Auctioning electricity transmission margins for competitive access to Brazil's National Interconnected System[1]

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ABSTRACT

Recent transformations in the Brazilian Electricity Sector (BES) have generated intense competition for access to transmission capacity in the National Interconnected System (NIS). This situation has highlighted the inherent scarcity of transmission resources and the inadequacy of the current queue criterion for allocating remaining margins. We address the country's new reality by proposing a straightforward and transparent competitive mechanism to enhance allocative efficiency and improve access dynamics. More specifically, we propose a Transmission Margin Auction (TMA) for the BES, based on an open ascending format, according to which all the available capacity established by the National System Operator's (ONS) expansion plan is offered sequentially, and participants are allowed to compete for any available connection point.

Key Words: Mechanism design, Transmission margin auctions, Brazilian national interconnected system, Transmission network access, Grid access.

1. Introduction

The rapid expansion of renewable energy sources and the increase in applications for electric power generation licenses under Law No. 14,120 of 2021 have fundamentally reshaped access to the Brazilian Electricity Sector's (BES) transmission system. These developments have led to intense competition for transport capacity in the Brazilian National Interconnected System (NIS), revealing the scarcity of transmission resources and the inadequacy of the current queue-based criterion for allocating remaining margins.

In light of the need to adopt a competitive mechanism for contracting transmission capacity in response to the sector's new reality, we propose an auction-based solution for granting access to the transmission system. While similar conceptual solutions have been discussed previously, our analysis goes beyond basic propositions and theoretical discussions.[2] We present a comprehensive, auction-theory-based proposal tailored to the specific context and characteristics of the BES, as well as its broader regulatory framework.

The primary outcome of our study is a Transmission Margin Auction (TMA) for the BES. According to this new mechanism, based on an open ascending format, all available margins outlined in the National System Operator's (ONS[3]) expansion plan are offered sequentially according to the planning horizon, and participants are allowed to compete for any available connection point. Notably, this study supported much of the Ministry of Mines and Energy's (MME) proposal outlined in Ministerial Ordinance No. 702/GM/MME (MME, 2022a) of November 1, 2022, and particularly in Ministerial Ordinance No. 716/GM/MME (MME, 2022d) of December 21, 2022, as well as its corresponding technical note (MME, 2022e).[4]

Given that grid access remains a significant challenge globally, and considering the continued reliance on variations of the "*First Come, First Served*" method, despite its drawbacks in current scenarios, our analyses, results, and conclusions, though grounded in the Brazilian context, offer valuable insights for other countries facing similar transmission capacity allocation challenges.

In addition to this introduction, the paper is organized as follows: Section 2 presents background information and a literature review. Section 3 examines the expansion of renewable energy in Brazil and the surge in generation license requests following Law No. 14,120. Section 4 outlines the rationale for a competitive mechanism to allocate transmission margins in the NIS. Section 5 details the proposed design, while Section 6 discusses aspects related to its implementation. Finally, Section 7 offers concluding remarks.

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[2] Thema Consulting Group (2020) notes that "*thinking about auctions has never progressed beyond the initial concept stage*", while Schittekatte and Batlle (2023) highlight that "*auctions for granting network access are not a new idea, but it has not been generalized so far*".

[3] The ONS is the entity responsible for coordinating and controlling the operation of power generation and transmission facilities in the NIS, as well as for planning the operation of the country's isolated systems.

[4] After undergoing the necessary detailing and formalization, the proposal advanced to Public Consultation. However, there have been no further developments since the country's change of government.

2. Background and Literature Review

2.1 Auctioning Access to Networks

The use of auctions to allocate network access is not a new concept. Over the past few decades, it has been widely discussed and evaluated across various domains, including electricity grids, railway tracks, airport slots, and gas transportation systems. Given the unique characteristics of network industries, the literature has highlighted not only the potential benefits of auctions but also their limitations, practical challenges, and the need for designs tailored to the specific requirements of each sector.

Several studies highlight that the assumptions underlying the desirable theoretical properties of auctions do not always hold in the context of network industries. In these sectors, valuations are often interdependent, bidders may be asymmetric, property rights can be unclear, and the auctioned asset is frequently an intermediate good required to compete in the final market (McDaniel, 2003). Under such conditions, competition becomes essential for achieving efficient outcomes (McDaniel and Neuhoff, 2002; Helm, 2003; Newbery, 2003; Stern and Turvey, 2003). While efficient allocation, favoring those with the highest valuations (i.e., lowest costs), should be the primary objective of the auction (McDaniel, 2003), it can be challenging to achieve when bidders' valuations depend on who else wins, particularly when participants are rivals in the final market (Janssen and Moldovanu, 2002). Nevertheless, auctions may outperform alternative allocation methods by enhancing efficiency and promoting transparency, a feature especially valuable in developing countries or those with weaker governance (McDaniel and Neuhoff, 2002; Newbery, 2003).

While auctions are widely regarded as effective for allocating access to existing capacity (Newbery, 2003; Stern and Turvey, 2003; Helm, 2003), their use to support long-term network investment is considered more challenging (McDaniel and Neuhoff, 2002; Helm, 2003; McDaniel, 2003, Stern and Turvey, 2003), especially when such investment is critical for system reliability and efficiency (Newbery, 2003). Nonetheless, short-term capacity auctions can still provide valuable information for long-term planning (Helm, 2003; Newbery, 2003; Stern and Turvey, 2003).

In electricity networks, the use of auctions is further complicated by the physical laws governing power flows, such as Kirchhoff's Laws, which make auction design considerably more complex (Newbery, 2003). Defining capacity can be difficult (Stern and Turvey, 2003), often leading to mismatches between contracted and physically deliverable capacity (Yarrow, 2003). These challenges limit decentralization efforts, particularly for planning and investment decisions (Helm, 2003; Yarrow, 2003), and underscore the need for auction designs tailored to the specific context in which they are applied (Yarrow, 2003).

Brandstätt and Poudineh (2020) emphasize the need to redefine and improve the allocation of electricity network access, arguing that efficient grid development and utilization depend on the efficient assignment of access rights. They note that connection procedures based on the order of application fail to reflect differences in user valuations and suggest that market-based mechanisms, particularly auctions, could yield better outcomes. A follow-up study observed that while auctions are now common in the electricity sector, their application to network capacity allocation remains limited (Brandstätt and Poudineh, 2021).[5] Similarly, Schittekatte and Batlle (2023) argue that grid access should no longer be granted for free, especially at the transmission level, and that auctions are a more suitable mechanism for allocating scarce connection opportunities.

2.2 Access to Electricity Networks: International Experience

Historically, electricity network access has rarely been allocated through market-based mechanisms. The prevailing model has been the "*First Come, First Served*" (FCFS), which was developed when network capacity was not significantly constrained. Under this model, projects are prioritized based on the order of application without accounting for capacity scarcity or the economic value of access. However, the rapid expansion of renewable energy has revived debates over access allocation, as transmission connection requests increasingly exceed available network capacity in many countries (Thema Consulting Group, 2020; Caspary et al., 2021; Clifford Chance, 2021; Gramlich et al., 2021).

In response to the growing demand for access, several countries have considered reforming their connection processes to better manage scarce network capacity. Alternatives under discussion include criteria-based prioritization (e.g., environmental impact); *open seasons*, in which connection applications are submitted within a defined window and jointly assessed to minimize costs and network interruptions; *conditional connections* that allow flexible or interruptible access to improve network utilization; and broader reforms aimed at improving the alignment of access rights with actual system needs and operational realities (Thema Consulting Group, 2020). Market-based allocation mechanisms have been briefly considered but have not progressed beyond early-stage discussions (Ofgem, 2018).

Despite the ongoing reform discussions, FCFS remains the predominant transmission access model, albeit often with adaptations. Experts in California have recommended a shift to a "*First Ready, First Served*" model and adopting open

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[5] Brandstätt and Poudineh (2021) note that auction-based allocation of energy network capacity was primarily discussed when Ofgem (the Office of Gas and Electricity Markets), Great Britain's independent energy regulator, proposed a market-based approach for allocating access to the UK's electricity transmission grid. Unsurprisingly, most of the references cited in the preceding paragraphs date from that period.

seasons (Gramlich et al., 2021). In Spain, where permits are generally granted on an FCFS basis, access capacity tenders may be used in exceptional situations, though auctions are excluded, as economic criteria are not part of the allocation process (Clifford Chance, 2021). Other countries, such as Denmark, Finland, Germany, Great Britain, Italy, and Norway, continue to rely primarily on FCFS (Thema Consulting Group, 2020), sometimes complemented by open seasons (Italy), conditional connections (Denmark, Norway, Germany), or prioritization of renewables (Denmark, Germany, Italy). In Great Britain, delayed projects risk losing their place in the queue, and prioritization is considered for projects that are expected to effectively release network capacity. The use of auctions for congested areas was also considered but ultimately set aside due to concerns about competitiveness, regulatory complexity, and potential entry barriers (Ofgem, 2018). In Norway, project maturity is also a factor in prioritization. Finland, by contrast, applies FCFS with no special provisions for managing connections when network capacity is limited, even for renewable generators.

3. The problem of access to the Brazilian National Interconnected System

The 2010s saw a significant expansion of renewable energy in Brazil, particularly in wind power generation (WPG) and photovoltaic solar generation (PSG), as shown in Fig.1. This period also witnessed the rapid growth of Distributed Micro and Mini Generation (DMMG), especially from photovoltaic solar sources, as illustrated in Fig.2. As a result, by 2021, renewables accounted for 85% of Brazil's installed electricity capacity, with photovoltaic solar, wind, and distributed self-generation contributing 20% of the total (EPE, 2022).

This expansion has been driven by Brazil's energy transition goals, abundant renewable potential, and declining technology costs (IRENA, 2022). However, in Brazil, growth has been further propelled by subsidies and policy incentives. Net metering (Silva, 2021) and state-level[6] tax reductions in the ICMS[7] have significantly boosted DMMG, while discounts on transmission and distribution tariffs (TUST and TUSD, respectively), introduced by Law No. 13,360 of 2016 and Law No. 13,203 of 2015, have been key to the growth of solar and wind generation.[8]

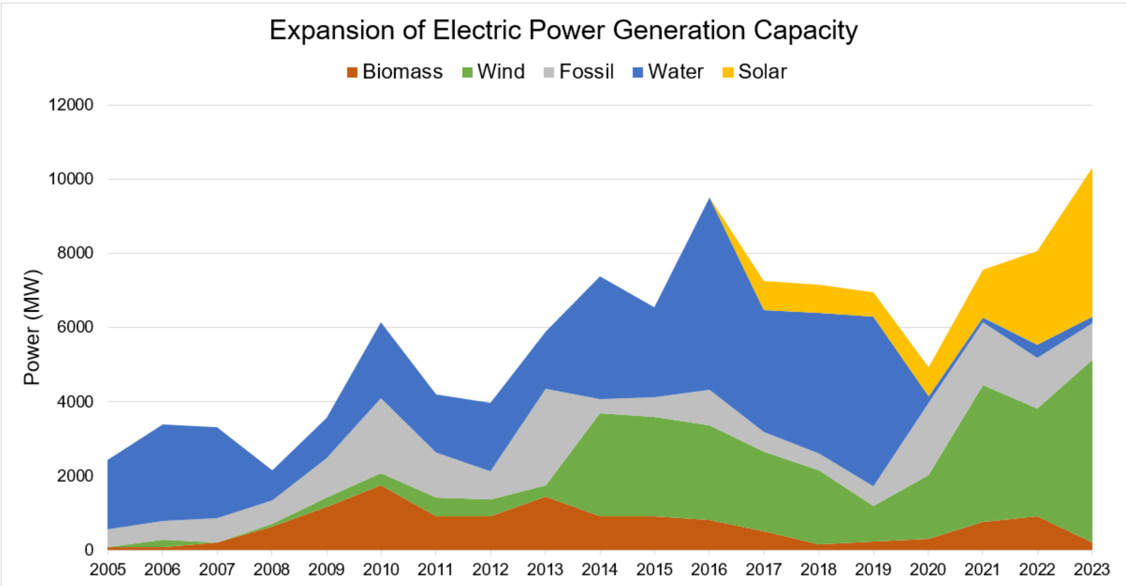

Fig.1. Brazilian yearly evolution of generation additions (2005-2023). Source: ANEEL, 2024a (adapted by the authors)

[6] See, for example, Law No. 23,672, enacted in 2021 in the state of Minas Gerais.
[7] ICMS stands for Tax on the Circulation of Goods and the Provision of Interstate and Intermunicipal Transportation and Communication Services. It is a value-added tax levied by Brazilian states on the circulation of goods and services in general.
[8] The laws stipulated that, for specific sources (including solar and wind generation) and under certain conditions, the National Electric Energy Agency (ANEEL) must consider reductions of no less than 50% of TUST and TUSD.

