Principles of Scarcity Pricing

Anthony Papavasiliou, UCLouvain → NTUA

CREG Scarcity Pricing Workshop

April 29, 2022

National Technical University of Athens

UCLouvain

Outline

- The Value of Balancing Capacity
- Implicit and Explicit Auctioning of Balancing Capacity
- Operating Reserve Demand Curves Based on LOLP
- The Missing EU Market for Real-Time Balancing Capacity
- The CREG Scarcity Pricing Studies

The Value of Balancing Capacity

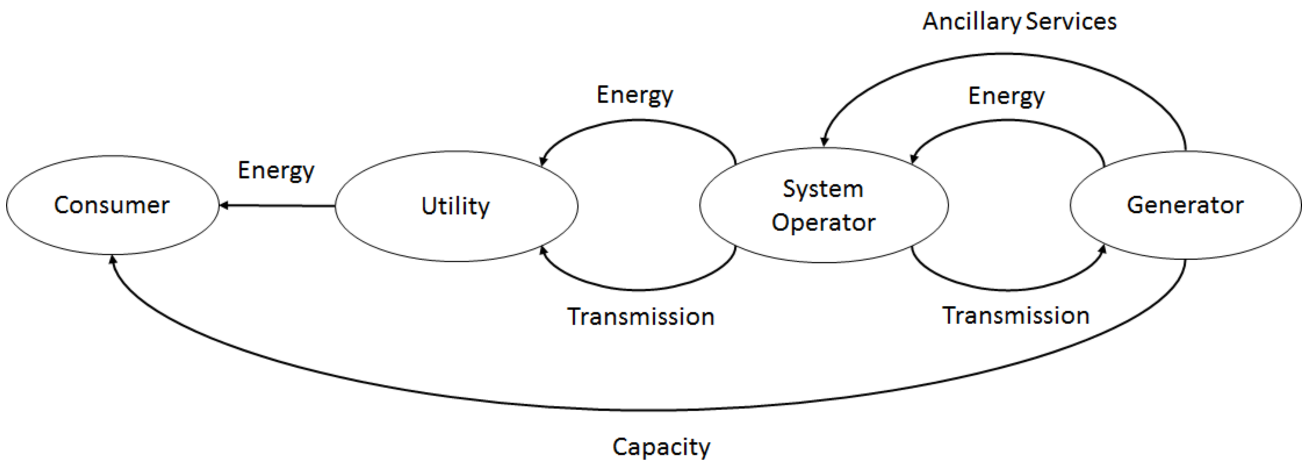
Anthony Papavasiliou
April 2022

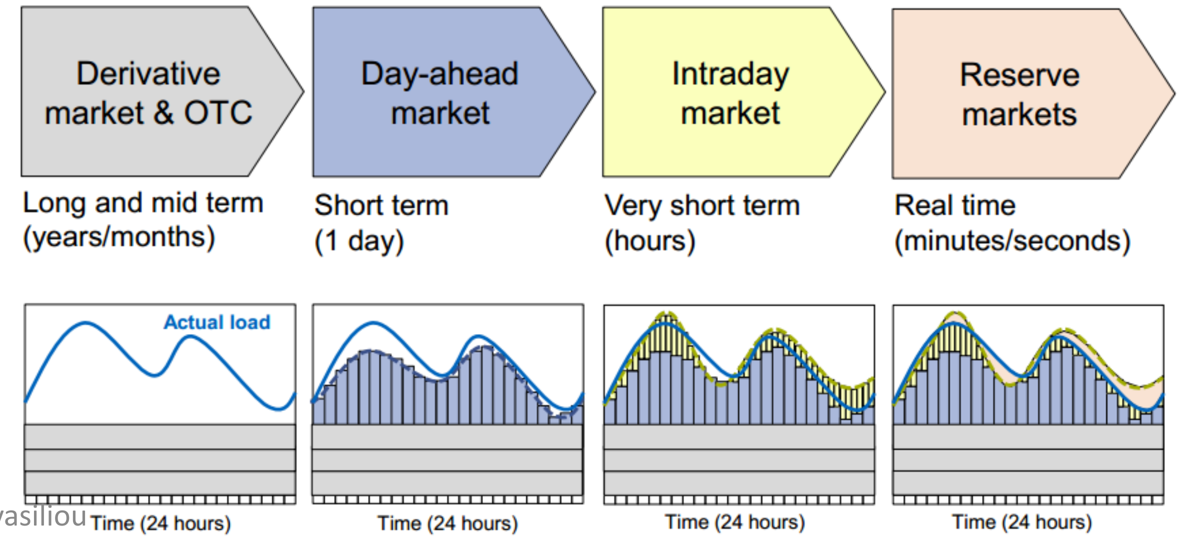
Mechanisms for Compensating Capacity

- Energy-only markets that rely only on VOLL pricing
  - The energy market without price caps is the only source of revenue
  - Risky for investors (-), politically contentious (-)
- Installed capacity requirements
  - Member States decide on a target capacity and TSO procures it through annual auctions
  - Safer for investors (+), capacity target is contestable/non-transparent (-), does not ensure flexibility (-), complex variations among Member States (-)
- Capacity payments
  - Energy prices are uplifted by capacity payment
  - Installed capacity may err significantly (-)
- **Energy-only markets with a scarcity pricing function**

