DRAFT – NOT TO BE CITED

[all sections still in progress]

Renewable electricity expansion and its effects on employment and regional migration in Brazil

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Abstract:

Keywords: renewable electricity; employment; Brazil; CGE modeling, migration

JEL Codes: D58; Q42; Q48; R13

1. INTRODUCTION

Brazil has been planning to increase the share of renewables in its electricity matrix mostly by raising the share of wind and solar sources. According to the last Brazilian Decennial Energy Plans (PDE 2026 and PDE 2027), during the next decade, the country should more than double its installed capacity for wind power and drastically increase its capacity for solar. Meanwhile, it also intends to reduce the share of oil and diesel sources.

To support this expansion, about US$ 60 billion are estimated only for new projects. This investment, however, will be mostly concentrated in the poorest regions of the country such as the Northeast region – best site for both wind and solar generation. Therefore, the expansion of renewables also entails economic and regional issues.

Under this context, Diniz et al (2018) applied the CGE model TERM-BR10 to study the economic impacts of the investment plan of PDE 2026. They concluded that the electricity expansion as planned by Brazilian Energy Agency could increase the national GDP by 0.12% in the period 2016-2035. If considered a higher share of renewables, especially solar, the national impact could be 0.45%. Regionally, this effect could reach 2.15% in specific regions at Northeast of the country.

In the labour market the authors showed that the electricity expansion, mainly by renewables, raises the employment in the North and Northeast regions meanwhile it reduces jobs in other parts of Brazil. Nevertheless, the analysis lacks details about the specialization of those jobs and migration between regions. However, these topics are quite relevant due to Brazil's regional inequality and to renewables sources employment multipliers being larger than traditional ones (BLYTH, W. et al., 2014; IRENA, 2011; MORENO; LÓPEZ, 2008; Simas & Pacca, 2013).

The aim of this paper is to extend the previous analysis made by Diniz et al (2018) to explore in detail the labour market effects of renewable expansion under the Brazilian Decennial Energy Plan scenarios for electricity generation. Our purpose is, specifically, to study the regional employment and migration in a disaggregated level by skills and groups to understand, for instance, if a small region that is growing faster than the others is attracting skilled jobs in renewables supply chain or these positions are created in other regions.

2. OVERVIEW OF REGIONAL DISPARITIES AND MIGRATION IN BRAZIL

Brazil's territory is divided into 27 states grouped into five main regions, namely: North (N), Northeast (NE), Center-West (CW), Southeast (SE) and South (S) (Figure 1). The SE and the South are the most developed and industrialised regions, concentrating large portions of GDP. They are therefore the most likely to host high-tech industries and to produce renewable power plants components. In fact, the majority of wind power supply chain is concentrated in those regions. For example, the main wind power plant manufacturer Vestas, until 2016, fabricated components exclusively in São Paulo, in the SE (Vestas, 2019). WEG, a Brazilian wind turbine producer has its factory located in the state of Santa Catarina, in the South region (WEG, 2019).

Figure 1. Brazil's geopolitical regions and states

Source: Brasil (2019)

On the other hand, the Northeast, albeit concentrating the greatest potential for alternative renewable energy generation, is the least developed region of Brazil, historically suffering from severe droughts. Although almost 28% of the Brazilian population live in this region, merely 14.2% of the country's GDP is produced there. It has thus the lowest per capita GDP and the lowest GDP share/population share ratio (Table 1).

In summary, the Southeast, the South and the Center-West regions produce higher levels of GDP relatively to their population share, while the Northeast and North regions produce much less GDP in relation to their population share (Table 1).

Table 1. Brazil's regions population, GDP, GDP per capita and corresponding shares in 2015

	2015 Population (10^6)	Population Share	GDP (2015 USD)	GDP Share	GDP per capita (2015 USD)	Ratio Share GDP/Share population
Brazil	**204.45**	**100%**	**1,800,536.64**	**100%**	**8,806.73**	**1**
North	17.47	8.5%	96,328.74	5.4%	5,513.12	0.63
Northeast	56.56	27.7%	254,814.74	14.2%	4,505.25	0.51
Southeast	85.75	41.9%	972,587.53	54.0%	11,342.72	1.29
South	29.23	14.3%	302,708.01	16.8%	10,356.01	1.18
Center-West	15.44	7.6%	174,097.61	9.7%	11,274.12	1.28

Source: Elaborated by the authors with data from IBGE (2015)

The whole of Brazilian economy is currently composed 73% of services, 22% of industries and 5% of agriculture and livestock activities (IBGE, 2018). The Southeast concentrates most of the country's industry and specialized services, with Sao Paulo state concentrating the largest share of both. Agriculture and livestock is mostly produced at South, Southeast and Centerwest regions. Although the North and Northeast regions do not lead the main sectorial value added, they are important players in electricity production due to their potential for hydropower (North) and wind and solar generation (Northeast).

For the purpose of the study, the 27 Brazilian states were aggregated into 11 specific regions due to their relevance in economic and energy aspects (Table 2). This approach is interesting once we have regions that differ from the average of their geopolitical area in economic terms and, specially, in electricity mix (Table XX, in Appendix).

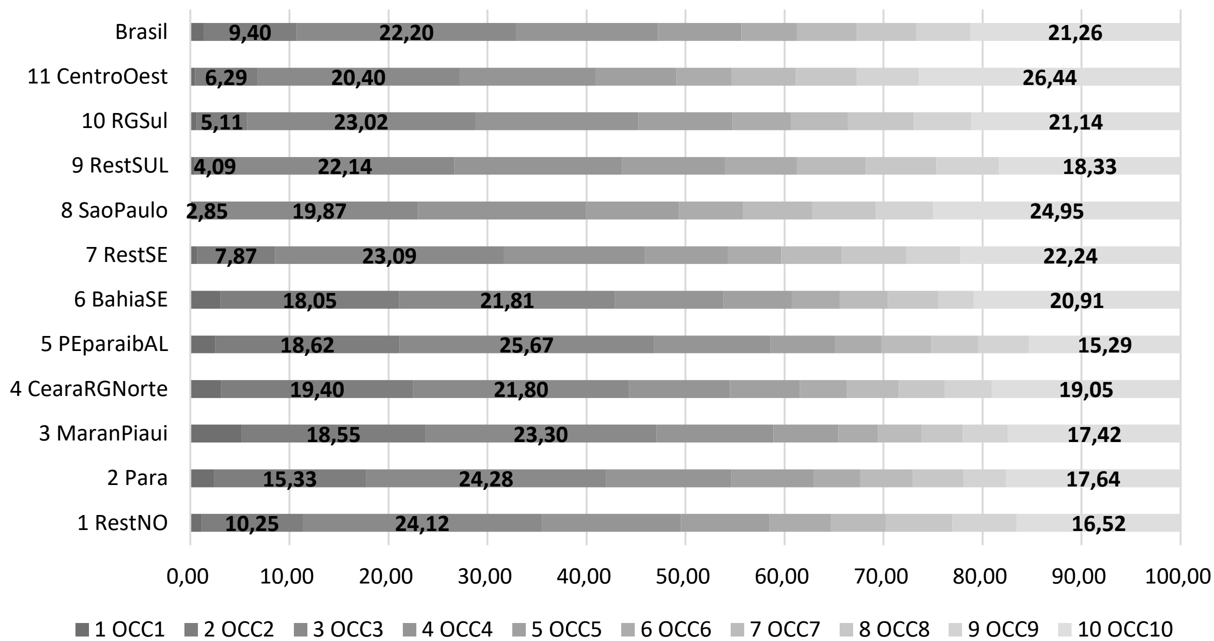
Table 2. Brazil's regional disaggregation

