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EFFECTS OF THE PENETRATION OF WIND POWER IN THE BRAZILIAN ELECTRICITY MARKET♣

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ABSTRACT

Climate variability has been the main driver for renewables in the Brazilian electricity market. This article analyzes the vulnerabilities of the dependence on hydropower in renewable energy production due to climate variation, as well as wind power penetration in Brazil, given a set of wind industry policies. Despite Brazilian renewable energy increase, the study shows the impact in energy supply in north region, due to the lack of transmission infrastructure. In Brazil, the potential trade-offs between renewables growth, and transmission infrastructure inconsistencies in terms of policy implementation are not yet well analyzed. Simulation results show the potential conflicts between energy policies aimed at increasing the wind power supply and boundaries in transmission infrastructure.

Keywords: Transmission lines, renewable energy, wind power, Brazil, simulation.

INTRODUCTION

The energy sector plays a principal role in Brazilian economic growth. According to ANEEL (2016) Brazil produced about 61% of their total generation capacity through hydro energy in 2016, with 1,215 hydropower plants. In contrast, wind energy only produced about 6% of the generated energy capacity. Brazil is the largest renewable-energy-developing country in Latin America. With rapid industrialization and urbanization, Brazil has maintained extensive growth in both industrial development and energy consumption. Brazil and South Korea are emerging as producers of wind technology, evidenced by their increased numbers of wind power manufacturers (Foley *et al.*, 2015).

The main energy sources used in Brazil are hydropower, fossil fuels, biomass and wind. Wind- and fossil-power have a great potential. Throughout Brazilian history, renewable energy penetration has been thought of as a key factor in their competitiveness. Therefore, the expansion of renewable energies will contribute to economic growth (Pao and Fu 2013) total renewable energy consumption (TREC . However, wind and solar energies show drawbacks because of its intermittences. The current climate change effects have also

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affected the Brazilian electricity sector in terms of a strategic planning. Policymakers in Brazil are not considering the constraints of climate change and supply chain design regarding the generation and transmission of renewable energy in addressing energy security.

The effects of climate variability have led to decreases in the availability of hydropower and increases in the participation of wind power in the electricity generation mix. Also technological development as well as government incentives through tax and regulatory aspects have led to a increase wind-power (Corrêa Da Silva *et al*., 2016). In this sense, lack of transmission infrastructure and intermittent generation are the main problems for the developing of wind energy.

Though renewable energy policies show improvements in sustainability in Brazil, the problems with renewable electricity distribution affect low-income areas. In the case of Brazil, Arango *et al.* (2006) draw attention to the supply problem as the major cause of high prices during the 2001 energy crisis. Brazil is facing energy problems that are similar to China problems, which compromise the expansion of transmission systems and energy supply chain planning. A solution to this issue involves new auction systems for transmission (Foley *et al*., 2015). The objective of this work is to understand the energy generation in north Brazil by analyzing the achievable potential of wind power generation as well as lack of transmission infrastructure.

A cause-loop analysis was conducted, which was followed by the construction of a simulation model to understand renewable energy policies' efficacy for Brazil. In this article shows of simulation 20 years to assess the long-term role of Brazilian existing energy policies.

Brazil electricity generation is predominantly based on hydropower (De Melo *et al*., 2016). Figure 1 shows the behavior of hydropower energy generation in Brazilian north during 2012 to 2015. In the year 2015, the electricity generation decreased between January and April in comparison with 2014. This decrease is due to low useful volume of hydropower reserve. In this sense, the climate variation has led to a decrease in the useful volume of hydropower reserves that involve an impact on Brazilian energy mix. De Lucena *et al*. (2009) provided an analysis of climate change impacts on hydropower generation and mentioned the special situation of the vulnerability of renewable energy in Brazil. In contrast, Pereira *et al.* (2011) proposed strategies to promote renewable energy but did not consider the climate variation that affect hydropower energy generation growth. Hence, these problems affect to the sustainability of the Brazilian energy market, as well as the expansion of power generation and transmission (Arango *et al.*, 2006).