Revenue Streams in Electricity Markets

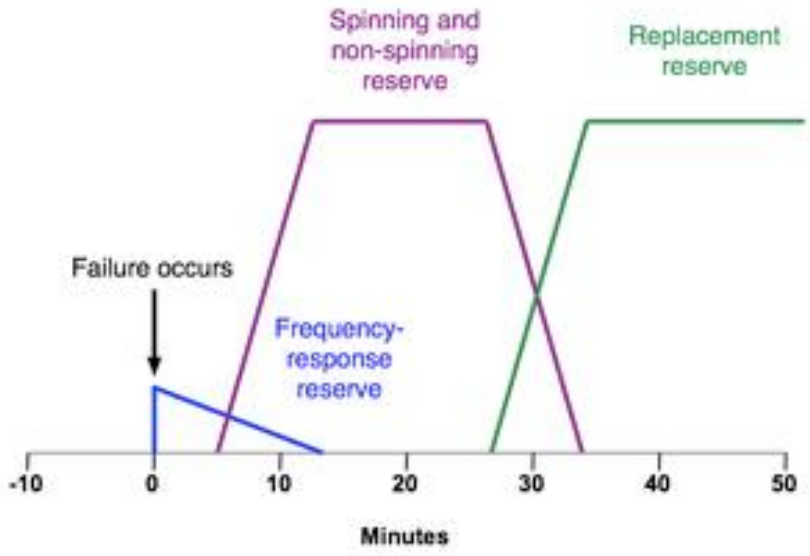
- Energy
  - Day-ahead 'uniform price' auction
  - Real-time uniform price auction for activated *energy*
- Balancing capacity
  - Month/week/day-ahead auction for reserve *capacity*
- Capacity
  - Auctioned annually in <u>some</u> markets
- Recent migration of value away from energy markets and into flexibility (balancing capacity)



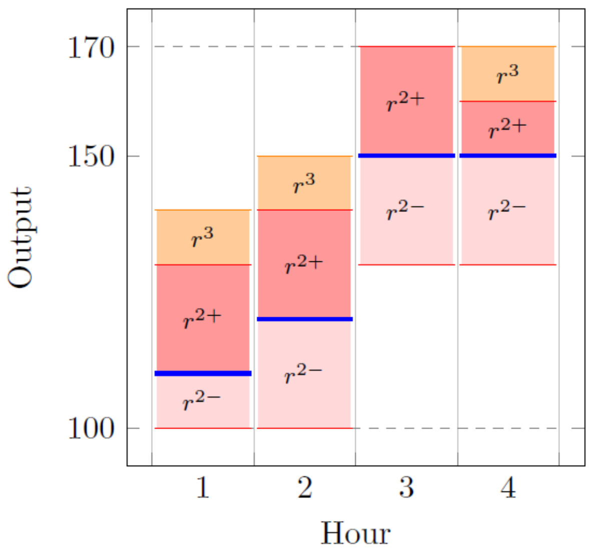


Balancing Capacity

- Frequency containment reserve (FCR): immediate response to change in frequency
- Automatic frequency restoration reserve (aFRR): reaction in a few seconds, full response in 7 minutes
- Manual frequency restoration reserve (mFRR): available within 15 minutes
- Replacement reserve
- Commitment of balancing capacity induces opportunity cost because it displaces energy sales



Focus of our proposal



Value of Balancing Capacity (in Real Time)

- Consider a system with imbalances distributed according to a normal distribution with mean of 0 MW and standard deviation of 10 MW
- Consider a market with two BSP offers:
  - BSPA: 10 MW @ 20 €/MWh
  - BSPB: 10 MW @ 50 €/MWh
- Suppose that the system experiences an imbalance of 15 MW:
  - Price-taking TSO demand for 15 MW
- At that level of stress, what is the value of additional capacity to the system?
  - With 5 MW left in the system, the probability of losing load is $\mathbb{P}[Imbalance \geq 5\ MW] = 30.9\%$
  - At this level, reserves prevent load shedding 30.9% of the time
  - If VOLL = 1,000 €/MWh, the value of an additional MW translates to 1,000 €/MWh x 30.9% = 309 €/MWh
- The balancing energy price in this example is 50 €/MWh

Implicit and Explicit Auctioning of Balancing Capacity

Anthony Papavasiliou
April 2022

Multi-Product Auctions

- Scarcity pricing based on operating reserve demand curves relies on the notion of auctioning energy and balancing capacity **simultaneously**, in *real time*
- Identical concept to day-ahead co-optimized allocation of balancing capacity (article 40 of EBGL), but rather applied to *real time*

A multi-product charity auction. Buyers place bids for multiple products **simultaneously**. When the gate of the auction closes, the auctioneer determines a price for each product, and allocates each of them to the winning bidder.

Some Notation

- Q_i: Quantity of energy bid i [MWh]
- P_i: Price of energy bid i [€/MWh]
- QR_i: Quantity of BSP offer / TSO demand i [MW-h]
- PR_i: Price of BSP offer / TSO demand i [€/MW-h]
- x_i: Fraction of accepted energy offer i
- xR_i: Fraction of accepted balancing capacity offer i
- λ: Energy price [€/MWh] in multi-product auction (co-optimization)
- λR: Balancing capacity price [€/MWh]
- $\tilde{\lambda}$: Energy price [€/MWh] in energy-only auction

