Analysis of the determinants of the Brazilian energy mix

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ABSTRACT

In 2004 came into force a new model for the Brazilian Electricity Sector (BES). This model was established based on three pillars: expansion of the installed capacity, reasonable tariffs and universalization of the access to electricity. The main change that took place was the resumption of the energy planning for the State's responsibility, which had been transferred to private players in the previous liberal period. This resumption takes place through the creation of the *Empresa de Pesquisa Energética* (EPE), whose purpose is the development of studies and researches to support the planning of the energy sector, guiding the government and industry players in their decision making process and guidelines establishment. Among the major studies carried out by EPE is the *Plano Decenal de Expansão de Energia* (PDE), that annually formulates forecasts for the expansion of the supply and demand of energy for a period of 10 years ahead, therefore becoming an important planning tool for the BES. Thus, the PDE indicates the future electricity mix for the sector. However, EPE's planning is only indicative, making it essential to analyze whether their propositions occur in reality. Therefore, the procurement of installed capacity to be added to the BES and the sources that will compose this future mix need to be investigated. Moreover, with the new model, the procurement of new installed capacity starts to occur through energy auctions. In these auctions, the concession of new plants occurs and it is guaranteed the future supply to attend the demand anticipated by the distribution companies for the regulated consumers. The electricity auctions aim to contract energy with reasonable tariffs. In order for that to happen, the criterion used to define the winner is the lowest rate offered. Thus it is through the electricity auctions that the government coordinates the expansion of the generating capacity and the winner sources will compose the future electricity mix. The composition derived from the results of the auctions often differs from the projections of the PDE, making this differentiation the central object of analysis in this article. In that way, the question that arises is what are the causes that explain the differences between the results of these energy auctions and what it was projected and estimated by EPE in its ten-year planning. The article seeks to make a comparison of PDE's projections since its first formulation in 2006, with the results of the new energy auctions held so far. Essentially, it seeks to answer if, through the indicative planning and the auctions, we are in fact moving towards a strategic electricity mix for the BES.

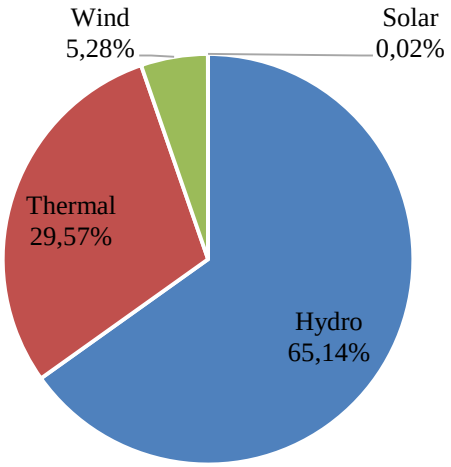
KEYWORDS: Brazilian electricity market; energy planning; electricity auctions

1. INTRODUCTION

Electricity is an essential commodity for all socio-economic sectors, and its uninterrupted supply, with reliability and affordable tariffs, is crucial for the national development. It is also not directly storable in large amounts, implying the need for its generation and consumption to happen simultaneously in order to have an instant balance (Pinto *et al.*, 2007). Investments in the energy sector are also capital-intensive with long-term maturity (Siffert et al., 2009). The combination of these features brings to the sector the need for medium and long-term planning, becoming a fundamental and strategic activity for the Brazilian Electricity Sector (BES), and requiring a deep understanding of its operation, mechanisms and possible adjustments to ensure the balance between supply and demand.

It should be noted that the BES is extremely complex, being fully interconnected[1] through transmission lines with continental proportions. The sector's uniqueness is also complemented by the composition of its energy mix, as can be seen in Graphic 1. In the new model of the BES, the procurement of new plants to compose this electricity mix began to occur through electricity auctions and the sector's planning is resumed.

Graphic 1 – Brazilian electric mix (2015)



Source: *Agência Nacional de Energia Elétrica* (ANEEL).

