Long Term Impacts of RES-E Promotion in the Brazilian Power System

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***Abstract*— This paper analyzes the impact on market prices of the policies that have been adopted in Brazil to foster electricity from renewable energy sources (RES-E), namely wind power. In recent years the Brazilian Government implemented a series of policies that enabled a strong growth of RES-E. Recently more than 14 GW of wind and solar power were contracted. However, as most of the assets are concentrated in specific regions, these policies will induce price differences among areas of the country. In this scope, this paper describes a System Dynamics based model of the Brazilian generation system to evaluate the impact on prices from the deployment of these new sources. The paper describes simulations using realistic data for the Brazilian power system and the results suggest that the difference of prices in the country tend to increase since the Northeast region of the country concentrates most of the wind parks.**

***Index Terms*-- Brazilian power system, Electricity Markets, Generation Expansion Planning, Long-term analysis.**

I. INTRODUCTION

The Electricity Power Industry has been evolving quickly and passing through a revolution in the recent years. Some of the main drivers of this revolution are the unbundling of the electricity sector, the fast renewable energy deployment and the improvement on computer and communication technologies [1]. These factors are quickly reshaping the way power systems are regulated, operated and planned.

As power systems are evolving, the Generation Expansion Planning (GEP) and the methods to approach this problem have been also passing through changes. Shortly, we can say that the GEP has evolved from a cost optimization paradigm (in the scope of the vertical integrated utilities framework of the past) [2], through a multi-criteria and large scale problem (in which uncertainties regarding the fuel costs and environmental targets became important) [3], and finally to a market environment [4]. In this case, there are typically many agents and technologies under competition leading to higher levels of uncertainties [5]. Considering this new framework and the unbundling of traditional utilities in generation, transmission, distribution and retailing activities, Agent Based Models (ABM) and System Dynamics (SD) started to be applied to the power sector. Botterund [6] developed a SD toll to evaluate the competitiveness of natural gas power plants in the Norwegian power system and Vogstad [7] expanded that model to analyze the entire Nord Pool. On the other hand, Pereira and Saraiva [8] evaluated the long term impacts of increasing wind power generation in the Iberian electricity day-ahead market price. The use of ABM based models also increased a lot in the energy sector. For instance, Wittmann [9] proposed the use of ABM tools to support investment decisions, and Calabria [10] developed an ABM model to support the proposition of a novel regulatory framework for Brazilian Electricity Market.

Rahmandad and Sterman [11] compared ABM based approaches with models based on differential equations concluding that both could provide similar mean results. At this point it is worth mentioning that given its stochastic nature, ABM generates results as a distribution of outcomes. However, they highlighted that "AB models will be useful when data or the underlying "physics" of a situation specify the network structure, suggest it is critical in the results, and that structure is stable over the time horizon of interest. Often, though, data … and the distribution of individual attributes are hard to obtain and highly uncertain, requiring extensive sensitivity analysis to ensure robust results."

Despite the conception of sophisticated planning tools, the evolution of the electricity sector is most of the times a result of the implemented policies. It is common though that the outcomes from the policies are excessive/unexpected and this is true for different power systems around the world as mentioned in [12], [13]. These issues are a result of the lack of Systems Thinking together with the difficulty in understanding the diverse feedback mechanisms that are intrinsic to complex and dynamic structures as power systems.

According to these ideas and recognizing that current models are often affected by this type of problems, this paper describes a System Dynamics based tool developed to perform expansion planning studies. In this case, this tool was used to analyze the impacts of the new wind power plants in the prices of the Brazilian electricity markets in the medium and in the long run. After this Introduction, Section II, overviews the Brazilian Power System and the main issues that it has been facing in recent years. Section III provides details on the main blocks of the developed SD based tool. Section IV presents some of the results obtained so far with this research and Section V draws the main conclusions and mentions some of the research directions to follow in the near future.

II. BRAZILIAN POWER SYSTEM

It is a well-known fact that the Brazilian Power System is largely dominated by hydro generation, and that most of these hydro stations integrate long cascades that, in several cases, are owned by different generation companies. In this context, the ISO is responsible for operating and dispatching the power plants, in order to guarantee the security of supply in the short and in the long term. After the crisis of 2001, in which the lack of planning and investments in the sector combined with a large drought led to an energy rationing in the country, a complete reform of the sector was put in place.

