



WHITE PAPER



Designing Cross-Zonal Balancing Capacity Markets

Potential Benefits, Challenges and Ways Forward

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Context

Balancing power systems is becoming increasingly complex due to factors such as the growing share of renewable energy in the generation mix and the electrification of mobility and industry. This results in an higher uncertainty on both generation and demand closer to real-time.

Given the European power markets' integration, the cross-zonal procurement of ancillary services is expected to improve operational security and economic efficiency. In particular, the latter is of utmost importance for system operators.

While the balancing energy platforms MARI and PICASSO are operational and European TSOs are progressively joining as this whitepaper is written, experience with the cross-zonal procurement of balancing capacity services remains limited. The experience is mainly confined to a robust "FCR Cooperation" for procuring primary reserves in central Europe and to a few borders procuring a limited amount of balancing capacity across different zones, notably in the Nordic countries and between Germany and Austria (for secondary reserves only). Nonetheless, several initiatives are being initiated across the continent. A remarkable example is the ongoing implementation of a Baltic Balancing Capacity Market whose development is being carried on by Navitasoft in collaboration with N-SIDE.

The discussion over these topics leverages the expertise developed by N-SIDE working on various assignments related to the procurement of ancillary services, notably on the [Enduring Auction Capability Market Design](#) for NESO in GB which went live in November 2023, and on the [Co-optimization Roadmap Study](#) performed in 2022 for the SDAC and SIDC Market Coupling Steering Committee on the co-optimization of energy and balancing capacity.

The idea behind the optimal allocation of cross-zonal balancing capacity refers to the fact that both transmission and generation assets should be allocated to the demand for energy and various balancing capacity products. While transmission and generation assets are currently coupled via the pan-European algorithm EUPHEMIA through the Single-Day Ahead Coupling and Intraday Auctions of the Single Intra-Day Coupling, it does neither allocate generation nor transmission capacity for balancing capacity purposes. We therefore discuss below methods considered in the regulation for the allocation of transmission resources for balancing capacity purposes, and then move to the important question of efficiently allocating generation assets - or flexible demand - by providing the right bidding language to market participants.

Throughout this whitepaper, we will discuss pricing, market efficiency, algorithmic stability and IT Governance, followed by our concluding thoughts.

Note (1): For the remaining of the document, cross-zonal capacity and transmission capacity should be seen as equivalent.

Alternatives for the cross-zonal procurement of balancing capacity

Allocating CZC: Cross-zonal Procurement Alternatives

Power market auctions allocate two scarce resources: **energy** (both consumption and generation) and **transmission capacity**. There are naturally strong interactions between the way both resources are allocated. We will focus on the allocation of transmission capacity, while also considering how this may influence the allocation of generation assets, particularly in relation to the feasibility of bid linking.

The COMMISSION REGULATION (EU) 2017/2195, called **Electricity Balancing Guidelines (commonly EBGL)**, was published in 2017 and regulates how balancing markets should operate. It proposes three possible approaches to allocating cross-zonal capacity to energy and balancing capacity: (i) the co-optimization approach, (ii) the market-based approach, and (iii) the economic efficiency approach. In this document, we focus only on the co-optimization and market-based approaches since the economic efficiency approach is a degraded version of the market-based approach which is not further considered by stakeholders. We also do not discuss the “probabilistic method” under consideration in ALPACA (balancing capacity cooperation for aFRR between Austria, Czech Republic, and Germany) as this approach is currently not under consideration at the European-wide level.