Explicit Auctioning of Real-Time Balancing Capacity

- Consider an application of EBGL article 40 on co-optimization to the illustrative example
- BSP energy bids (Q_i MW @ P_i €/MWh):
  - BSPA: 10 MW @ 20 €/MWh
  - BSPB: 10 MW @ 50 €/MWh
- TSO energy bids (Q_i MW @ P_i €/MWh):
  - Price-taking for 15 MW
- BSP balancing capacity bids:
  - BSPA: 10 MW @ 0 €/MWh
  - BSPB: 10 MW @ 0 €/MWh
- TSO balancing capacity demand:
  - 10 MW @ 309 €/MWh
- Balancing energy price λ: 359 €/MWh
- Balancing capacity price λR: 309 €/MWh

Energy welfare — BC welfare

$$max_{x \geq 0, xR \geq 0} \underbrace{Q_i \cdot P_i \cdot x_i}_{\text{Energy welfare}} + \underbrace{QR_i \cdot PR_i \cdot xR_i}_{\text{BC welfare}}$$

$$x_i \leq 1$$

Linking of bids

$$x_i + \frac{QR_i}{Q_i} xR_i \leq 1$$

$$(\lambda): \sum_i Q_i \cdot x_i = 0$$

$$(\lambda R): \sum_i QR_i \cdot xR_i = 0$$

This is an **explicit multi-product auction** for energy and balancing capacity, applied **in real time**

The equilibrium price for balancing capacity **reflects the value of balancing capacity** in the system

Implicit Auctioning of Real-Time Balancing Capacity

- Our proposal, inspired by US designs, auctions the balancing capacity **implicitly**
- Motivation: seamless (to the extent possible) integration with EU design, while maintaining the intended benefits of scarcity pricing based on ORDC

How it works

1. Run the energy-only balancing auction (e.g. MARI)

$$max_{x\geq 0\geq 0}\ Q_i \cdot P_i \cdot x_i$$

$$x_i \leq 1$$

$$(\tilde{\lambda}): \sum_i Q_i \cdot x_i = 0$$

2. Compute the same scarcity adder as the one that would have resulted from explicit auctioning: λR=309 €/MWh

3. Correct the balancing price by accounting for linking of bids: λ=$\tilde{\lambda}$+ λR = 50 + 309 = 359 €/MWh

How To Execute Step 2? Choosing Operating Reserve Demand Curves

- It depends on how the TSO values reliability, but it is always based on the amount of *leftover balancing capacity* in **real time**

- Inelastic operating reserve demand curve:

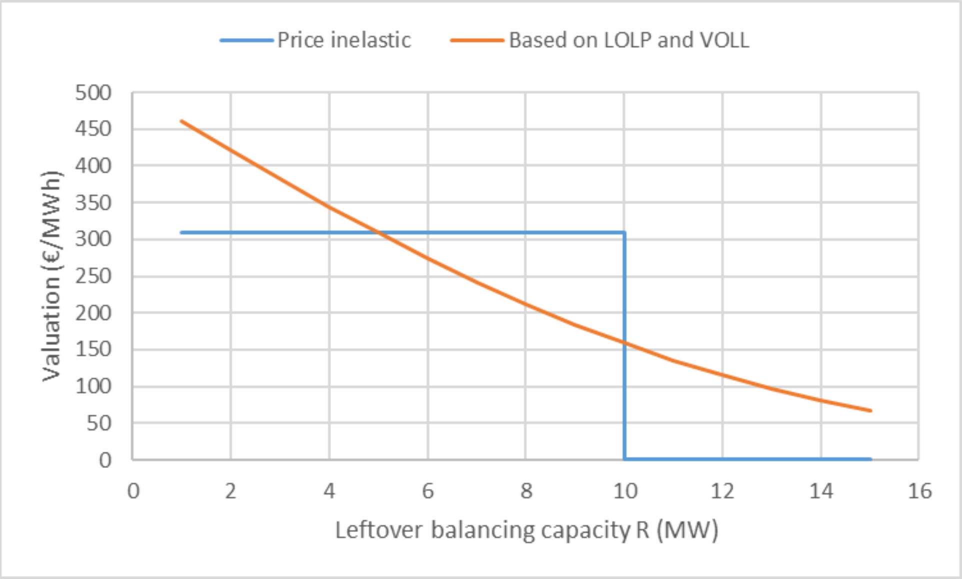
10 MW @ 309 €/MWh

→ Mathematically, $\lambda R = 309$ €/MWh if $R < 10$ MW, $\lambda R = 0$ otherwise

- Operating reserve demand curve based on LOLP:

1 MW @ 460.1 €/MWh, 1 MW @ 420.7, €/MWh, …

→ Mathematically, $\lambda R \approx (VOLL - \widehat{MC}) \cdot LOLP(R)$



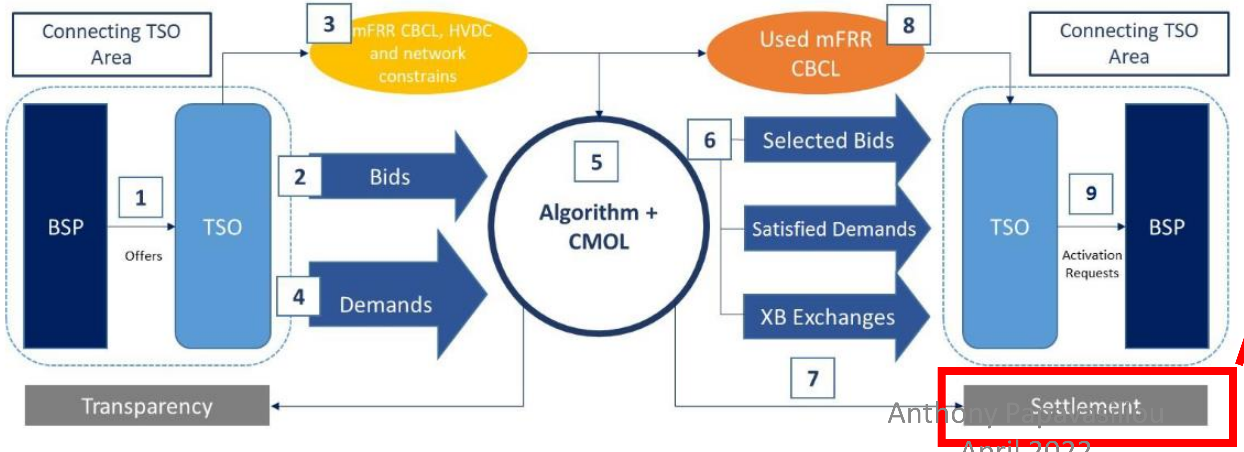
Some Remarks

- The market clearing condition for energy can be rewritten equivalently as

$$(\tilde{\lambda}): \sum_{i \in BSP} Q_i \cdot x_i = BRPImb$$

This suggests a unique energy price for BSPs and BRPs (since a unique product is traded, namely real-time energy)

- It is implicitly assumed that BSPs bid a zero cost for balancing capacity, since in the basic model there are no explicit / non-opportunity costs for balancing capacity
- The implementation of the real-time market for reserve can be implemented in the context of balancing platforms by applying the adder as indicated in the figure

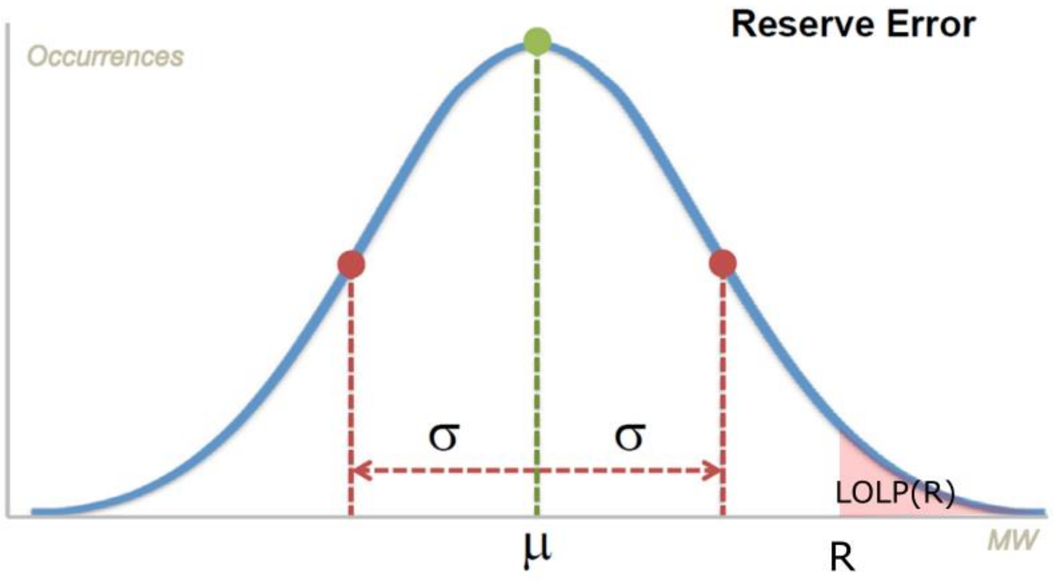


$$(\lambda^B + \lambda^R) \cdot qa -$$
$$(\lambda^B + \lambda^R) \cdot (Imb - ai) - C \cdot (qa + ai)$$
$$+\lambda^R \cdot (P^+ - qa - aiqa^R)$$

1. Balancing price adjustment
2. Imbalance settlement adjustment
3. Market for BC imbalances

Loss of Load Probability

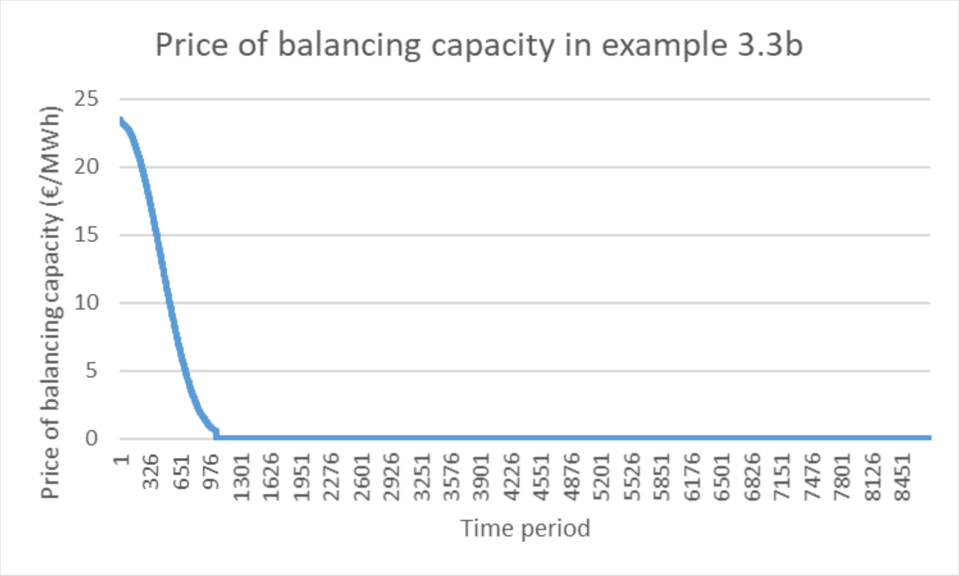
- Uncertainty Δ in real time due to:
  - demand forecast errors
  - import uncertainty
  - unscheduled outages of generators
- $LOLP(R) = Prob(\Delta \geq R)$ is the probability that real-time uncertainty exceeds reserve capacity R

