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USING SIMULATION TO ANALIZE WIND POWER PENETRATION: THE CASE OF NORTH AND NORTHEAST REGION

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ABSTRACT: Brazil is rich in renewable sources that can be used for energy generation. The renewable source of energy generation predominantly in Brazil is hydropower. However, the availability of hydropower depends on the useful volume reserves, which is subject to rainfall. Consequently, wind power is a renewable source that is being integrated into the electricity-interconnected system in Brazil. The growth of wind power generation depends on the financial resources and the delays in transmission projects. Despite the Brazilian incentives policy in wind power, the insufficient of transmission infrastructure affects to electricity price in electricity market. This paper addresses the effects of the insufficient of transmission on electricity price through a simulation model. The developed model is implemented to analyze the region of North and Northeast Brazil.

Key words: System dynamics. Brazil. Wind power. Supply chain. Electricity price.

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1 INTRODUCTION

Brazil possesses major potential in term of renewable energy resources as well as largest growth in wind industry. The wind power plays a principal role in the Brazilian sustainable development. Consequently, the Brazilian Incentives Program for Alternative Source of Electricity Energy (PROINFA) promotes the development of wind power industry (KISSEL; KRAUTER, 2006). These characteristics have been allowed increase the supply of wind power. In 2015 installed wind power capacity reached 9 GW, and its potential is concentrated in the Northeast and Southern regions (PEREIRA et al., 2012).

Despite the strategies to promote wind power in the region of Northeast Brazil, one of the limiting factors on wind growth is associated to the insufficient of transmission infrastructure. The problems with dispatching energy, which affect the security of supply, might be associated with industrial and energy policies. In this sense, lack of appropriate policies can generate supply energy problems in more poor regions. Developing countries need to increase their electricity supply to poor regions in order to meet their social, environmental and economic needs for sustainable development. The dispatch problems indicate that to obtain a large share of potential for wind power generation in Brazil, more effective policies are needed (WWF-BRASIL – FUNDO MUNDIAL PARA A NATUREZA, 2015). Therefore, the transmission-infrastructure policy is an important aspect in electricity dispatch and plays a key role in security of supply. Electricity dispatch problem caused by insufficient transmission infrastructure have limited the development of wind power in Brazilian poor regions. Overall, Brazil has successfully implemented some but not all policy instruments regulation and economic incentives on electricity transmission, which generated impacts on electricity price.

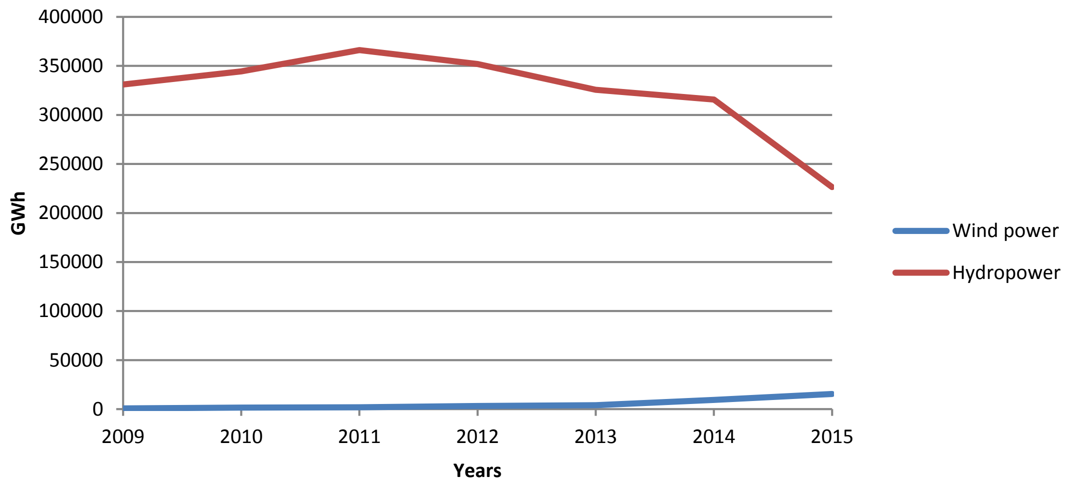
The policy instruments include regulations and economic incentives, which generate impacts on electricity price and consumer behavior (CARDENAS; FRANCO; DYNER, 2016; DYNER; LARSEN, 2001; HANNON; FOXON; GALE, 2015). Analysts and policymakers have called for new and more policies to increase electricity transmission capacities (ABRELL; RAUSCH, 2016). Therefore, the electricity transmission capacity impacts affect the amount of low-cost of renewables. Unfortunately, the expansion of transmission system has drawbacks due to the insufficient of financial resource. Prior studies show the importance of investment incentives in energy sector to increase installed capacity generation (ARANGO; DYNER; LARSEN, 2006; PEREIRA et al., 2011, 2012; ZULUAGA; DYNER, 2007). Kissen and Krauther (2006) maintain that when the investment in wind power has been amortized, feed-in tariff could be reduced considerably. Indeed, strong energy and economic policies allow coordination among the players in the energy supply chain. This paper explored the effects of the penetration wind power in Brazil on electricity price due to the insufficient of transmission infrastructure to the North and Northeast.