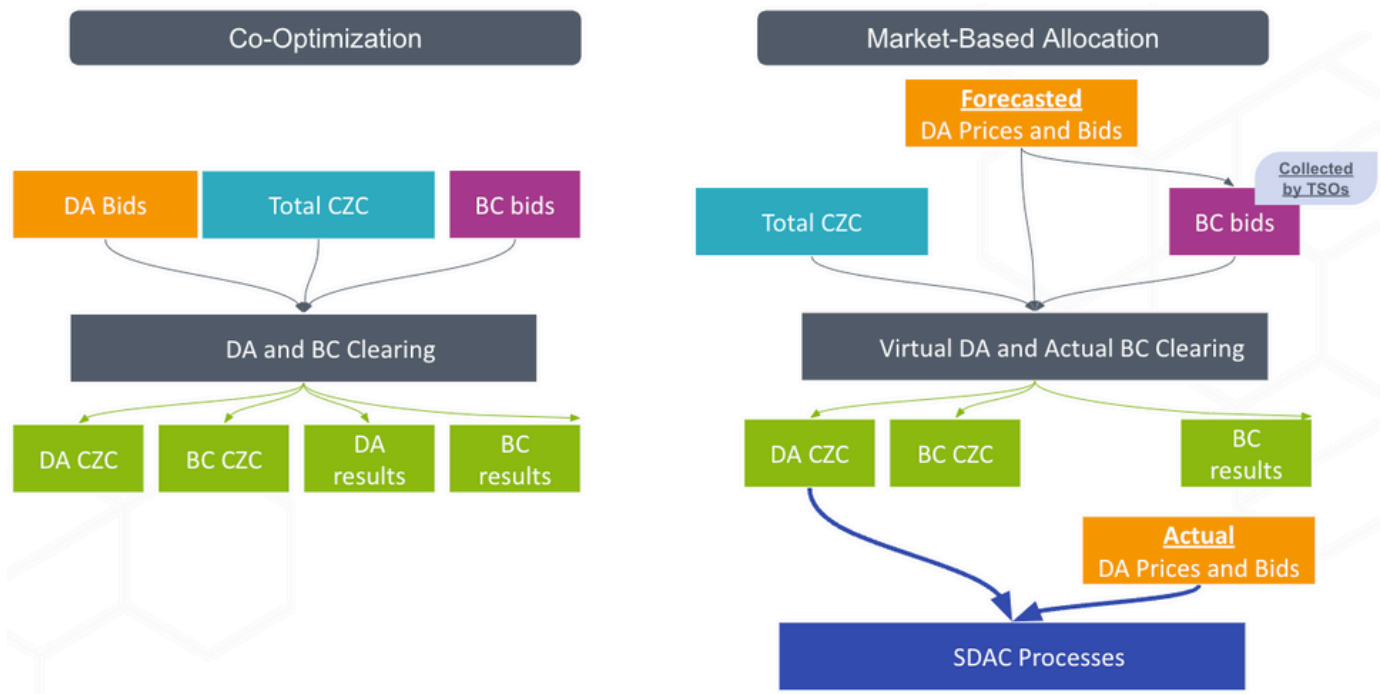


Figure 1: Schematic comparison of co-optimization and market-based allocation from a process viewpoint.

1) The co-optimization approach

Co-optimization seeks to **optimally allocate multiple products** (for instance, energy and aFRR capacity in either direction) **concurrently with transmission resources**.

Efficiency

This approach is **theoretically** the most **optimal** way to allocate the resources as it considers in the best possible way the techno-economical interdependencies in the provision of these products. However, the theoretical best allocation of resources can only be achieved if we have **adequate bidding language available for expressing the interdependencies**. We further discuss the topic in the dedicated section Bidding Products.

An important observation is that in a co-optimization setup, provided the right bidding language and pricing market participants do not need to explicitly factor estimated missed profits in the energy market into their balancing capacity bid prices: the market will ensure that balancing capacity prices allow participants to cover any lost profits from the energy markets.

The balancing capacity bid price can, however, reflect any other type of costs associated with the provision of balancing capacity that adds up to the opportunity cost faced in the energy market. These considerations apply to the “natural marginal prices” that can be derived in the absence of non-convexities (introduced, for instance, by block orders with a minimum acceptance ratio, complex orders, etc). We leave aside the challenging question of pricing in the presence of non-convexities, which we allude to in the dedicated **section on pricing**.

In a combined auction for energy and balancing capacity, each existing bidding zone in SDAC would be divided into separate bidding zones for each product to account for power balance conditions specific to each zone and product. For example, the Belgian bidding zone would be split into a Belgian energy bidding zone, a Belgian bidding zone for upward aFRR, and a Belgian bidding zone for downward aFRR.

Under such a setup, co-optimization for the allocation of cross-zonal capacity can intuitively be seen as “full implicit coupling” as it is done today for the energy only. This view will enable the cross-zonal capacity to be optimally allocated given the price spreads between the different bidding zones – both for energy and balancing capacity. This is possible because the full information on the cross-zonal capacity value for the exchange for energy and for the exchange for balancing capacity can be deduced by the optimization, from the energy and balancing capacity bids in each zone.