Therefore, this paper seeks to make a comparison of the planning proposed by its main instrument, the *Plano Decenal de Expansão de Energia* (PDE), since its first formulation, with the results of the energy auctions held so far, analyzing the energy sources where the greatest discrepancies between what was planned and what was procured occurred. Essentially, it seeks to answer if through the current planning and auction mechanisms, we are in fact moving towards a strategic energy mix for the BES[2].

Accordingly, the first section brings a brief description of the recent history of the BES, followed by the section that characterizes its new model, established between 2003 and 2004. The third section debates one of the major changes that have occurred in this new model: the procurement of electricity through auctions. In the fourth section, it is discussed the resumption of the sector's planning after the energy shortage crisis that occurred in the country in the biennium 2001-2002, succeeded by an analysis of the comparative results between the planning and the actual result of the auctions. Finally, there is a brief conclusion about the elaborated analysis.

2. BRIEF HISTORY OF THE BRAZILIAN ELECTRICITY SECTOR

[1] Except for the states of Roraima and Amazonas.

[2] It should be noted that this paper is part of a research that the author is developing for her master's degree.

Throughout the twentieth and twenty-first century, the responsibility for planning the BES changed hands a few times. The regulatory framework has undergone several transformations in that period, especially regarding the participation of the State, alternating moments of predominant participation of public and private capital, be it domestic or foreign (Dias Leite, 2014).

When it comes to the more recent stages of the BES, in the mid-1990s was implemented a liberal reform with the privatization of companies in the sector, beginning in the year 1995. The liberal model also brought up the definitive unbundling of the production chain of the companies in the sector by separating the segments of generation, transmission, distribution and commercialization of electricity. The competition in generation and commercialization segments was encouraged, keeping regulated the distribution and transmission because they are considered natural monopolies in the industry.

Therefore, it can be noted that the BES has moved from a State monopoly system to a market oriented type. As a result, until February 2000, about 65% of the national distribution market had already been transferred to the private sector, with significant participation of international groups, especially from Europe and the United States (Pires, 2000).

However, with the implementation of this new liberal model for the electricity sector, the formulation of energy policies and medium and long-term planning were neglected, since there was no entity responsible for such activity and the regulatory system was not fully mature. During this period the sector planning was set aside and transferred to the responsibility of private agents (Castro *et al*., 2012).

The lack of planning coupled with technical and environmental issues culminated in 2001 in a serious energy supply crisis that generated many discussions about BES's direction. Such crisis resulted in the need for rationing of 20% of the electricity consumption, thus exposing the current model's weaknesses.

As follows, since that model did not appear sustainable, in 2001 the Committee of Revitalization of the Electricity Sector Model is created, with the primary function to draw up proposals to fix current dysfunctions and improve the sector model. Its work resulted in a set of recommendations for amendments in the BES.

In conclusion, the liberal reform implemented in the BES between 1995 and 2002 was ineffective in securing the main objectives of a public service, such as supply reliability, low tariffs and universality (Tolmasquim, 2011). One of the points that explained their inefficiency was the lack of planning. As a result, it begins the implementation of a new model for the BES. The new model brings a resumption of the coordination and planning with a more active role of the State (Tolmasquim, 2011).

3. THE NEW MODEL OF THE BRAZILIAN ELECTRICITY SECTOR

The new model, implemented between the years 2003 and 2004, modified the electric power procurement method and resumed the centralized planning in the sector. In contrast to the earlier time of a more liberal model, this new one is characterized by being hybrid, marked by greater State participation through public private partnerships, with the State in a position of complementarity and orientation in regards to private companies.

The new model was built upon three fundamental objectives: expansion of the installed capacity to meet demand growth, reasonable tariffs and universal access to electricity (Castro *et al*, 2012). In order to meet these objectives, one of the introduced changes was the creation of two energy procurement environments: the Free Market (FM), where it is possible to have a greater negotiation of the supply contracts; and the Regulated Market (RM), in which the procurement of electricity occurs through energy auctions, observing the criterion of the lowest price. The energy procurement in the RM is formalized through regulated bilateral contracts between selling agents and distributors who participate in these auctions.