Analysed region name	Meaning	Geopolitical Region
1 RestNO	Rest of North region	N
2 Para	Para state	N
3 MaranPiaui	Maranhão and Píaui states	NE
4 CearaRGNorte	Ceara and Rio Grande do Norte states	NE
5 PEparaibAL	Pernambuco, Paraíba and Alagoas states	NE
6 BahiaSE	Bahia and Sergipe States	NE
7 RestSE	Rest of the Southeast region	SE
8 SaoPaulo	Sao Paulo state	SE
9 RestSUL	Rest of South region	S
10 RGSul	Rio Grande do Sul state	S
11 CentroOest	Center West	CW

Beyond economic concentration, regional disparities in Brazil is also noticeable in social aspects such as education. According to IBGE (2019), in the Northeast region the share of population with 11 or more years of education is 31% and in North is 33%, while the national average is 39% and in the Southeast this share is 45%. In the other extreme, the share of population with none or up to one year of education is about 15% in Northeast while the national average is 8% and in the South and Southeast regions this share is 6%.

Those differences in economic activity and years of education are reflected by regional labour market. In Northeast regions (BahiaSE, PEparaibAL, CEaraRGNorte and MaranPiaui) the lowest-skilled jobs (OCC1 and OCC2) represent about 21% to 23% of work force, while the national average is 10,7% and in SaoPaulo this share is 3,10%. These categories gather jobs that wages are up to 1 minimum wage[1]. On the other hand, the share of work force that is composed by higher skilled jobs (OCC10) is about 15,3% to 19,0% in Northeast regions while the national average is 21,2%, whilst SaoPaulo has this share at 25%. (Graph 1).

Graph 1. Regional work force by skilled levels (%)



Source: Elaborated by the authors with data from IBGE (2011)

Internal migration patterns have historically reflected those regional disparities shown above. Throughout the twentieth century, population flows in Brazil were massively directed from the Northeast to the most developed regions; Southeast and South (Brito, 2009; Fusco, 2013; Working *et al.*, 2016). During this period, population distribution among Brazilian regions was marked by industrialization and agriculture frontier, being the former the main drive of migration from 1970. This caused large outflows from the North and Northeast with inflows mainly to the state of São Paulo, as well as an intense rural depopulation process, with migration inflows to urban areas (Baeninger, 2013).

However, since the 1990 decade, this pattern has been in transition, mostly due to successive economic crisis and changes in the agricultural frontiers (Brito and Carvalho, 2006; Working *et al.*, 2016). About this, Hakkert and Martine (2007) argue that in the twentieth-first century, changes in sectoral patterns have caused a trend of return migration across regions, with the so-called "Southeast expulsion" phenomenon. Industrial job creation stabilized in its lowest level from 1999 to 2004, while the service sector increased its job creation. However, the latter does not demand as large amounts of workforce as the industrial sector used too, and workers who lost their jobs in industry tend not to be qualified enough to be reallocated to positions in the service sector (Hakkert and Martine, 2007).

[1] For 2009, year of labour market database, the minimum wage was R$ 465,00.

3. RENEWABLES EXPANSION AND ITS REGIONAL ASPECTS

While Brazil's electricity demand is continuously rising, future projections show a challenge in maintaining the renewable profile of Brazil's electricity generation mix. The national Energy Research Company (EPE, 2017b) in the Decennial Energy Plan (PDE 2026) projected that, between 2016 and 2026, Brazil's total electricity demand will increase by 3.7% per year. Electricity per capita consumption has risen steadily since 1975, at higher rates than other developing countries such as Mexico, Russia and South Africa. Brazil's per capita demand increased by 45% from 2000 to 2017 (World Bank, 2018).

The Brazilian electricity generation mix is mostly composed by large hydropower plants. However, this source has seen its share lose ground from almost 85% in 2012 to 60% in 2018, according to data from the Energy Research Company and National Agency of Electric Energy (EPE, 2017a; ANEEL, 2019). This generation was replaced by other renewables and mostly by conventional thermal plants, that have been increasing their share during the last years. Most of those units use oil, diesel and gas and have a high operational cost, contributing to increase the average price of national system[2].

Hydropower is expected to continue losing share of Brazil's electricity mix due to irreversible changes in the rainfall regime and environmental impacts mostly associated to dams. Recent projections for the electricity sector in Brazil have concluded that already in 2030 and still in 2050 the hydropower installed capacity will have stopped expanding and therefore its share will have decreased – or been stagnant (Marcovitch, 2010; CENTROCLIMA, 2017; MCTI, 2018;PSR, 2018; Lucena *et al.*, 2016, 2018; Nogueira de Oliveira *et al.*, 2016; Santos *et al.*, 2017, 2018; Instituto Escolhas, 2017).

Since the 1990 decade, constructing new hydropower dams has been avoided in Brazil due to the socioenvironmental impacts of flooded areas. Flooding indigenous reserves and biodiversity loss have been considered the most relevant threats. Since then, run-of-the-river projects have been prioritised, reducing the system's firm energy (Marcovitch, 2010). The main project that has been changed for this reason was the Belo Monte plant. The first studies to deploy the plant were conducted from 1975. But, in 1994, the 11 GW project was altered to operate run-of-the-river instead of building dams, reducing environmental risks but also firm energy provided, which became 40% of the capacity (Tancredi and Abbud, 2013).

Parallelly, changes in the rainfall regime have become critical since 2013, lowering reservoirs levels and increasing the marginal cost of operation of the National Integrated System (SIN). This has led to the adoption, in 2015, of a new charging system to compensate for the costs of activating thermal plants which are more expensive. Consumers pay an extra charge up to approximately US$1.5 per 100 kWh depending on the extent to which the system is resorting to thermal plants (ANEEL, 2018). Also, according to a report developed by the Brazilian Panel on Climate Change (MMA, 2019), rainfall regime changes will be the highest impact consequence of climate change in Brazil. A decrease of rainfall levels is expected specially in the Northeast region, which is, as mentioned, already the area most affected by droughts.

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[2] Thermal plants currently account for almost 26% of the total electricity generated and mainly use gas. Brazil also have units that operate using coal, oil and diesel, that are usually more expansive.

Those aforementioned facts and constraints are quite relevant in planning how Brazil will meet the growing demand and still maintain a sustainable, low-emissions electricity generation mix.

As one of the main alternatives, wind energy has outstanding potential in Brazil, which has increased its share over ten-fold from 2012 to 2017. It now accounts for 8.25% of the total installed capacity of the country, with 13.19 GW (ANEEL, 2018). Since 2011, its installed capacity has increased over 9 times and over US$28 billion were invested in wind power projects between 2006 and 2016 (Valor Econômico, 2016). According to ANEEL (2008), the potential for wind power generation in Brazil is 143 GW. In 2018, national power generation installed capacity was around 167 GW and wind power accounted for 16 GW of that (ANEEL, 2018).