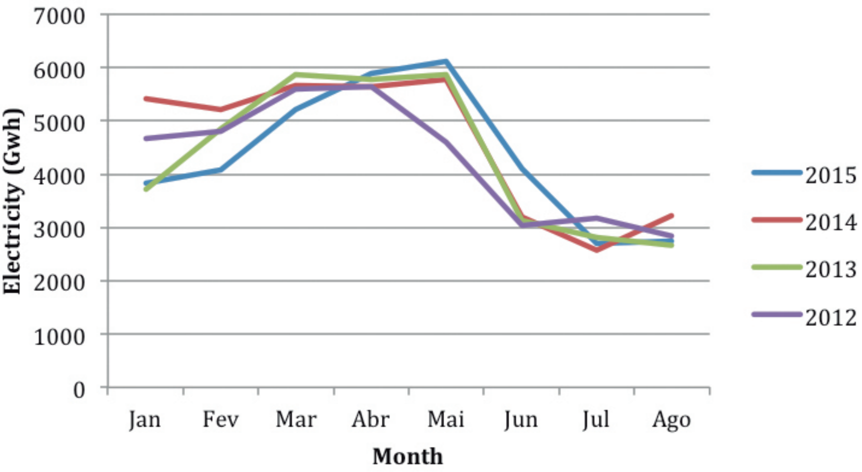

Figure 1. Hydropower energy generation in Brazilian north between 2012 and 2015
Source: Elaboration based on data from ANEEL (2016)

The implementation of the Brazilian Incentive Programmed for Alternative Sources of Electrical Energy (PROINFA) favored an increase in wind-power installations (Corrêa Da Silva *et al.,* 2016). Figure 2 presents the behavior of wind power generation in Brazilian north. Thus, during the 2012-2015 period, the increase in wind power generation can be associated with investment incentives policies. Numerous studies examined the perspectives regarding the expansion of renewable energy sources in Brazil. Pereira *et al*. (2012) and Tiba *et al.* (2010) specifically reported on Brazilian energy planning in their research. These studies proposed a planning tool for energy systems and current status analysis. However, the studies failed to consider the transmission infrastructure problem. This view is supported by WWF-Brazil (2015), which supported the importance of transmission infrastructure in wind power growth.

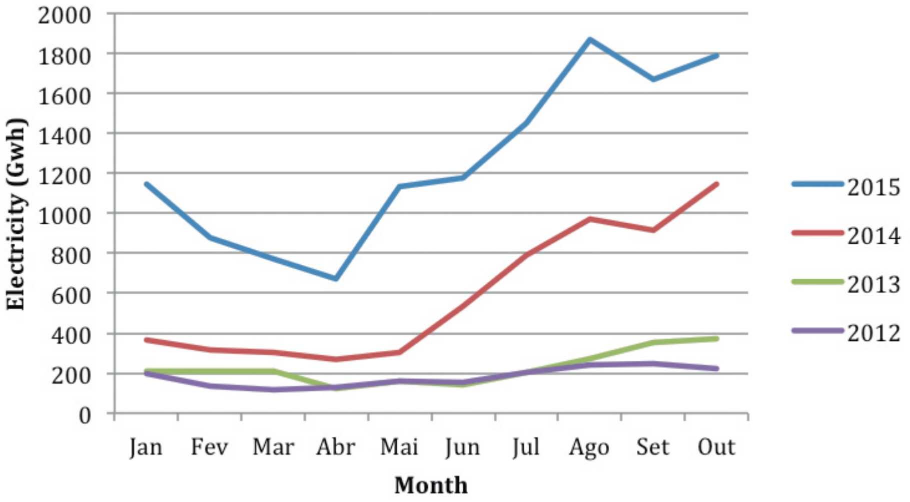

Figure 2. Wind power generation in Brazilian north between 2012 and 2015, Source: Elaboration based on data from ANEEL (2016)