A. Electricity market and price formulation

Barroso et al. [14] explain in a very concise way the main features of the Brazilian power system after the sector was reorganized in 2004. Mandatory, ex-ante and physically backed contracts are required for all consumers. This means that free consumers cannot be uncontracted and take part on short-term settlement market for their energy consumption, otherwise they are penalized. This mechanism guarantees the security of supply and long term contracts for producers at the same time that avoids that free consumers are able to 'freeride' in moments of cheap electricity in the short-term settlement market. It is also important to mention that in Brazil domestic consumers must purchase power from distribution companies under a regulated scheme.

The prices in the short-term market are defined according to a cascade of computational programs, NEWAVE and DECOMP. The logic of the operation of these software tools is based on the trade-off of using or saving water resources [15] which also means that the prices are not the result of the relationship between demand and supply as in the market mechanisms in operation in many countries.

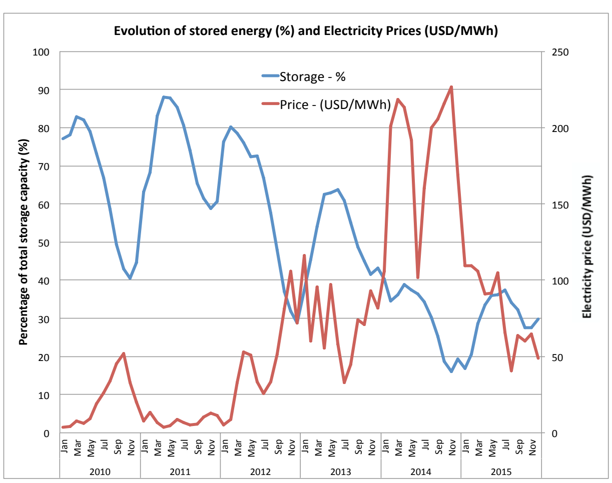

Figure 1. Evolution of energy storage in the reservoirs of the country and the electricity prices in the short term market in recent years. Sources: CCEE, www.ccee.org.br and ONS, www.ons.org.br, accessed 07/05/2016.

However, in recent years, the share of hydro generation started to decrease, namely because of a sequence of dry years from 2012 to 2015. During these years, the hydro reservoirs got drained out and the electricity prices on the short term clearing market peaked as shown in Figure 1.

B. Generation Expansion

In Brazil, expansion planning is performed in a centralized way by EPE, Energy Research Company. Since the new legal framework established in 2004, this entity was created and became responsible for the research and provision of projections for the expansion of the generation system in the whole country through two different plans: Ten Year Energy Plan (PDE) and the National Energy Plan (PNE) [16] [17].

PDE and PNE provide an indicative evolution of the power system. However, in practice generation expansion is promoted trough public auctions. The tenders are carried out to supply the demand in the regulated market. Every year the Brazilian regulatory agency, ANEEL, requires that distribution companies measure up and forecast the demand for the next years, indicating the amount of energy that should be purchased. The aggregated amount of 'new' energy demanded by all distribution companies will be then contracted in a centralized auction performed jointly by ANEEL and by the Electricity Trade Chamber. In this scope, Calabria [10] provides a review on the Brazilian electricity market design and the model of contracting new power plants.

In recent years though, the government adopted a more active role in the sector in order to foster RES-E, namely wind and solar PV. The policies that were implemented ranged from feed in tariffs in the scope of the PROINFA program, till tax exemption and also auctions exclusively opened for renewable sources [13]. As a result of these policies, the country was able to obtain a fast paced growth of these intermittent sources in contrast to what has been planned previously. Table I provides a comparison of the installed capacity for several sources in terms of what was estimated in the PDE 2016 and what was really observed by the end of 2015.

TABLE I. COMPARISON OF THE INSTALLED CAPACITY (IN GW) IN BRAZIL BY 2015, DATA FROM PDE 2016 AND ANEEL.