Solar PV energy, in contrast with the country's privileged potential, still represents 1.15% of Brazil's electricity mix with 1.3 GW of installed capacity (ANEEL, 2019). The first solar PV projects procured in electricity auctions in Brazil were procured in a reserve energy auction in 2014, a 889.7 MW capacity to start supplying in 2017 (ANEEL, 2018b). According to the Brazilian Ministry of Mines and Energy (MME, 2017), radiation within Brazil's territory varies between 1,200 and 2,400 kWh/m2/year. This means that the weakest radiation in Brazil is on average equal to in Germany's strongest radiation (1,200 kWh/m2), the fourth country in the world in PV installed capacity with 39.6 GW in 2016 (Wirth, 2018; World Energy Council, 2018). Irradiation variability is also quite favorable. According to Pereira et al. (2017), all five regions of Brazil show lower variability than countries where solar PV is already well stablished like Germany, Portugal, Spain and Italy, with variations that can be smaller than 0.5 kWh/m2/day.

Aa another alternative, one of Brazil's main virtue is its use of biomass-fired thermal plants. Currently, 6.7% of total electricity generated comes from sugar cane bagasse. When accounting for all biomass fuel, including agroindustrial fuels, liquid biofuels, forests, animal waste and solid urban waste, its share of the national electricity mix is 8.75% according to data from ANEEL (2018).

For Brazil to attain progress in increasing non-hydro renewable electricity share, the NE region is key, as it concentrates most of the country's physical potential for solar and wind power generation, and a relevant potential for biomass-fired plants. The region has a wind energy capacity potential of 75 GW (around 144 TWh per year) which represents over half of Brazil's potential (ANEEL, 2018b). The NE semiarid region is also the most appropriate area for PV generation, showing comparable radiation to the best spots on earth, such as Dongola in Sudan and the Mojave Desert in California (ANEEL, 2008). For example, Brazil's maximum radiation (2400 kWh/m2/year) lies in the central area of the state of Bahia, which is located in the NE Semiarid region (Pereira et al., 2017). It also a relevant region in terms of sugar cane production and forest biomass, with the Caatinga biome being quite suitable for eucalyptus plantation for example (Anselmo and Badr, 2004; Lima Júnior et al., 2014; Soria, Portugal-Pereira, et al., 2015; ABIB, 2016; Fichter, Soria, Szklo, Schaeffer and Andre F. P. Lucena, 2017)

The North region, where the Amazon is located, although concentrates the remaining hydropower potential of Brazil, it does not present similar potential for wind and solar power. The potential for solar generation is less than 1,400 kWh/year in contrast with an average of 1,800 kWh/year in the NE (Pereira et al., 2017). For wind power, speed is under 4.5 m/s in all its territory, whilst in the NE speed reaches a maximum of 13 m/s.

Since 2014, new electricity generation capacity and reserve energy auctions have prioritized wind, natural gas thermal and solar plants. Recent auctions procured projects investment from 2014 to 2024 will be 38% in wind energy, 31% in solar PV, 19% in natural gas and 4% in biomass-fired (mostly sugar-cane bagasse) thermal plants, totalizing 73% of new and reserve energy investment in non-hydro renewable energy (ANEEL, 2018b). The NE potential for solar and wind generation has been recognised. Since 2014, 65% of projects procured in electricity auctions were in the NE. Solar PV energy accounted for 142 projects, 27% of total, 73% of which are located in the NE. Wind energy accounted for 229 projects, 45% of total and 99% of which are in the NE (ANEEL, 2018b).

Thus, under this geographic, environmental and market conditions, the aforementioned Decennial Energy Plan (PDE 2026) (EPE, 2017b) is elaborated by the national Energy Planning Company, which is part of the Brazilian Ministry of Mines and Energy. The plan aims to provide information regarding the government's plan for energy supply and demand over the following ten years from when it is published.

The plan we use as base for simulations in this study, the PDE 2026, presents several different scenarios for electricity generation expansion until 2026 and all follow the recent auction trends, being wind, solar and natural gas the major sources across all eight scenarios (so called cases) it presents. Centralised PV reaches 7,000 MW of increased capacity is most of the cases, whilst wind power reaches a maximum of 19,725 additional MW of installed capacity in case 1 (15,780 of those in the NE), with no less than 10,000 additional MW in all cases (EPE, 2017b)

Among the options offered by PDE 2026, we restricted our study to four scenarios: Case 1 - reference scenario, Case 4 – more intensive in solar expansion, Case 5 – with no new hydro dams, and Case 8 - directed expansion. This choice was based on the fact that these Cases share the same economic and electricity demand assumptions as well as exogenous constraints (Figure A1, in Appendix). Hence, they are comparable. Besides, they embody relevant policy and environmental issues, such as hydrologic scarcity, more rigorous conditions for environmental licenses and, as already highlighted, huge increase in renewable sources.

Each region is affected in a different way in each scenario. For instance, although the SE region does not show a comparable physical potential for renewable energy generation, it is responsible for 55% of Brazil's industrial GDP, while the NE share of industrial GDP is 12.9% of the total. Whilst the SE represents 49.5% of the industrial labour force in Brazil, the equivalent figure in the NE is 15.2% (CNI, 2018). Thus, it is not trivial to project where and how labour market benefits will occur and, consequently, the direction of migration flows and in which type of labour it will happen.

4. METHODOLOGY[3]

4.1 The TERM-BR10

As an extension of Diniz et al (2018) study, this work uses the same CGE framework, the TERM-BR10 model. The TERM-BR10 is a regional, bottom-up and multi-period (dynamic)

[3] Part of this topic is based on Diniz et al (2018).

computable general equilibrium model, based and closely similar to its predecessor, the TERM-BR.

The model is calibrated based on the 2010 Brazilian Input-Output table and represents the 27 Brazilian regions (11 after database aggregation). It also distinguishes ten different types of labour, classified according to wage income groups, as a proxy for skills. The income earned by those ten different labour types is assembled to compose the household income – the expenditure unit of the model. Then, TERM-BR10 distinguishes ten different household types, classified by their income.

