Day-ahead and reserve prices in a renewable-based system: Adapting the market design for energy storage

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Introduction

Context

- **Increasing share of renewables in energy mix.**

- **Supply/Demand equilibrium must be challenged with non-dispatchable energies**
  - Increase in need for reserves
  - Less dispatchable generation, currently supplying reserves

  → Investments in storage and flexible resources are necessary

- **Can reserve capacity markets send price signals for such investments?**

Motivations

- **Objective: To study the evolution of reserve prices with large shares of renewables and storage**

- **Approach**
  - We use a fundamental optimization model with interconnected markets (several European countries) and interrelated markets (day-ahead and reserves markets).
  - Only automatic reserves (FCR and aFRR) are considered because of a larger hamonisation in Europe.

- **Main results**
  - Leading role of batteries in equilibrium of reserve-capacity markets
  - Batteries have zero opportunity costs in most cases
  - Reserve capacity prices tend to zero. As a result, reserve markets are less and less profitable (missing-money problem).

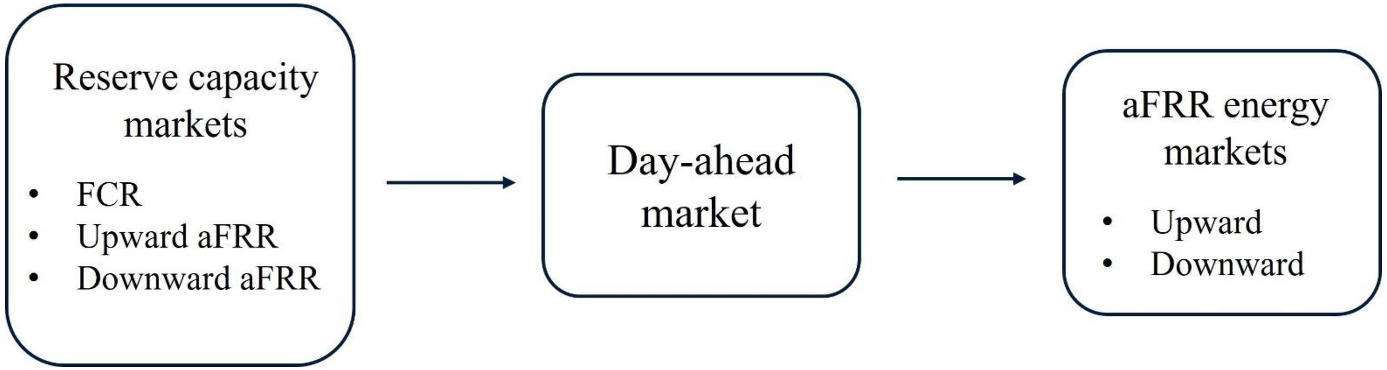
Literature

- **Fundamental models of day-ahead and reserve markets to identify the most efficient market design**
  - Joint market more efficient than sequential design (Dominguez et al. 2019; Van den Bergh & Delarue, 2020)
  - Cost reduction with market integration (Farahmand and Doorman, 2012; Jaehnert and Doorman, 2012, Van den Bergh et al. 2018).
  - Role of product characteristics (Dallinger et al. 2018)

    Contract duration, frequency of clearings, asymmetrical products

Main assumptions

A three-step model:



As in the literature, we assume:

- We do not include uncertainties in our model: Steps are simultaneously cleared;
- Perfect competition between technology blocks or suppliers;
- Each country is represented as a node.

The variable cost of reserve energy supply is identical to the variable generation cost.

The model

- **Minimization of the total costs to meet the demand in the day-ahead and reserve energy markets**
  - Variable costs, start-up costs, demand-response costs, lost load

- **Subject to**
  - Demand/supply equilibrium
  - Generation and transmission constraints
  - Reserve supply constraints: ramping capacity and operating range

- **Reserve capacity costs not in objective function because opportunity costs → dual variables (marginal prices) do not correctly them.**