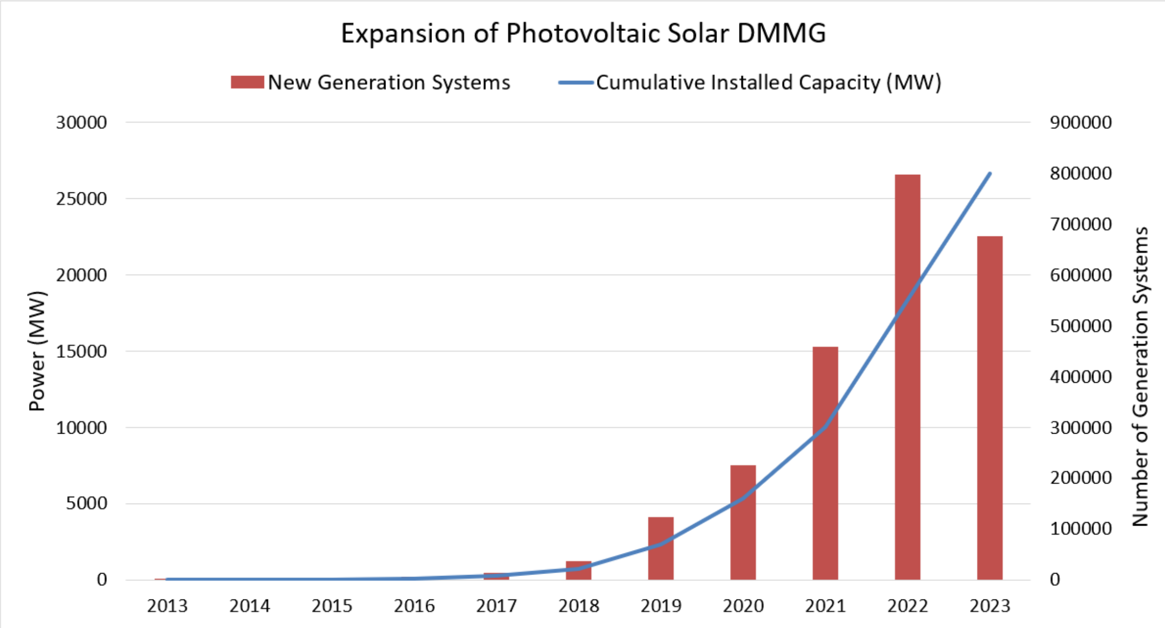

Fig.2. Brazilian expansion of photovoltaic solar DMMG (2013-2023) Source: EPE, 2024 (adapted by the authors)

As renewable sources have gained a larger share of the Brazilian electricity matrix, generation growth has shifted away from large hydroelectric projects with energy negotiated through centralized auctions in the Regulated Contracting Environment (RCE). Instead, a growing number of geographically dispersed projects, mainly operating in the Free Contracting Environment (FCE), now drive most of the expansion (Abraceel, 2022). This transformative shift has made it more difficult to manage information about future supply, reducing the predictability of project volumes and locations (EPE, 2022). Moreover, FCE projects, particularly those involving wind and photovoltaic solar generation, are often implemented on short timelines (ANEEL, 2023a), creating a mismatch with the typically longer lead times required for transmission infrastructure. Together, these developments complicate the coordination between generation and transmission, posing new challenges for planning and expanding the transmission system.

Additionally, Law No. 14,120 of 2021 eliminated TUST and TUSD discounts for renewable sources while establishing a 12-month transition period[9]. The impending end of tariff discounts prompted a surge in generation license requests, primarily for photovoltaic solar projects and, to a lesser extent, wind projects. Fig. 3 illustrates this trend through the evolution of Preliminary Authorizations (DROs)[10] issued between 2015 and 2023. Consequently, the number of generators seeking access to the NIS has exceeded the system's capacity and surpassed long-term demand projections for centralized generation[11], making it difficult to justify expanding the grid to accommodate this surplus. This situation has intensified the competition for access to the remaining transmission capacity in the NIS.

In this context, the existing queue-based access criterion (chronological order) has become inadequate. To better reflect the current reality of the sector and improve allocative efficiency[12], access dynamics, and coordination between generation and transmission, a competitive mechanism is needed for allocating scarce transmission capacity (Schittekatte and Batlle, 2023). In line with this, the Brazilian government issued Decree No. 10,893 of 2021, authorizing such a mechanism's implementation.

[9] Law No. 14,120 maintained transmission and distribution tariff discounts for generators who applied for a license within 12 months of the law's publication and commenced operation of all their generating units within 48 months of the license date. Subsequently, Provisional Measure No. 1,212 of 2024 authorized requests for a 36-month extension of the deadlines initially set for entry into operation.

[10] The DRO is a document issued by ANEEL to agents who submit a request for authorization to operate a generation plant.

[11] From January 2021 to October 2021, Technical Statements issued for the North and Northeast regions, as well as for the states of Minas Gerais and Goiás, indicated an interest in adding approximately 165 GW solely of new wind and photovoltaic solar generation (ONS, 2021b). To put this value into perspective: (i) Brazil's installed generation capacity, excluding DMMG, was approximately 205 GW as of August 2024 (ANEEL, 2024c); (ii) the reference scenario projected for 2031 in the Ten-Year Energy Expansion Plan (PDE) suggests that the country's installed capacity at the end of this period will reach 275 GW, with approximately 43 GW of this growth achieved through centralized generation expansion (EPE, 2022).

[12] Throughout this article, the term *efficiency* always refers to *economic efficiency*, as commonly defined in the economic literature.

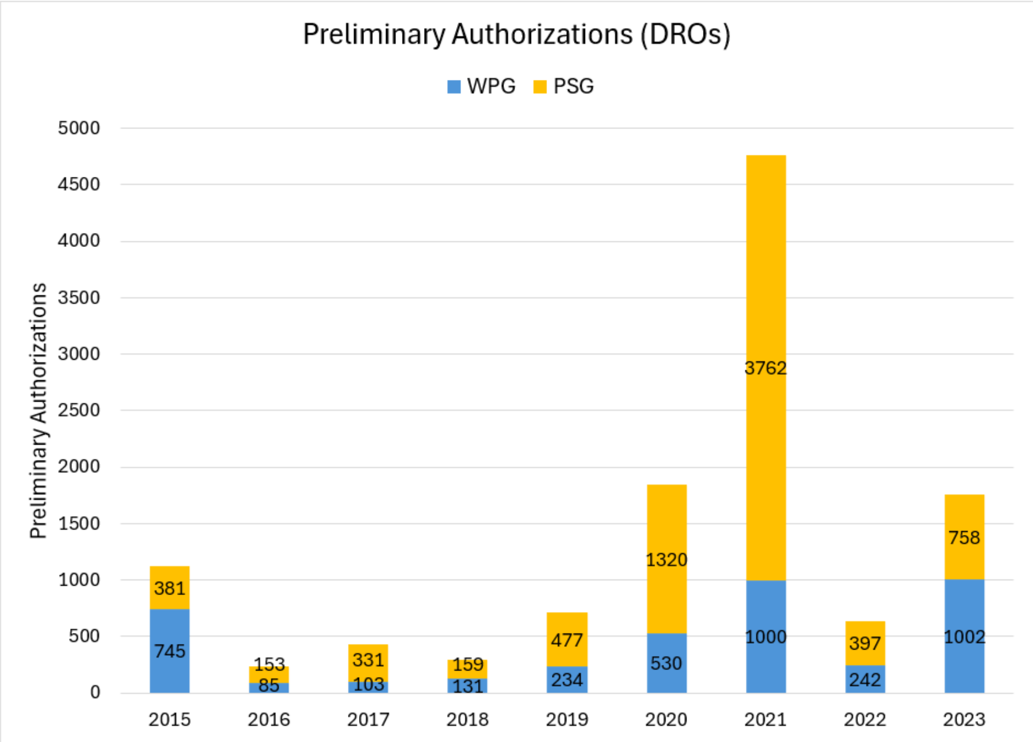

Fig. 3. DROs issued between 2015 and 2023 (WPG and PSG). Source: ANEEL, 2024b (adapted by the authors)

4. On the rationale for a competitive mechanism

While the "*First Come, First Served*" (FCFS) method and its variations are traditionally employed in the electricity sector, both in Brazil and in most countries, a chronological order criterion for allocating transmission capacity in a scenario of rapid generation supply expansion (and/or a high number of access requests) has drawbacks, two of which stand out. The first is extended timelines. Since access requests must be analyzed individually, queue-based methods lead to longer timelines, "congestions," and a substantial increase in the effort required to conduct the necessary analyses. The second is allocative inefficiency. Projects with stronger technical and economic fundamentals, which therefore assign a higher value to the remaining capacity, may fail to connect to the system if they are less favorably positioned in the queue, leading to a suboptimal allocation of the remaining transmission margins (see Fig. 4[13]). Moreover, the inefficiencies of the FCFS method become especially pronounced under conditions of high competition or limited network capacity (see Appendix D), as is the case in Brazil.

The FCFS model also raises the risk of allocating capacity to agents who are unlikely to meet connection deadlines or may never implement their projects. This inefficiency is already evident in Brazil (see Fig. 5).[14] Finally, beyond its low transparency, FCFS is highly susceptible to discretion, capture, and legal disputes,[15] leading to outcomes far from the social optimum.

Given these drawbacks, also found in other non-market approaches such as administrative processes or *beauty contests*, competitive mechanisms offer a more effective alternative, particularly auctions. Auctions promote more efficient and transparent allocation, elicit valuable private information, and generate revenue that could benefit the system's users, for example, by reducing tariffs.

[13] To estimate the allocative efficiency gains of the TMA over the FCFS model, we conducted Monte Carlo simulations across a wide range of scenarios, varying generator demand, bidder valuations, available transmission margins, and the number of competitors. See Appendix D for details. We thank the anonymous referees for suggesting this analysis.

[14] In this case, it is important to highlight that the proposal to grant "*exceptional regulatory treatment*" for generation licenses and CUSTs (ANEEL, 2023b), which established a so-called "Pardon Day" for generators, not only fails to address the original issue but also risks exacerbating it by creating a moral hazard problem, as it could lead to the expectation that such a solution might be used again in the future.

[15] In the Brazilian context, there is evidence that generating agents are submitting administrative and judicial requests to ANEEL to obtain "special treatment" in the queue (see, for example, case 48500.001699/2023-15 in ANEEL, 2023c).

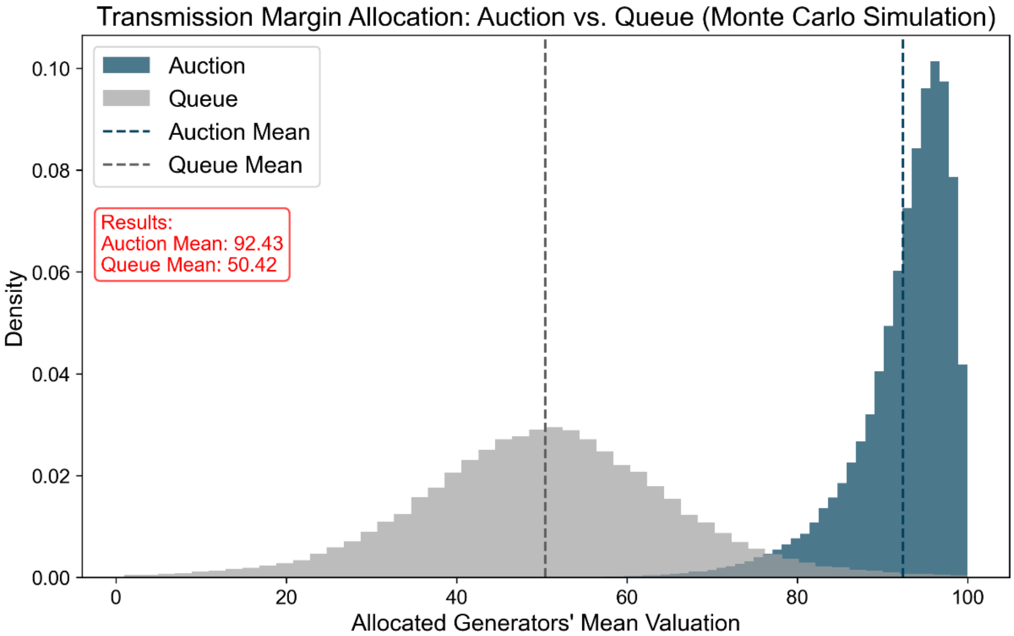

Fig. 4. Distribution of mean valuations for allocated generators across 100,000 Monte Carlo simulations, comparing auction-based and queue-based allocation mechanisms. Simulation parameters: Generator demands ~ U(25, 100) MW; Valuations ~ U(1, 100); Transmission Margins ~ U(50, 500) MW; Number of competitors ~ U(15, 75). Results: Auctions yield efficiency gains exceeding 83%. Source: Authors' calculations. For details, see Appendix D.

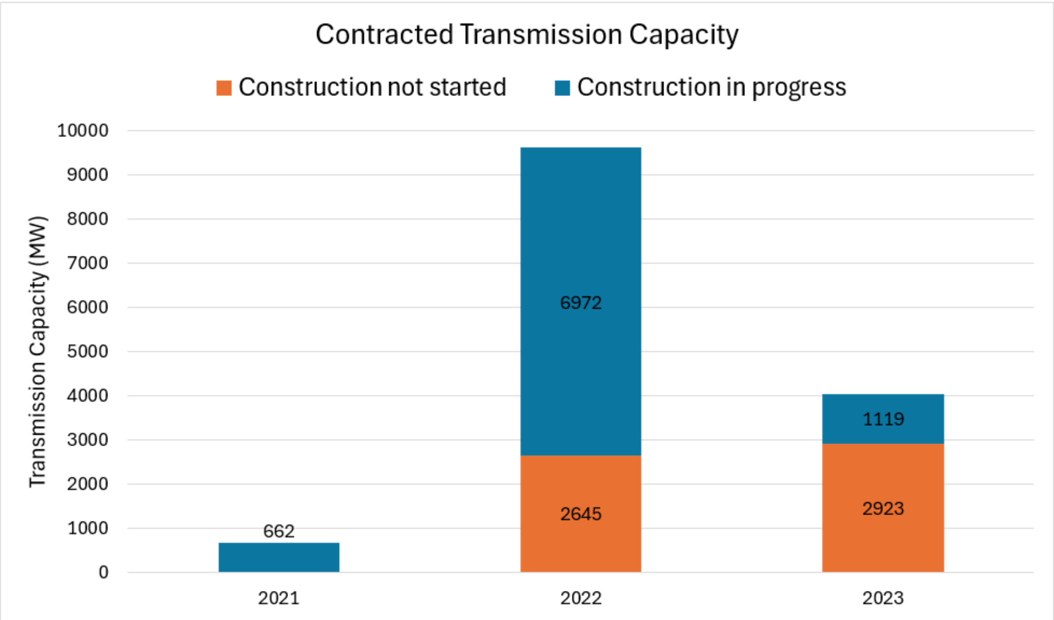

Fig. 5. Transmission capacity contracted in March 2023 by power plants with CUST (Transmission System User Agreements) in effect but not yet in commercial operation, according to the year the CUST went into effect. Source: ANEEL, 2023b (adapted by the authors)

However, despite their benefits, auctions for allocating remaining transmission capacity still face strong resistance, mainly due to two concerns: (i) their potential impact on energy prices and (ii) opposition to grid access charges (MME, 2022b; Filho and Guarnier, 2023).