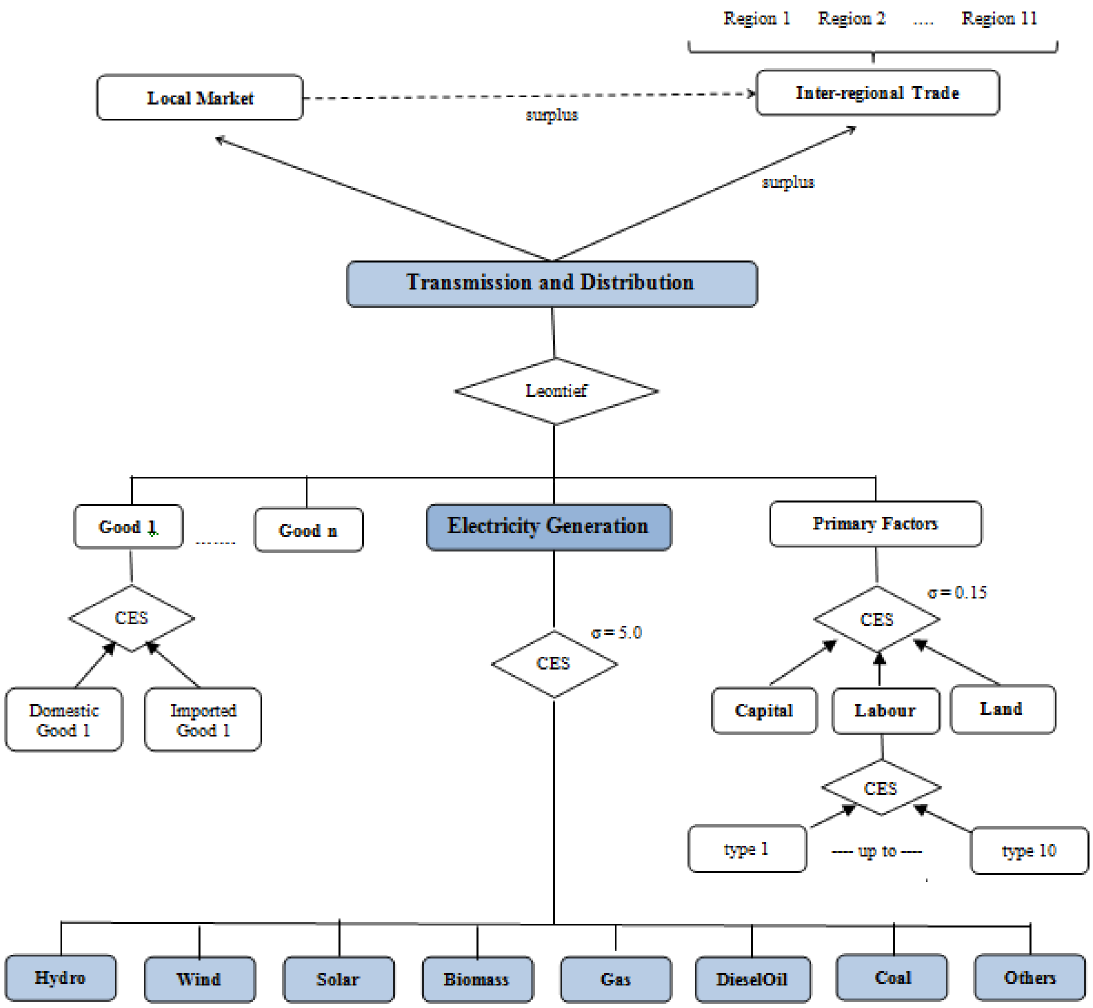
The equation system follows TERM's models tradition. As described by Horridge (2011), the producers choose a cost-minimizing combination of intermediate and primary factor inputs, subject to production functions which are structured by a series of Constant Elasticity of Substitution (CES) "nesting" assumptions. The primary factors and intermediate inputs are each demanded in proportion to industry output (Leontief assumption). The primary factor aggregate is a CES composite of capital, land and a labour aggregate – which it is itself a CES composite of labour by skill group. The aggregate intermediate input is a CES composite of different compound commodities, which are in turn CES composites of goods from different sources: imported and/or national, which could be from one or a mix of those 27 regions (11 after aggregation). The exception is for Transmission and Distribution (T&D) industry, that we assume a Leontief combination of electricity and other goods to compose the aggregate intermediate input (Figure 2).

The model has eight types of electricity generation commodities, composed by four renewables sources (wind, solar, hydro, sugarcane biomass) and four non-renewables (oil and diesel, coal, gas, and other generations). The sugarcane biomass electricity is produced by sugar and ethanol industries, while all the others are produced by their own sector.

In the TERMBR10, the Transmission and Distribution industry collects the electricity produced by all generation activities locally and then supply it to households and other industries. The excess of each region is distributed along the national territory, via inter-regional trade. With this approach, the electricity supplied by each region is a mix of the production of the generation types. The share of each source in this electricity composed is subject to changes accordingly to relative prices under a CES system, with the elasticity of substitution equal to 5,0. It means, in other words, that our model could properly substitute one type of electricity by another in response to changes in production and prices regionally (Diniz, Ferreira Filho and Horridge, 2018).

With this structure, TERM-BR10 closely represents the Brazilian electricity system. In Brazil, the government coordinates supply through auctions and operates the national grid focused on energy security, universal access and lower cost. This last point means that, subject to supply security and transmission restrictions, the cheapest electricity type will be dispatched and transported across the country. Our model, by its turn, reflects all these main aspects.

Figure 2. Electricity production and trade mechanism in TERM-BR10.



Source: Diniz et al. (2018).

The model's recursive dynamics consists of three mechanisms: (i) a stock-flow relation between investment and capital stock, which assumes a 1-year gestation lag; (ii) a positive relation between investment and the rate of profit; and (iii) a relation between wage growth and regional labour supply. The capital in each period grows by an amount equal to the rate of investment at the beginning of the period, subtracted a deduction for depreciation. Thus, a change in investment this period (t) affects the growth rate of capital not in this period but in the next (t+1). The investment allocation in its turn is driven by two components: a) investment/capital ratios are positively related to expected rates of return; and (b) expected rates of return converge to actual rates of return via a partial adjustment mechanism (Horridge, 2002)

Under this approach, TERM-BR10 represents installed capacity of electricity generation by the capital stock flow of electricity generation industries. Thus, the model could handle an expansion plan for renewable energy, for instance, by subjecting the capital stock (or investment) in these specific generation industries to the same growth path of the plan, following the mechanisms above described.

Regarding labour market dynamics, the model mechanism is a relation between wage growth and regional labor supply. In TERM-BR10 the real wage definition follows the traditional TERM framework. As pointed out by Wittwer (2012), real wage is determined by regional labour market supply and demand, with the regional labour market adjustment mechanism given by the Equation (1) (in levels):

$$\left(\frac{w_t^r}{wf_r^t} - 1\right) = \left(\frac{w_{t-1}^r}{wf_{t-1}^r} - 1\right) + \alpha\left(\frac{EMP_t^r}{EMPf_t^r}\right) - \left(\frac{LS_t^r}{LSf_t^r}\right) \qquad (1)$$

In which:
w_t^r= real wage in region r in period t;
EMP_t^r = labour market demand in region r in period t;
LS_t^r = labour market in region r in period t;
α is a positive parameter;
f represents that the variable in its equilibrium trajectory.

The interpretation of this equation is the following: if the proposed shock weakens the labour market in region r, period t, so that $EMP_t^r < EMPf_t^r$, real wage would therefore decrease relatively to its equilibrium forecasted trajectory. In subsequent years, the gap between the labour market supply and demand would be closed, returning to forecast, through a further decline in real wage. α represents the speed of this labour market adjustment.

Additionally, the employment level in each of the regions is affected by inter-regional migration. The latter is determined by regional real wage variations relatively to the national variation. The labour force from regions with a real wage increase smaller than the national average will migrate to regions with a real wage increase greater than the national average. This is represented by the Equation (2) (in levels):

$$\frac{LS_t^r}{LSf_t^r} = \frac{(W_t^r)^\gamma}{\sum_q (W_t^q)^\gamma S_t^q} \Big/ \frac{(Wf_t^r)^\gamma}{\sum_q (Wf_t^q)^\gamma Sf_t^q} \qquad (2)$$

Where:
S_t^q = Share of region q in the national employment in period t;

γ is a positive parameter. We could extend this aforementioned mechanism to analyse the region to region migration. In TERM-BR10, it could be summarised by the Equation (3), where the regional real wage effect in order to drive migration flows is clear:

$$M_{ord} = F_{ord} \cdot \left[L_{or} \cdot \left({}^{L_{od}}/_{L_o}\right)\right] \cdot \left[{}^{Realwage_{od}}/_{Realwage_{or}}\right]^a \qquad (3)$$

where:
M_{ord} = number of workers skill type o migrating from region r to region d;
F_{ord} = constant of proportionality, set to replicate initial data**;**
L_{or} = employment of workers skill type o in region r;
L_o = national employment of workers skill type o;
$Realwage_{od}$ = Real wage of workers skill type o in region d;
a = elasticity, currently set to 3.