Type	PDE	Reality	Difference
Large hydro's	104.6	93.3	-11.3
Small hydro's	5.7	5.1	-0.6
Nuclear	3.3	2.0	-1.3
Biomass	3.9	13.8	+9.9
Wind	0.3	9.5	+9.2
Natural Gas	13.8	13.0	-0.8
Coal	3.5	3.6	+0.1
Fuel Oil	1.8	4.0	+2.2
Diesel	1.9	4.7	+2.8

C. Conclusion

Summing up, the Brazilian power system went through a restructuring process in the recent years. After the crisis in 2001, expansion planning activities were centralized and large investments were directed towards a renewable and more diversified electricity matrix. However, differently from the plans developed before, wind power and biomass were responsible for a major part of the expansion. Thus after a sequence of dry years, which almost originated the system's collapse, it is worth to evaluate the policies that were applied and their effects in the prices on the medium and long run.

III. The Brazilian Power System SD Model

The developed System Dynamics model structures the Brazilian power sector in two subsystems. The first one is termed as "NONE" and it corresponds to the North and Northeastern power subsystem and the second was termed as "SECOS" and represents the Southeast/Center-West and South subsystems. This organization is used because it reflects some of the features of the Brazilian system regarding generation technologies and their geographic location together with the most frequent electricity interchange patterns. The main characteristics of these two subsystems are stated below:

- NONE - this subsystem has an average load of 14.7 GW over the year. Additionally, the average natural energy flow to its hydropower plants is of 15.5 GW and the total installed thermal power capacity is of 9 GW. The operation cost of the thermal plants range from 19.43 USD/MWh to 280.31 USD/MWh;
- SECOS - this subsystem has an average load of 47 GW over the year. The average natural energy flowing to its water basins is of 43.8 GW and the total thermal capacity is of 14.8 GW, with thermal power plants operation costs ranging from 5.56 USD/MWh to 330.45 USD/MWh[1].

Figure 2 shows a screen-shot of part of the developed SD model to represent the Brazilian System. Each of the two subsystems, NONE and SECOS, are composed by a generation module, a consumption (demand), a price module and a transmission section, in which the price is defined through calculations and data inputs from both the generation and consumption models. Additionally, the SD model also considers the energy transmission limit between both regions.

The general functioning of the developed model is explained as follows. For each time step, a demand level is established in each subsystem. This demand is calculated considering a price/demand elasticity and a stochastic evolution. From the demand and a specified percentage to internalize grid losses, it is defined the total generation that must be scheduled in each subsystem. Considering the difference of prices between the two subsystems it is then defined the amount of electricity that should be exchanged between them also taking into account the transmission limit. The energy shall flow from the region having a lower energy price to the one with higher price in order to balance the prices in the country if transmission capacity is enough. After setting the amount of energy transfer between the two subsystems, the power that each subsystem generates is recalculated and the dispatch is updated. In this process, wind generation has priority meaning that all available wind energy is accepted in the system. All thermal power plants that have operation costs lower than the price at that time step will be dispatched, and the hydro units operate as slack resource and are responsible for fulfilling the difference between the demand and the wind plus the dispatched thermal units. Using the difference between the amount of water (energy) that inflows to the system and the quantity that must be used in the electricity dispatch and taking into consideration the total amount of energy available in the reservoirs, the electricity price is updated in each iteration. This means that if the difference between the inflow renewable energy resource (water) and the needed hydroelectricity to be dispatched is negative, then the price tends to increase. If that occurs, it will be induced a larger thermal power utilization and in the long term foster new generation investments.

Ref. [15] provides a deeper explanation regarding the detailed formulation used in the model. The only differences observed from the model used in previous studies and the one used now is in the introduction of a spillage mechanism in the Hydropower module and the introduction of a new item/factor in the price formulation to improve the use of hydro resources, avoiding the occurrence of spillage. Therefore the equation used to obtain the Reservoir levels, Res_t , is now dependent on the spillage, Sp_t, on the energy flowing in the rivers, ENA_t, and the dispatched hydropower, $P_{Hy,t}$. Spillage occurs when the Reservoirs, reach their full capacity, $\mathrm{Res}_{\mathrm{Max}}$.