3.1. The electricity procurement auctions

The energy auctions are an essential tool for the expansion and sustainability of the BES, since it is through them that occurs the procurement of electricity to meet the future demand from distributors and it is granted the

concession of new plants. The distributors must guarantee through the auctions the energy to meet the total consumption of its market in the RM. Thus, the amount of energy to be contracted is defined based on the projections of future demand of such distributors in their respective concession areas.

In addition, the electricity auctions seek to procure energy to ensure reasonable tariffs. This objective should be met since the auction winners are based on those suppliers that offer electricity at the lowest price per megawatt-hour (MWh), as the criterion used is the lowest rate. By setting the price of the supply contracts and the participation of energy sources used to generate energy, the auctions also influence the tariffs paid by the final consumers and the quality of the energy mix.

Accordingly, a greater understanding of its functioning and impacts is indispensable to coordinate a sustainable electricity sector. Furthermore, it is important to note that the resulting contracts from auctions are long term and may last between 15 and 30 years when it comes to new plants. Thus, it is clear that decisions taken within that framework will influence the sector for a significant period of time. For that reason, all influencing factors must be studied carefully.

Energy auctions take place on an annual basis and are subdivided into two main categories: the existing energy auctions and new energy auctions. Reserve energy auctions may also occur. The new energy auctions can be for the beginning of supply in three years (A-3), which, given the short time frame for implementation, thermoelectric plants tend to be more competitive, or five years (A-5), in which hydropower plants, a cheaper energy source[3] but with a higher implementation time, are supposed to be more competitive. Wind power has proved effective in auctions with both time frames. The new energy auctions can also be of a structural type, designed to procure energy from generation projects that have some type of priority in its implementation[4] or alternative sources, to promote the procurement of energy form wind power projects, biomass or small hydroelectric plants.

Existing energy auctions, on the other hand, are performed each year in order to contract energy derived from plants already built and for delivery of energy in the year following its realization, as contracts in force expire. These auctions also allow an adjustment of the contracts since conditions may change according to variations in the consumption of energy and costs, ensuring a greater contractual flexibility so that distributors can handle market risks. There are three types of existing energy auctions: in addition to alternative sources, there are also adjustment auctions, aimed at adapting the contracting of electricity by distributors, and A-1 auctions, for energy delivery one year after the purchase.

Finally, there are the reserve energy auctions, in which new plants that provide the BES a generation reserve capacity are procured. Reserve auctions were designed to mitigate the hydrological risk and incorporate bioelectricity in the Brazilian energy mix, increasing the safety of the system (Castro, 2008). This process takes place so that there is an increase in the security of supply of electricity. Figure 1 summarizes the types of auction.

[3] When compared to thermal plants in Brazil.

[4] Traditionally, large hydroelectric plants.

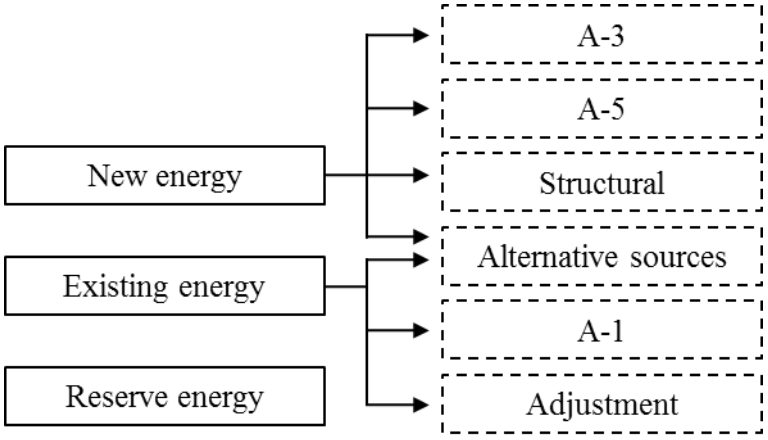


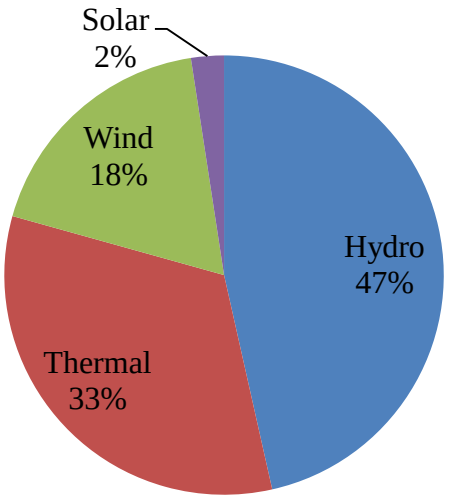
Figure 1 – Types of auctions for the procurement of energy in the Brazilian Electricity Sector.