The main data source for labour force and migration in this study in the Pesquisa Nacional por Amostra de Domicílios – PNAD (National Household Sample Survey) (IBGE, 2019) to the year 2011[4]. PNAD is a comprehensive household survey and is normally the main data source for household studies, as shown by Horridge and Ferreira-Filho (2016). PNAD provides data for each Brazilian state about employment and wage levels for each economic sector.

The elasticity parameter for migration, a, is currently set to 3. However, there is a scarce background about this number between regions, specially if considered by skilled level. For this reason, we run a Systematic Sensitive Analysis on this parameter, following the methodology approach purposed by Pearson e Arndt (1998).

The same way as pointed out by Horridge and Ferreira-Filho (2016), migration flows calculated by the TERM-BR10 refer to the worker dimension. It therefore doesn't encompass effects of family migration to accompany the migrant worker or migration for other reasons apart from work.

4.2 Scenarios and simulation strategy

The simulation conducted in this study analyses labour market and migration implications of policy scenarios for the future expansion of the Brazilian electricity installed capacity developed by the national Energy Research Company (EPE, acronym in Portuguese) for the Decennial Energy Plan 2026 (PDE 2026) (EPE, 2017b). For this purpose, a baseline trajectory is modelled first to describe the expansion of the Brazilian economy and electricity supply according to current trends. Then, policy scenarios in which the government interferes in the electricity capacity expansion represent "perturbations" to the current trend, allowing for an analysis of net impacts of those policy scenarios.

As aforementioned, PDE 2026 presents scenarios of future capacity expansion named as "cases". For the purpose of the present simulations, Case 8, called "directed expansion" is used as the baseline. This is the scenario with the lowest level of government intervention and therefore the closest to a natural expansion pathway. The policy scenarios modelled were Case 1, a reference scenario, Case 4, which considers a 40% reduction in centralised solar investment costs from 2023 and Case 5, with no expansion of hydropower (big dams)[5].

The differences between the Cases are restricted to the expansion planned for the period 2020-2026. From Table 3, it is possible to notice that non-hydro renewables will drive the expansion as well as gas thermal plants. Besides, regional distribution and even the renewable mix differs between Cases.

Table 3. Total expansion (MW) for 2020-2026 under selected scenarios provided by PDE 2026

	Case 1	**Case 4**	**Case 5**	**Case 8 (Reference)**
Hydro	2,631	2,631	-	2,631
Small Hydro (PCH/CGH)	1,500	1,500	1,500	1,500
Biomass	2,804	2,804	2,804	2,804
Forest Biomass	400	400	400	400

[4] The main data source is PNAD 2011. However, initial migration flows are based on 2005 edition. An updating is in progress.

[5] The scenarios are not described in details. For further information about them check Diniz et al (2018) and, mainly, PDE 2026 document.

Wind (south)	2,365	2,006	2,187	2,790
Wind (Northeast)	9,460	8,024	8,749	11,159
Photovoltaic	7,000	10,508	7,000	6,000
Natural Gas (Southeast)	112	-	995	83
Natural Gas (South)	1,054	1,198	-	1,459
Natural Gas (Northeast)	1,500	1,500	1,500	-
Peak alternative* (South)	3,070	4,049	368	4,181
Peak alternative* (Northeast)	184	1,436	-	939
Peak alternative* (Southeast)	8,944	7,117	12,457	7,686
Coal	-	-	2,000	-
TOTAL (MW)	41,024	43,173	39,960	41,633
Estimated Investment (R$ millions)	174,480	180,853	167,468	179,227

Source: (EPE, 2017b)

Note: The table shows the total expansion by aggregated regions, as published by PDE 2026. To split this expansion to TERM-BR10 regions is used the shares proposed by Diniz et al (2018).

* Following NT DEA 015/17, we are assuming natural gas for peak alternative.

As a long-term dynamic simulation, the evolution of the economic system is mostly based on the evolution of primary factors and technical progress. The TERM-BR10 has three primary factors, namely: labour, capital and land. The expansion of electricity generation from each of the sources and region is done through the supply side via investment in order to increase the model's capital stock by the same rates of installed capacity in the PDE 2026 scenarios[6]. This represents a control over the evolution of capital in electricity generation industries. The following assumptions are made for the simulation:

i. Labour supply is driven by regional labour market conditions. As aforementioned, labour flows occur between regions depending on relative real wage variations;
ii. Capital is endogenous and varies according to investment, which in turn depends on rates of return. Except electricity generation industries which investment is exogenous and subject to policy shocks.
iii. Land is mainly used by agriculture and livestock industries, with a small use from mining, oil and gas as hydroelectricity industries.

Regarding technological progress, productivity gains considered are 2% per year for land and 0.5% for Transmission and Distribution of electricity. On the demand side, a growth rate of 2.5% for exports (quantity) was adopted and the PDE's rates for GDP during the period 2017-2026 and an average rate of 3.0% after that.

Investment in electricity industries relating to the PDE scenarios are assumed to be funded through foreign savings.

5. PRELIMINARY RESULTS

[6] With this approach our policy shocks are large matrices with four dimensions (Year x Case x Generation type x Region)

Our preliminary results show that all policies have a positive deviation from the baseline in macroeconomic aggregates. This gives us a first insight that government guidelines embodied by those scenarios are resulting in economic benefits. The exception is Exports. However, we could interpret this as an outcome of our long-run closure, where the investment is supported by foreign savings and, consequently, implies appreciation of the exchange rate (Table 3). The strict relations between Capital Stock and Investment as well as Household consumption and GDP were also verified. As a long run simulation, the national aggregate employment follows a natural rate and then does not change between scenarios.

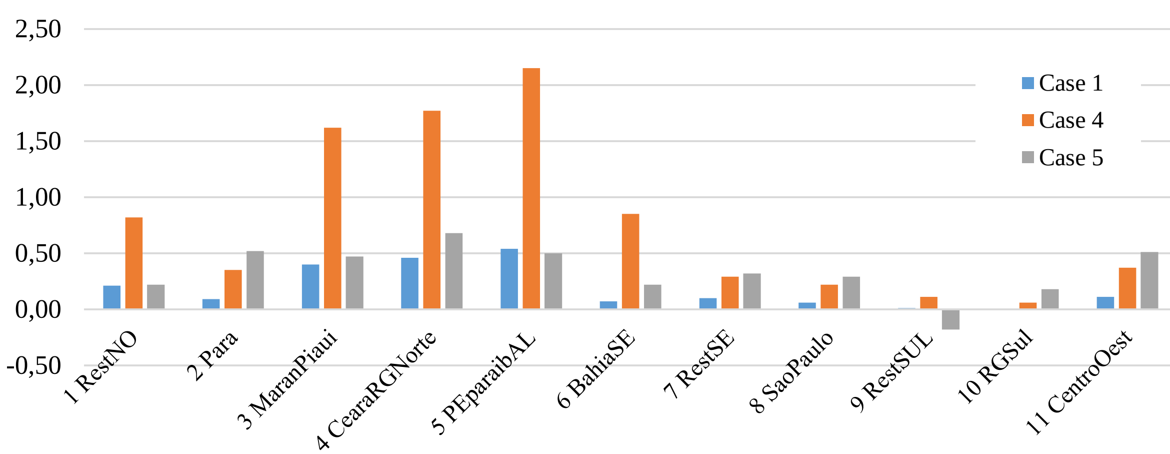
Table 4. Macro variables: % cumulative deviation (2016-2035) from baseline

	GDP	Real Household consumption	Real Investment	Capstock	Exports Volume	Exchange Rate
Case 1 (Reference)	0.12	0.14	0.40	0.27	-0.82	-0.24
Case 4 (Solar)	0.45	0.52	1.43	1.11	-2.58	-0.90
Case 5 (no-hydro)	0.07	0.09	0.24	0.18	-0.47	-0.12

Source: model results.