The remainder of this paper is organized as follows. Section 2 describes the background of the research. This is followed, in section 3 by the structure of simulation and validation model. Section 4, the results of simulation model is presented. Finally the concluding remarks are provided.

2 BACKGROUND

The Brazilian power sector is characterized by the strong presence of hydropower. Hydroelectricity currently have 92,32 GW of installed capacity, which represents 63% of the total generation capacity. However, the availability of hydropower suffer drawback due to climate variation. The low rainfalls have reduced useful volume reserves in hydroelectric dams. Consequently, Brazil promoted the wind power to complement the energy generation system. Figure 1 shows the generation dynamic of wind and hydropower in Brazil. The decrease in hydropower generation due to the climate variation has assisted to promote wind power. Despite the investment incentives to increase the installed capacity of wind power, still major efforts in terms of financial resources. Additionally, lack of transmission-infrastructure policy is affecting to wind-power growth in the North and Northeast regions. Thus, the wind power generation has a high price due to the costs of transmission implementation in isolated regions.

Figure 1 – Wind and hydropower generation of Brazil (2009-2015)

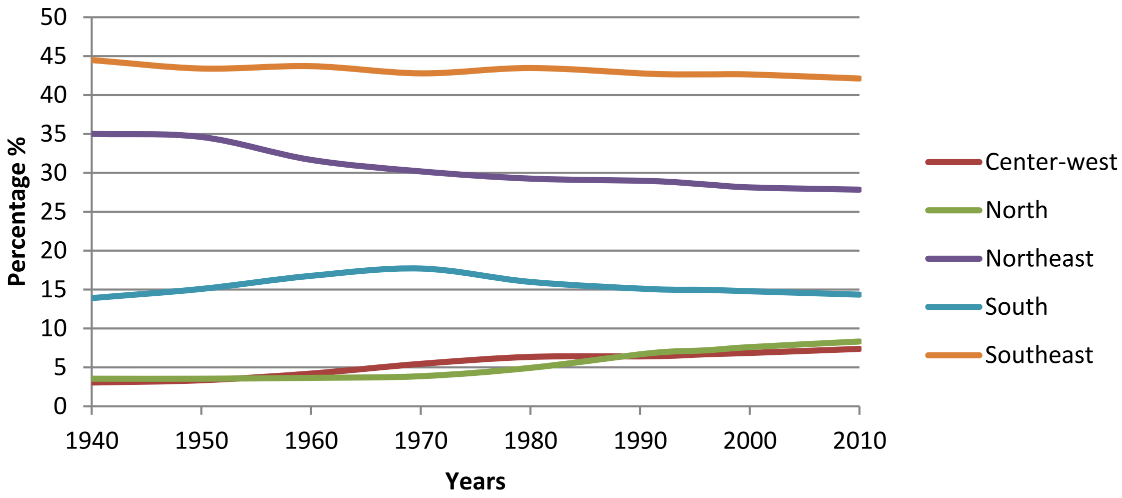


Source: Elaborated by the authors