Price signals

In terms of price signal, co-optimization ensures that the allocation of the cross-zonal capacity is fully coherent with the cross-zonal price spreads of energy and of balancing capacity in the sense that the cross-zonal capacity is allocated where it is the most valuable. Figure 2 below shows how that coherence was demonstrated in simulations performed for the [SDAC Co-optimization Roadmap Study \(2022\)](#). For example, as shown in Figure 2, during periods 7, 8, 10, 18, 22, 23, and 24, the cross-zonal capacity is allocated to energy in the direction of a positive energy spread, reflecting the value of this capacity for energy exchange. In contrast, it is not allocated to balancing capacity, as the zonal price spread for balancing is zero, indicating no value for such an exchange.

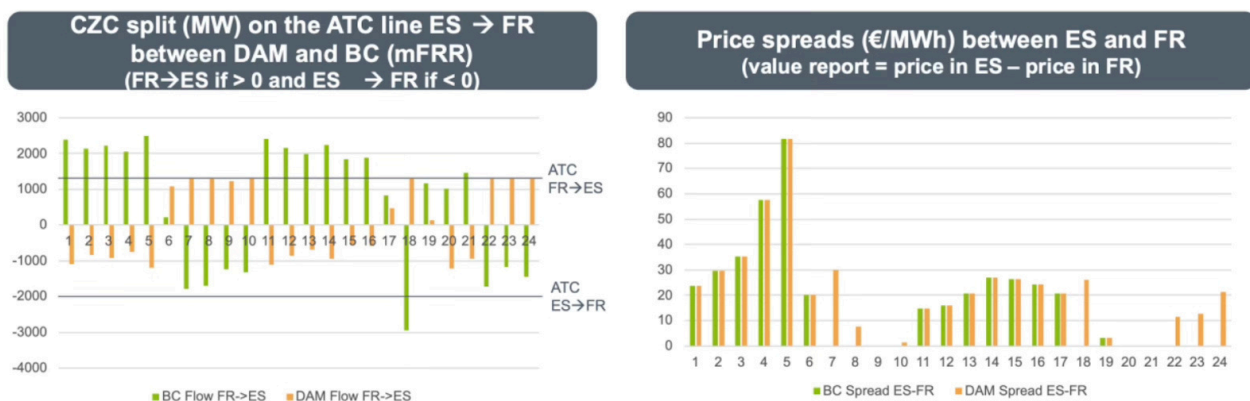


Figure 2: Cross-zonal capacity allocations and zonal price differences for a representative business day (July 26th, 2021). Periods 7, 8, 10, 18, 22, 23, 24 showcases with (i) a positive energy price spread in the direction FR to ES, alongside (ii) all the CZC being allocated to energy in that direction, together with (iii) no BC price spread between the two zones, along with (iv) a BC flow in the direction ES to FR without congestion in that direction.

Source: [SDAC Co-optimization Roadmap Study \(2022\)](#), page 61.

Algorithm scalability

The algorithm scalability will largely depend on the specific design choices and their implementation. Decisions with a direct impact on the technical feasibility are: (a) the types of products offered at the different time resolutions, (b) bid linking opportunities, and (c) the pricing mechanism.

IT Governance

IT governance represents in itself a formidable (and probably the most significant) challenge for the multiple organizations and stakeholders currently contributing to the market clearing processes. First, a co-optimization setup requires gathering in the same IT system all the balancing capacity bids (which today are collected by TSOs) and all the energy bids (typically collected by NEMOs) – with potential interlinking. Expressing the interdependencies between the energy and the balancing capacity provision most likely implies to collect all bids through a single platform.

Whatever the variants considered, we expect massive changes in pre-coupling, coupling and post-coupling processes handled by NEMOs and TSOs. For an overview of the processes behind market coupling today, we refer to the forthcoming [Handbook of European Electricity Market Coupling](#).

The large impact in existing well-functioning and established processes may lead stakeholders to favor an incremental approach. Such a coordination will favor the implementation of key market design ingredients for the procurement of balancing capacity that generates the most added value. Other research activities might be limited to perform a cost benefit analysis that weighs all the various market and operational impacts.

From this pragmatism, the market-based approach emerges as an interesting first move towards the optimal allocation of cross-zonal capacity.