Opportunity costs of reserve capacities

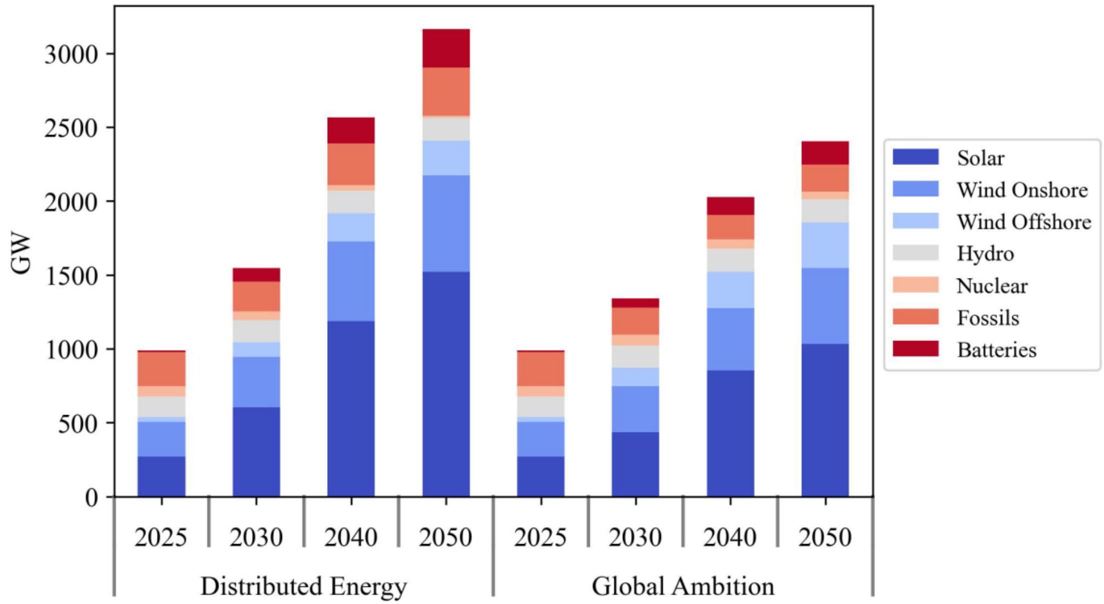
- **According to the literature, we replace dual variables by opportunity costs of bidding in reserve capacity market (Müsgens et al. 2014, Dallinger et al. 2018):**
  - Infra-marginal units: losses if one MW is moved from day-ahead to reserve market;
  - Extra-marginal units: losses of being on the day-ahead market to supply reserves

- **We propose a definition for batteries:**
  - Opportunity cost > 0 only when trade-off with day-ahead market

	Upward reserve	Downward reserve
$C_b \leq p_{n,t}^{DA}$	$p_{n,t}^{DA} - C_b$	0
$C_b > p_{n,t}^{DA}$	0	$C_b - p_{n,t}^{DA}$

Case Study (1)

- **Eight countries of Western Europe.**
- **Ten-Year Network Development Plan (TYNDP) scenarios from ENTSO-E & ENTSO-G (2022):**
  - « Distributed Energy »: Higher energy-efficiency levels, higher electrification rates of heating and transport, solar and onshore wind.
  - « Global Ambition »: Hydrogen, offshore wind.

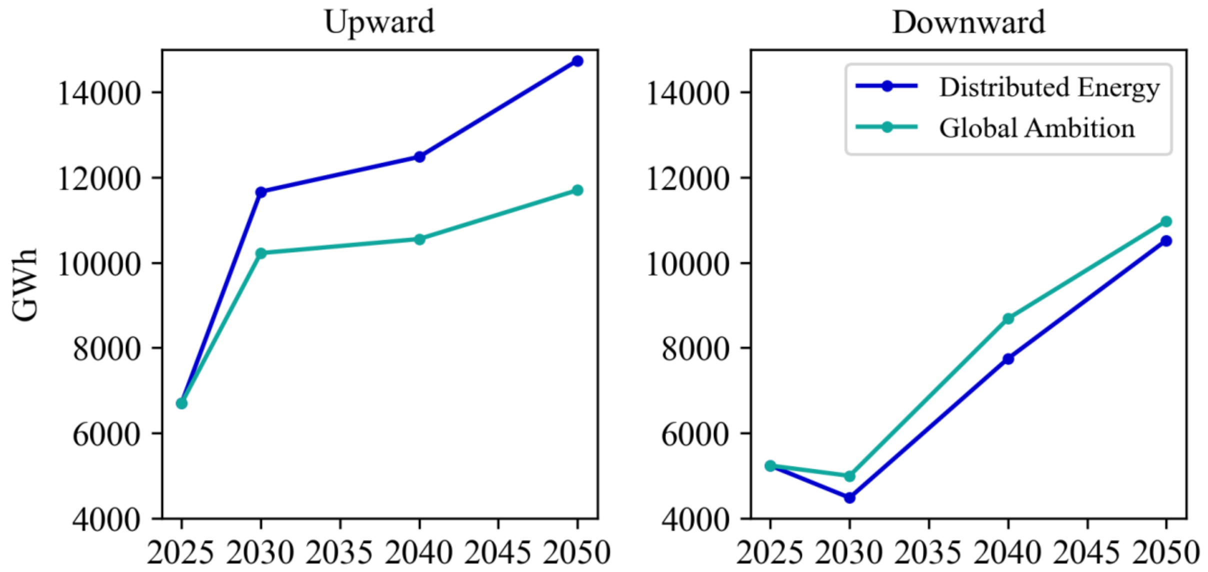


Installed capacity in the TYNDP scenarios (GW)

Case Study (2)

The demand for aFRR:

- The aFRR energy demand levels are forecasts obtained from a time-series model.
- Autoregressive moving-average models with exogenous variables (ARMAX) are used (Deman and Boucher, 2022).