In the resent years, researches have studied renewables using several approaches (ABRELL; RAUSCH, 2016; CORRÊA DA SILVA; DE MARCHI NETO; SILVA SEIFERT, 2016; DE MELO; JANNUZZI; BAJAY, 2016; FRANCO; CASTANEDA; DYNER, 2015; HENAO et al., 2012; TROOST; WALTER; BERGER, 2015). Pereira et al. (2012) specifically researched on Brazilian energy planning. This study proposed a planning tool for energy system and current status analysis. However, this study failed to consider the insufficient of transmission infrastructure. WWF-Brazil (2015) draw attention to the importance in transmission infrastructure in the wind power growth.

The best conditions of wind can be found in the Northeast of Brazil. The North and Northeast regions had growth rapidly between 1970 and 2010 as a result of interregional migration (see Figure 2). However, these regions have a high level of insolation, low hydric resources and scarce rainfall. Due the territorial extension of Brazil have been required of long transmission lines to the supply of energy in this regions. Therefore, an increase in financial resources is needed to bring the sustainable development in poor regions of Brazil. In this sense, the development of alternative technologies required a new institutional framework aimed to guarantee the quality of life (SILVA et al., 2013). The rational development of power sector depends on strong policy and investment incentives on energy supply chain.

Figure 2 – Dynamic of population growth of Brazil (1940-2010)



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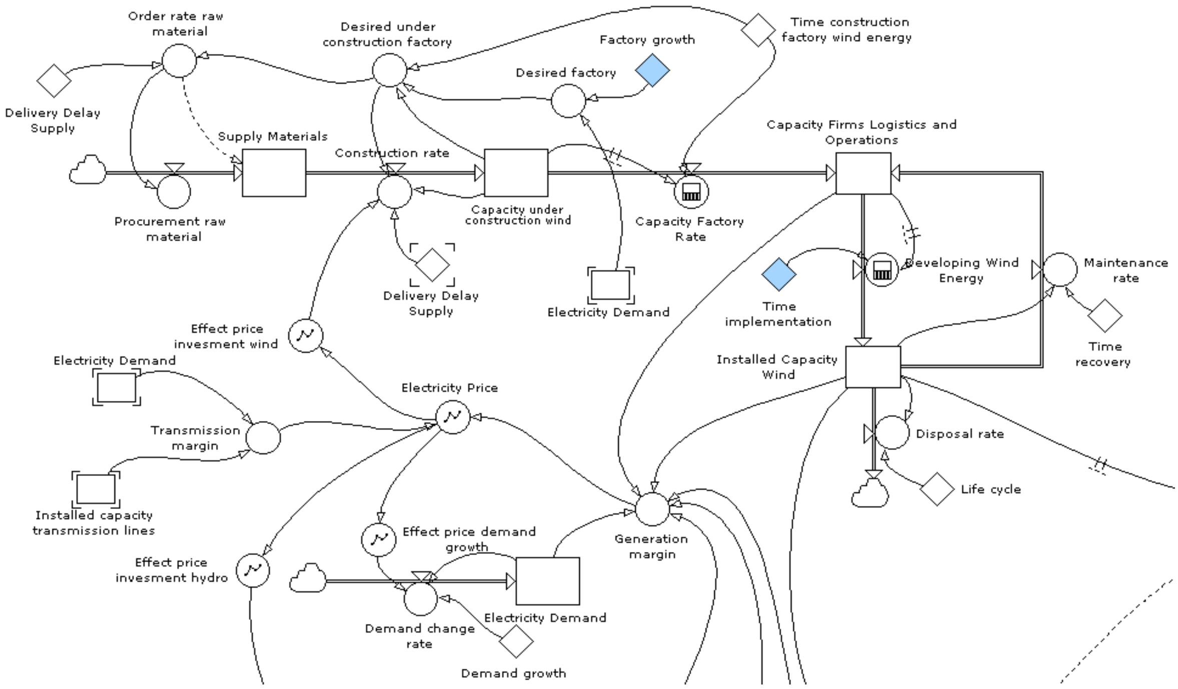
Despite that these regions can be appropriated to the penetration of wind power, the electrical transmission line infrastructure is not well developed (KISSEL; KRAUTER, 2006). Another aspect is related with the delay of transmission projects, which limited wind power growth.