The first concern is that auction costs will be passed on to end consumers through higher energy prices. However, this argument overlooks the distinction between fixed and marginal costs. Despite auction payments, winning generators will price energy to maximize their profits.[16] While prices may be influenced by regulation or market conditions, the auctions

[16] A useful approach to examining this objection is to extend the argument to the real estate market and reflect on its implications. As highlighted by Binmore and Klemperer (2002): "*The price of new housing is no lower when the developer had the good fortune to obtain the land below its current market value (e.g., because it was obtained free through inheritance or was bought before planning permission was available) than when the developer has paid the full market value. In either case, the price is determined by the housing market at the time the new housing is sold.*"

do not cause such distortions. Due to their efficient outcomes, the systematic adoption of auctions may reduce final energy prices over the medium and long term.[17]

Regarding the second objection, limited NIS capacity and rising generator demand mean that transmission margins inevitably hold value. Whether directly, as with the TMA, or indirectly, access to the transmission system will have a price, even if generators are not charged[18]. Since the transmission system is a public asset funded by all users, granting free access to a few generators provides an unjustified advantage.

Finally, as free access to transmission lines in Brazil is also intended to ensure demand fulfillment, concerns may arise that charging for access could increase the risk of unmet demand. However, the *pass-through* mechanism (see Section 6.2.11) and the auction design mitigate this risk: access will be priced only when generators are willing to pay and only up to the amount they are willing to pay. Therefore, the systematic adoption of the auction is not expected to increase the likelihood of unmet demand.[19]

5. Designing a Transmission Margin Auction for the Brazilian Electricity Sector

5.1 Methodology

Auctions are mechanisms for pricing and allocating scarce resources, particularly in the absence of fully developed markets. However, they are not a "*one size fits all*" solution. Effective outcomes require designs tailored to specific objectives and economic conditions (Klemperer, 2002a). Poorly specified auctions can lead to inefficiencies, revenue losses, and manipulation, ultimately undermining their core benefits (McAfee and McMillan, 1996; Binmore and Klemperer, 2002; Klemperer, 2002b; McAfee et al., 2010).

In light of the above, this study adopted a rigorous yet pragmatic framework that balances theoretical foundations with the practical realities of transmission access. The TMA design was developed incrementally, guided by the specific features of the Brazilian electricity sector and the intended policy objectives. Where possible, the mechanism draws on established auction theory results; in areas where general theoretical solutions are lacking, we applied context-specific simplifications or incorporated relevant findings from the literature. In some cases, existing demonstrations were adapted to the margin auction setting; however, as these involved only minor refinements, we chose not to reproduce them in full, opting instead to reference the relevant sources.

Recognizing the novelty of the TMA for all stakeholders, special care was also taken to ensure that the mechanism's design was clear and accessible. A complex or unclear mechanism could lead to misunderstandings and poor decisions, ultimately resulting in inefficient outcomes.

5.2 Main Objectives

The MME established allocative efficiency as the paramount objective for the competitive procedure. The goal was also to devise a solution that would, given the current constraints, maximize grid utilization, improve access dynamics, and foster competition. Notably, revenue generation was not a primary focus. The directive stipulated only that any generated revenue should be allocated to reduce public transmission service tariffs.

Although congestion management is a highly relevant issue within the BES, it falls beyond the scope envisioned for the TMA. However, as detailed in subsection 5.3, the mechanism is expected to contribute positively in this regard. The auction aims to allocate the remaining margins in the NIS, as identified by ONS studies, which would otherwise be assigned through the connection queue. The goal is to manage excess demand for access more effectively, concentrating on improving allocative efficiency, reducing timelines, and simplifying the process. Central to this endeavor and our study is the development of a well-designed auction mechanism tailored to achieve these objectives.

Specifically, regarding improvements to the current access dynamics, it is important to note that adopting the TMA already addresses a substantial portion of this objective, as only the access requests of auction winners are analyzed, whereas, under the current queue-based procedure, all requests are examined. [20]

5.3 Margins to be Auctioned

In line with the current functioning of the Brazilian electricity sector, the transmission capacities to be auctioned in the TMA correspond to the remaining margins calculated in the relevant studies conducted by ONS. These studies are preceded by a jointly developed ONS and EPE document, defining the methodology, key assumptions—including network

[17] Although we do not expect an increase in energy prices, there will be an impact on generators' returns. Thus, we expect that participating generators and their associations will use arguments of this nature to influence the discussion. However, it should be noted that the impact on generators' returns essentially represents a transfer of part of the firms' earnings to the government. By appropriately directing the collected funds (for example, towards tariff reduction), the government would essentially be reclaiming a portion of a socially owned resource in benefit of society. Moreover, in the Brazilian context, this option would also help reduce distortions caused by sector subsidies, redirecting funds from subsidized agents to benefit those who ultimately bear the subsidy costs, namely, end consumers.

[18] Given the current scenario, part of the value of generation ventures for which access has been granted would be associated precisely to the guarantee of connection to the NIS.

[19] The authors are grateful to the anonymous referee who highlighted the importance of addressing this issue.

[20] For more details about the improvement in the current access process, such as the elimination of the current Access Information stage, refer to Guedes et al. (2024).

configuration, load levels, and generation scenarios—and the criteria for determining the remaining NIS capacity.[21] For the TMA, these criteria include N and N-1 contingencies, compliance with Network Procedures, and the absence of special protection systems. Based on these guidelines, ONS calculates the remaining NIS capacities through power flow analyses, short-circuit studies, equipment operating capacities, and physical availability.[22]

Thus, the capacities to be allocated through the TMA resemble those assigned via the existing queue system; the new mechanism does not materially change how capacities are calculated. However, by requiring connection applications to be submitted within a defined window and evaluated jointly in a single study, the auction process is expected to reduce the risk of constraints emerging in later access stages or during operation, resembling the benefits of open seasons (see subsection 2.2). While this may help with congestion management, this contribution's magnitude is insufficient to alter the current allocation of congestion-related risks in the BES, which will remain governed by the existing regulatory framework.[23]

5.4 Selection Criteria

Several selection criteria (i.e., types of bids) were considered for potential adoption in the TMA. The main options assessed included an upfront payment (in R$/kW)[24], anticipation of charges (an upfront payment in R$/kW with subsequent deduction from transmission usage charges)[25], a security deposit (in R$/kW), and a premium on the TUST (expressed either as a percentage or in R$/kW).

The higher risk of default or renegotiation with payments contingent on project operations (Binmore and Klemperer, 2002; Bugarin and Ribeiro, 2021), potentially exacerbated by the country's legal and institutional framework, led us to favor options involving payments made in advance (such as the first two options). However, the complete evaluation of these alternatives took legal and political aspects into account at a level of detail that exceeded the intended scope of this article. Therefore, based on the analyses conducted, we limited our discussion to the fact that the initial choice was to adopt bids based on upfront payments. However, due to resistance from specific agents who cited potential legal disputes and the risk of procedural nullification (MME, 2022b), and considering that revenue generation was not one of the primary objectives of the TMA, the MME decided to change the initial choice to bids based on the anticipation of charges.

5.5 Auction Format

5.5.1 Pricing Rules

Since the TMA represents a new solution for all agents involved, with no prior records of payments for access (exacerbating the lack of information regarding values assigned to the transmission margin), we considered it essential from the outset to adopt a pricing rule that reduces the informational complexity of the bidding process. As a result, we aimed to develop a solution whose characteristics were those of second-price auctions.[26]

In a private values scenario[27] and in the absence of budget constraints, *bidding truthfully*, according to the real value attributed to the good, is a weakly dominant strategy in second-price auctions (i.e., optimal from the perspective of payoff maximization regardless of the bids of other participants)[28]. In other words, unlike first-price auctions, second-price auctions under these assumptions do not require inferences about other bidders' valuations or behavior and, therefore, do not demand greater sophistication from participants. Moreover, given the standard allocation rule in which the participant who makes the highest bid wins, the behavior of making *truthful bids,* in this case, results in efficient outcomes.

The optimal strategy for second-price auctions under private values is not only simple, but also remarkably robust. Since outcomes can be derived through *ex-post* analyses, the equilibrium does not rely on any probability distributions and, therefore, does not require assumptions such as independence or symmetry of values. Consequently, the only relevant assumption of the Independent, Private, and Symmetric Values (IPS)[29] reference model are the private values.[30] Even when the assumption of private values is relaxed, under certain conditions, such as auctions involving affiliated values

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[21] See, for example, ONS (2022a).
[22] See, for example, ONS (2022b).
[23] A key driver of current curtailment issues in the transmission system is the growing mismatch between load and generation, both at the local and national levels, largely due to the rapid expansion of distributed generation. Shifting curtailment risk would require broader discussions on improving forecasting models and modifying margin calculation methodologies, which fall outside the scope of this mechanism.
[24] R$ is the symbol for the Brazilian currency (the "Real").
[25] In this alternative, the amount paid at the auction would subsequently be deducted from the winner's transmission usage charge according to rules to be defined by ANEEL. In other words, the bid would not correspond to a new expense to be paid by the generator, but rather be an anticipation of the charges it would incur when connecting to the NIS.
[26] In a second-price auction the highest bidder wins but pays a price equal to the second-highest bid.
[27] In a private value situation, each bidder knows the value they attribute to the object at the time of bidding, and this value remains unaffected by the knowledge of other bidders' values.
[28] In scenarios of private values with budget constraints, the dominant strategy in second-price auctions remains quite straightforward: bidders should place a bid equal to the lower value between their budget constraint and the value attributed to the good.
[29] The IPS (Independent, Private and Symmetric Values) scenario, which corresponds to the basic reference model in auction theory, adopts independently and identically distributed private values as its key assumptions, as well as risk neutral agents.
[30] In contrast, the fundamental results of first-price auctions specifically depend on the probability distributions of other participants' values, thus emphasizing the significance of assumptions about independently and symmetrically distributed private values.

and symmetric models, a bid based on a simple strategy similar to the one previously described remains optimal for second-price auctions in various equilibria (Krishna, 2010).

5.5.2 Open vs. Sealed-Bid

To promote the disclosure of participants' information (i.e., values) during the auction, enabling better estimation and strategy adjustments, we adopted an open format. Specifically, given the chosen pricing rule (second-price), an open ascending format, or *English Auction*[31], was selected. This decision was once again guided by the innovative nature of the solution and the lack of historical price information (due to the legacy of queue-based allocation and the absence of access charges). In this context, information disclosure is expected to play a key role in achieving the auction's efficiency goals.

In a setting of interdependent values, which is likely in the TMA (McDaniel, 2003), open ascending formats also help mitigate the risk of the *winner's curse.*[32] Moreover, when participants are asymmetric, open formats tend to be more efficient (McAfee et al., 2010), and under certain conditions involving asymmetric interdependent values, where no other auction is efficient, open ascending auctions are more likely to yield efficient outcomes (Maskin, 1992).[33]

Finally, some secondary attributes of open formats might also be of particular interest to the TMA, especially to ensure continuity of its adoption despite initial resistance. These attributes mainly regard the absence of regret (winning participants do not end up with bids much higher than the second-place bid), legitimacy (all participants are allowed to beat the highest bid), and assurance to winners that other participants were willing to pay values close to their bid (Cramton, 1998; McAfee et al., 2010).

However, open formats also have weaknesses, with the risk of collusion being the primary issue (Cramton, 1998; Klemperer, 2002a). Participants' ability to directly observe the behavior of others facilitates collusion (Graham and Marshall, 1987; McAfee et al., 2010) and, therefore, makes open formats susceptible to a greater number of collusive equilibria (Milgrom, 1987). In addition, the deterrence of entry and the encouragement of predatory behaviors may also be identified as other problematic aspects of open formats (Klemperer, 2002a).

Regarding these issues, the key aspect to consider for the TMA is intense competition for the system's remaining capacity, with many generators competing for limited margins (MME, 2022c; ONS, 2022c). Given this competitive context (assuming such conditions persist), the main risks associated with open formats are largely mitigated.[34] Nevertheless, considering their ease of implementation and minimal impact on the desirable attributes of the mechanism, it is reasonable to adopt measures that are commonly recommended to strengthen the robustness of open auctions (McAfee and McMillan, 1996; Cramton, 1998; Klemperer, 2002a; McAfee et al., 2010). These measures essentially include maintaining the anonymity of participants and the prior specification of price increments, thereby making it more challenging to use bids as signals to other participants. Both measures were incorporated into the final design of the proposed TMA.

5.5.3 Final Design

The initial analyses guided us toward an open ascending auction, which encompasses the desired pricing rules and information disclosure characteristics. However, there was an immediate concern regarding this option due to the nature of the TMA, which typically involves multiple-unit auctions (the available transmission margins at each connection point are not unitary and can usually accommodate the connection of multiple generators). In such scenarios, open ascending auctions generally lack crucial characteristics that were decisive in our previous pricing rule choice, particularly those pertaining to *truthful bidding*.[35]

Nevertheless, while the transmission capacity supply per connection point is not unitary, each participant's demand exhibits a unitary characteristic. Given the current regulatory framework, participants are only entitled to contract a predetermined transmission capacity corresponding to their power generation. Therefore, each generator demands uniquely and exclusively a transmission margin equivalent to its generation capacity. In simpler terms, each participant has a single-unit demand[36] that matches its power output.

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[31] In the single unit, independent private value setting, the *English Auction* is the open strategic equivalent of the sealed-bid second-price auction (Krishna, 2010).

[32] This phenomenon occurs when the winning bidder overestimates the value of the item and consequently pays more than its actual worth. However, it is important to note that the *winner's curse* effect only manifests itself when participants fail to accurately determine their strategy based on all available information and knowledge, including acknowledging that being declared the winner can lower their estimated value (Krishna, 2010).

[33] Although secondary to the primary objectives of the TMA, this format also mitigates an effect related to the *winner's curse*, in which participants may bid too cautiously to avoid potential overpayments (the fear of the *winner's curse* can lead to overly conservative bidding, ultimately resulting in lower prices). Additionally, due to the positive correlation between information disclosure and auction revenue (Linkage Principle), revealing information may also reduce the informational rents earned by winning bidders, potentially leading to higher final prices (Milgrom, 1989), although this result does not necessarily extend to multi-unit contexts (Perry and Reny, 1999).

[34] Concerning the risk of collusion, one only needs to acknowledge the immense coordination challenges in these circumstances, while the large number of potential competitors addresses concerns about deterrence of entry and predatory behavior.