In regional terms, those regions located in the Northeast of the country (MaranPiaui, CearaRGNorte, PEparaibAL and BahiaSE) increase their GDP at higher rates than the other regions. This result reflects the large investments in renewables that occur in those regions in all scenarios. In particular, the cumulative deviation from Case 4 to our baseline shows the potential benefits that an expansion intensive in renewables could bring to specific regions such as PEparaibAL(2.15%).

Figure 3. Regional GDP: % cumulative deviation (2016-2035) from baseline by policies alternatives.

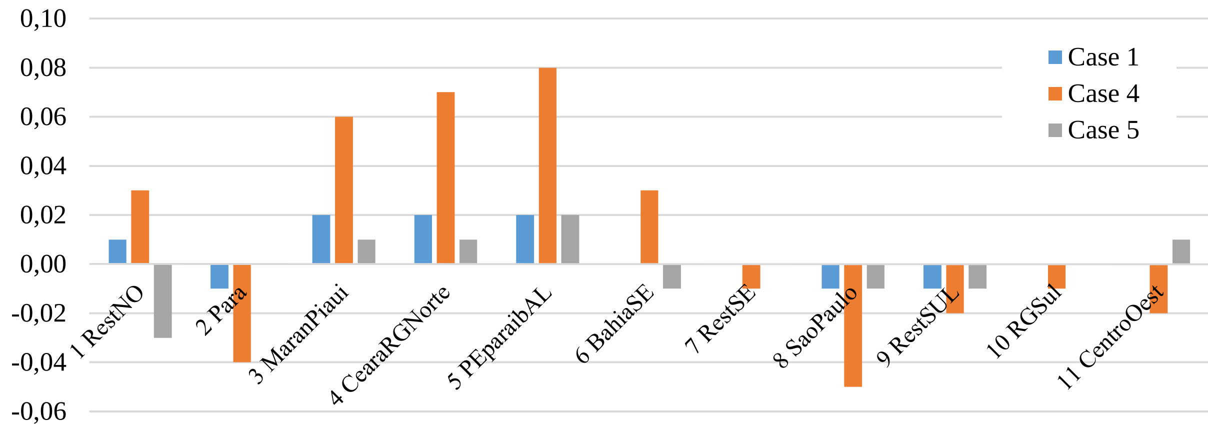


Source: model results.

Consequently, their labour markets also experience larger and more positive deviations from baseline in comparison to the remaining regions (Figure 3). The regions MaranPiaui, CearaRGNorte and PEparaibaAL, located in the Northeast, experience positive regional employment in all cases. Case 1 clearly provides the highest levels of net employment generation when compared to the baseline, with deviations between 0.06% and 0.08% in the three regions. Sao Paulo and RestSul, in contrast, experience negative deviations from baseline in all cases, reflecting the clear direction of investments to the Northeast region.

Besides, our regional results also show that a scenario with environmental restrictions (case 5) but still with a large expansion of renewables cause economic losses to one specific region (RestSul) while national economy is not affected negatively.

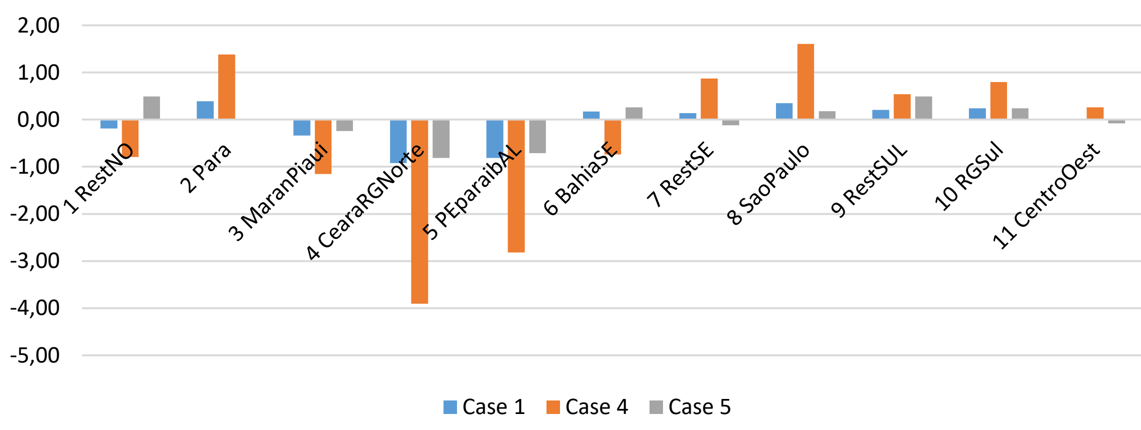
Figure 4. Regional Employment: % cumulative deviation (2016-2035) from baseline by policies alternatives.



Source: Model results.

As a consequence, regions with a weak labour market experience outwards emigration to regions with economic growth (Figure 4). This effect was also driven by regional real wage variation differences. As real wage, as well as GDP, varied more positively in regions in the Northeast, migration flows were directed to them.

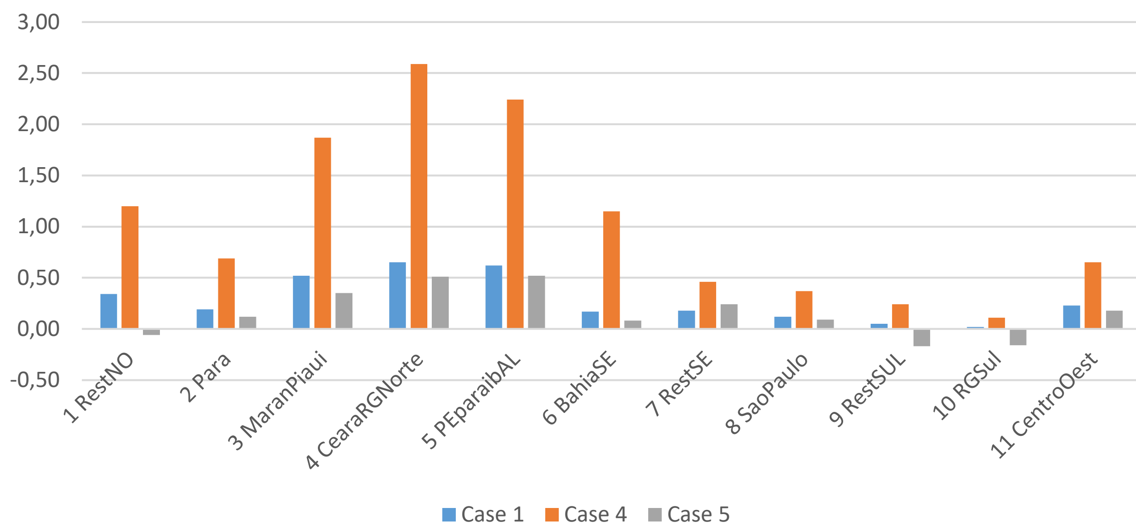
Figure 5. Regional Migration by Source: % cumulative deviation (2016-2035) from baseline by policies alternatives.