Source: Prepared by the authors with data from the Ministry of Mines and Energy (MME).

Hence, it is evident that the new energy auctions are largely responsible for the expansion of the national installed capacity, since they promote the purchase of energy from new generation projects, implemented and operated by the auction winners. However, as the new energy auctions, the reserve auction also add new installed capacity to the BES.

Graphic 2 shows the share of each source in the total procurement of energy occurred through auctions[5], since the first one held in 2005. It is noted that the most procured source was hydroelectricity, followed by thermal plants. Wind farms were also great winners in the auctions, especially in recent years. The solar source, in turn, still has a very low insertion in the Brazilian energy mix.

Graphic 2 – Energy procurement in auctions that have added new installed capacity to the BES (2005-2015)



Source: Prepared by the authors with data from the *Empresa de Pesquisa Energética* (EPE) and *Câmara de Comercialização de Energia Elétrica* (CCEE).

[5] Only auctions that have added new installed capacity to the BES were considered.

It is noteworthy that, since the longer time frame for the beginning of supply of energy procured at an auction is five years and the lowest is three years, the national energy mix is now fully procured by the year 2018. Among the years 2018 and 2020, is partially procured, once the execution of an A-3 auction in the future may also lead to changes between these years.

Concluding, the success of the auctions is key to the balance between supply and power consumption and hence to reduce the deficit and rationing risks. It is through the new energy auctions that the government coordinates the expansion of generating capacity and are their winning sources that will make up the future electricity mix. For this reason, such auctions end up being one of the main instruments of planning in the BES. Therefore, an analysis of their effectiveness as such is relevant. Thus, in addition to projects already contracted via auctions, it is necessary to analyze what is contained in the planning of the BES.

3.2. The resumption of planning in the new model of the Brazilian Electricity Sector

Besides the change of the form of power procurement, another modification of utmost importance brought by the new BES's model was the return of centralized planning for the sector. That decision followed an arduous moment experienced by the country: the shortage crisis and the consequent rationing of electricity occurred in the 2001-2002 period. This situation demonstrated the indispensability of planning to ensure energy security in the country without compromising three central aspects: economic, social and environmental.

Thus, in 2004 it was authorized the creation of the *Empresa de Pesquisa Energética* (EPE), in order to conduct studies and researches to subsidize the energy sector planning, guiding the government and other agents in their decision making and establishing guidelines. The studies carried out by EPE cover various horizons, making projections of economic and energy scenarios to ensure the future supply in a safe and economically viable path for the whole society.

Among these studies, the PDE must be highlighted. PDE is elaborated on an annual basis and makes forecasts for the expansion of supply and demand for a period of 10 years ahead. For this purpose, scenarios of sustainable energy supply are elaborated through the analysis of macro-economic, environmental, social and technological variables. Such projections are essential for a sector where investments are capital intensive and have long-term maturity as aforesaid, that is, its guidelines must be established with responsibility and in advance. Accordingly, PDE is an important tool for planning the BES.

On the other hand, although the PDE indicates the future energy mix for the sector, its results are only indicative[6]. Indeed, despite EPE's recommendations, the winning bidders in the auctions are the sources that will make up the future mix. Thus, it is essential to evaluate whether EPE's propositions occur in reality or not, through a study of the mechanisms that put it into practice. In this scope, it is relevant to elaborate a comparative analysis between the projections of the PDE and the result of the electricity auctions which procured new capacity for the BES, since its first formulation.