$$Res_t = \int (ENA_t - P_{Hy,t} - Sp_t).\,dt \tag{1}$$

$$\mathrm{Sp_t} = \max\,(0;\ \mathrm{Res}_t - \mathrm{Res_{Max}}) \tag{2}$$

Regarding the price formulation, a new factor was inserted multiplying the Thermal Power Term, $P_{th,t}$, in equation (10) explained in [15]. After introducing the spillage, it was observed that the power system has spillage in periods of higher electricity prices. During these periods, because of the large Thermal Power dispatch induced by the energy prices, Hydropower was lost even when available. Thus the new formulation for the price variation index, $\Delta\pi_t$, was developed considering the balance of Hydropower dispatched, $\mathrm{P_{Hy,t}}$, and the energy flowing in the rivers, $\mathrm{ENA_t}$, together with the thermal power, $P_{th,t}$, multiplied by a coefficient that reduces the impact of thermal power on electricity prices when the reservoirs levels approach theirs maximum values as follows:

$$\Delta\pi_t = \pi_t * \left[\frac{\mathrm{P_{Hy,t}} - \mathrm{ENA_t} + \left(\mathrm{P_{th,t}} * (1 - (\mathrm{Res}_t/\mathrm{Res_{Max}}))\right)}{\mathrm{Res}_t}\right] \tag{3}$$

IV. Results and Discussion

The SD model described above was implemented in the Powersim Studio software [18] and the simulations were performed for a horizon of 10 years with time-steps of 1 week.

[1] Data from ANEEL - Agência Nacional de Energia Elétrica. Generation Information Bank, BIG, available in www.aneel.gov.br, accessed in 12/09/16. Also from ONS, IPMO – Monthly Information Operation Program: Janeiro, available in www.ons.org.br, accessed in 07/05/2016. Also from ONS, Operation Data/ Inflow natural energy, available in www.ons.org.br, accessed in 07/05/2016. The electricity prices displayed were obtained considering the exchange rate of R$3.55 for 1.00USD.