The climate-policy modeling was studied by Bahn *et al*.(2011), Ioakimidis *et al*. (2012), Strachan (2011) and Karplus *et al*. (2016). They used deterministic and econometric models to analyze greenhouse gas reduction policies. Further, several authors applied general equilibrium modeling and agent-based modeling in their analysis of climate policies (Abrell and Rausch, 2016; Cabalu *et al*., 2015; Ioakimidis *et al*., 2012; Bale *et al*., 2015; Troost *et al*., 2015). However, complex issues require new modeling methods to understand the dynamics of an energy system (Qudrat-Ullah, 2015). The energy system is characterized by complex causality generated by relationships among stakeholders and its business processes. In this sense, the simulation is a suitable methodology that allows better understanding the relationships in energy system of Brazil. System dynamics modeling has been used for more than 30 years to better understand electricity markets (Aslani *et al*., 2014; Qudrat-Ullah, 2014). Preliminary work on electricity markets in South America was undertaken by Arango *et al*. (2006), Haselip *et al*. (2005), Larsen *et al*. (2004), Ochoa and van Ackere (2014), Ponzo *et al*. (2011), Zuluaga and Dyner (2007), Arango *et al*. (2006) discuss lessons of the evolution of deregulation systems for four countries in South America. A main conclusion of this study proposes the regional integration among neighboring countries for improvement the Latin American electricity market. In a similar vein, Ochoa and van Ackere (2014) explored the potential benefits of integration in terms of interconnector capacity among countries. They showed that electricity market integration bring benefits in terms of lower supply cost and use of resources. This condition is given through of market coupling mechanisms that allows levels of coordination among stakeholders.

Regarding the integration of wind power into the transmission grid, de Jong *et al*. (2016) present an analysis with regard to the feasibility of integrating large scale wind power in the Northeast of Brazil. In the case of wind farms, the increasing penetration of distributed generation was the central issue Pereira *et al*. (2013) study, in which the authors discussed the effects of new Iberian electricity market reform on the price of electricity. Hasani and Hosseini (2011) proposed a simulation model for long-term capacity investment decisions in a liberalized electricity market. This study suggests that electricity-market renewables policies are needed.

METHODOLOGY

Dynamics Hypothesis

The Energy Expansion Plan 2030 aims to ensure the balanced expansion of energy supply based on several growth scenarios (Ministerio de Minas e Energia 2007). Despite renewable energy growth, Brazil has an electricity dispatch problem as well as also the climate variation that affect to renewable energy production. To assess Brazilian electricity market, this study used the dynamics hypothesis. Dynamics hypothesis is formal structures of system that allows better understand the behavior and relations among the variables (Sterman, 2000; Herrera and Orjuela Castro, 2014). Figure 3 shows the dynamics hypothesis that describes the behavior of renewable energy penetration and dispatch problems.

The negative feedback loop (B1) shows the reserve margin, which depends on the difference between electricity demand and installed capacity. Therefore, the reserve margin affects electricity price, and this influences electricity demand. The response of price to electricity demand involves long delays. The next negative feedback loops (B2 and B3) describe electricity price effect on investment incentives and capacity for generation (hydro and wind), which in the mid-term influences the reserve margin.

Negative feedback loop B2 shows climate variation effect on the capacity for hydropower generation, and B3 shows the supply chain development effect on the capacity for wind power generation. As installed capacity increases due to investments in renewables, the need for electricity transmission increases and leads to major infrastructure necessities: the reinforcing loop, R1, limits the effectiveness of renewable energy penetration due the transmission infrastructure need.