[35] In a multiple unit scenario, open ascending auctions are not the open equivalent format of second-price sealed-bid auctions. Instead, in such scenarios, the open equivalent of the latter is the Ausubel auction (Krishna, 2010).

[36] In all instances where the term "*single-unit demand*" is used throughout the text, it should be understood as referring to "*symmetric single-unit demand*". Further details are provided in Appendix A.

In such a scenario, considering the factors previously outlined, along with the detailed discussion presented in Appendix A, an open ascending auction emerges as an optimal choice for the TMA. It is an alternative that meets the key desired characteristics for the mechanism and, in addition, offers a simple design whose potential weaknesses are mitigated by the highly competitive implementation context. Furthermore, this auction format performs well not only in the basic reference scenario (multiple units and unitary demand, with private, independent, and symmetric values) but also in settings that more accurately reflect the likely conditions of the TMA, namely, multiple units and unitary demand, with interdependent and affiliated values under a symmetric model.

Accordingly, the proposed TMA adopts an open ascending auction, specifically, the *ascending clock auction* format, in which price increments are determined by the auctioneer and applied at predetermined time intervals.

6. Implementing a Transmission Margin Auction for the Brazilian Electricity Sector

6.1 General Features

In line with the objectives of enhancing allocative efficiency and optimizing grid utilization, the design is based on the premise that all capacity available under ONS's current Expansion and Reinforcement Plan (PAR/PEL[37]) should be offered in its entirety. Since PAR/PEL's planning horizon spans five years (ONS, 2021a), each year's available capacity should be auctioned separately in the same TMA. Additionally, it would also be important to ensure that all participating generators had the opportunity to compete for any available connection point.

These two characteristics offer competitors more connection alternatives, both temporally and spatially, thereby enhancing the efficiency of the allocation process. Moreover, they allow generation sources with locational flexibility to identify other available access points in the transmission system, enabling better use of existing and future transmission networks and potentially reducing tariffs for electric power transmission services. In addition, incorporating all the PAR/PEL planning horizon margins eliminates any discretion in the auction's product selection, reducing the risk of undesirable practices (e.g., selecting nodes that favor a particular participant), increasing transparency, and minimizing potential legal disputes.

However, given the substantial workload involved in calculating the remaining margins by the ONS, the automatic offering of all available margins across every busbar in the NIS would needlessly complicate the process.[38] To avoid unnecessary calculations for access points for which there are no interested agents, participants should be required to indicate their busbars of interest in advance.

6.1.1 Sequential Auctions vs. Simultaneous Auctions

Considering the premises outlined in subsection 6.1, all available margins across the multiple busbars indicated by participants for each year in the planning horizon would be auctioned by the mechanism under the same competitive procedure. Two alternatives are possible: simultaneous auctions or sequential auctions.

The simultaneous auction option entails offering all available busbars for each year of the planning horizon simultaneously through individual open ascending auctions. Although generators typically have a limited set of viable busbar options, this approach adds additional complexity to the decision-making process of a completely new procedure, potentially leading to efficiency losses due to suboptimal choices. Thus, in the context of the TMA, adopting a simultaneous auction format would only be justified if substantial benefits were involved.

However, the greatest benefits of simultaneous auctions are related to the presence of complementarity and substitution among different units (McMillan, 1995; McAfee and McMillan, 1996; Cramton, 1998; Binmore and Klemperer, 2002; Milgrom, 2004). In a scenario with unitary demands, such as in the TMA, benefits related to complementarity among units can be disregarded.[39] As for the benefits related to substitution, these would be limited due to the technical and economic restrictions for a generator to connect at different locations in the system.[40] Moreover, given the non-revenue nature of the TMA, the *spill-over* effect of competition, one of the main benefits of simultaneous auctions in the presence of substitution (McAfee and McMillan, 1996; Binmore and Klemperer, 2002), might also be overlooked in favor of a simpler solution that could enhance allocative efficiency.

In the case of sequential auctions, the main concerns involve the potential for predatory bidding in early rounds and the risk of regret resulting from a failure to achieve planned complementarities (McAfee and McMillan, 1996). However,

[37] The PAR/PEL is the Medium-Term Electrical Operation Plan of the NIS, prepared by the ONS. It includes electrical studies to support transmission expansions and assess the NIS's performance over a five-year horizon. PAR refers to the Expansion and Reinforcement Plan, while PEL refers to the Electrical Operation Plan.

[38] For readers unfamiliar with terms and nomenclatures of electrical systems, it suffices, in this case, to understand busbar as the connection point at which generators can access the transmission system.

[39] An exception could arise in situations involving projects that belong to the same company or controlling group, in which the implementation of specific projects might yield greater synergies and economies of scale. However, since this exception is not expected to significantly impact the TMA (McAfee and McMillan, 1996), we disregarded any of its potential effects.

[40] These limitations on the benefits of substitution, stemming from technical and economic constraints, may be further exacerbated by intense competition for transmission capacity. Given the number of generators that would prefer a particular busbar as their primary option, any generator with less interest in that specific busbar (e.g., due to its relatively higher connection cost) would be at a competitive disadvantage in its auction.

once again these concerns would not arise in single-unit demand scenarios like the TMA.[41] Another challenge concerns the necessary inferences if units are substitutes, leading to the strategic issue of choosing between securing victory early or waiting for a later opportunity with potentially fewer competitors (Portugal and Bugarin, 2021). Technical and economic restrictions to connecting at different locations in the system and the context of intense competition for transmission margins would also mitigate this problem.

Based on the results from a sequential setup in scenarios with single-unit demand and identical units, as detailed in Appendix B, and considering previously discussed factors such as the characteristics of the TMA, the implementation context, the primary objectives, and the preference for a simple solution, the decision was made to adopt sequential auctions. Accordingly, the initial design consisted of a competitive procedure that would progress sequentially over the years of the PAR/PEL planning horizon (in increasing chronological order) and also sequentially across the eligible busbars (in decreasing order of competitiveness[42]).

6.1.2 Implementation of Sequential Auctions

The proposal for a sequential auction that spans the years of the PAR/PEL's planning horizon, which also progresses sequentially for eligible busbars in each year, while appealing from a mechanism design perspective, presents a practical concern: the procedure may become excessively long depending on the volume of transmissions margins and the number of busbars to be auctioned.[43]

In light of the directive to reduce the potential duration of the auctions[44], it became necessary to consolidate the proposal as follows: during a registration stage, each participant indicates their busbars of interest, based on which the ONS performs the margin calculation and defines the set of eligible busbars. Subsequently, before starting the auctions for each offered year, each participant must select a single preferred busbar to compete for the available margin in that specific year (limited to the set of eligible busbars). The option for an open ascending format was retained for busbar auctions. Table 1 provides a summary of the auction design.[45]

Table 1. Auction Design Summary

	Design Feature	**TMA Proposal**	
Auction Format	Pricing Rule	Second Price	Open Ascending Auction
	Information Disclosure	Open	
Auction Implementation	Multi-Year Margin Offer	Sequential	
	Multiple Busbar Offer	Simultaneous*	

* Each participant can only compete in their selected busbar.
Source: Authors

6.2 Design Details

The following subsections address key implementation aspects of the proposed TMA. A summarized flowchart is presented in Fig. 6.

6.2.1 Eligibility

Guided by principles of technological neutrality and equality among sources and contracting environments, and to avoid additional distortions when granting access, any generation project without a valid CUST or CUSD (Distribution System User Agreement), regardless of the source of power or whether it held a generation license, was considered eligible to participate in the TMA.

[41] Possible exceptions would once again pertain to scenarios such as those discussed in footnote 39, which are ignored here for the same reasons explained previously.
[42] The prior establishment of an order for busbar auctions was adopted to mitigate risks associated with arbitrary ordering, such as order manipulation and legal disputes. A descending order of competitiveness aims to promote greater competition throughout the bidding process.
[43] A quick analysis, using the 2022 New Energy Auction (LEN A-5) as a reference (see ONS, 2022b), revealed a scenario in which over 130 sequential auctions would need to be conducted for a single year of the planning horizon in the competitive procedure.
[44] Since discussions of the TMA began, all official entities involved have expressed significant reservations regarding lengthy procedures. Therefore, to address this concern and reduce the potential duration, we evaluated several variations of the original proposal, despite recognizing that these changes could potentially lead to a reduction in efficiency and/or an increase in complexity. See Silva (2023) for further details regarding the different proposals analyzed.
[45] In cases where shorter auction durations are desirable, a hybrid format consisting of an ascending auction with limited rounds followed by a sealed-bid phase (as in the *Anglo-Dutch* model; Binmore & Klemperer, 2002) may warrant future research (we thank the anonymous referee for this suggestion). However, given the original rationale and caveats of this format, any departure from established, theory-backed mechanisms must be justified by particularly strong results.

6.2.2 Different Products

To accommodate the available margins for each year in the current PAR/PEL planning horizon, our design treats each year as a distinct product. These products (i.e., years) must be offered sequentially in ascending order, with a reasonable predetermined interval between them (this interval allows participants time to assimilate the results from the previous product and, if necessary, adjust their strategies to the subsequent ones).

In each of these products (i.e., years), all eligible busbars would be offered simultaneously through *ascending clock auctions*.

6.2.3 Eligible Busbars

During the TMA registration phase[46], participants must indicate their candidate busbars to support the calculation of the transmission margins offered in the auction. ONS would then calculate and disclose the available margins for each candidate busbar based on the participant's indications. Busbars with remaining transmission capacity and physical connection availability would be eligible for the competitive procedure.

6.2.4 Stages of the Competitive Procedure

Auctions for busbars within a specific product (i.e., year) would only start after completing all preceding product auctions (including additional rounds for area and subarea constraints, as described in subsection 6.2.7). Before the start of each product, there would be a preliminary stage at which every participant must select their preferred busbar for the upcoming product, regardless of the options indicated during the registration phase. Once selected, participants could only compete for their preferred busbar for that specific product (i.e., year).

After all participants have selected their preferred busbar for the current product (or opted not to compete), simultaneous auctions will be conducted for each eligible busbar selected by a participant. Following the proposed format, busbar auctions would be conducted in a single, continuous, ascending-value stage. Participants must indicate their willingness to remain in the auction at the current prices (in R$/kW) within a predefined time interval. Each busbar auction would continue until its demand is either less than or equal to its available remaining transmission capacity (see example in Appendix C).

If a price increase results in no demand for transmission capacity at a particular busbar, the respective auction would revert to the previous price and be closed. The remaining participants would then be ranked in descending order of capacity. In the event of a tie, participants would also be ranked by chronological order of bids (which, in this case, corresponds to the chronological order of indicating willingness to remain in the auction in the previous round).

6.2.5 Duration of the Competitive Procedure

Unlike the customary practices in the BES, which typically advocate brief, uninterrupted auctions that start and conclude on the same day, the TMA design adopted a different approach. It is considered that once the competitive procedure begins, no pre-established deadline should dictate its conclusion.

In addition to being a good (and commonly adopted) practice for auctions in general, with auctions concluding only when there is a convergence in final prices, this aspect becomes particularly relevant in this case since the TMA introduces an entirely new procedure, wherein participants, including the conducting institution, lack prior information about the actual value of the asset being auctioned.

6.2.6 Disclosed Information

Another departure from the usual practice in the BES concerns the information made available to participants during the auctions. Aside from the standard information usually provided to participants, such as the Initial Price and Current Price, for the TMA, we recommended disclosing the number of remaining participants and their total power capacity in the current round while preserving bidder anonymity. This decision directly correlates with adopting an open auction format and the desired outcomes associated with its information disclosure effects.

It is also important to disclose information on the presence of subarea and/or area constraints in the auction of each busbar, signaling to participants that, after the ongoing dispute, they may not emerge as final winners (as described in Subsection 6.2.7).

6.2.7 Area and Subarea Constraints

The interconnections within the NIS and its resulting power flows can impose constraints on busbars that are more restrictive than their initially assigned capacities (ONS, 2017). These constraints, known as area and subarea constraints, arise when additional generation at busbars competing for the same transmission resource leads to a violation of pre-established requirements and criteria[47]. Properly addressing these additional restrictions is essential in the competitive procedure to accurately determine the winners.

[46] For further details on the registration phase refer to MME (2022a).
[47] See, for example, ONS, 2022a.

Given that in an open ascending auction winners do not reveal their willingness to pay—the auction ends at the willingness to pay of the marginal loser—the more straightforward solution of ranking busbar winning bids in descending order within each subarea or area would not be suitable for the envisioned TMA format.[48] Such a methodology would likely result in an incorrect final ranking of winners and, consequently, in an inefficient allocation of remaining margins.

In the TMA, winners of busbars within a subarea facing constraints would need to participate in an additional auction, competing for the available margin in that subarea. Similarly, if there were additional area constraints, winners from each involved subarea would need to engage in an additional auction, now competing for the available margin within the respective area (see example in Appendix C).

6.2.8 Initial Price

Following the decision to adopt an open ascending auction and the possibility of *pass-through* when margin supply exceeds demand at a specific busbar (as described in Subsection 6.2.11), the design established a starting price of R$0.00 per kW for all busbar auctions.

Exceptions to this initial price would occur in the additional auctions triggered by subarea and/or area constraints. In such instances, we suggested adopting a criterion according to which the winners of busbars (or subareas) would commit to the prices attained in their preceding auctions.[49] This measure would prevent participants from securing victories in the subsequent auctions at values lower than the final prices determined in the auctions for their respective busbars (or subareas).

6.2.9 Price Increment

The decision on the appropriate price increment balances the need to prevent excessively long auctions with the requirement for sufficient granularity to allow fine adjustments, particularly toward the auction's conclusion. Consequently, for all auctions within the procedure, including those related to area and subarea constraints, the standard price increment would be set at R$1.00[50] per kW.[51]

A rapid examination, using the power capacity of participants from recent energy auctions as a reference, revealed that this value would not result in exceedingly small increments. At the same time, concerns about the increment being too high are mitigated by analyses showing that larger increments do not significantly impact the efficiency of outcomes (McAfee et al., 2010). These larger increments may, in fact, be the most effective approach for expediting the auction process (McAfee et al., 2010).

6.2.10 Bid Acceptance Time

In determining the time for bid acceptance, our objective was to strike a balance between avoiding excessively long auctions and ensuring participants have adequate time to assess the effects of the previous increment before making decisions for the current round.