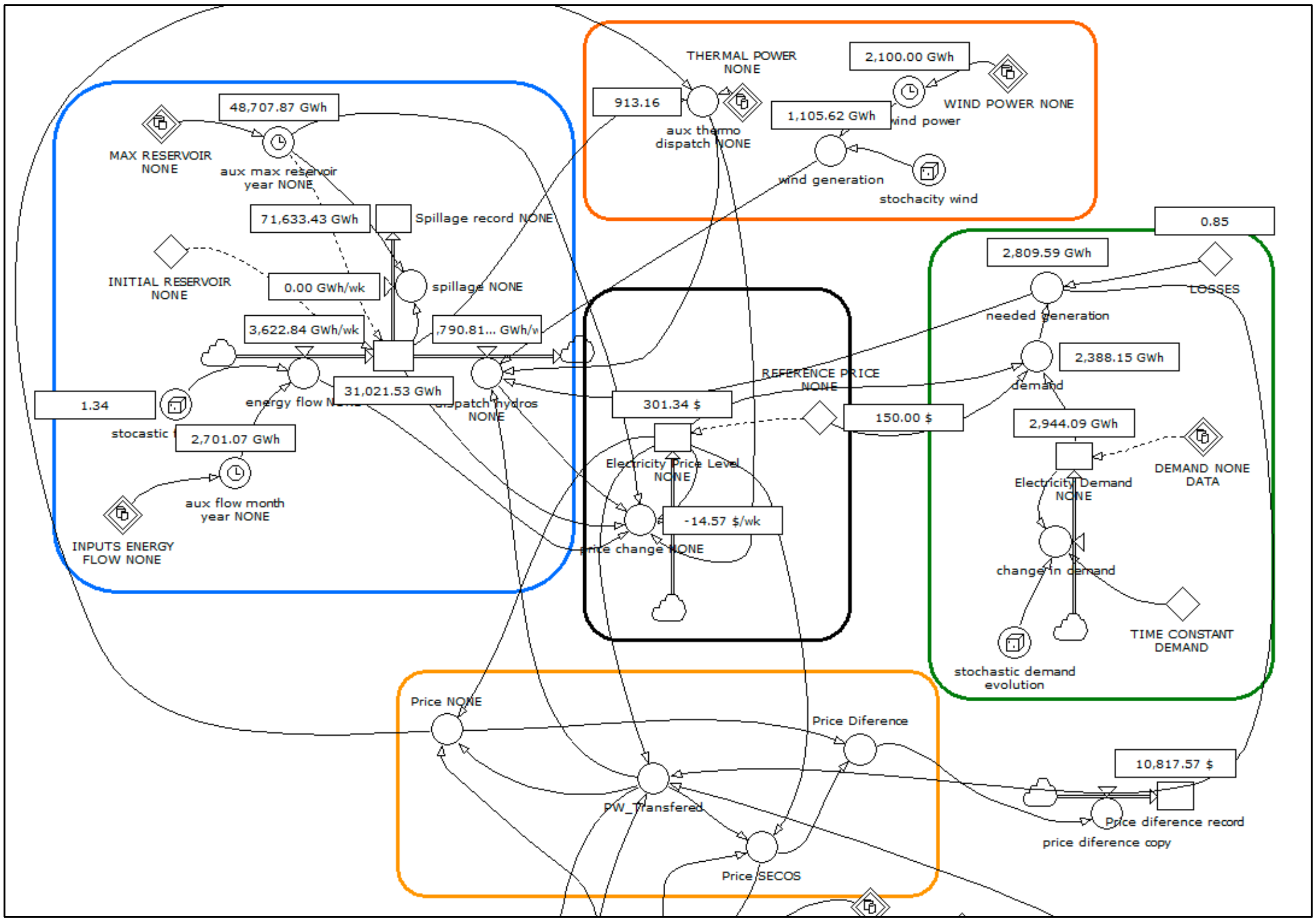

Figure 2. Screen shot of part of the developed SD. In blue, we highlight the Hydro Power module, in red we have the Wind and Thermal power systems, in green the electricity demand, in black the price module and in orange the Transmission module.

The results obtained indicate that the model is able to adequately reflect some of the real operation conditions of the Brazilian system. Figures 3 and 4 displays two graphs obtained from the Powersim Studio software with the energy in GWh transferred between the two subsystems (in the figures positive values indicate transfers from the SECOS to the NONE). In Figure 3 we are simulating the Power System with the presence of the wind power assets in the NONE region while for Figure 4 the simulations were performed without these assets. It can be observed that transmission limits are reached mostly when the power is transferred from the NONE to the SECOS region and mainly in periods of large inflows to the water basins of the NONE and also when wind parks located in the NONE have larger outputs.

It is also possible to notice that in the presence of the wind power plants in the northeast subsystem, the NONE region becomes a great exporter of electricity and that in the absence of these units a better balance in the exchanges of electricity is verified. In the first case, power was transferred from NONE to SECOS region during 81% of the time, being the energy transferred from NONE to SECOS of 338 TWh while in the opposite direction the transmitted energy is reduced to 32 TWh. In the second case, the transmission occurred from NONE to SECOS for 66% of the time, as the transmitted energy from NONE to SECOS remained around 2.75 times the energy transferred from SECOS to NONE subsystems.

These large differences in the transmitted electricity between the regions will then influence the difference of prices over the simulation period as detailed below.

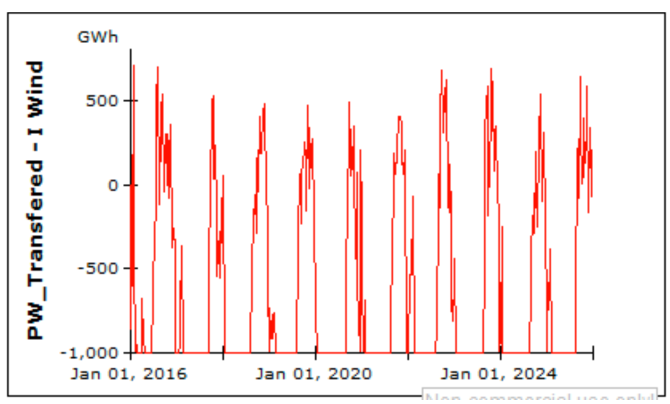

Figure 3. Transferred energy (GWh) between SECOS and NONE subsystems in the presence of the new wind assets at NONE Region.