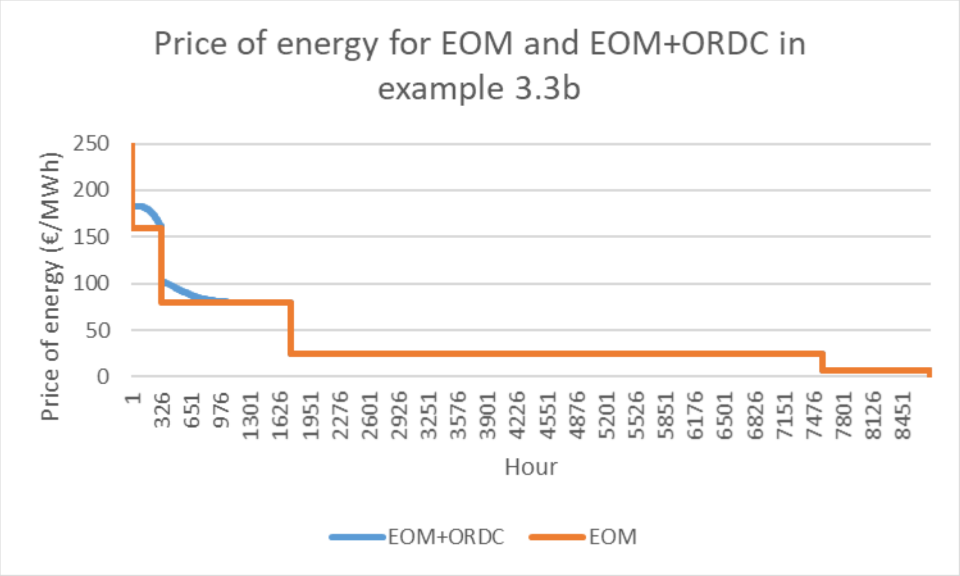


Scarcity Price Adders Based on VOLL and LOLP

- Price adder: $\lambda R = (VOLL - \lambda) \cdot LOLP(R)$, where λ is the marginal cost of the marginal producer, R is the available balancing capacity
- More frequent, lower amplitude price spikes
- Price spikes can occur while relying on marginal cost bidding
- Through arbitrage, scarcity adders back-propagate to forward (day / week / month-ahead) balancing capacity auctions
- Scarcity pricing can co-exist with capacity mechanisms, however precedence matters: important to give the energy-only market design a chance to function properly *first*