The proposal recommended setting a bid acceptance time of 5 to 10 minutes for all auctions in the competitive procedure, including those related to area and subarea constraints. Extending the bid acceptance times beyond these recommendations would not pose significant issues; this could likely improve the procedure (the restrictions on bid acceptance times were primarily driven by concerns about the auction's duration raised by the involved official entities).[52] We also included a rule whereby the system automatically moves to the next round if all remaining participants accept the bid before the expiry of the time limit.

6.2.11 Pass-Through

Following the preliminary stage, during which participants select their preferred busbars for the subsequent product, a *pass-through* mechanism would be employed if any busbars had a lower margin demand than the remaining available transmission capacity. In such cases, these busbars would not be auctioned, and all participants who selected them as their preferred choice would secure access at the initial price (in this instance, R$0.00 per kW).

This solution aligns the proposed mechanism with the currently prevailing access rules in cases where the margin demand remains lower than the supply, and no charges would be imposed for access to the NIS in such situations. Furthermore, it is a solution consistent with the economic logic that underpins the rest of the proposal and simplifies the

[48] This is the methodology currently employed in Brazilian energy auctions for managing such additional constraints.

[49] The detailed proposal for this criterion, including a suggested preliminary algorithm, can be found in Silva, 2023.

[50] On February 28, 2024, R$1 corresponded roughly to US$0.20.

[51] To enable better calibration, our design considered the possibility of adjusting the price increment criterion during the auctions, subject to prior communication to all participants via the auction system and adherence to some pre-established criteria that would be disclosed in the auction public notice. This flexibility allows for increasing the price increment at the outset of the auctions, facilitating their advancement when there is a larger number of active participants. Conversely, as the number of participants decreases towards the end, reducing the increment would permit finer adjustments, enabling participants to manifest subtle differences in the values they assign to the remaining margin.

[52] Once again, to enable better calibration, the design considered the possibility of changing this acceptance time during the auctions (with prior communication to all participants via the auction system and according to some pre-established criteria that would be disclosed in the auction public notice).

execution of the procedure by avoiding unnecessary busbars auctions.[53]

6.2.12 Residual Margins

Given the low probability that the power of winning projects at a specific busbar would exactly match its remaining available margin, it was also important to consider how to handle the residual margin that might remain at the end of certain busbar auctions. Since the same TMA would include various products corresponding to the different years of the PAR/PEL planning horizon, the residual margin from a specific busbar will be allocated to its auction in the following product (i.e., year). Residual margins from the last product would be carried over to the next TMA.

6.3 Enforcement

In addition to an appropriate design, the participation of the "right bidders" and ensuring that winners will honor their payments (and, when applicable, their other commitments) are all crucial factors for the success of an auction (Milgrom, 2004).[54] Therefore, addressing the level of enforcement was another crucial issue to ensure the effectiveness of the newly proposed solution for accessing the NIS.

This topic becomes even more relevant when considering Brazil's current generation expansion scenario, where several projects have secured access to the transmission system but have not commenced operations in the scheduled timeline (see Fig. 5 presented previously). As the process of reclaiming access and its corresponding reserved margin tends to be lengthy, potentially involving legal action, this problem may ultimately lead to unnecessary expansion of the transmission system to compensate for capacity that is not used but remains reserved for a specific generator.

The main measures proposed for the TMA regarding this issue were (i) specifying an additional security deposit at the registration phase ("participation guarantee"), (ii) requiring a performance bond for the faithful fulfillment of the connection and utilization of the transmission system contract ("execution guarantee"),[55] and (iii) stipulating that bids placed by winners would not be refunded in the event of non-compliance with the obligations after the auction.[56]

The proposal also established that winners' contracts could not be advanced or postponed, nor could they undergo changes regarding the connection point and technical characteristics related to the reserved transport capacity.

Moreover, in the event of non-compliance with previously determined conditions, the generator would have their contract terminated, and without prejudice to the application of regulatory penalties, the respective guarantees would be executed, and the reserved margin would once again be made available to the NIS. In such situations, ventures affiliated with the same controlling group would not be eligible to compete again for the same margin during a pre-established period (to be determined by the National Electric Energy Agency).

7. Conclusions and Policy Implications

Motivated by recent changes in the Brazilian transmission access landscape, we propose a Transmission Margin Auction (TMA) with a design firmly grounded in the principles of auction theory while also considering the specific characteristics of the BES and its broader regulatory framework. By introducing a competitive allocation mechanism, the TMA seeks to enhance allocative efficiency, improve access dynamics, and optimize grid utilization. Departing from the traditional "*First Come, First Served*" model, it provides a more efficient and transparent way to allocate scarce transmission capacity while reducing the risk of restrictions during operational phases.

Beyond general social welfare gains, driven by the more efficient allocation achieved by selecting generators that value transmission capacity most (typically lower-cost projects), the TMA may also deliver direct benefits to end consumers. Improved use of existing and future grid infrastructure could help lower transmission tariffs, while prioritizing cost-effective generators may, over time, contribute to reduced energy prices.

Although challenges remain, such as the need for robust monitoring, enforcement, and integration with existing BES processes[57], the proposed auction provides a promising path for addressing the growing complexities of the Brazilian electricity market. As the sector evolves, continuous evaluation and refinement will be essential to ensure the mechanism's

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[53] This pass-through mechanism also introduces significant flexibility into the procedure, making it suitable even in scenarios with lower competition for transmission margins (see, for example, the concerns raised in Ofgem (2018) regarding such scenarios). Consequently, it also diminishes the relevance of the recurring debate, particularly in the Brazilian context, over whether the current situation reflects a temporary or structural issue.

[54] If default costs are low, participants would actually be competing for prize options rather than the prize itself. Moreover, if smaller participants were able to sidestep commitments through bankruptcy, the auction would then favor these participants over larger competitors (who would face greater difficulties in defaulting). In such scenarios, aggressive behavior in the auction, evidenced by exceedingly high bids, could simply indicate that the enforcement mechanisms established for the procedure are lenient (Klemperer, 2002a).

[55] As determined by Decree No. 10,893 of 2021, this should be an additional guarantee beyond the one already required for signing the CUST.

[56] Refer to MME (2022a) for further details on these enforcement measures.

[57] This topic is crucial not only from a regulatory and legal perspective, but also because the way the TMA is integrated into existing processes may alter incentives and affect generators' contracting strategies. For more details on existing BES processes, see Hochberg and Poudineh (2021) and Tolmasquim et al. (2021).

effectiveness and adaptability. The TMA may also be a stepping stone toward more sophisticated designs as market participants gain experience.

If the new mechanism is implemented, an empirical analysis comparing its outcomes with the current queue-based system could offer valuable insights into the TMA's real-world performance. If not yet adopted, a regulatory sandbox could be used to test its feasibility, calibrate parameters, and assess the broader implications of the proposed design in a controlled environment. Developing a computational model would further support design refinements by simulating outcomes under alternative scenarios.

Future research could explore the creation of a secondary market for connection rights allocated via the TMA[58], allowing projects to bid for variable margin quantities (rather than a fixed amount tied to project capacity) and enabling those with a signed CUST agreement, but not yet in operation, to offer margins in the auction[59]. On the theoretical side, relaxing assumptions, such as symmetric demands or the simplifications used in the sequential auction analysis, may help assess the mechanism under broader conditions. Another promising avenue is to examine the potential of margin auctions to support transmission expansion and improve coordination between generation and grid development.

As grid access becomes an increasingly global challenge, the findings and proposals presented here, though rooted in the Brazilian context, offer insights that may inform policy and regulatory debates in other countries facing similar constraints. By addressing the complexities of transmission capacity allocation in Brazil, this study contributes to the broader discourse on grid planning and infrastructure development.

[58] While such markets may enhance efficiency, especially in more complex auction formats where perfect allocation is less likely (Binmore & Klemperer, 2002; McDaniel & Neuhoff, 2002; Brandstätt and Poudineh, 2020), the literature remains inconclusive regarding their net benefits (McAfee & McMillan, 1996; Krishna, 2010; Klemperer, 2002b).

[59] In the latter case, this would provide a way to release margins currently tied to projects facing significant delays or unlikely to move forward, thereby avoiding unnecessary grid expansions and contributing to lower tariffs and reduced costs for end consumers.

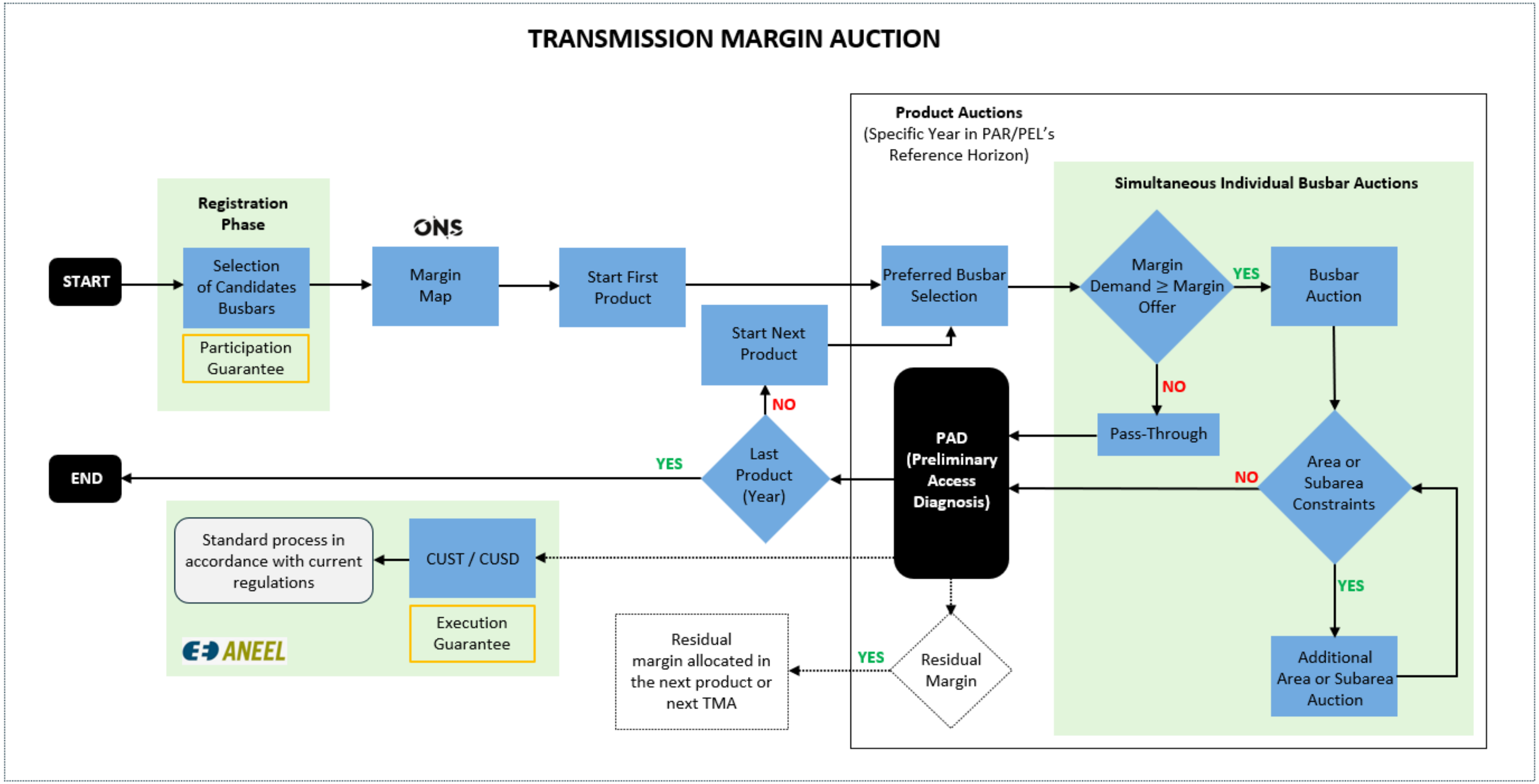

Fig. 6. Transmission Margin Auction Flowchart.[60] Source: Authors

[60] PAD refers to Preliminary Access Diagnosis, a document that consolidates the technical analyses of the Margin Map and enables the issuance of a preliminary authorization for the signing of the CUST or CUSD.

CRediT authorship contribution statement

Lucas Santos e Silva: Conceptualization, Formal analysis, Investigation, Methodology, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. **Mauricio Soares Bugarin**: Conceptualization, Methodology, Supervision, Validation, Writing – review & editing.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work, the authors used ChatGPT to check grammar and improve language clarity. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the published article.

Appendix A. Multi-unit Open Ascending Auction

We begin our analysis by considering the simplifying assumption of symmetric demands. This assumption posits that all generators competing for a specific connection point have identical generating capacities, thus characterizing their demand for transmission margins as a standard case of single-unit demand. While we acknowledge that this assumption does not perfectly reflect reality, it highlights the most relevant aspects of the situation under analysis while ensuring that the models remain reasonably treatable.[61]

Reference Scenario (Private Values)

In a scenario involving multiple units, single-unit demand, and private values, multi-unit open ascending auctions inherit the strategic characteristics of a second-price sealed-bid auction (Krishna, 2010).

In this context, unlike situations with multiple demands, a participant's bid for an additional unit—once that additional unit no longer exists—cannot influence the price of their initial unit. As a result, there is no longer an incentive for behaviors such as bid shading and demand reduction.[62] Therefore, under these assumptions, the multi-unit open ascending auction presents the characteristics considered pivotal for the pricing rule selection and effectively achieves the desired objectives for the current application.[63]

[61] Ultimately, a scenario with asymmetric generation capacities would constitute a variation of the Knapsack Problem, leading to what is known as a Knapsack Auction (Khezr et al., 2024).
[62] See Krishna (2010) for a discussion of these aspects and their impacts on multiple-object auctions.
[63] Under these assumptions, the multi-unit open ascending auction is strategically equivalent to the Ausubel auction (this follows directly from a straightforward adaptation of the results presented in Milgrom (1985) and Krishna (2010)).

To see this, let x^i, $i = 1, \ldots, N$, be the value assigned to the transmission margin for each of the N generators in the auction, and let $\lambda^i: X^i \rightarrow B^i$, $i = 1, \ldots, N$, be the bid function of each generator, which assigns a bid to be made in the auction for each of their values.