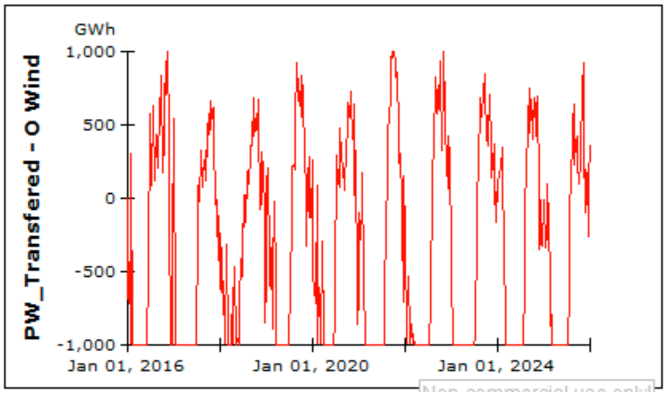

Figure 4. Transferred energy (GWh) between SECOS and NONE subsystems, without the presence of the new wind assets at NONE Region.

Figures 5 and 6 display the difference of prices between the two subsystems when large assets of wind power in NONE are operating (Figure 5) and when these units are not considered (Figure 6). As it can be observed and expected from the previous results, the presence of the wind parks in the NONE is contributing to further increase the differences of prices between the two regions. These figures display the difference of price of the SECOS region regarding the prices on NONE, which means that positive values indicate that the prices in the SECOS are higher. The simulation shows that the prices in SECOS can be as large as 3 times the prices in NONE in the case of the presence of wind parks.

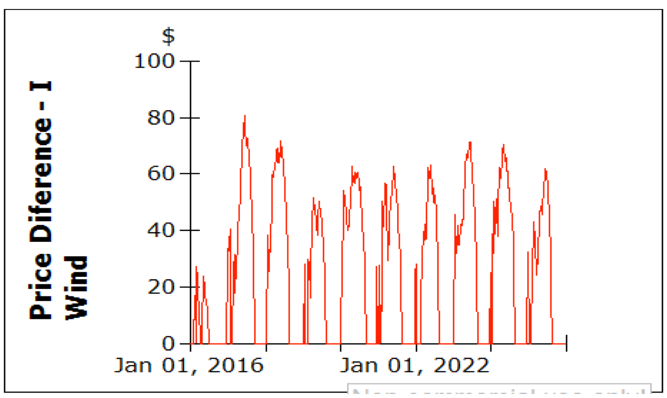

Figure 5. Evolution over time of the difference of electricity prices between SECOS and NONE subsystems in USD/MWh, with wind assets.

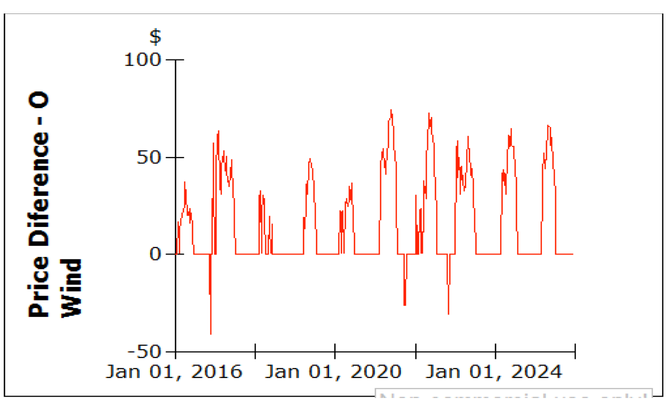

Figure 6. Evolution over time of the difference of electricity prices between SECOS and NONE subsystems in USD/MWh, without wind assets.