Source: Model Results.

Regional real wage variation results are presented in Figure 6. Noticeably, they reinforce the view that the largest inwards migration flows are related to the regions with the highest positive real wage variations relative to the baseline. These results are therefore consistent with the larger employment creation relative to the baseline in the same regions, namely: MaranPiaui, CearaRGNorte and PEparaibAl. Even though all regions experience net employment generation (Figure 6), migration flows still occur attracted to regions where it increased the most. Outwards migration flows, thus, are not necessarily driven by employment reduction. In this case, they come from regions where relative employment generation was lower towards regions where it was higher.

Figure 6. Regional Real wage: % cumulative deviation (2016-2035) from baseline by policies alternatives.



Source: Model Results.

Finally, Table 4 is the inter-regional migration flow matrix showing all the net migration results between the source region and the destination of flows, for Case 1 relative to the baseline. From Table 4, it is noticeable that the highest migration flows occur from more industrialised southern and southeastern regions (SaoPaulo, RestSul and RGSul) to the regions which concentrate investment in wind and solar energy, namely MaranPiaui, CearaRGNorte and PEparaibAL.

Table 5. Regional migration flows: % cumulative deviation (2016-2035) Case 1 to baseline.

Source / Destination	1 RestNO	2 Para	3 MaranPiaui	4 CearaRG Norte	5 PEparaib AL	6 BahiaSE	7 RestSE	8 SaoPau lo	9 Rest SUL	10 RGSul	11 CentroOes t
1 RestNO	**0.2**	**-1.62**	**0.9**	**4.04**	**2.1**	**-0.56**	**-2.06**	**-1.98**	**-2.65**	**-3.2**	**-1.49**
2 Para	**1.75**	**-0.12**	**2.37**	**5.61**	**3.67**	**1.02**	**-0.81**	**-0.8**	**-1.39**	**-1.93**	**-0.14**
3 MaranPiaui	**-0.66**	**-2.78**	**0.25**	**3.45**	**1.21**	**-1.34**	**-3.84**	**-4**	**-4.32**	**-4.9**	**-3.18**
4 CearaRGN orte	**-3.34**	**-5.1**	**-2.23**	**0.68**	**-1.28**	**-3.8**	**-5.8**	**-5.98**	**-6.48**	**-6.94**	**-5.31**
5 PEparaibA L	**-1.73**	**-3.73**	**-0.57**	**2.32**	**0.37**	**-2.23**	**-4.87**	**-5.26**	**-5.67**	**-5.93**	**-4.31**
6 BahiaSE	**0.94**	**-1.16**	**1.42**	**4.75**	**2.66**	**0.12**	**-1.87**	**-2.07**	**-2.54**	**-3.11**	**-1.32**
7 RestSE	**2.56**	**0.57**	**2.9**	**6.31**	**4.35**	**1.75**	**-0.09**	**-0.22**	**-0.75**	**-1.25**	**0.53**
8 SaoPaulo	**2.43**	**0.51**	**2.48**	**5.94**	**4.16**	**1.57**	**-0.12**	**-0.19**	**-0.7**	**-1.21**	**0.59**

9 RestSUL	**3.29**	**1.26**	**4.73**	**7.14**	**5.09**	**2.46**	**0.58**	**0.46**	**-0.07**	**-0.6**	**1.22**
10 RGSul	**3.58**	**1.99**	**5.26**	**7.75**	**6.11**	**3.18**	**1.27**	**0.96**	**0.41**	**-0.07**	**1.77**
11 CentroOest	**1.85**	**-0.08**	**2.23**	**5.58**	**3.73**	**1.05**	**-0.71**	**-0.77**	**-1.34**	**-1.82**	**-0.06**

Source: Model results.

5.1 Systematic Sensibility Analysis

As aforementioned, there is a scarce literature about elasticity parameter for migration (SIGMAMIG), a. We previously set this parameter to 3. However, once we are interested in migration and labour market behavior this elasticity is central for model results. Then, we run a Systematic Sensitive Analysis (SSA) following the methodology approach purposed by Pearson e Arndt (1998).

The scenario selected for SSA was the Case 4 due to its large policy shocks. We use an ordinary change of 2, which means that model was solved for SIGMAMIG equal to 1, 3 and 5. We also set all dimension (OCC, REG, DST) to vary together and run the SSA simulation using a triangular distribution.

The SSA does not show significate variations for national macro aggregate such as national GDP, household consumption and investment. Under regional approach, however, the standard deviation of model results to their mean due to changes in migration elasticity is more noticeable (Table 6). For RGSul region the deviation was about 6.7%, while in SaoPaulo and RestSul it was around 4.5%.

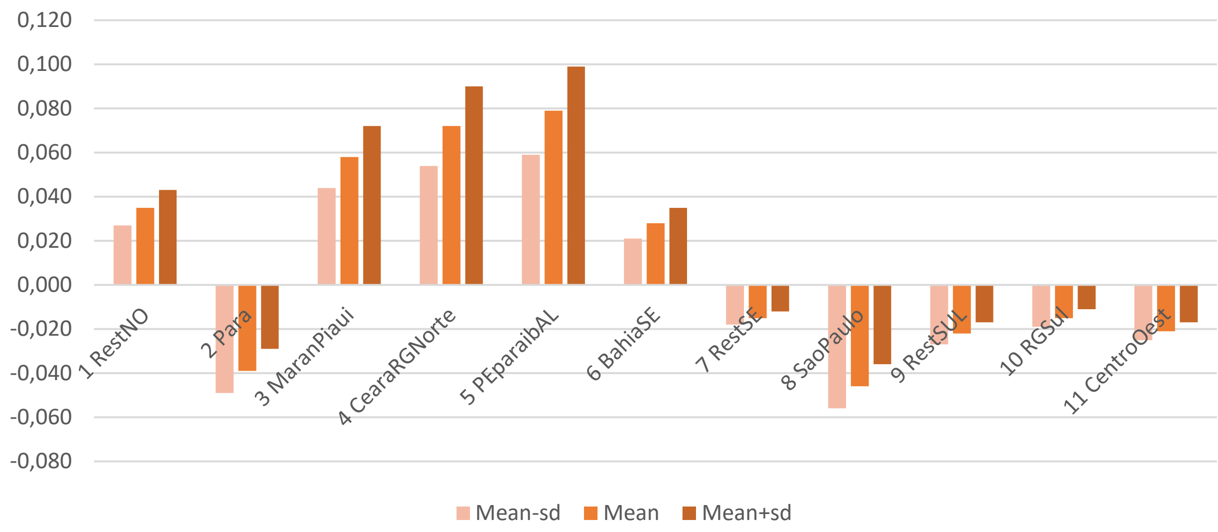
Table 6. SSA results for regional real GDP in Case 4, cumulative deviation (2016-2035)

	RealGDP		
	Mean	SD	%
1 RestNO	0.822	0.003	0.36%
2 Para	0.346	0.007	2.02%
3 MaranPiaui	1.618	0.008	0.49%
4 CearaRGNorte	1.768	0.012	0.68%
5 PEparaibAL	2.147	0.016	0.75%
6 BahiaSE	0.847	0.004	0.47%
7 RestSE	0.287	0.003	1.05%
8 SaoPaulo	0.219	0.010	4.57%
9 RestSUL	0.109	0.005	4.59%
10 RGSul	0.060	0.004	6.67%
11 CentroOest	0.368	0.006	1.63%

Source: SSA results.