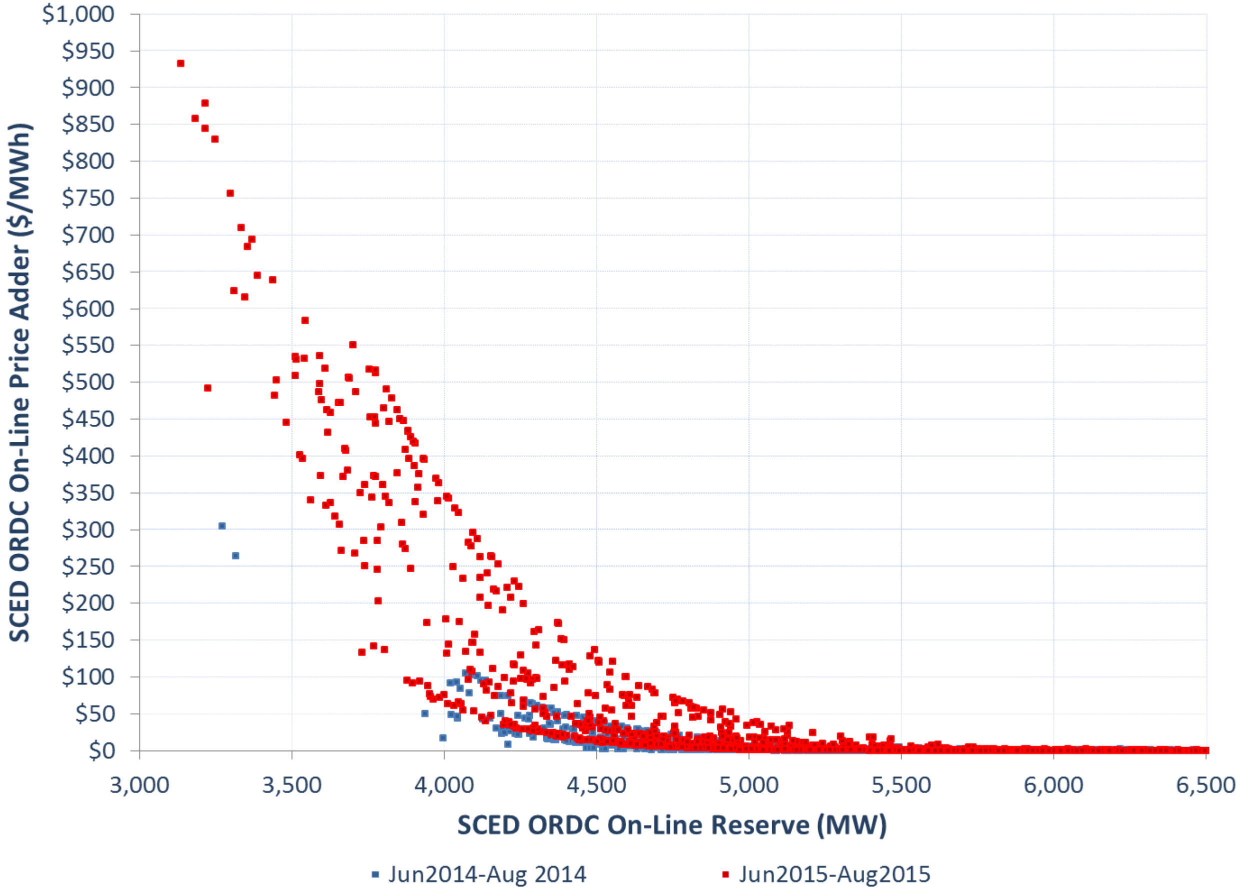
Price Stabilization Effect of ORDCs

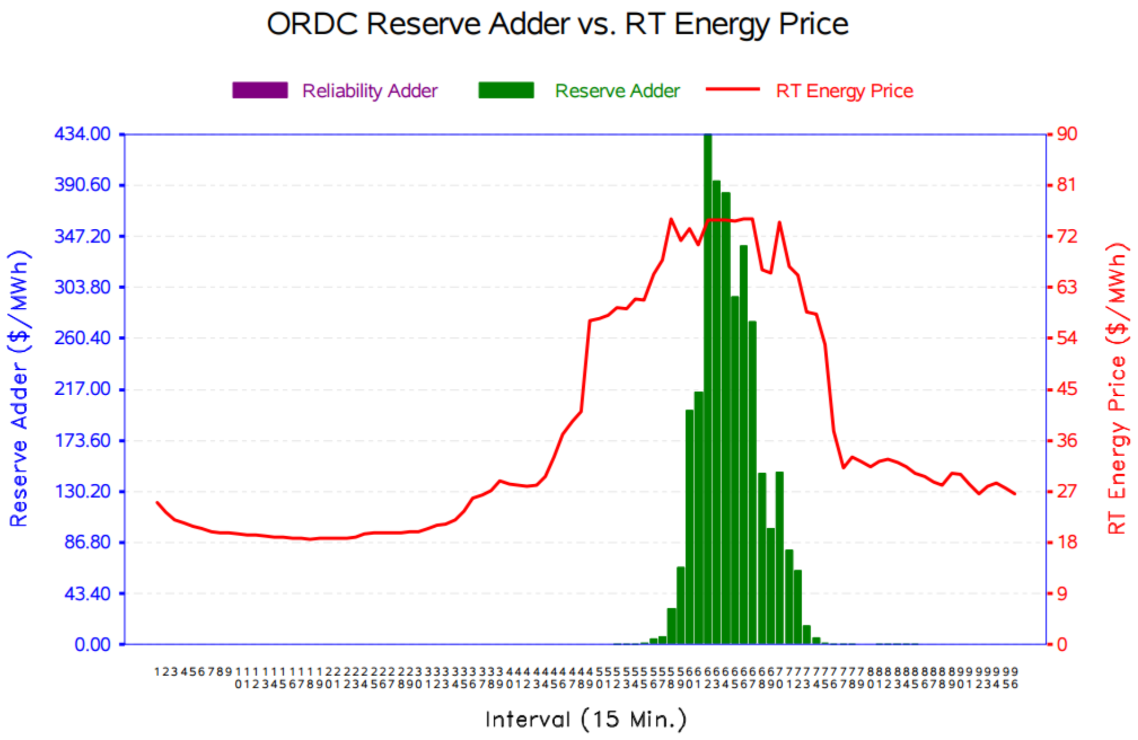




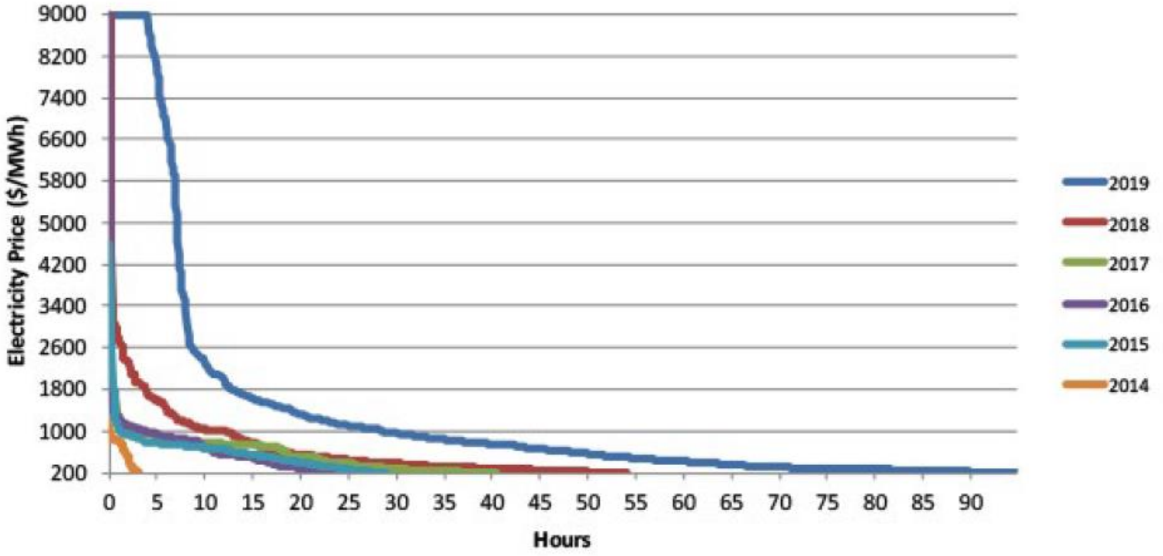
- Balancing capacity prices (left) lift energy prices with them (right), thereby producing a more dependable cash flow for flexible resources
- Whereas EOM long-run equilibrium prices can support optimal short-term dispatch, not all competitive short-term prices can support optimal long-term capacity mix. ORDC largely corrects this issue.