<u>Proposition A.1</u>*: In a private values setting with single-unit demand, bidding an amount equal to one's own value is a weakly dominant strategy for each participant in the Multi-unit Open Ascending Auction. That is,* $\lambda^i(x^i) = x^i$, $\forall x^i \in X^i$, *is a weakly dominant strategy for each participant* $i = 1, \cdots, N$ *and the resulting allocation is efficient.*

<u>*Proof*</u>: Initially, to simplify the proof, consider the strategic equivalence, in the scenario of private values, between the Multi-unit Open Ascending Auction and the Uniform-Price Auction.[64]

Now, take a Uniform-Price Auction for the remaining margin at a given bus j, with N participants, and fix an arbitrary participant i.

Suppose that the capacity of participant i's project is less than or equal to the remaining margin available at j. In this case, participant i assigns a value x_j^i to their demand for margin at the bus (in R$/kW).

Let p be the highest losing bid and, therefore, the final price assigned to the margin in the auction in question (in R$/kW).

In this case, if participant i chooses the bid $b_j^i = x_j^i$:

- They win if $x_j^i > p$, obtaining a payoff of $\Pi^{\text{i}} = x_j^i - p$;
- They lose if $x_j^i < p$, obtaining a payoff of $\Pi^{\text{i}} = 0$;
- They have an *ex-post* utility equal to zero if $x_j^i = p$.

Based on the results above:

(1) If participant i chooses a bid $z_j^i < x_j^i$:

- If $x_j^i > z_j^i > p$, then their payoff remains unchanged.
- If $p \geq x_j^i > z_j^i$, again, there is no change in their payoff.
- If $x_j^i > p \geq z_j^i$, then their payoff drops from $\Pi^{\text{i}} = x_j^i - p > 0$ to $\Pi^{\text{i}} = 0$.

Thus, participant i cannot improve their payoff by lowering their bid (lowering the bid can only worsen or leave the payoff unchanged).

(2) If participant i chooses a bid $z_j^i > x_j^i$:

- If $z_j^i > x_j^i > p$, then their payoff remains unchanged.
- If $p > z_j^i > x_j^i$, again, there is no change in their payoff.
- If $z_j^i \geq p > x_j^i$ or $z_j^i > p \geq x_j^i$, then their payoff drops from $\Pi^{\text{i}} = 0$ to $\Pi^{\text{i}} = x_j^i - p < 0$.

Thus, participant i cannot improve their payoff by increasing their bid (raising the bid can only worsen or leave the payoff unchanged).

Therefore, participant i cannot improve their *ex-post* payoff by deviating from the strategy of *bidding truthfully* (submitting a bid equal to their true value), i.e., $\forall x^i \in X^i$, $\lambda^i(x_j^i) = x_j^i$.

Hence, $\boldsymbol{\lambda} = (\lambda^1, \ldots \lambda^N)$ where $\lambda^i(x_j^i) = x_j^i$ for all $i = 1, \ldots, N$ constitutes a Bayesian Nash Equilibrium (BNE) in weakly dominant strategies for the Multi-unit Open Ascending Auction in a private values and single-unit demand setting.

Finally, since in equilibrium the participants with the highest valuations for the remaining margin win the auction, the mechanism is efficient. ■

However, the initial rationale for adopting an open format suggests that, in the context of the TMA, the assumption of private values may not be suitable. Considering the nature of its application (McDaniel, 2003) and given the innovative nature of the proposal, a more accurate assumption would involve interdependent values, particularly affiliated values.

[64] Without the assumption of private values, the results of Proposition A.1 would be limited to the Uniform-Price Auction, as the latter would no longer be strategically equivalent to the Multi-unit Open Ascending Auction.

Interdependent and Affiliated Values

Open ascending auctions provide a highly robust equilibrium independent of the signal's distribution[65] in scenarios with single units and interdependent and affiliated values under a symmetric model[66]. Moreover, participants' equilibrium strategies exhibit a particularly important feature: the absence of regret. Since these strategies form an *ex post* equilibrium[67], participants do not regret the outcomes at the end of the auction, regardless of the signal realization. Under the same conditions, this characteristic is not present in other traditional auction formats (Krishna, 2010).

In the aforementioned scenario, traditional auction formats also differ with regard to expected revenue. The expected revenue of open ascending auctions is never lower than that of second-price sealed-bid auctions, which, in turn, provide revenue at least as large as that of first-price sealed-bid auctions or descending open auctions (Milgrom and Weber, 1982; Weber, 1983).

Finally, in terms of efficiency, none of the traditional formats yield efficient outcomes for the configuration under analysis.[68] All of them have ascending symmetric equilibria, but these equilibria are ascending for the signals of the participants, not their values.

While these results are relatively favorable for open ascending auctions, they apply specifically to scenarios involving the sale of a single unit. Given that TMA potentially involves multiple units in the same auction, we consider whether these results extend to the case under analysis.

Many of the difficulties associated with multi-unit auctions result from the multiplicity of items demanded by participants rather than the multiplicity of items sold by the auctioneer. Thus, a single-unit demand scenario, such as the one in the TMA, often allows extending the various results obtained in simpler setups to contexts with multiple units. Indeed, this partly occurs in a scenario of affiliated values, symmetric model, and single-unit demand. Under such assumptions, the previous ranking of expected revenues remains valid in the context of multiple units, and consequently, positive results for open ascending auctions are still observed. Specifically, we have the following ordering for the expected revenues ($E[R]$) of open ascending auctions (OAA), uniform price sealed-bid auctions (UPSA), and discriminatory price sealed-bid auctions (DPSA) (Weber, 1983; Milgrom, 1985): $E[R_{OAA}] \geq E[R_{UPSA}] > E[R_{DPSA}]$.[69]

Appendix B. Sequential Auctions

For the analysis of sequential auctions in the context of the TMA, the following assumptions were made: (i) all busbars relevant to a specific project were treated as identical units; (ii) interest in the same set of busbars was shared for projects located in the same region. We use independent and symmetric private values as a basic reference scenario (remembering that the TMA entails a unitary demand scenario) and assume that participants will not discount the payoffs of later auctions.

Given these specifications, there is an equilibrium for the sequential open ascending auction that yields efficient results and does not rely on the announcement of previous outcomes (Krishna, 2010).[70] To see this, consider a sequential auction with K identical units and N risk-neutral participants. Following the approach recommended by Klemperer (1999), we begin by analyzing a different format, namely, the Sequential First-Price Auction, and then apply revenue equivalence to derive the desired results for the format of interest: the Sequential Open Ascending Auction.

Sequential First-Price Auction

A strategy for a given bidder i in this auction consists of a set of K functions, $\lambda_1^i, \cdots, \lambda_K^i$, where $\lambda_j^i(x_i, p_1, \ldots, p_{j-1})$ corresponds to the bid in the auction for the *j*-th unit, given that the bidder's valuation is x_i and the prices in the previous $j-1$ unit auctions are, respectively, $p_1, p_2, \ldots, p_{j-1}$.

Let $Y_j \equiv Y_j^{(n-1)}$ be the random variable representing the *j*-th highest value among the realizations of the other participants; that is, Y_j is the *j*-th order statistic of the remaining $N-1$ valuations.

[65] The signals are the participants' private information that, if revealed to other competitors, could change their values.
[66] In a symmetric model, the signals of all participants are drawn from the same interval. Additionally, the function that determines the value assigned to the object is the same for all participants and is symmetric with respect to the signals of the other competitors (the order of these signals can be swapped without affecting the resulting value). See Krishna (2010) for further details.
[67] An *ex post* equilibrium is a Bayesian-Nash equilibrium with the added requirement that, even if a bidder knew all other players' signals, it would still be optimal for them to follow the strategy prescribed by that equilibrium. See Krishna (2010) for further details.
[68] If the "Single Crossing Condition" is satisfied for the function that determines participants' valuation of the item, then all these auction formats exhibit efficient equilibria. However, this conclusion does not hold in the presence of asymmetries between participants. In such cases, the "Single Crossing Condition" property guarantees the existence of an efficient equilibrium for open ascending auctions only in auctions restricted to two participants. A more general result, encompassing a larger number of participants, can be achieved only by fulfilling the "Average Crossing Condition" (Krishna, 2010).
[69] The results presented depend on the assumption of risk neutrality among participants. In a situation where participants are equally risk-averse, the discriminatory price sealed-bid auction would yield a higher expected revenue than the uniform price sealed-bid auction (Weber, 1983).
[70] These results remain valid even when some of the fundamental assumptions of the model are relaxed (Weber, 1983). For example, they hold true when the total number of participants is unknown to all competitors or when the assumption of private values is dropped (while still maintaining the hypothesis of independent values and assuming a type of symmetry derived from identical valuation functions for all participants).

<u>Proposition B.1</u>*: For the basic reference scenario, if a symmetric, differentiable, and strictly increasing equilibrium exists in the Sequential First-Price Auction, the strategies in this equilibrium take the following form:*

$$\lambda_j^I(x_i) = \mathrm{E}\left[Y_K \mid Y_j < x_i < Y_{j-1}\right]$$

where $\lambda_j^I(x_i)$ corresponds to the bid in the auction for the j-th unit.

<u>Proof</u>: See chapter 15 in Krishna (2010).

However, *Proposition B.1* only tells us that participants' strategies will follow the specified form in a symmetric, differentiable, and strictly increasing Bayesian Nash Equilibrium of the game. It remains to be shown that if all participants play according to $\lambda_j^I(\cdot)$, then it is optimal for a participant with valuation x_i to submit a bid $b = \lambda_j^I(x_i)$.

<u>Proposition B.2</u>*: In the Sequential First-Price Auction, the strategy profile $\lambda_j^I(\cdot)$ defined by:*

$$\lambda_j^I(x_i) = E\left[Y_K \mid Y_j < x_i < Y_{j-1}\right]$$

constitutes a symmetric, differentiable, and strictly increasing Bayesian Nash Equilibrium of the game.

<u>Proof</u>: See Silva (2023). Also available upon request.

Sequential Open Ascending Auction

Once the Sequential First-Price Auction results are established, we will use them to indirectly derive the strategies and outcomes of the Sequential Open Ascending Auction.

We begin by considering, under the adopted assumptions, the strategic equivalence between the Second-Price Auction and the Open Ascending Auction. We then observe that, for the reference model, the allocation will be efficient if $\lambda_j^{II}(x_i)$ is a symmetric, increasing equilibrium in the Sequential Second-Price Auction (Krishna, 2010). This result implies revenue equivalence between this format and the Sequential First-Price Auction.[71] Consequently, the expected payments for a given participant will also be equivalent across the two auctions.

Let $m^I(x_i)$ e $m^{II}(x_i)$ denote the expected payments of a given participant i, with value x_i, in the Sequential First-Price Auction and the Sequential Second-Price Auction, respectively. Revenue equivalence initially guarantees only the equivalence of total expected payments. Hence, we define the expected payment of participant i in the *j*-th auction, under each format, as $m_j^I(x_i)$ and $m_j^{II}(x_i)$, respectively. This yields:

$$m^I(x_i) = \sum_{j=1}^{K} m_j^I(x_i)$$
$$m^{II}(x_i) = \sum_{j=1}^{K} m_j^{II}(x_i)$$

In the final auction, the information available to all $N - K + 1$ participants is the same in both formats. By focusing specifically on this last stage, the revenue equivalence principle gives us that $m_K^I(x_i) = m_K^{II}(x_i)$. Proceeding recursively, we can establish that $m_j^I(x_i) = m_j^{II}(x_i)\ \forall j$. This general equivalence is then used to demonstrate the following proposition:

<u>Proposition B.3</u>*: For the basic reference scenario, the symmetric, differentiable, and strictly increasing equilibrium in the Sequential Open Ascending Auction is given by the following strategy:*

$$\lambda_K^{II}(x_i) = x_i$$
$$\lambda_j^{II}(x_i) = \lambda_{j+1}^I(x_i)\ \forall j < K$$

where $\lambda_{j+1}^I(x_i)$ corresponds to the bid for unit $j+1$ in the equilibrium of the Sequential First-Price Auction.

<u>Proof</u>*:* First, consider a Sequential Second-Price Auction. Fix an arbitrary participant i (who assigns a value x_i to a unit of the good) and assume that all other competitors follow the strategy $\lambda_j^{II}(\cdot)$.
Similar to what is observed in the sealed-bid second-price auction, where bidding one's own value is a weakly dominant strategy, the same result holds in the final period ($j = K$) of the Sequential Second-Price Auction.[72] Therefore:

$$\lambda_K^{II}(x_i) = x_i$$

Note, then, that in the earlier periods, where $j < K$, for participant i to win the *j-th* auction, their value must satisfy the condition:

[71] For further details, see Weber (1983) or Krishna (2010).
[72] For further details, see Krishna (2010).

$$Y_1 > \cdots > Y_{j-1} > x_i > Y_j > \cdots > Y_{K-1}$$

In this case, they will pay the value of the second-highest bid, given by $\lambda_j^{II}(Y_j)$, and their expected payment will be:

$$m_j^{II}(x_i) = prob[Y_{j-1} > x_i > Y_j] \times \mathrm{E}[\lambda_j^{II}(Y_j) \mid Y_{j-1} > x_i > Y_j]$$

In the case of a Sequential First-Price Auction, where the payment corresponds to the submitted bid, their expected payment would be:

$$m_j^{I}(x_i) = prob[Y_{j-1} > x_i > Y_j] \times \lambda_j^{I}(x_i)$$

But, as shown in *Proposition B.1*, $\lambda_j^I(x_i) = E[Y_K \mid Y_j < x_i < Y_{j-1}]$, therefore:

$$\lambda_j^I(x_i) = E[E[Y_K \mid Y_{j+1} < Y_j] \mid Y_j < x_i < Y_{j-1}]$$

$$\lambda_j^I(x_i) = E[\lambda_{j+1}^I(Y_j) \mid Y_j < x_i < Y_{j-1}]$$

Thus, since the expected payments for both formats are equal:

$$prob[Y_{j-1} > x_i > Y_j] \times \mathrm{E}[\lambda_j^{II}(Y_j) \mid Y_{j-1} > x_i > Y_j] = prob[Y_{j-1} > x_i > Y_j] \times \mathrm{E}[\lambda_{j+1}^{I}(Y_j) \mid Y_j < x_i < Y_{j-1}]$$

Hence, by differentiating both sides of the equation with respect to x, we obtain:

$$\lambda_j^{II}(x_i) = \lambda_{j+1}^{I}(x_i)$$

Since, under the assumptions of the basic reference scenario, the Second-Price Auction and the Open Ascending Auction are strategically equivalent, the results obtained above also apply to the latter.