2) The market-based approach

The market-based approach is essentially a sequential market clearing, as previously illustrated in Figure 1. In this setup, the balancing capacity market is expected to be cleared first, at which step the cross-zonal capacity allocation is also split between balancing capacity and energy markets. This split is performed by considering a forecast of the cross-zonal capacity value for the exchange of energy, which is implicitly compared to its actual value for the exchange of balancing capacity.

To continue with the implicit coupling analogy above, it is similar to allocating the cross-zonal capacity implicitly like in the co-optimization setup, but instead of considering the actual value of the cross-zonal capacity for the exchange of energy based on the actual energy bids, the market-based approach uses a forecasted value. This forecasted value can be in its simplest form the **forecasted energy price spreads**, or in a more advanced setup, the **forecasted energy bids**, or a **“cross-zonal capacity demand curve”** for the exchange of energy that result from the forecasted energy bids.

On the side of generation assets, by design, separated bids should be provided for the balancing capacity markets and for the energy markets, since they are operated and cleared sequentially. This requires market participants to adequately **price their balancing capacity services**, by setting **a price that should reflect their opportunity costs related to the expected missed profits in the energy markets due to their commitment resulting from the balancing capacity market** (missed profits that are not known at the time of bidding in the balancing capacity markets).

Efficiency

Compared to the co-optimization setup, inefficiencies can come from forecast errors in the forecast of the value of cross-zonal capacity calculated by the operators (see for instance Figure 3 with values for the Nordics aFRR Capacity Market in 2023, which follows the market-based approach), and also in the forecasted opportunity costs calculated by market participants to explicitly price their balancing capacity offer.

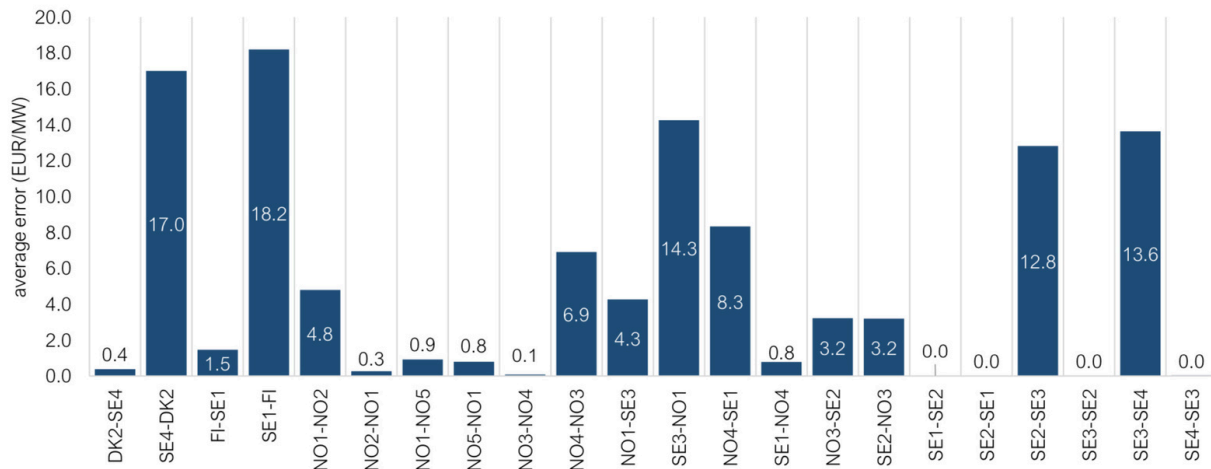


Figure 3: Average SDAC spread error (€/MWh) in 2023 for the market-based approach in the Nordics.
Source: [Evaluation Report 2023 of the The Nordic aFRR capacity market](#), page 8.

Other inefficiencies, which are highlighted in a [recent study performed on behalf of ACER](#) by leading academics, revolve around how fixed costs and other sources of “non-convexities” pose additional challenges in sequential markets. On another hand, the study also suggests that opportunity cost forecast errors can be significantly mitigated thanks to adjustments in intraday markets.

As of today, to the best of our knowledge, two studies have been performed to quantify the gains in a co-optimization setup compared to a market-based approach. On the one hand, the study on [Welfare Benefits of Co-Optimising Energy and Reserves](#) mentioned above estimates the gains with the market-based approach and with the co-optimization setup compared to the study quo, based on a fundamental bottom-up model of the European power system focusing on the CORE region. On the other hand, the [Evaluation Report 2023 of the The Nordic aFRR capacity market](#) considers the Nordic region and is based on a different methodology. Results of both studies differ substantially which may be explained by the differences in the regions subject of the study, the assumptions taken and the methodology applied.