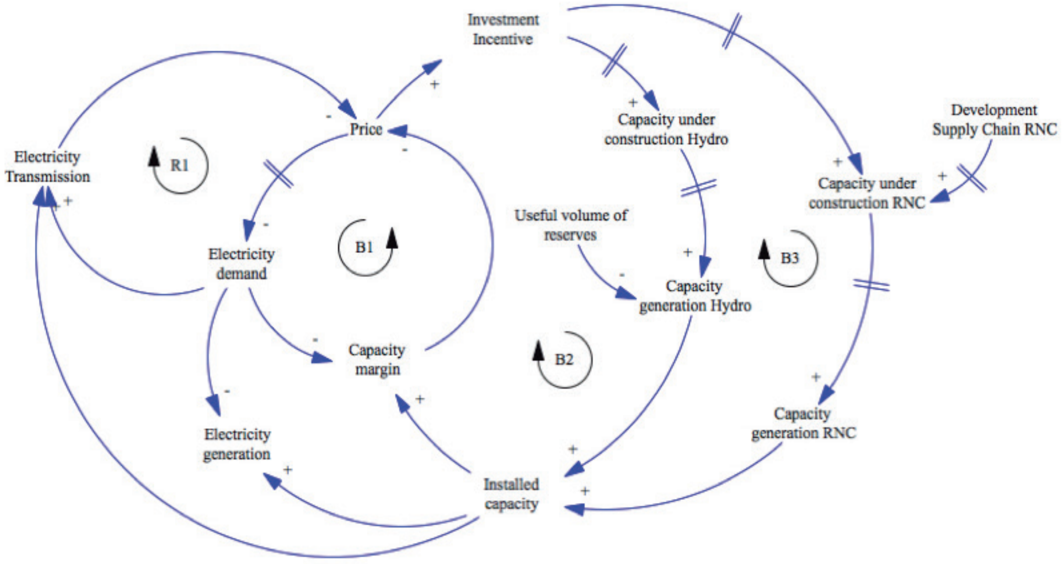

Figure 3. Dynamics hypothesis of Brazilian electricity market

The lack of transmission infrastructure may be critical to both energy suppliers and the government. The electricity dispatch problem may cause a delay in transitioning to renewable energy sources. In this sense, an analysis of wind power expansion in Brazil is needed for better understand the climate effects and installed capacity of the transmission lines in isolated regions.

SIMULATION RESULTS

The system dynamics modeling approach was chosen because it allows us to analyze complex problems with a focus on policy analysis and design. The time horizon of the simulation model ranged between 2016 and 2050 to capture the transition to renewables and the effects of climate variation in Brazil. The purpose of the model was to evaluate Brazilian energy policies according to the following aspects: their impact on the development of renewables and their impacts on the electricity dispatch. The time horizon of the simulation model allows understanding of the transition to renewables, the behavior of electricity dispatch and climate change effects for Brazil.

Validation model

To validate the accuracy of the proposed model, the results were compared to real outputs and forecasting from the years 2005 to 2019 in terms of the installed energy capacities of wind and hydropower and Brazilian electricity demand. The standard test proposed by Sterman (2000) were used to validate the model. Reviewing the variables with mean-absolute-percent-error (MAPE) is below 2,7%, R2 equals 0,92, which presented a small bias, and the residuals do not show a significant trend. The results obtained from the validation analysis are shown in Figure 4. Therefore, the validation reproduces the observed structural characteristics of system as well as captures the observed historical behavior.