3 MODEL STRUCTURE AND VALIDATION

The energy system requires a methodology that allows understanding the dynamic of electricity market of Brazil and the penetration effects of wind power on price. Regarding system dynamics modeling applied in energy policy, several studies addressed to: capacity expansion and economy analysis, distribution energy, carbon capture and climate action plans (QUDRAT-ULLAH, 2015). To assess the penetration effects of wind power in Brazil, this study used the system dynamics modeling. The Powersim Software was used to develop a wind power penetration model. The proposed model shows a stock and flow diagram, which represent the wind-power supply chain structure. The simulation model was built using detailed descriptions of the players in the wind-power supply chain. The model design takes account of the structures proposed by (CARDENAS; FRANCO; DYNER, 2016; FRANCO; CASTANEDA; DYNER, 2015; HERRERA; ORJUELA CASTRO, 2014; ORJUELA; HERRERA; CASILIMAS, 2015; STERMAN, 2000). The time horizon of simulation model to capture the effects of the penetration of wind power was taken from 2016 to 2050. The stock and flow diagram structure of the model is presented in Figure 3. The diagram represents the wind power supply chain with the time delays of wind industry projects and their effect in electricity price.

Figure 3 – The stock and flow diagram of wind-power supply chain



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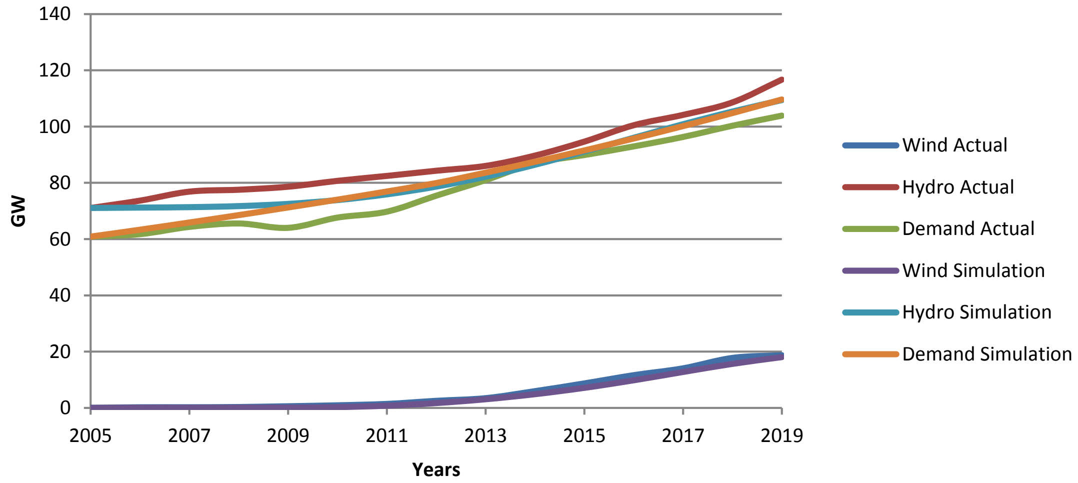
The supply networks of energy firms in the region that execute wind-power projects are characterized by significant uncertainties, such as logistics conditions, environmental permits and time lost during infrastructure construction, all of which primarily affect project costs. These uncertainties affect on electricity price and the investment incentives on wind power industry.