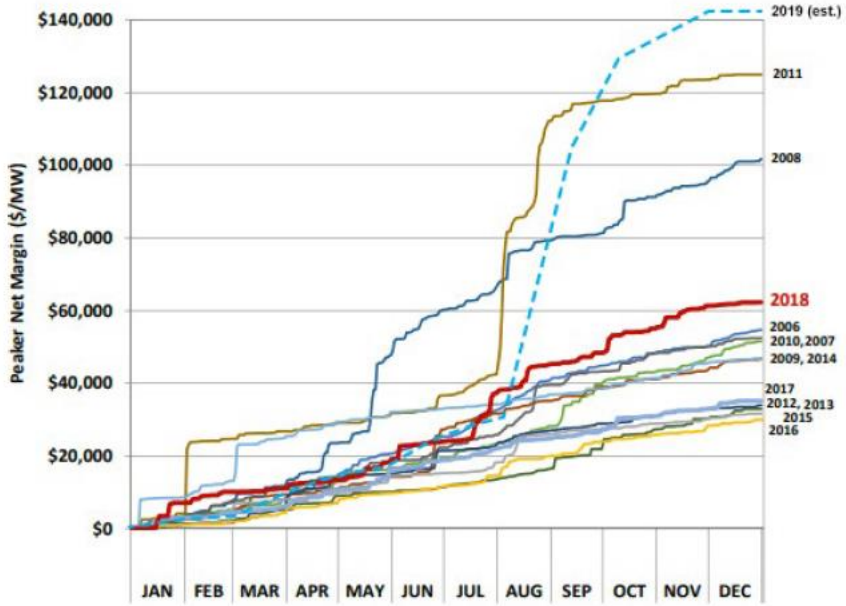
Illustration from Texas: July 30, 2015





Texas in 2019





Source: RTO Insider, “ERCOT 2019: Final Proof of a Successful Market Design?”, by Rob Gramlich, October 15, 2019

The Missing EU Market for Real-Time Balancing Capacity

Anthony Papavasiliou
April 2022

BRPs and BSPs

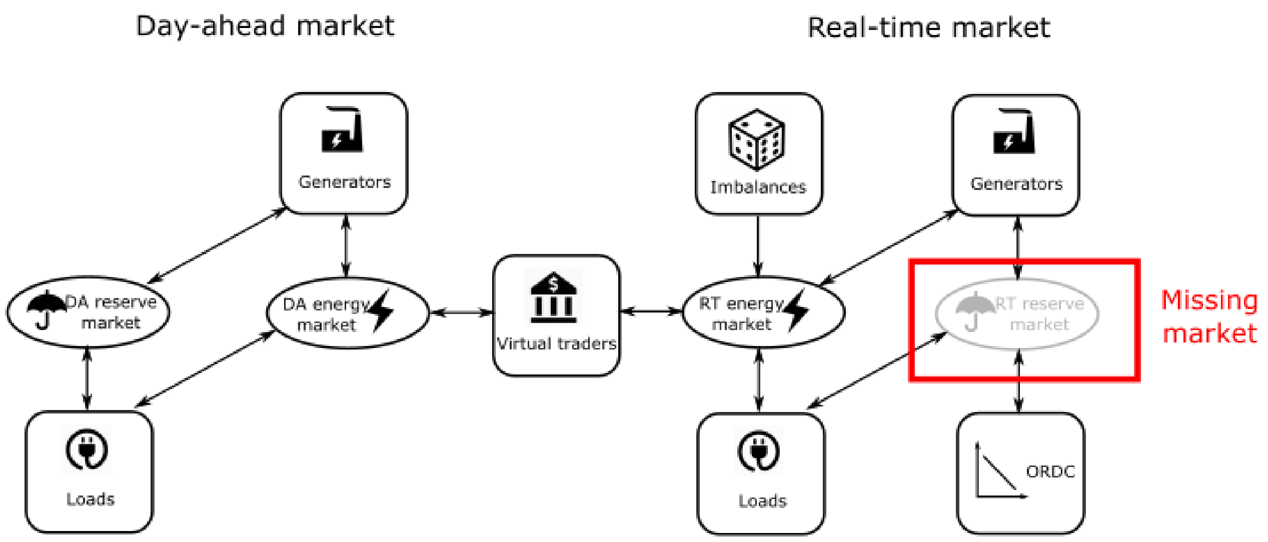
- **Balancing responsible parties (BRPs)**: *price-inelastic* buyers or sellers of real-time energy
- **Balancing service providers (BSPs)**: *price-elastic* buyers or sellers of real-time energy
  - BSPs commit to bidding at least DA reserve capacity to RT balancing markets
  - Each BSP must be attributed to at least one BRP portfolio (EBGL)
- BRPs and BSPs face a different price for real-time energy:
  - BRPs: imbalance price
  - BSPs: balancing price

Translating First Principles to the EU Design

- ORDC essentially sets a RT price for reserve
- In equilibrium, energy and reserve prices follow each other in lock step

So what does it mean to introduce ORDC adders to the EU market, if we do not have a RT market for balancing capacity?