Price signals

Compared to the co-optimization setup, the allocation of cross-zonal capacity to balancing capacity and to energy **may not be fully aligned with the price spreads** in each of these markets. The reason lies on the split of CZC for these two usages, which is based on a forecasted value for energy - **a value that can materialize differently in practice**.

On the other hand, price coherence for the different balancing capacity products can be ensured since these products and the allocation of CZC for their exchange are computed in the same market clearing step.

Algorithm scalability

The algorithm's scalability is expected to be better than the scalability in the co-optimization setup, regardless of the latter case's specific scalability. This is because, in a sequential market clearing, each clearing step involves a smaller problem than the single, larger-step clearing process used in co-optimization. However, a quantitative analysis is needed to establish whether the difference in scalability is substantial or insignificant in a specific context.

IT Governance

The IT governance may be less challenging compared to co-optimization in terms of project implementation as it would require a lower level of coordination among stakeholders, since bids for balancing capacity markets and bids for energy markets can be collected separately by the same entities performing this task today: NEMOs for the energy bids, and TSOs for the balancing capacity bids.

Coordination challenges may already be substantial among TSOs for organizing the integrated market-based approach at the European level since it requires harmonization of products, price computations, and settlements.

In this respect, the market-based approach could represent a significant milestone that is challenging to achieve, yet offers considerable added value compared to the current status quo. This is because it facilitates the cross-zonal procurement of balancing capacity.

Real-time deliverability of the cross-zonal balancing capacity

Balancing capacity can be seen as an option product: the procured balancing may or may not be activated in real-time. If only part of the procured balancing capacity is activated in some locations, it will result in reduced cross-zonal exchanges on some borders. In an ATC setup, reducing such exchanges is always possible, but this does not hold in a flow-based setup. Indeed, specific patterns of real-time activation of the balancing capacity may lead to violations of the flow-based constraints. The reason is that partial activations of the procured balancing capacity - compared to full activations - may reduce some cross-border exchanges that were providing relief on specific critical network elements, leading to violations.

TSOs have hence formulated a requirement that has been named the "flow-based deterministic requirement" (deterministic since it must be satisfied with certainty, not with a given confidence level). The flow-based deterministic requirement can be phrased as follows: "TSOs that have procured balancing capacity from other zones may or may not activate this capacity in real-time. The procurement must be determined so that the network can cope with any activation of energy by TSOs for the procured balancing capacity."

Note (2): This is the case if the so-called "zone-to-zone" Power Transfer Distribution Factor (PTDF) is negative.

The implementation of the deterministic requirement is computationally complex because there are an infinite number of ways in which TSO demands may be activated in real time. Even if we consider only corner cases (zero and full activation), there exist an exponential number of combinations of TSO demand activations (2^n , where n is the number of TSO demands that are matched in the market).

Extensive expertise has been developed on the topic at N-SIDE, resulting in a highly scalable algorithmic approach that has been implemented and tested in Euphemia in the frame of the [SDAC Co-optimization Roadmap Study \(2022\)](#), along with other potentially efficient approaches under consideration.

The approach developed as part of the [SDAC Co-optimization Roadmap Study \(2022\)](#) involves accounting for all possible ATC domains compatible with the flow-based domains allocated for the exchange of balancing capacity, as illustrated in Figure 3. This method demonstrates, on the one hand, that it adequately enforces the deterministic requirement, and on the other hand, relies on the fact that the union of ATC domains can be represented through a highly scalable set of constraints. These constraints are also applicable in various contexts, such as ATC extraction for shadow or intraday auctions, or ensuring intuitiveness in flow-based market coupling.

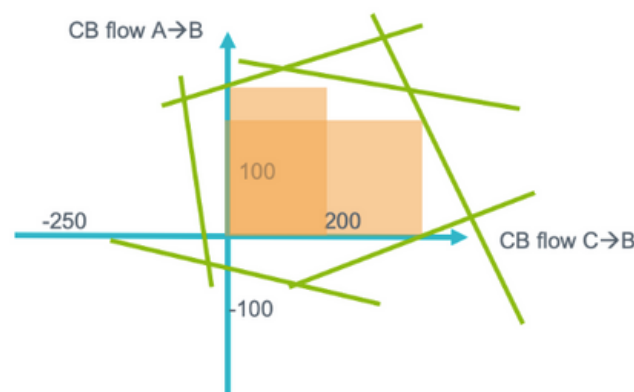


Figure 4: Illustration of the inscribed boxes method used for enforcing the deterministic requirement

Bidding Products: Well-designed bidding products are important

In both the market-based and co-optimization approaches, well-designed bidding products are fundamental. They are essential not only for market participants and TSOs but to ensure overall market efficiency for all parties.