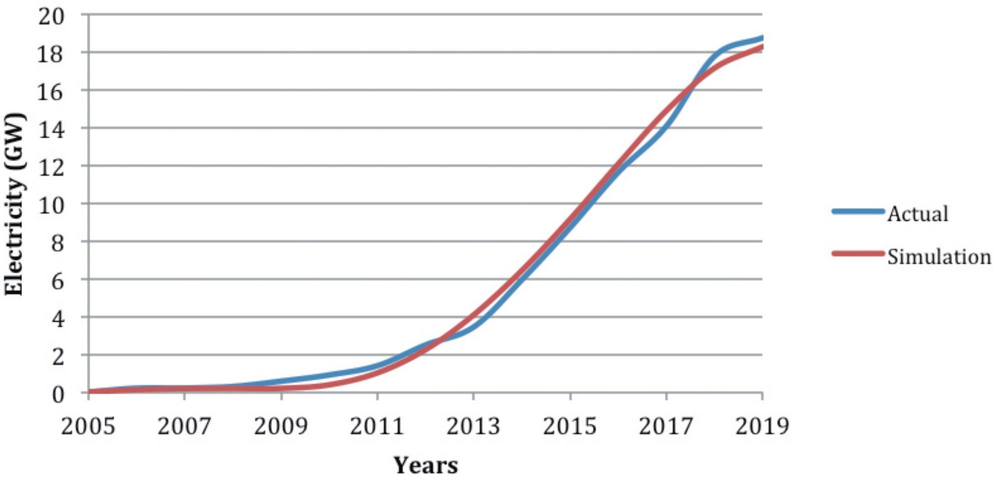

Figure 4. Validation process and calibration of total installed capacity

Impacts of climate variation on installed capacity hydropower

Though hydroelectricity has great potential of renewable energy generation for the Brazilian energy matrix, there are weaknesses related with the climate variation that affect its availability (Corrêa Da Silva *et al.*, 2016). This section shows how the climate variation may impact the installed capacity of hydropower in long term, which generates great interest for the wind power. Figure 5 presents the results obtained from the analysis of behavior of the installed capacities of wind and hydropower with a decrease of 1,8% in useful volume of reserves caused by a low level in the hydropower dams. This result showed that although there exists a significant potential in hydroelectricity generation, also there are growth limits associated with climate changes. This situation is principally associated on rainfall and temperature change, which reduces the amount of useful hydropower energy reserves. Figure 6 exhibited the behavior of installed capacity hydropower with a decrease of 4% in useful volume of reserves. In this scenario, environmental restrictions were considered and associated with regulation of power sector expansion. Therefore, an increase in the climate variation affects the installed capacity hydropower, which motives the development of wind power, particularly in the northeast region of Brazil.