3.1 Simulation model validation

The simulation model was validated through of the historical fit of data. Also, dimensional consistency tests and behavior reproduction tests are used (LUNA-REYES; ANDERSEN, 2003; OLIVA, 2003; STERMAN, 1984, 2000). Consequently, the results were compared to real outputs and forecasting from the years 2005 to 2019 in terms of the installed capacity wind and Brazilian electricity demand. The validation variables are the installed capacity and electricity demand, as shown in Figure 4. The graph represents the historical installed capacity and the simulation data from the model. The results obtained from the validation analysis have the ability to capture trends and replicate historical data.

Figure 4 – Validation and calibration of the simulation model



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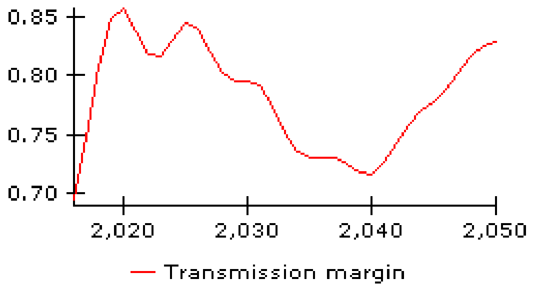
The purpose of the model was to evaluate Brazilian energy policies according to the following aspects: their impact on the development of renewables, their electricity transmission impacts on the price and their environmental effects on installed capacity. Initial data on the installed capacity of each technology correspond to the year 2016, according to ANEEL (2016). The time horizon of the simulation model allows understanding of the transition to renewables, the behavior of electricity transmission-infrastructure and climate variation effects for Brazil.

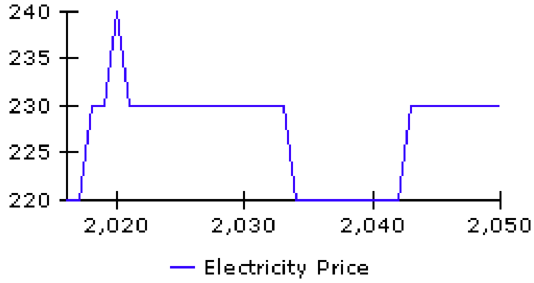
4 RESULTS AND DISCUSSION

This section discusses the results of simulation to the penetration effects of wind power. In Brazil, wind power has major potential as a high power, low-cost energy production option. However, the transmission-infrastructure effects generate an impact on electricity price. Figure 5 show an increase in electricity price from 2018 to 2030 due to the insufficient of transmission of the North and Northeast regions of Brazil, and high margin of electricity dispatch. In contrast, the results show a steady decrease in electricity price from 2031 to 2048 caused by their low margin in energy generation. The reserve margin of generated electricity and transmission probably will decline steadily after 2020, with investment incentives for each player in the wind-power supply chain.

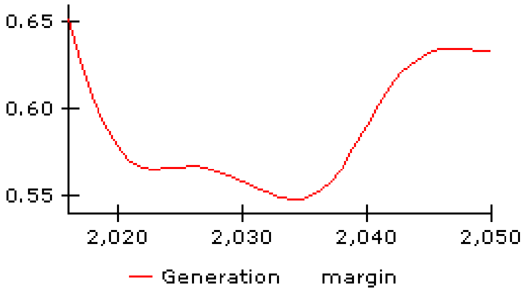
Figure 5 – Evolution of electricity price vs. reserve margin of electricity dispatch and generation



(a) Reserve margin of electricity dispatch



(b) Electricity price



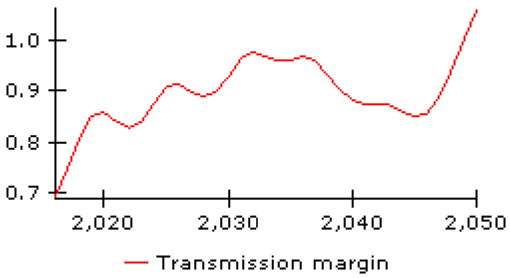
(c) Reserve margin of generation capacity

Source: Elaborated by the authors

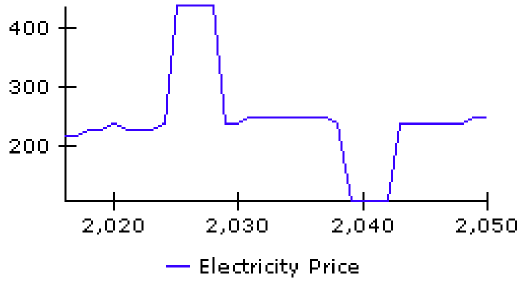
In sum, the high cost of electricity dispatch is one of the main obstacles to the development of wind power of the North and Northeast regions. Additionally, incentive improvements of stakeholders are expected in the future.