4. COMPARATIVE RESULTS BETWEEN THE AUCTIONS AND THE PLANNING PROJECTIONS

As previously mentioned, the PDE considers a ten-year horizon for the composition of the future electric mix in the BES. Aiming for greater clarity in comparing the data from the studies and the results from the auctions, the sources analyzed were unified in four major groups: hydro, thermal, wind and solar. It is worth mentioning that solar just started being considered by the PDE (it first appeared in the 2014-2023 edition), thus, lacking values for the other periods.

The collected data refers to the evolution of the installed capacity by power source, in each of the seven plans analyzed[7]. Once these data was selected, it was attempted to find the increase planned by source for each of the

[6] Except for large hydropower plants.

[7] There are no data for the 2009-2018 period because PDE was not elaborated by EPE for that horizon.

years, as seen in Table 1. For example, the line for the PDE 2010-2019 for the hydroelectric source shows the increases projected by the plan that encompasses such ten-year horizon, for each of the years under consideration. That is, according to this plan, in 2011, 2,387 MW from hydroelectric plants would be entering the national energy mix.

The first factor that stands out with the analysis of Table 1 relates to the wide variation found between the plans. As an example, it can be investigated the planning of wind source for the year 2015; while the PDE 2007-2016 did not project any increase, the study for the years 2014-2023 planned an increase of 3,567 MW for that year. Such variations can also be found in other sources and for other periods.

On the one hand, it is understood that it is natural to have some differentiation between studies, possibly due to economic and environmental issues. However, so that the BES can benefit from an integrated long-term vision, it is essential to the planning to have a more uniform central direction. Moreover, it is important to compare the planned values of such increases to the BES with the actual results of the auctions. Evidently, the development of a planning with a ten-year horizon is not trivial. Therefore, it is expected that the forecasts for the coming years to be more realistic than those prepared with a higher timeslot. In this sense, the values highlighted in bold and underlined in Table 1 refer to the ones that were last planned to each year that was considered. For example, for the thermal source in 2013, the last projected value was an increase of 2,885 MW, that is, that amount should be close to the one that was actually procured through the auctions. Thus, Table 1 reflects this comparison. The "Auction" line refers to the amount that was actually procured for the beginning of supply to the energy mix in the year highlighted.

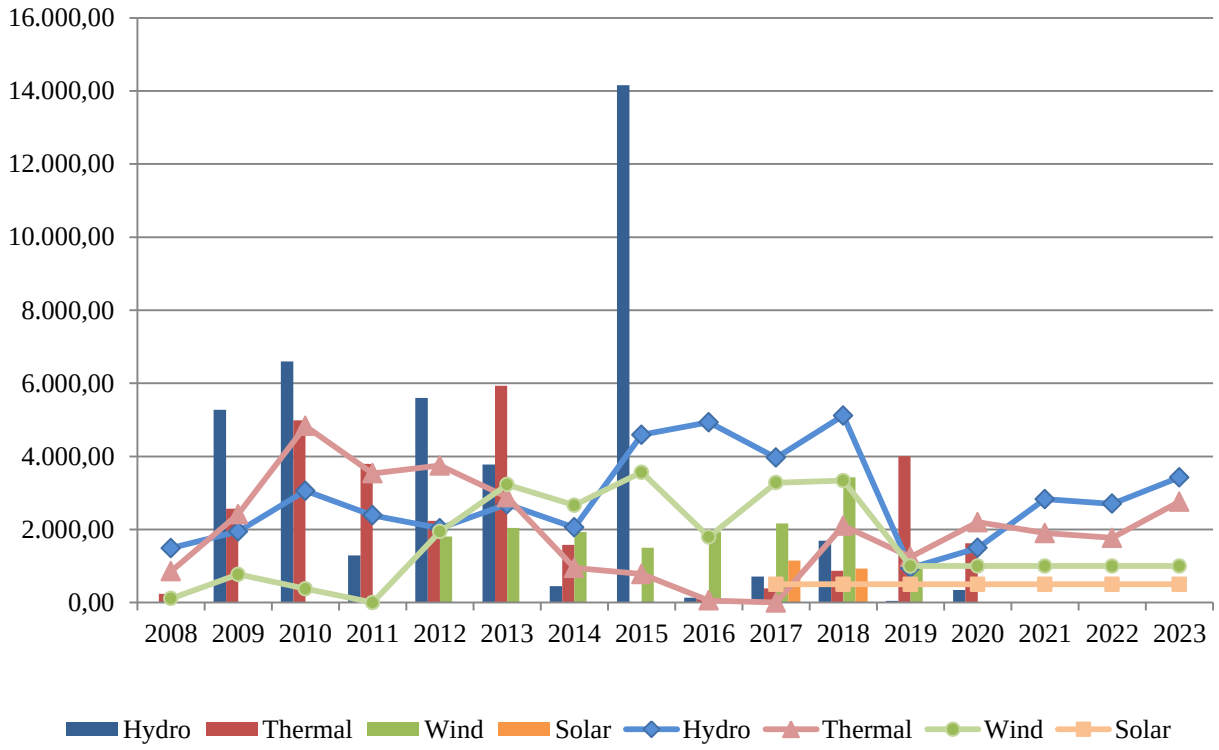
Table 1 – Increase to the installed capacity planned by the PDE *vs*. procurement in the auctions by source (MW).