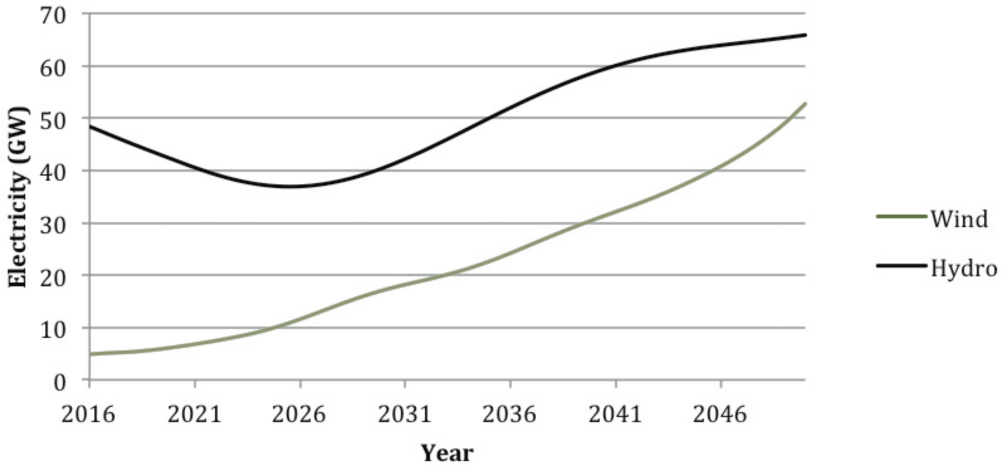

Figure 5. Behavior of the installed capacity wind and hydropower

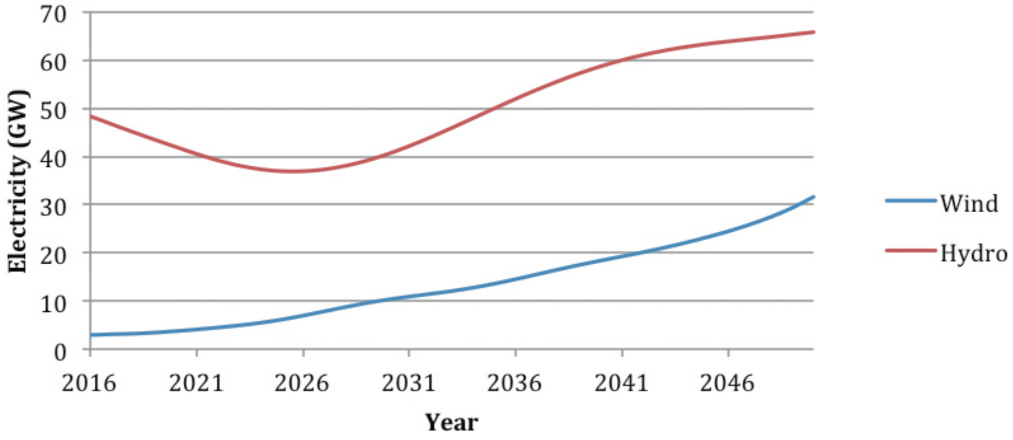

Figure 6. Behavior of the climate effects on the installed capacity hydro vs. wind power

Impacts of installed capacity in transmission lines on penetration of wind power

The Northeast region faces an increase of energy consumption by the industrial and residential sectors that affect the amount of available electricity. The energy consumption is about 3% per year, which involve new transmission lines for energy distribution. However, the construction of new transmission lines has suffered delays that affect the energy supply in this region. Figure 7 shows the generation capacity reported more growth than transmission capacity between 2016 and 2050 in the northern region of Brazil. Despite that Brazil presents an increase in the wind power generation, the insufficient of transmission lines affect the energy supply. For instance, the transmission capacity may be low more than wind power generation from year 2030 to 2050. This situation is generated due to the accumulated delays in the construction of transmission infrastructure. Therefore, this problem may be mitigated through energy policies that allow a synchronous between the development of transmission lines and the construction of wind farms.

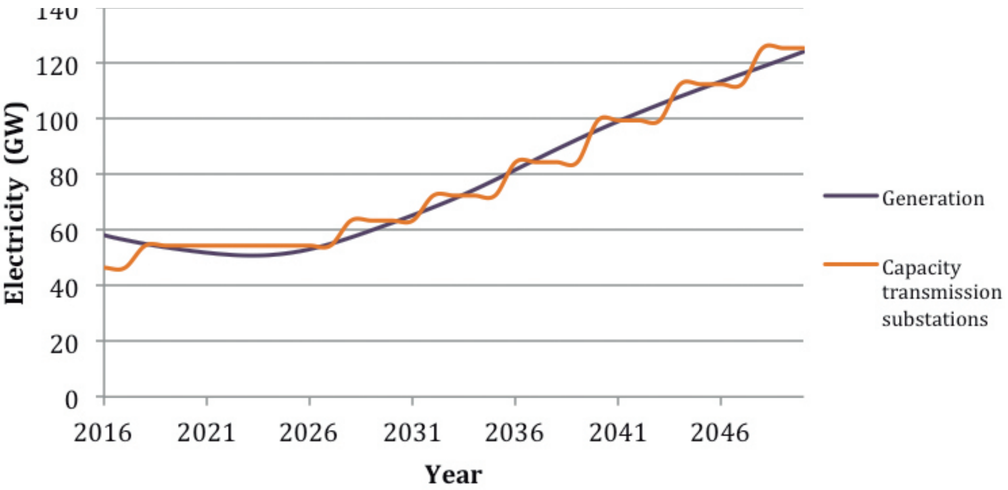

Figure 7. Behavior of the transmission capacity without an increase in the generation capacity

