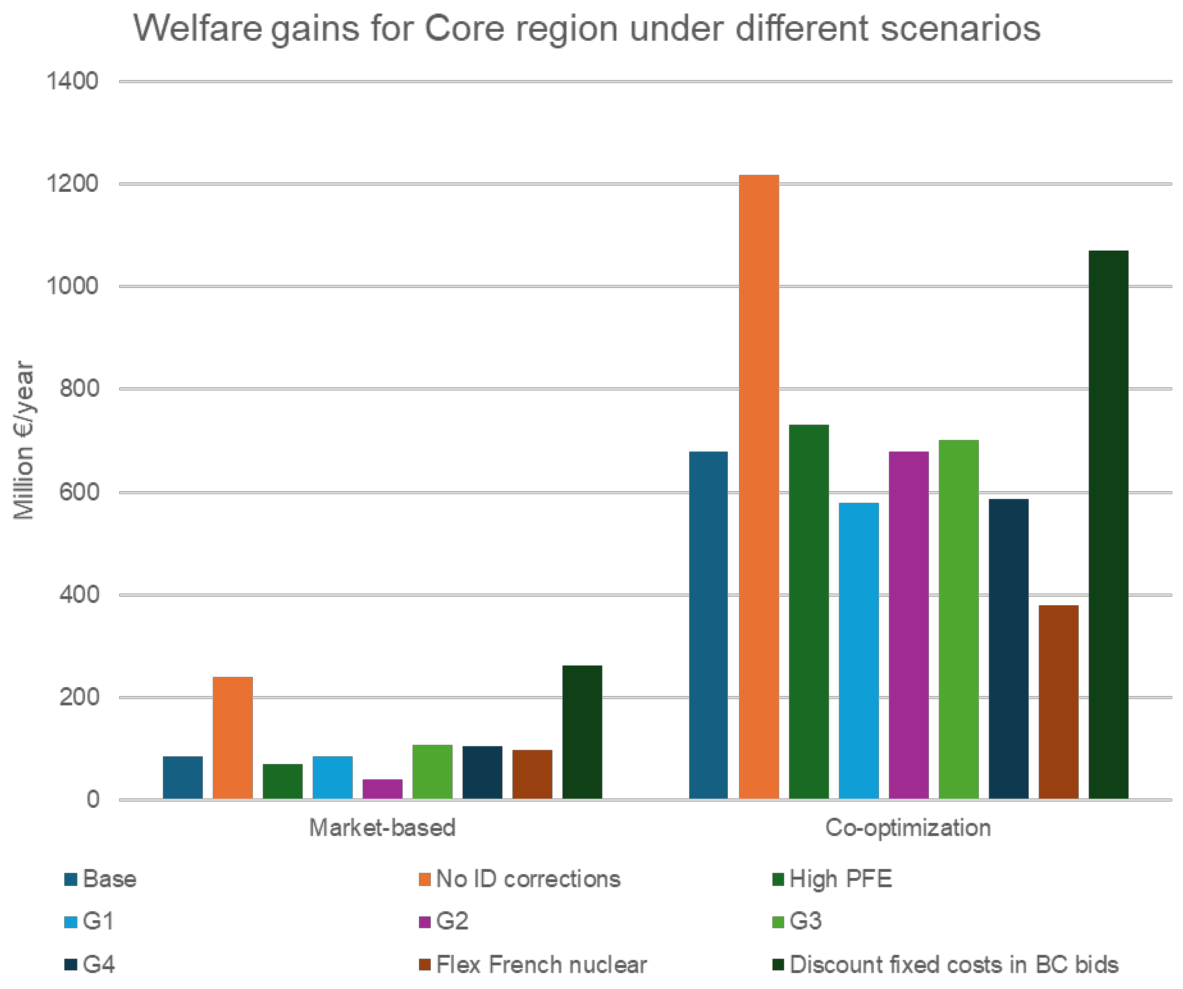
The role of forecast errors





The day-ahead inefficiencies introduced by forecast errors can largely be **corrected through intraday adjustments** (assuming such adjustments are possible in practice) because **largely the same units are committed in both cases**

Sensitivity analyses



Sensitivities	Variations relative to base case
Base case	
No ID corrections	No intraday corrections
High PFE	Price forecast errors estimated based on 2020-2022 (including crisis years)
G1	Appendix G1: Explicit bidding of opportunity costs for balancing capacity in co-optimisation
G2	Appendix G2: Lift 10% limit on allocation of CZC for balancing capacity
G3	Appendix G3: Remove possibility to trade up to 80 MW of BC on Austrian-German border
G4	Appendix G4: Reduce availability of French nuclear to historical levels of 2023
Flex French nuclear	50% of French nuclear capacity is dispatchable
Discount fixed costs in BC bids	Fixed costs in BC bids are discounted by the anticipated profit accrued in the day-ahead energy market