	PDE	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Hydro	2007-2016	**1.489**	912	2.661	2.047	2.059	4.982	7.046	6.963	4.608							
	2008-2017		**1.944**	**3.058**	1.887	688	2.875	2.861	5.397	7.342	6.536						
	2010-2019				**2.387**	812	2.604	1.732	5.475	6.070	3.925	4.797	8.651				
	2011-2020					**2.034**	2.371	1.147	4.521	5.123	5.739	5.277	2.522	3.899			
	2012-2021						**2.690**	1.605	4.436	4.730	4.998	4.037	2.421	3.387	5.463		
	2013-2022							**2.053**	4.182	3.665	3.921	5.048	1.785	2.855	2.815	5.568	
	2014-2023								**4.590**	**4.934**	**3.966**	**5.118**	**947**	**1.494**	**2.832**	**2.705**	**3.428**
	Auction	0	5.275	6.599	1.293	5.601	3.782	450	14.162	135	710	1.692	44	346			
Thermal	2007-2016	**855**	1.283	1.542	3.099	2.971	1.530	1.550	200	500							
	2008-2017		**2.418**	**4.833**	2.694	776	5.216	1.350	900	0	0						
	2010-2019				**3.534**	1.684	5.092	399	1.755	200	150	350	400				
	2011-2020					**3.750**	5.152	372	300	1.705	350	330	370	460			
	2012-2021						**2.885**	4.296	50	1.455	100	750	950	900	1.850		
	2013-2022							**949**	93	0	100	2.652	1.060	1.210	1.380	700	
	2014-2023								**780**	**60**	**0**	**2.103**	**1.250**	**2.200**	**1.900**	**1.770**	**2.760**
	Auction	238	2.569	4.985	3.794	2.236	5.929	1.584	0	100	389	873	4.010	1.627			
Wind	2007-2016	**112**	0	0	0	0	0	0	0	0							
	2008-2017		**771**	**378**	0	0	0	0	0	0	0						
	2010-2019				**0**	1.805	400	400	400	400	400	400	400				
	2011-2020					**1.941**	2.048	900	850	760	900	850	1.000	1.000			
	2012-2021						**3.227**	1.943	949	1.283	500	1.150	1.650	1.430	1.450		
	2013-2022							**2.663**	2.536	1.683	1.283	1.000	1.000	1.000	1.200	1.200	
	2014-2023								**3.567**	**1.797**	**3.283**	**3.340**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**
	Auction	0	0	0	1.806	2.048	1.929	1.505	1.934	2.171	3.425	926	0	0			
Solar	2007-2016																
	2008-2017																
	2010-2019																
	2011-2020																
	2012-2021																
	2013-2022																
	2014-2023							**0**	**0**	**0**	**500**	**500**	**500**	**500**	**500**	**500**	**500**
	Auction	0	0	0	0	0	0	0	0	1.154	929	0	0	0			

Source: Prepared by the authors with data from EPE and CCEE.

In order to emphasize this comparison, Graphic 3 shows the data for the line highlighted in bold and underlined in Table 1 with the energy that was effectively procured in the auctions. As for the thermal source, the increase planned and the one procured are sometimes equivalent, but when it comes to hydro, such fact does not occur. In general, the data indicates a mismatch between the planning and its main tool: the procurement through auctions.