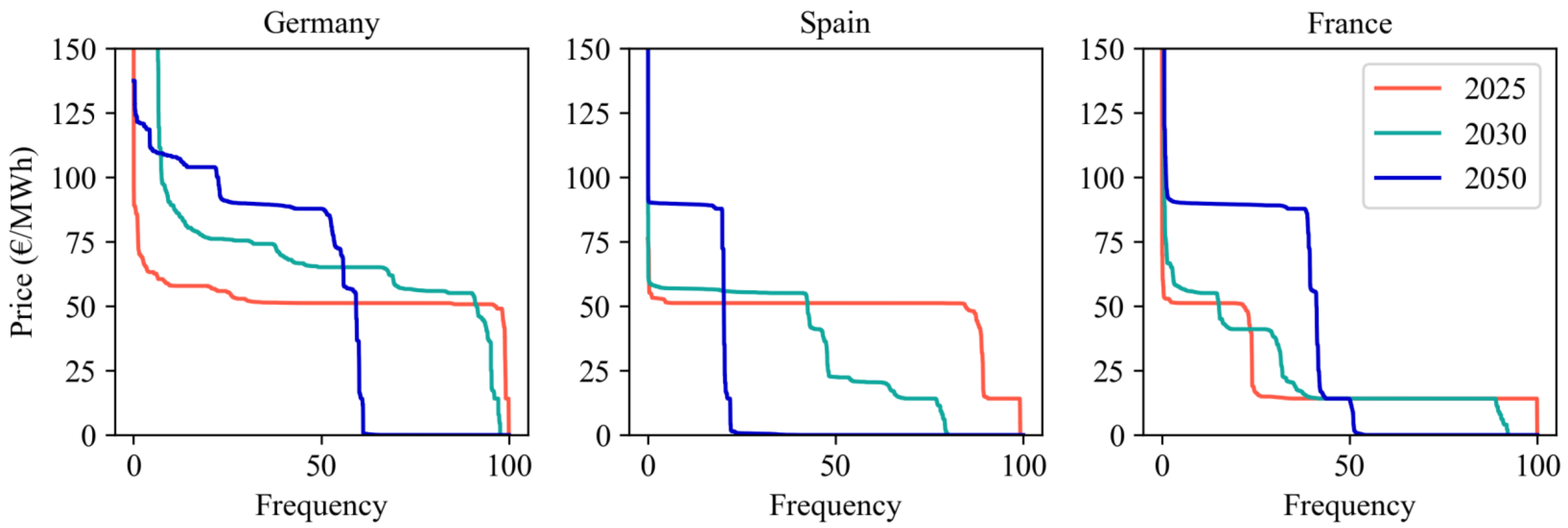


Annual aFRR energy demand (GWh)

The FCR capacity demand levels are determined keeping the 3 GW requirement for the Continental area (Veyrenc et al., 2021).

Results (1)

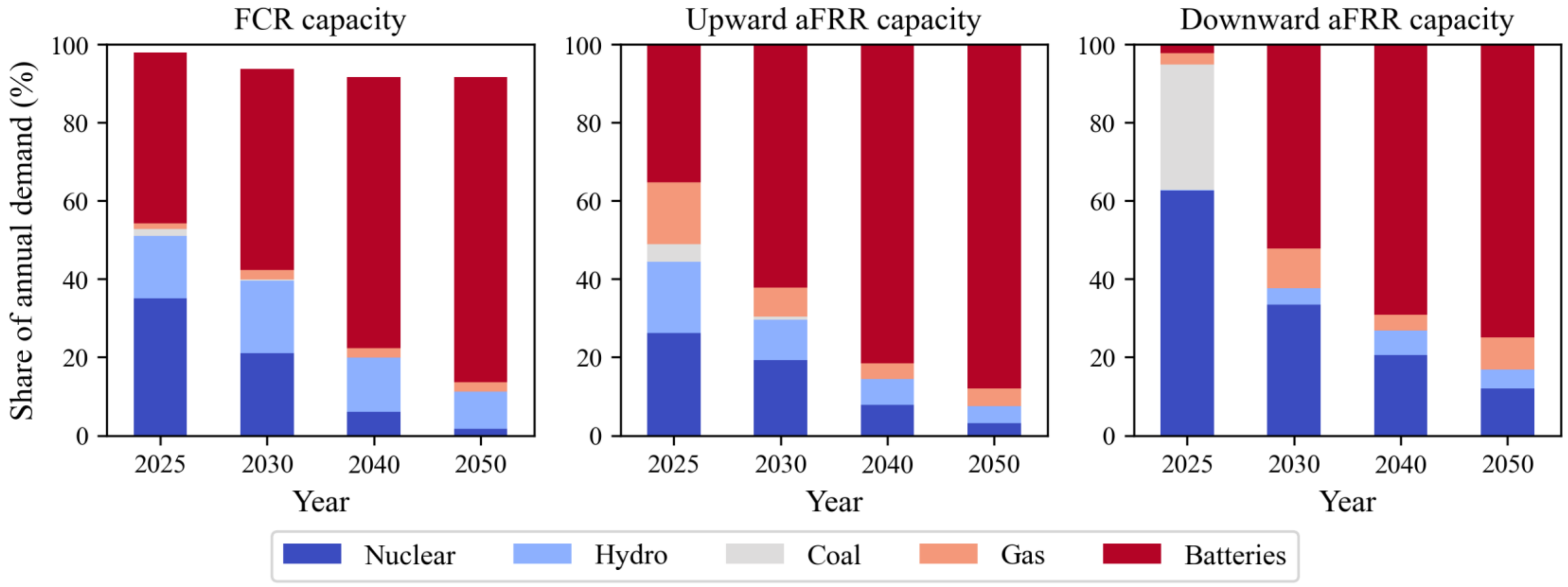
- **Energy prices: Renewables lead to low prices during several periods, decreasing the profitability of dispatchable power plants.**
  - Conventional technologies supply reserves and also back up.
  - They stay online during hours of low residual load due to start-up costs.
  - They also do a trade-off between supplying reserves or back-up and being switched off.