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Conclusions

Conclusions

- Co-optimisation could deliver **~1.3 billion € per year** of welfare gains in the EU relative to the status quo
- The market-based approach is estimated to deliver **159 million € per year** of welfare gains in the EU relative to the status quo
- Savings originate from **complex interaction of fixed costs and technical minima**, which allow for deeper integration of low-cost non-dispatchable technologies
- **Intraday corrections** (due to, e.g., portfolio effects) can be highly beneficial for correcting some of the scheduling inefficiencies of the status quo and market-based
- **Price forecast errors**, which can increase coordination inefficiencies due to misrepresentation of opportunity costs in the balancing capacity market, can be largely corrected by intraday adjustments
- Many alternative attempts at **representing fixed cost discounts in the day-ahead balancing capacity market model** in sequential designs do not outperform full bidding of fixed costs in the sequential designs in our model

Thank you for your attention!

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Appendix

Inefficiencies in sequential clearing: Price forecast errors

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Anticipating energy prices becomes a tall ask for market participants, especially in the presence of multiple **interacting balancing capacity products** and with markets of **higher time resolution**. Forecast errors may alter the **merit order curve**, leading to suboptimal results.

G1: MC_1 = 20 EUR/MWh, λ^*_1 = 50 EUR/MWh

OC_1 = max (0, λ^*_1 - MC_1) = 30 EUR/MWh

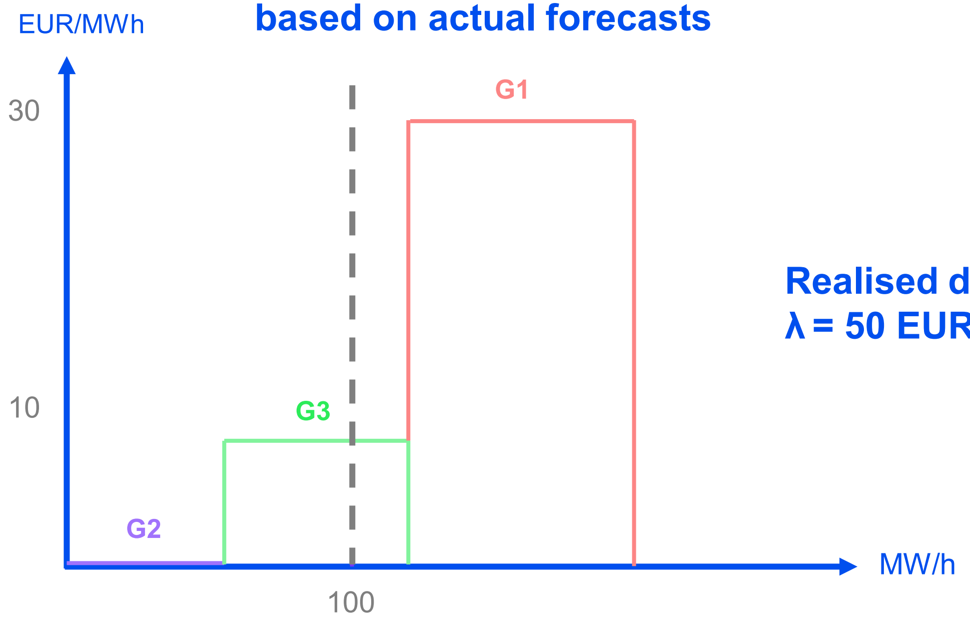
G2: MC_2 = 45 EUR/MWh, λ^*_2 = 45 EUR/MWh