However, although the price differences increase as a result of the presence of wind parks in the NONE, it is very important to highlight at this point that the presence of wind parks contributes to lower the energy prices over the simulation period as they represent more availability of renewable energy in the integrated system. In fact, Table II displays the results of the simulations for the yearly average energy prices with the presence and without the wind units in the NONE for the two subsystems. As it can be observed the electricity prices in the NONE subsystem are consistently lower than the ones in SECOS, what justifies the energy flows. These facts stress the need of reinforcing transmission lines between the SECO and the NONE in order to further increase the global benefit from the operation of wind parks. Additionally, they indicate that a better planning regarding the geographic location of the new assets could result in more balanced prices over the country. Finally, these results also indicate that although the price differences increase as a result of the wind parks connected in the NONE, both subsystems benefit from their presence because the electricity prices decline in both cases when compared with the ones that would exist in each system without considering these wind parks.

TABLE II - AVERAGE ELECTRICITY PRICES OVER THE YEARS PER SUBSYSTEM IN BOTH CASES WITH AND WITHOUT WIND ASSETS (PRICES IN USD/MWH).

Year	NONE		SECOS	
	With Wind	Without	With Wind	Without
2017	$57,40	$49,47	$59,38	$52,28
2018	$64,40	$49,63	$67,65	$52,96
2019	$63,88	$54,81	$65,09	$60,90
2020	$66,15	$51,66	$65,22	$58,45
2021	$69,49	$65,32	$67,84	$69,25
2022	$70,89	$61,80	$75,49	$68,82
2023	$70,13	$54,49	$71,32	$64,44
2024	$77,12	$66,99	$78,57	$73,71
2025	$81,67	$64,42	$73,50	$72,31

V. CONCLUSIONS AND FINAL COMMENTS

This paper reports the development of a Systems Dynamic tool focusing on the Brazilian generation system and also reflecting its organization in different subsystems having transmission constraints between them. This model has proven to be a valuable tool to provide different kinds of long term analysis in Brazilian power sector. Thanks to its flexibility, it is possible to analyze on the long term the behavior of the generation system under different perspectives, to construct, simulate and analyze different evolution scenarios namely in view of different policies adopted by the government to induce investment in some particular technologies.

In this study we accessed the long term influence of the policies that enabled a fast paced growth in the wind power installations, more specifically located in the Northeastern region of the country. The reasons for this localized boom are related with the wind power potential, the federal policies that promoted exclusive renewable energy auctions, along with tax exemptions and other incentives adopted by state governments. These factors supported the installation of more than 14 GW of wind power in the region and as a result an important part of the generation expansion contracted in recent years was done using this renewable primary source.

As observed in the simulations, the large concentration of the new wind power units is increasing the difference of electricity prices between the electricity submarkets in the country. Moreover, transmission limits have been reached frequently. Nevertheless, this study also indicates that there is a systemic benefit in terms of the reduction of electricity prices along the country and that these new generation assets are in fact needed. Therefore, this study corroborates the conclusion reported by other studies regarding the need to construct new transmission assets to enable a better integration of the country and also the need of tenders in specific regions of the country as stated in [19]. The results observed so far show that the formulation is being succeeded since we have been able to access quantitatively the impacts of the policies implemented to foster RES-E and wind power in particular.

Several developments are still being implemented so that the model can better reflect the reality and consequently the conclusions to be obtained become more assertive. The model is being expanded so that it includes the 4 submarkets that in fact exist in Brazil. A generation expansion module is also being deployed, so that the dynamics of prices influencing the construction of more generation assets as the horizon develops can be accessed. Finally, the deployment of other distributed generation technologies will also be considered in the future as part as an integrated response to Climate Change concerns.

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Biographies

Mário D. P. Coelho was born in Pirapora, Brazil in 1988. In 2011 he received his diploma as Electrical Engineer from UFMG. After working for 5 years with the deployment of Distributed Generation projects in Brazil, he joined the Executive Master in Sustainable Energy Systems in the framework of the MIT Portugal Program at FEUP, where he is pursuing the PhD degree.

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J. T. Saraiva (M’00) was born in Porto, Portugal in 1962. In 1987, 1993 and 2002 he got his MSc, PhD, and Agregado degrees from FEUP, where he is currently Professor. In 1985 he joined INESC Porto where he is head researcher and worked in projects in the scope of consultancy contracts with the Portuguese Electricity Regulatory Agency and generation, transmission and distribution companies.