Distribution of day-ahead prices (Distributed Energy scenario)

Results (2)

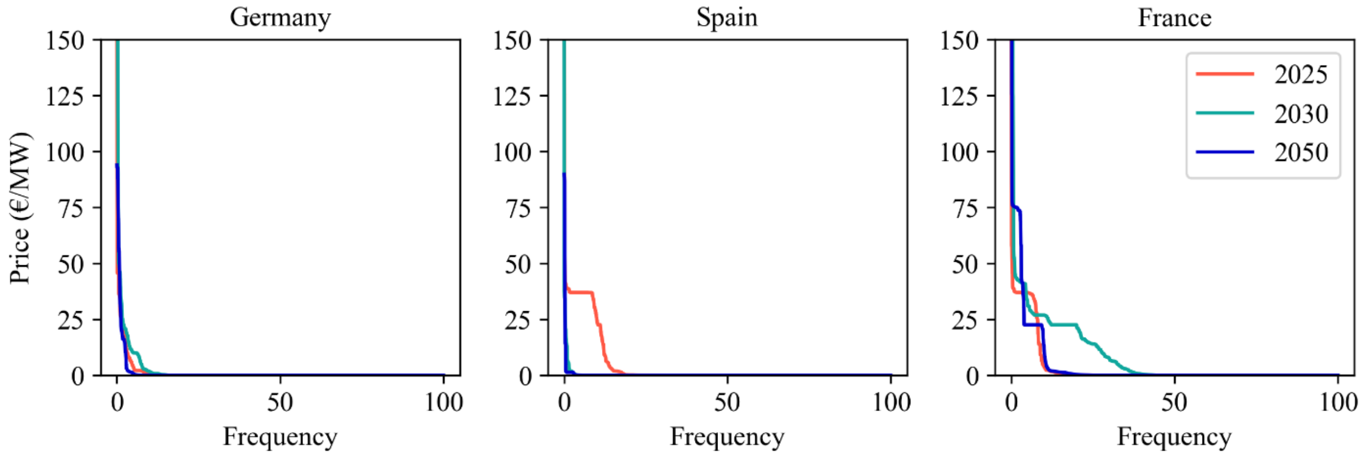
- **Supply of reserves: Batteries become the main supplier of reserve capacities.**
  - Generally less costly because they could supply reserves without being on the day-ahead market.
  - The only technology to supply reserve capacities in Germany, with nuclear power in France and with gas in Spain.



Distribution of reserve capacity supply in Germany, Spain and France (Distributed Energy scenario)

Results (3)

- **Prices of reserves: Often low as opportunity cost of batteries is zero**
  - When there is no arbitrage with the day-ahead market (batteries only supply reserves).
  - When they are marginal in the day-ahead market → indifference between the two markets.



Distribution of upward aFRR capacity prices (Distributed Energy scenario)

- **Reserve prices do not remunerate dispatchable energy (missing money problem) and investment costs.**

Conclusions

- **Increasing renewables and batteries reduce prices on the day-ahead and reserve markets.**
- **Some dispatchable units could be pushed out of the market: their profitability is challenged.**
- **Adding reserves capacity markets does not solve the missing money problem.**