OC_2 = max (0, λ^*_2 – MC_2) = 0 EUR/MWh

G3: MC_3 = 50 EUR/MWh, λ^*_3 = 60 EUR/MWh

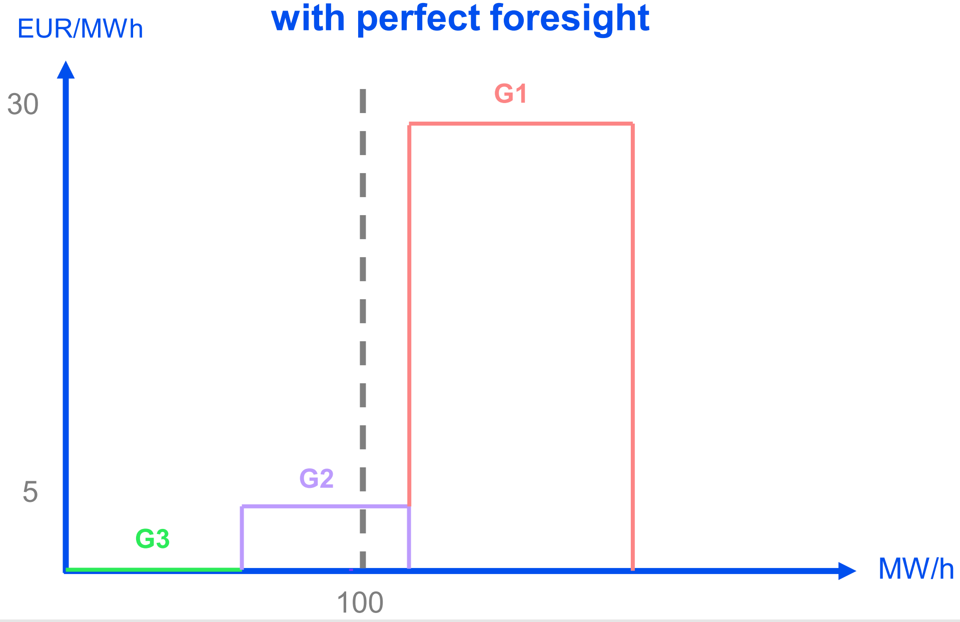
OC_3 = max (0, λ^*_3 – MC_3) = 10 EUR/MWh

Balancing capacity auction based on actual forecasts



Realised day-ahead price: λ = 50 EUR/MWh

Balancing capacity auction with perfect foresight



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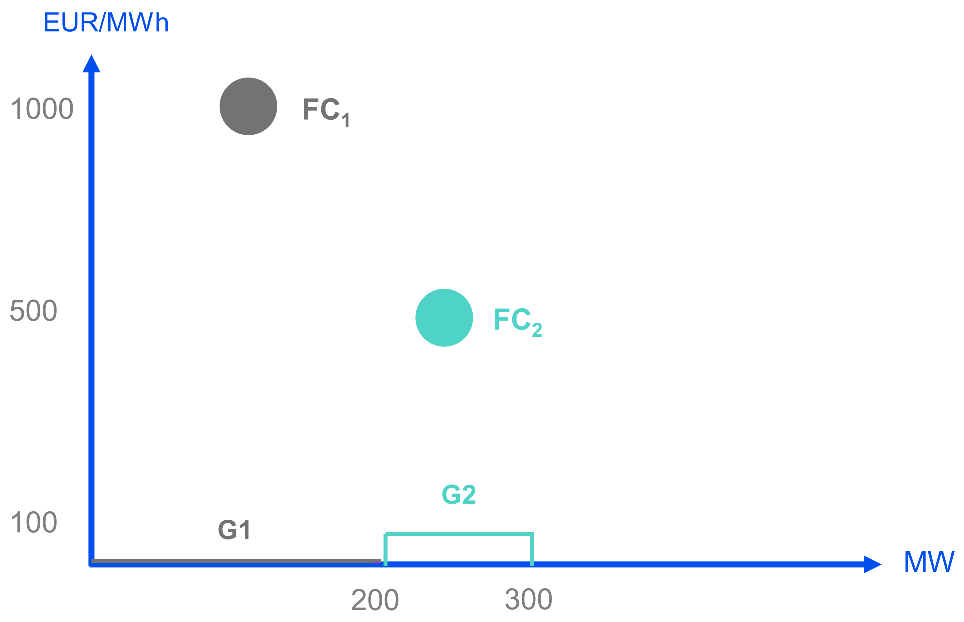
Inefficiencies in sequential clearing: The role of fixed costs

Even in case of accurate price forecast, **coordination inefficiencies remain**. **Fixed costs**, which are incurred for providing both balancing capacity and energy, **are fundamentally non-separable**. Forcing their separation can lead to an **inefficient allocation of units in the two markets**.

G1:
C_1 = 200 MW
MC_1 = 0 EUR/MWh
FC_1 = 1000 EUR

G2:
C_2 = 100 MW
MC_2 = 100 EUR/MWh
FC_2 = 500 EUR

DA load = 100 MW
BC requirement = 100 MW



Model	DA costs [EUR]	BC costs [EUR]
Co-optimisation	1000	
Seq. clearing	1000	500

Co-optimisation: **Only G1 is committed** as it can cover both energy and balancing capacity needs at the lowest cost, **despite its higher fixed cost**

Sequential clearing: **G2 is dispatched for balancing capacity** due to its lower fixed cost. This commitment is independent on the expected day-ahead energy price