Figure 8 shows the behavior of transmission capacity and the generation capacity growth produced by the penetration of wind power. The simulation results shows a wave effect of the installed capacity in transmission lines generated by time-delays in the auctions for the construction of new infrastructure. Also, the insufficient of financial resources and territorial conflicts affect the expansion of wind farm as well as its transmission infrastructure, principally in the Northeast region of Brazil (Brannstrom *et al*., 2017). The results detected evidence for future electricity dispatch and supply problems that will affect Brazilian poorest regions. As a result, the northern region of Brazil is negatively affected. This situation produces an asynchronous development between the infrastructure of electricity generation and transmission lines.

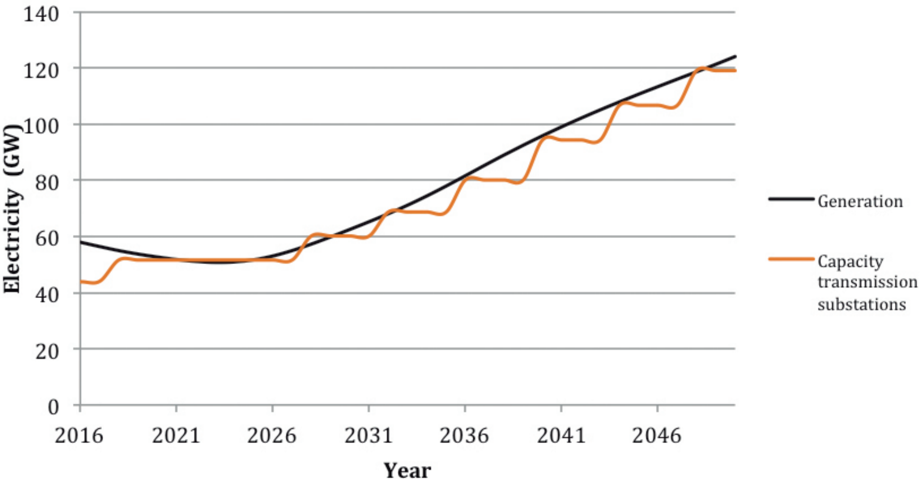

Figure 8. Behavior of the transmission capacity with an increase in the generation capacity caused by the penetration of wind power

In sum, Brazil has experienced an increase in wind energy, which allows energy diversification. However, the problems associated with transmission infrastructure can cause high electricity prices and affect the security of energy supply in isolated regions. In this sense, the synchrony of policies and decisions made by Brazilian government will be a determinant factor for mitigating this problem in the Brazilian poorest regions.

CONCLUSIONS

The modeling results indicate that given the current energy generation growth in Brazil. The north region has a substantial decrease in useful volume of reserve, which can affect their installed capacity to hydropower produce. In this sense, wind energy has major potential as a high-power, low-cost energy production option. However the transmission infrastructure is not sufficient to cover energy demand. These impacts would negatively affect the Brazilian north. The growth of transmission infrastructure depends on the location of renewable plants. In this way, it can be more effectively distributed throughout an electrical grid.

The result of the increased use of wind power in the electricity matrix must include infrastructure growth in Brazilian north. As long as developments in the transmission infrastructure occur, wind power use will grow and be deployed as a renewable energy source. In this context, it is important to assess the impact that the penetration wind power might bring about to electricity market and power exchange between Brazilian regions.

From 2016 to 2050, it examined the effect of wind power penetration combined with an investment incentives policy on wind industry. The incentives provided to renewable energy sources must be considered all stakeholders of Brazilian electricity sector. An integral investment in the wind-energy supply chain clearly provides more benefits than any partial investment in the supply chain. The results indicate that if the aim of policy is to increase electricity generation, then Brazilian market presents interesting options for the penetration of renewables.

The simulation-model results are useful to compare dynamic consequences that may result from the energy policy, along with decisions that may arise from the penetration of wind power.

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