Therefore, the strategy given by $\lambda_K^{II}(x_i) = x_i$ e $\lambda_j^{II}(x_i) = \lambda_{j+1}^{I}(x_i)\ \ \forall j < K$ corresponds to the symmetric equilibrium of the Sequential Open Ascending Auction. ■

First, we note that the equilibrium strategy is independent of the disclosure of winning bids in earlier rounds. Regarding efficiency, since the equilibrium strategies are increasing functions of the participants' values, the units are awarded in decreasing order of valuation and are thus efficiently allocated.

However, under these assumptions, efficient outcomes are also achieved by other traditional sequential and simultaneous auction formats, which are also equivalent in revenues (Weber, 1983; Klemperer, 1999). Hence, under these circumstances, there is no difference between the sequential and simultaneous auction results.

In situations characterized by affiliated values, even with unitary demands and identical units, the information revealed in previous periods would become relevant to participants' strategies. As a result, the previously presented results would no longer hold (Weber, 1983). However, in a scenario with affiliated values, unitary demands, and identical units, some general conclusions can still be drawn: (i) sequential first-price auctions generally yield higher revenue than simultaneous discriminatory price auctions; (ii) sequential open ascending auctions and sequential second-price auctions generally generate higher revenue than simultaneous uniform price auctions (Milgrom and Weber, 2000).

Appendix C. Example

To better illustrate the dynamics of the proposed auction, we present a simple numerical example below, considering two buses identified in the ONS study for the 2022 New Energy Auction LEN A-5/2022 (ONS, 2022b), along with their respective remaining transmission capacities. The number of generators competing at each busbar, their respective capacities, and the valuation of the margins are all hypothetical and chosen solely for illustrative purposes.

Table C.1 presents the remaining capacities for the auction, including the subarea and area constraints, while Tables C.2 and C.3 present the generators competing at each busbar, along with their capacities and margin valuations.

Table C.1. Quantities of Remaining Capacity

			Remaining Capacity for the Auction (MW)		
UF	**Candidate Busbar**	**Voltage (kV)**	**Busbar**	**Subarea**	**Area**
MA	Caxias II - Peritoró - C1 (CXD_PRT_C1)	230	≤ 280	≤ 450	≤ 450
MA	Chapadinha (CPD)	230	≤ 380		

Source: ONS, 2022b

Table C.2. CXD_PRT_C1 Candidates

Generator	Project Capacity (MW)	Margin Valuation (R$ per kW)
CXD Generator 1	80	2,85
CXD Generator 2	70	1,70
CXD Generator 3	70	2,20
CXD Generator 4	60	0,95
CXD Generator 5	90	3,15

Source: Elaborated by the authors for illustrative purposes.

Table C.3. CPD Candidates

Generator	Project Capacity (MW)	Margin Valuation (R$ per kW)
CPD Generator 1	40	2,15
CPD Generator 2	160	4,00
CPD Generator 3	150	3,55
CPD Generator 4	35	0,70
CPD Generator 5	40	3,20

Source: Elaborated by the authors for illustrative purposes.

Figures C.1 and C.2 present the individual auctions for busbars CXD_PRT_C1 and CPD, as detailed in Section 6.2, including the specified initial price and price increment values. Given subarea constraints involving busbars CXD_PRT_C1 and CPD, the auction winners must also participate in an additional auction, competing for the remaining subarea margin. This stage is presented in Figure C.3.

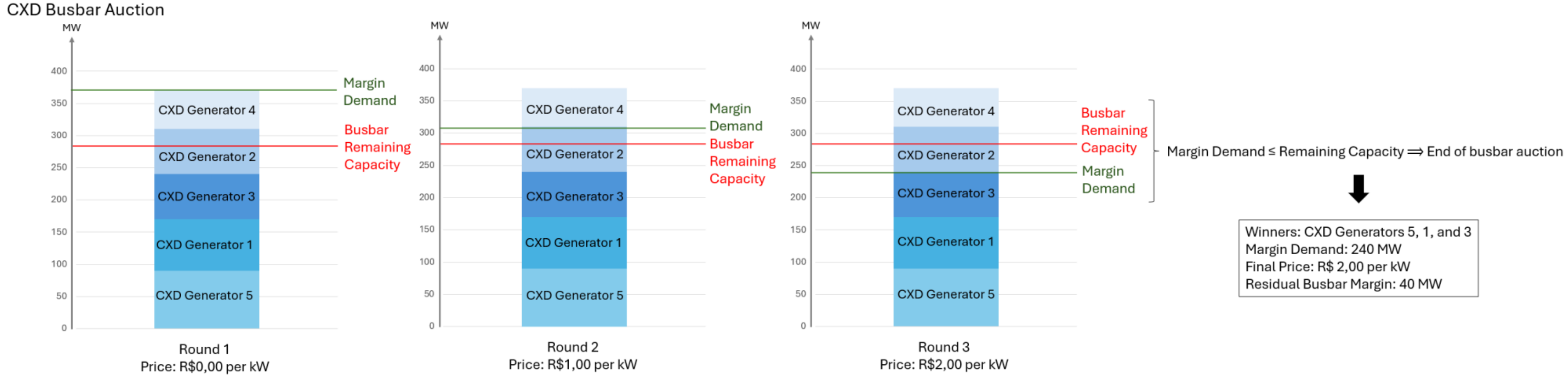

Fig. C.1. CXD_PRT_C1 Busbar Auction. Source: Authors

Fig. C.2. CPD Busbar Auction. Source: Authors

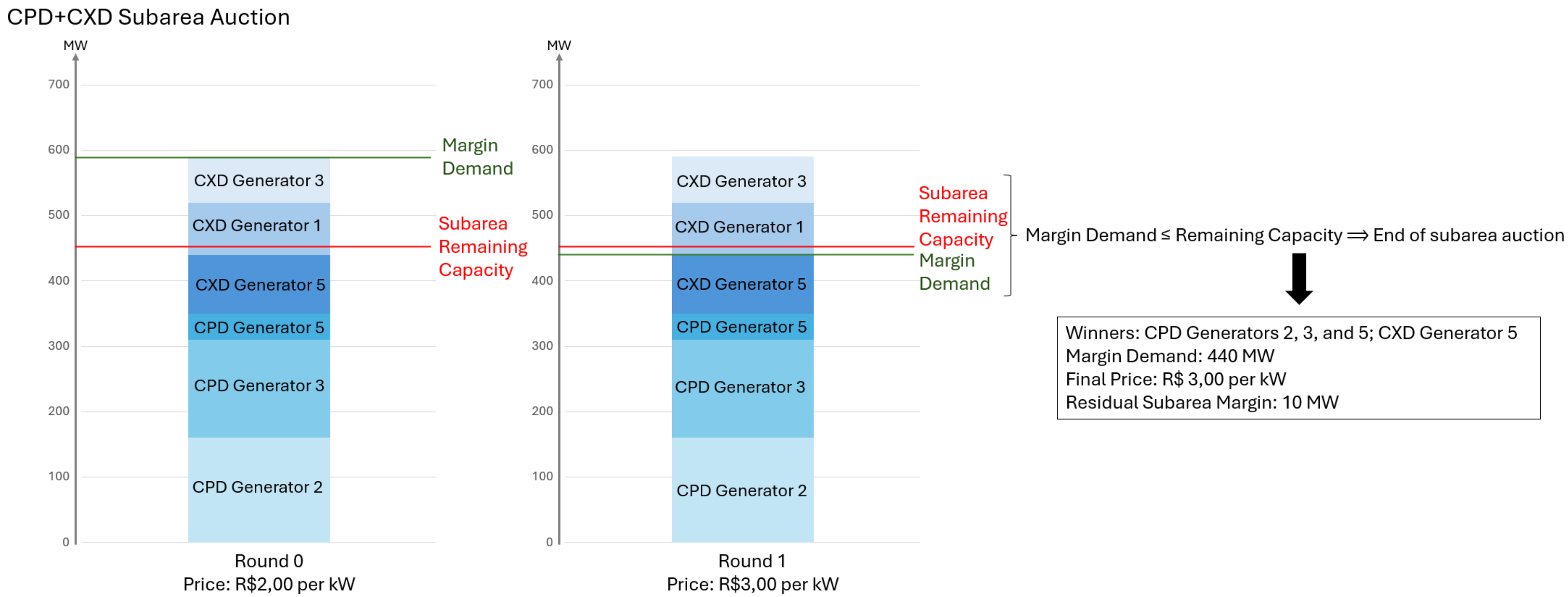

Fig. C.3. Subarea Auction. Source: Authors

Appendix D. Simulation

To highlight the relative benefits of using auctions and better illustrate their potential impact on allocative efficiency, we ran Monte Carlo simulations comparing auction-based and queue-based allocation mechanisms across various configurations and assumptions.

We began our analysis by conducting a Monte Carlo simulation of a more general case involving symmetric demands. The simulation comprised 100,000 iterations, assuming a fixed demand of 50 MW per generator. Valuations were drawn from a uniform distribution between 1 and 100, transmission margins were uniformly distributed between 50MW and 500MW, and the number of competitors ranged uniformly from 15 to 75. As expected, the results presented in Figure D.1 indicate substantial efficiency gains from adopting auctions, with the mean valuation of allocated generators increasing by more than 80%.

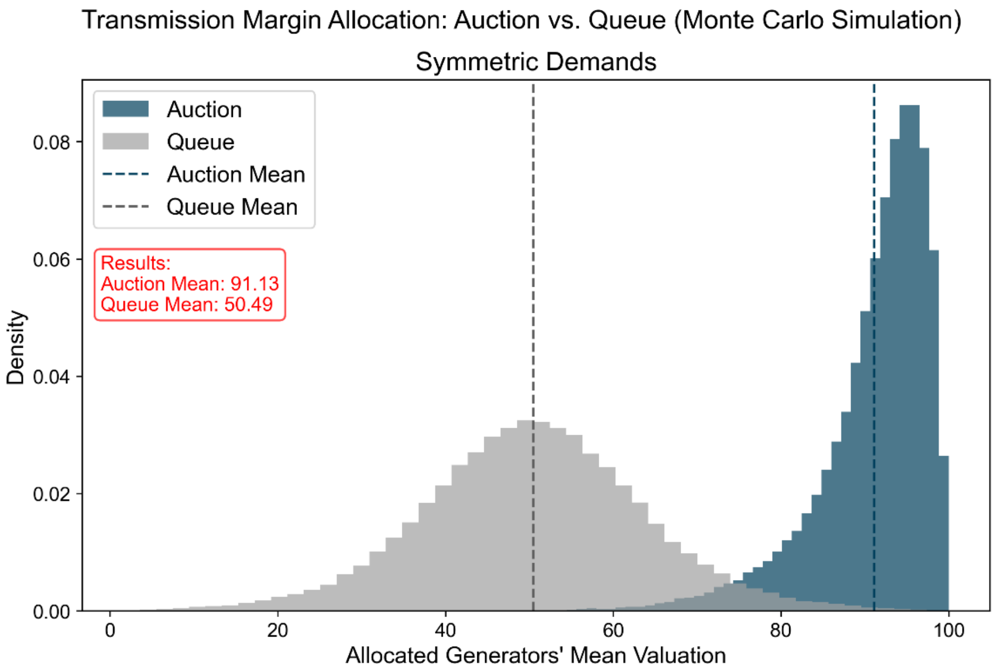

Fig. D.1. Distribution of mean valuations for allocated generators across 100,000 Monte Carlo simulations, comparing auction-based and queue-based allocation mechanisms. Simulation parameters: Generator demands = 50 MW; Valuations ~ U(1, 100); Transmission Margins ~ U(50, 500) MW; Number of competitors ~ U(15, 75). Source: Authors' calculations

To better understand the effect of each parameter, we conducted additional simulations for specific scenarios, varying the number of competitors and the amount of available transmission margin. We maintained a symmetric demand of 50 MW per generator in all simulations and assumed valuations drawn from a uniform distribution between 1 and 100. Each Monte Carlo simulation consisted of 10,000 iterations. As expected, again, auctions consistently resulted in higher mean valuations for the allocated generators. Moreover, the difference between the auction and queue-based methods became more pronounced in scenarios with greater competition or lower available margins, conditions that reflect the Brazilian context. The results are presented in Figures D.2 through D.6. Across all simulations, auctions yielded efficiency gains of at least 67%, with improvements exceeding 86% in more constrained scenarios.