The policies and decisions made by Brazilian government will be the principal factor affecting security of supply in poorest regions. Figure 6 (b) shows that there will be a gradual decrease in the electricity price beginning in 2038, due to an increase in electricity transmission and installed capacity generation. The electricity price reaches a peak between 2024 and 2026 because of a fall in the installed capacity generation (i.e. climate variation effect).

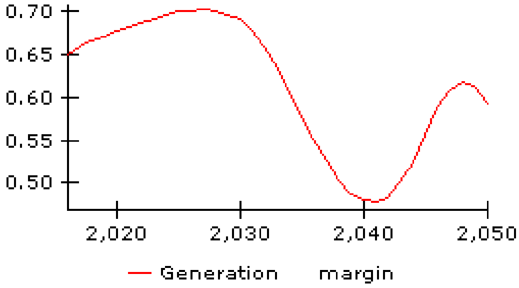
Figure 6 – Behavior of electricity price vs. reserve margin of electricity dispatch with investment incentives in wind power



(a) Reserve margin of electricity dispatch



(b) Electricity price



(c) Reserve margin of generation capacity

Source: Elaborated by the authors

In sum, Brazil has demonstrated exemplary policies. However, the current state of climate variation also has affected the Brazilian electricity sector in terms of strategic planning for renewables. The high cost of electricity transmission is one of the main obstacles to the development of wind power. Additionally, incentive improvements of stakeholders are expected in the future.

5 CONCLUDING REMARKS

The modeling results indicate that given the current energy generation growth in Brazil, even with policies measures will have economic impacts on electricity price. In this sense, the increased use of wind power in the electricity matrix must include infrastructure growth in Brazilian poorest regions (North and Northeast).

This study identified the vulnerability in installed capacity of transmission regarding the development of wind energy, which affected energy security of Brazil and electricity prices. In this way, the Brazilian competitive can suffer drawback, which affect the sustainable development.

The northern and northeast regions of Brazil are areas currently exhibiting high levels of poverty and social underdevelopment. The social costs of implementing unsustainable policies generate energy exchange problems associated with installed capacity generation, the wind-power supply chain and energy policy. This paper is the first step toward analyzing the wind-power supply chain and design to alternative sustainable policy in North and Northeast of Brazil.

UTILIZANDO SIMULAÇÃO PARA ANALISAR PENETRAÇÃO EÓLICA: O CASO A REGIÃO NORTE E NORDESTE

RESUMO: O Brasil é rico em fontes renováveis que podem ser usadas para geração de energia. A fonte renovável de geração predominantemente no Brasil é a hidrelétrica. No entanto, a disponibilidade de energia hidrelétrica depende das reservas de volume útil, que está sujeita a chuvas. Consequentemente, a energia eólica é uma fonte renovável que está sendo integrada no sistema elétrico-interconectado no Brasil. O crescimento da geração de energia eólica depende dos recursos financeiros e dos atrasos nos projetos de transmissão. Apesar da política brasileira de incentivos em energia eólica, a insuficiência da infraestrutura de transmissão afeta o preço da eletricidade no mercado de eletricidade. Este artigo aborda os afeitos da insuficiente transmissão sobre o preço da energia elétrica através de um modelo de simulação. O modelo desenvolvido é implementado para analisar a região do Norte e Nordeste do Brasil.

Palavras-chave: Dinâmica do sistema. Brasil. Força do vento. Cadeia de suprimentos. Preço da eletricidade.

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