- Adders to the imbalance price (BRPs)?
- Adders to the balancing price (also BSPs)?
- What about RT balancing *capacity*?



The CREG Scarcity Pricing Studies

Anthony Papavasiliou
April 2022

The Belgian Scarcity Pricing Studies

- **First study (2015)** [1]: How would electricity prices change if we introduce ORDC in the Belgian market?
  - **Finding**: it could enable the majority of combined cycle gas turbines, which are currently operating at a loss, to *recover their investment costs*
- **Second study (2016)** [2]: How does scarcity pricing depend on
  - strategic reserve
  - value of lost load
  - restoration of nuclear capacity
  - day-ahead (instead of month-ahead) clearing of reserves
- **Third study (2017)** [3, 4]: can we take a US-inspired design and plug it into the existing European market?
  - **Finding**: essential role of *real-time market for reserve capacity* for back-propagation of adders to forward reserve markets
- **Fourth study (2019)** [7, 8, 11]: cross-border effects, calibration of the ORDC, and interplay of scarcity pricing with BRPs and BSPs
  - **Finding**: limiting scarcity adder to imbalance price will not induce back-propagation of reserve value to day-ahead market
- **Fifth study (2020)** [14, 15]: support questions of market players on market design proposal [3], analyze material in scarcity pricing public consultation of Belgian TSO ELIA
  - **Finding**: quantitative methodology for calibration of ORDC, analysis of cross-border interactions, and ability of ORDC to co-exist with CRM

Thank You

For more information

papavasiliou@mail.ntua.gr

https://ap-rg.eu/

References (I)

[1] A. Papavasiliou, Y. Smeers. “Remuneration of Flexibility under Conditions of Scarcity: A Case Study of Belgium”, the *Energy Journal*, vol. 38, no. 6, pp. 105-135, 2017.

[2] A. Papavasiliou, Y. Smeers, G. Bertrand. “An Extended Analysis on the Remuneration of Capacity under Scarcity Conditions”, *Economics of Energy and Environmental Policy*, vol. 7, no. 2, 2018.

[3] A. Papavasiliou, Y. Smeers, G. de Maere d'Aertrycke, “Study on the general design of a mechanism for the remuneration of reserves in scarcity situations”, June 6, 2019.

[4] ELIA, “Study report on Scarcity Pricing in the context of the 2018 discretionary incentives”, December 20, 2018.

References (II)

[5] Federal Public Service Economy, 2019. Belgian electricity market: implementation plan, Brussels: Federal Public Service Economy.

[6] European Commission, 2020. *Commission opinion of 30/04/2020 pursuant to article 20(5) of Regulation (EC) No 2019/943 on the implementation plan of Belgium,* Brussels: European Commission.

[7] A. Papavasiliou, "Scarcity Pricing and the Missing European Market for Real-Time Reserve Capacity", under review in the Electricity Journal.

[8] A. Papavasiliou, B. Gilles, "A Modeling Framework for Analyzing European Balancing Markets".

[9] Paul Giesbertz, "The power market design column – The scarcity of scarcity pricing", available online: https://www.linkedin.com/pulse/power-market-design-column-scarcity-pricing-paul-giesbertz/

References (III)

[10] Anthony Papavasiliou, 95th Session of the Harvard Electricity Policy Group, “Market Reforms for Stressed Conditions: the Case of Europe”, Harvard University, Boston, MA, June 14, 2019

[11] A. Papavasiliou, “Modeling Cross-Border Interactions of EU Balancing Markets: a Focus on Scarcity Pricing”, chapter in *Mathematical modelling of contemporary electricity markets: New challenges and methodologies*, Elsevier

[12] A. Papavasiliou, G. Bertrand, “Market Design Options for Scarcity Pricing in European Balancing Markets”, under review in *IEEE Transactions in Power Systems*

[13] ELIA, “Preliminary report on Elia’s findings regarding the design of a scarcity pricing mechanism for implementation in Belgium”, September 2020.

References (IV)

[14] A. Papavasiliou, J. Cartuyvels, G. Bertrand, A. Marien, "Implementation of Scarcity Pricing without Co-Optimization in European Energy-Only Balancing Markets", under review

[15] J. Cartuyvels, A. Papavasiliou, "Calibration of Operating Reserve Demand Curves Using a System Simulator", under review

[16] A. Papavasiliou, "Investigation of the Possibility of Implementing a Scarcity Pricing Mechanism in the Context of the Operation of the Greek Electricity Market under the Target Model", report prepared on behalf of the Greek Regulatory Authority for Energy

[17] A. Papavasiliou, "An Overview of Probabilistic Dimensioning and Scarcity Pricing with a Focus on the Greek Electricity Market", https://www.rae.gr/wp-content/uploads/2021/05/Report-II-ProbabilisticDimensioning-final.pdf