The reason is that an asset can often deliver multiple balancing products and/or energy, but some economic and technical constraints should be clearly expressible within the auction. The interdependencies are notably of two types: a product may be delivered only if another product is also delivered (**complementarities**), and a product may be delivered if another is not (**substitutability**).

Moreover, product deliveries are also conditioned by techno-economic characteristics like minimum stable generation, minimum run times and shutdown times of a unit, ramp conditions, and fixed costs (start-up costs, minimum load costs, etc). Such constraints are often referred to as “non-convexities” due to their non-continuous aspects introducing “non-convex” elements in the underlying mathematical optimization models.

A natural venue for typical energy assets (e.g. thermal generation, storage, or demand response) would be to allow market participants to express their detailed commitment constraints directly, by specifying all these standard technico-economic constraints.

On another hand, it is in principle possible to design an expressive bidding language based on the current bidding products offered in SDAC, combined with adequate linking options, to enable market participants to describe the interdependencies in their balancing capacity and energy offers.

A key consideration **in a co-optimization setup is that market participants do not need to factor the opportunity costs they face in the energy market**—such as missed profits from providing balancing capacity—**into their balancing capacity bids**, as long as the bidding structure and pricing are properly designed. Under reasonable conditions, the balancing capacity prices will ensure that these opportunity costs are fully covered. This happens without requiring participants to forecast energy prices, as the balancing capacity prices will naturally align with both the energy market clearing prices and individual energy costs.

In a market-based setup, designing an appropriate bidding language that balances the expressiveness needed by market participants with the scalability of the algorithm requires focused design efforts. However, this balance can be successfully achieved by leveraging the extensive expertise N-SIDE has gained in auction design and market clearing algorithms across numerous projects in Europe (including the experience in Great Britain), Japan, and India.

In the Enduring Auction Capability (EAC), fully designed and developed by N-SIDE for NESO in Great Britain—where energy products are not included—a wide range of interdependencies can be expressed through the concept of “baskets,” in which bids can be stacked together.

Pricing

Pricing will certainly be a key focus and challenge from a market design perspective, whether in the context of co-optimization or a market-based approach. This is particularly true when multiple balancing capacity products—both in the upward and downward directions—need to be priced.

Many facets of the pricing problem impact multiple factors, including the procurement costs of balancing capacity, bidding incentives, congestion rents, and how the allocation of certain products influences the pricing of others. For example, the demand for balancing capacity could lead to fluctuations in energy prices, either pushing them up or down.

We identify three main concerns when it comes to pricing:

1. How to relate the prices of different products (energy and balancing capacity). Ideally, these relationships would be derived from standard marginal pricing principles, although this approach is inherently less intuitive when applied to multiple products compared to a single product.
2. How to account for fixed costs or indivisible bids (i.e. non-convexities) in the pricing rules, and how these factors influence the pricing of the respective product.
3. How should cross-zonal capacity be priced for the various uses and products. Specifically, how to link the price differences between various locations and among the different products being traded.

Conclusions

The discussion on market design and performance challenges highlights the complexity of integrating balancing capacity markets across Europe. Nevertheless, addressing this challenge is essential, given the increasing need for balancing services as the share of renewable energy in the mix continues to grow.

N-SIDE is committed to supporting its customers to address these challenges, leveraging years of experience in power market design and market clearing algorithms in Europe, India, and, more recently, Japan. N-SIDE offers unmatched expertise to combine three critical design elements while ensuring computational scalability: (i) bidding products that accurately capture techno-economic constraints, (ii) the deliverability of balancing capacity across the network, and (iii) price calculation that ensures the best possible short-term and long-term efficiency.

Authors



Alberte Bouso
Senior Energy
Consultant



Yves Langer
Senior Power
Market Expert



Mehdi Madani
Senior Consultant -
Market Design &
Optimization



Giancarlo Marzano
Senior Account
Management Lead