Graphic 3 – Last increase to the installed capacity planned for each year by the PDE *vs.* procurement in the auctions.



Source: Prepared by the authors with data from EPE and CCEE.

The aforementioned mismatch can be seen clearly in Graphic 3. As an example, the latest data available from the planning in the year 2009 on the PDE 2008-2017 foresaw an increase in the installed capacity from hydroelectric power of 1,944 MW. However, the energy procured by the auctions to begin supply in that year accounts for 5,275 MW, more than 2.7 times what was expected. Similarly, for the year 2015, the latest forecast was 4,590 MW to be added to the mix. Because of the procurement of energy from Belo Monte (11,233 MW) in a specific structural auction for that plant, the value was 209% higher, resulting in the procurement of 14,162 MW, with the supply beginning in 2015. Other similar occurrences can be noticed in Graphic 3.

Analyzing the dispersion between the planned and the procured in the auctions through the Mean Squared Error (MSE)[8], it is clear that the hydro source presented the greatest difference between both[9]. Excluding Belo Monte from the analysis, the MSE has fallen almost by half, however, it was still six times higher than that presented by thermal. In turn, wind power had an MSE 44.26% lower than that reported by thermal, while solar presented the lowest MSE, but it is worth noting that solar energy is only present in the sample from 2017 on.

[8] The MSE analysis allows a comparison of which source presented the greatest difference between what was planned by the PDE and what was procured at the auctions.

[9] Since for the years 2018 onwards it is still possible that new auctions that result in the procurement of new installed capacity occur and alter the data analyzed, it was considered to the MSE analysis only the period from 2008 to 2018.

Finally, it should be noted that from the year 2020 on, energy has not yet been procured, since, as mentioned above, the auction with the longer term is that of type A-5 for power supply five years after its execution. However, due to the ten-year planning of the sector, the forecasted data can already be observed, as seen in Graphic 3. Therefore, it is essential to continue this study in the future in order to analyze if the noted mismatch remains. Concluding, the indicative planning of the sector is not being observed in reality; auctions have obtained significantly different results when compared to the PDE.

5. CONCLUSION

First, it is important to note that a sector with as many specifics as the electricity sector requires significant caution in regard to its long-term sustainability. As mentioned, due to the unique characteristics of electricity, a well-structured planning is essential, and the BES has suffered from its absence. In this sense, this paper aimed to make an analysis of such planning and its effectiveness through the electricity procurement mechanism via auctions.

Among the main changes brought by the new model of the BES, certainly the resumption of planning stands out. Through the creation of EPE and its plans, such as the PDE, Brazil regained its long-term vision when it comes to the energy mix composition. However, what is observed in reality is an inconstancy of the elaborated projections, with many modifications in relation to their various annual editions. Although it is understandable that there can be differences between the studies, planning generally requires a better defined guideline.

Regarding the practical implementation of these plans, it was demonstrated that there is a mismatch between the two factors. Since the new energy auctions are usually generic and rarely have any directions concerning with are the energy sources that must be procured and its winners are defined by the criterion of the lowest price, what has ultimately been happening is that the definition of our future energy mix is being based only on the reasonable tariffs goal.

On the one hand, it is understood that price reductions to final consumers is essential to the competitiveness of the economy. However, it is essential that the sector moves towards a strategic energy mix, with diversified sources to mitigate risks and take full advantage of national potentials. The criterion of the lowest rate does not seem sufficient to achieve this goal; reasonable tariffs alone is not adequate to ensure the expansion of the system safely.

In conclusion, there is a lack of synergy between the main pillars of the BES. Auctions should have a better signaling as to which energy sources it will procure, and such information should be consistent with a well-structured sectorial planning. Moreover, future studies that seek to analyze in greater depth the economic pricing methodology of auctions in order to specify the necessary changes in it, can be of great relevance. Only with the use of accurate and appropriate mechanisms that we will, in fact, move towards a greater unity between planning and auctions: a strategic mix for the BES.

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