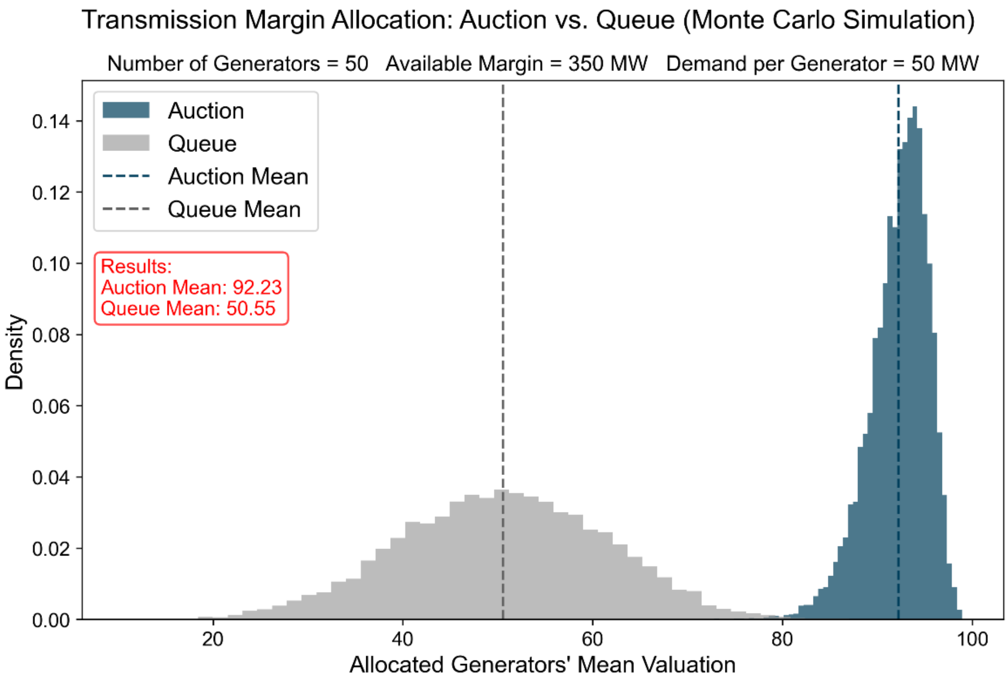

Fig. D.2. Distribution of mean valuations for allocated generators across 10,000 Monte Carlo simulations, comparing auction-based and queue-based allocation mechanisms (Scenario 1). Source: Authors' calculations

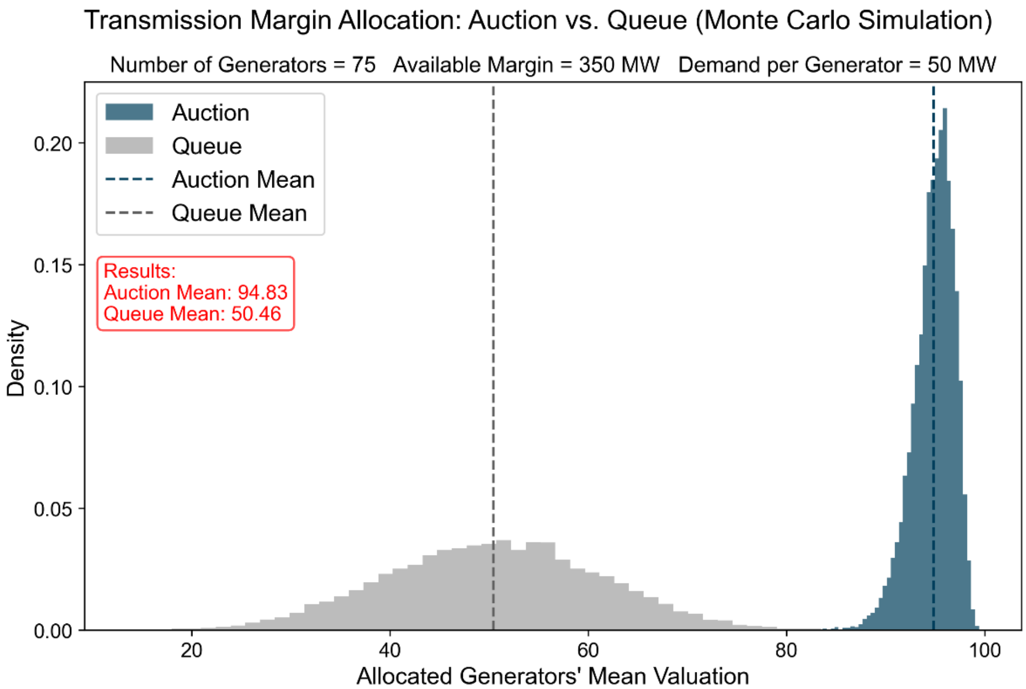

Fig. D.3. Distribution of mean valuations for allocated generators across 10,000 Monte Carlo simulations, comparing auction-based and queue-based allocation mechanisms (Scenario 2). Source: Authors' calculations

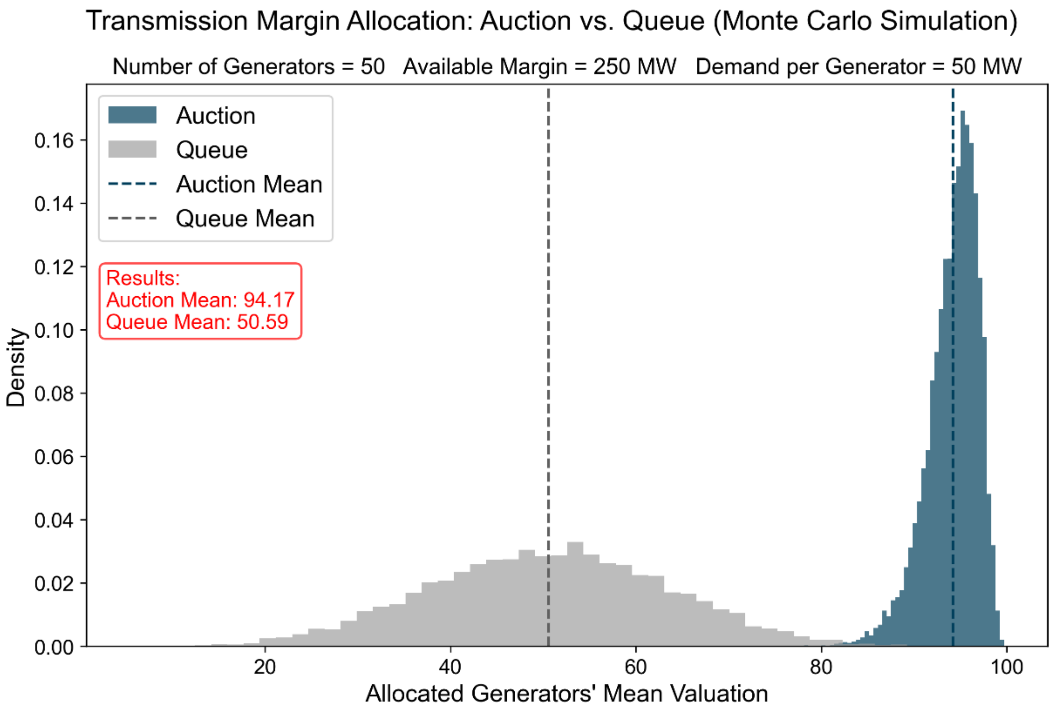

Fig. D.4. Distribution of mean valuations for allocated generators across 10,000 Monte Carlo simulations, comparing auction-based and queue-based allocation mechanisms (Scenario 3). Source: Authors' calculations

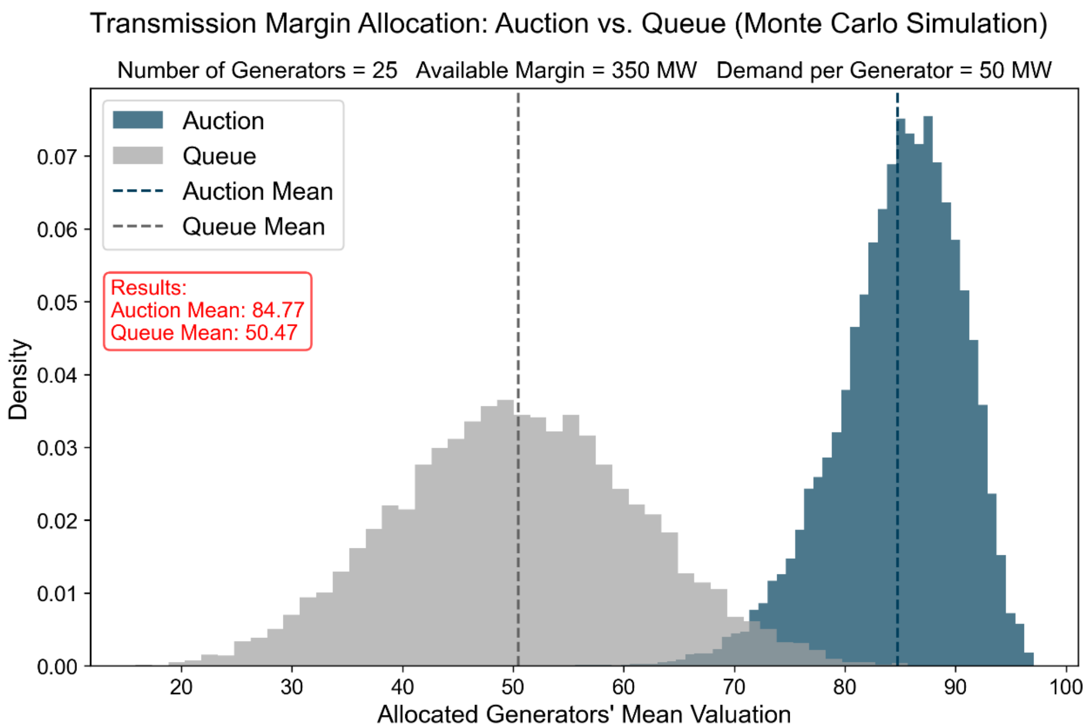

Fig. D.5. Distribution of mean valuations for allocated generators across 10,000 Monte Carlo simulations, comparing auction-based and queue-based allocation mechanisms (Scenario 4). Source: Authors' calculations

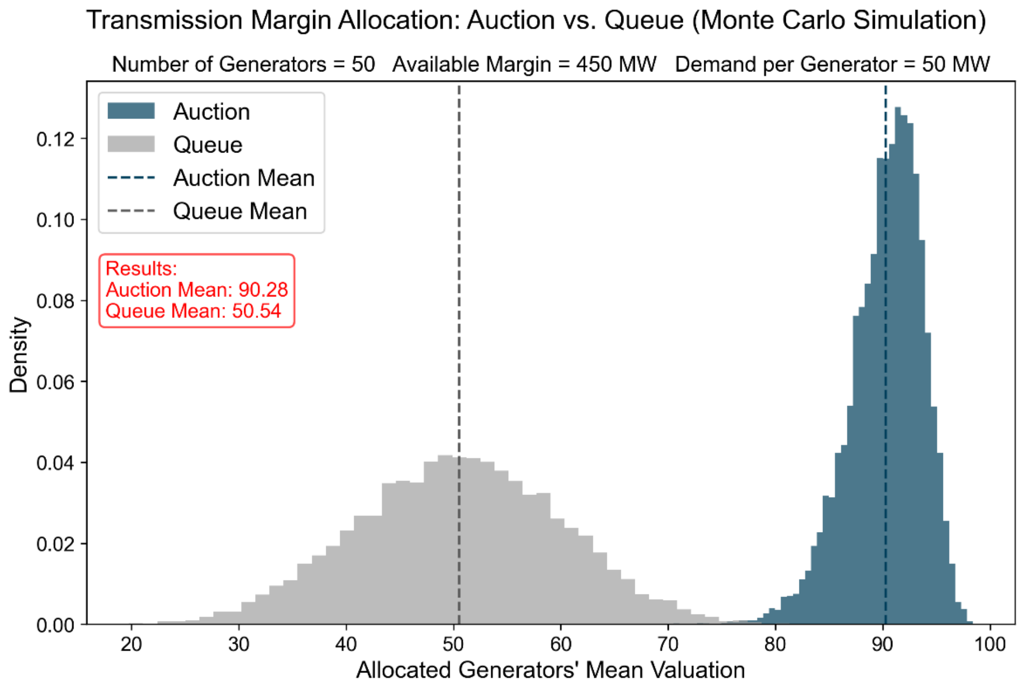

Fig. D.6. Distribution of mean valuations for allocated generators across 10,000 Monte Carlo simulations, comparing auction-based and queue-based allocation mechanisms (Scenario 5). Source: Authors' calculations

Finally, we conducted a Monte Carlo simulation of 100,000 iterations to simulate scenarios with asymmetric demand. We used uniform distributions for all variables: generator demands ranged from 25 MW to 100 MW; valuations from 1 to 100; transmission margins from 50 MW to 500 MW; and the number of competitors from 15 to 75. As expected, the results presented in Figure D.7 indicate substantial efficiency gains from adopting auctions, with the mean valuation of allocated generators increasing by over 83%.

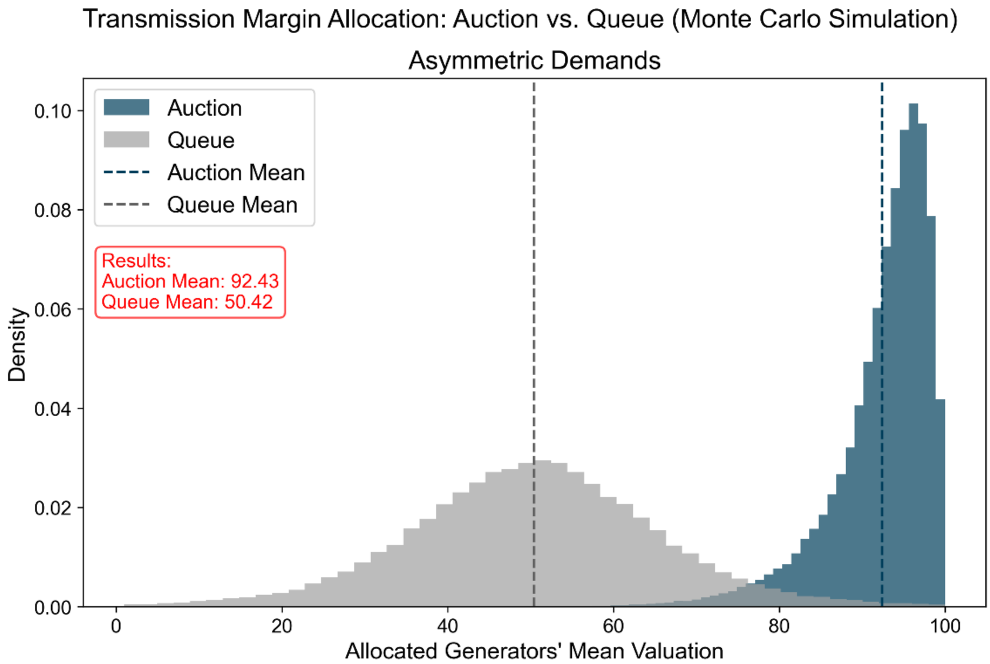

Fig. D.7. Distribution of mean valuations for allocated generators across 10,000 Monte Carlo simulations, comparing auction-based and queue-based allocation mechanisms. Simulation parameters: Generator demands ~ U(25, 100) MW; Valuations ~ U(1, 100); Transmission Margins ~ U(50, 500) MW; Number of competitors ~ U(15, 75). Source: Authors' calculations

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