This sensibility in terms of regional GDP was also reflect by the labour market variables. The regional employment results shown differences according to elasticity number (Figure 7), even though we not verified any sign changes due to SSA results. As a direct consequence, labour market variables as migration and real wages have their results also affected.

Figure 7. SSA results for regional employment in Case 4, cumulative deviation (2016-2035)



Source: SSA results.

6. FINAL REMARKS

This paper has analysed the migration flows related to investment in the long-term electricity capacity expansion in Brazil using scenarios from the national government plan, PDE 2026 (EPE, 2017b), for its simulation. Modelling results have shown that as the potential for renewable energy sources, mostly wind and solar power, is mostly concentrated in the Northeast region, migration flows are mostly directed to Northeastern states. This is noticeably a countertrend compared to historical migration flows in Brazil. As the Northeast is the least developed region of Brazil, with less skilled labour and capabilities, migration flows have normally been directed outwards of the Northeast towards the Southeast.

Further studies can explore in better detail migration flows starting from updating the data for the migration module with more recent data from the PNAD survey. Further work on computing migration elasticities would also be able to enhance the accuracy of results, once our sensitivity analysis showed that model results are sensible to this parameter. Finally, quite recent changes in labour legislation and corporate taxation which have not yet been analysed could affect boundary conditions.

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APPENDIX

Figure A1 – General and policy assumptions for selected PDE 2026' scenarios

General assumptions and constraints

- An average rate of 2.5% for Brazilian GDP (2017-2026);
- Nuclear power plant Angra 3 operation start date: jan/2026;
- No renewal for those Diesel and Oil thermal units with contracts finishing during the PDE horizon;
- An uniform expansion for wind power (to be optimized by the investment decision model) from 2021, being 80% at Northeast and 20% at South region;
- An uniform expansion for solar photovoltaic (to be optimized by the investment decision model) from 2021 of at least 1.000 MW by year;
- An uniform expansion for biomass power from 2021, subject to sugarcane supply;
- Expansion of forest biomass thermal plants from 2023, limit to 100 MW annually;

Policy guidelines

Case 1
Reference Scenario

i) Expansion of 1000 MW of wind power in 2020, being 800 MW at Northeast region and 200 MW at the South;

ii) Expansion of 1000 MW of solar photovoltaic in 2020;

iii) Installation of a thermal plant (gas) at Northeast region in 2023

Case 4
Solar Scenario

i) Considers 40% reduction in the cost of investment for solar photovoltaic generation from 2023.

ii) Therefore, after 2023 the solar expansion is greater than the minimum determinate by general guidelines.

iii) As an implication, the wind expansion is reduced relatively to the reference scenario due to peak supply reasons.

Case 5
No new hydro dams

i) Due to licensing delays and environmental impacts, this scenario considers an expansion without new hydro dams until 2028.

ii) To support this constraint, this scenario allows expansion in thermal generation from coal source.

Case 8
Directed Expansion

i) The optimization without the general constraints results in an expansion mostly concentrated in one source, then not reasonable (Case 7 in the plan)

ii) Case 8 consist of make the free expansion implementable, inputting general constraints in the optimization.

iii) Among realistic scenarios, it is the one with less intervention.

Source: elaborated by authors based on EPE (2017).

Table 2. Migration by destination and income group in case 1- % cumulative deviation (2016-2035).

CASE 1	RestNO	Para	MaranPiaui	CearaRGNorte	PEparaibAL	BahiaSE	RestSE	SaoPaulo	RestSUL	RGSul	CentroOest
1 OCC1	0.34	-0.31	0.15	0.96	0.43	-0.11	-0.26	-0.10	-0.40	-0.92	-0.06
2 OCC2	0.65	-0.52	0.64	1.09	0.90	0.12	-0.25	-0.45	-0.32	-0.60	-0.04
3 OCC3	0.31	-0.36	0.61	1.08	0.93	0.06	-0.09	-0.52	-0.27	-0.44	0.01
4 OCC4	0.11	-0.25	0.62	1.01	0.90	-0.04	-0.04	-0.45	-0.22	-0.33	-0.04
5 OCC5	0.09	-0.27	0.68	1.02	1.06	-0.04	-0.09	-0.43	-0.22	-0.33	-0.05
6 OCC6	0.09	-0.25	0.60	0.91	1.06	-0.07	-0.10	-0.37	-0.21	-0.32	-0.07
7 OCC7	0.14	-0.39	0.85	0.92	1.32	-0.15	-0.11	-0.43	-0.26	-0.39	-0.05
8 OCC8	0.09	-0.31	0.69	0.99	1.21	-0.15	-0.12	-0.36	-0.23	-0.35	-0.09
9 OCC9	0.15	-0.43	0.90	1.00	1.50	-0.22	-0.17	-0.41	-0.31	-0.44	-0.06
10 OCC10	0.25	-0.45	0.94	0.92	1.54	-0.14	-0.18	-0.48	-0.32	-0.44	-0.12

Table 3. Migration by destination and income group in case 4- % cumulative deviation (2016-2035).

CASE 4	RestNO	Para	MaranPiaui	CearaRGNorte	PEparaibAL	BahiaSE	RestSE	SaoPaulo	RestSUL	RGSul	CentroOest
1 OCC1	1,39	-1,16	0,43	4,31	1,60	-0,18	-1,21	-0,44	-1,64	-3,52	-0,31
2 OCC2	2,68	-1,82	2,18	5,00	3,19	1,59	-1,27	-1,83	-1,07	-2,07	-0,50
3 OCC3	1,40	-1,21	2,09	5,09	3,22	1,62	-0,65	-2,12	-0,60	-1,25	-0,57
4 OCC4	0,51	-0,79	2,09	4,61	3,00	1,33	-0,45	-1,84	-0,35	-0,83	-0,64
5 OCC5	0,43	-0,95	2,46	4,57	3,74	1,62	-0,65	-1,86	-0,55	-0,99	-0,57
6 OCC6	0,39	-0,87	2,19	3,98	3,82	1,30	-0,70	-1,60	-0,56	-1,00	-0,52
7 OCC7	0,41	-1,30	3,30	4,14	4,90	1,56	-0,83	-1,92	-0,72	-1,22	-0,50
8 OCC8	0,20	-1,09	2,64	4,22	4,45	1,24	-0,84	-1,61	-0,67	-1,13	-0,50
9 OCC9	0,41	-1,41	3,54	4,59	5,66	1,41	-1,10	-1,90	-0,88	-1,40	-0,60
10 OCC10	0,74	-1,45	3,70	3,99	5,76	1,88	-1,12	-2,22	-0,85	-1,41	-0,69

Table 4. Migration by destination and income group in case 5- % cumulative deviation (2016-2035).

CASE 5	RestNO	Para	MaranPiaui	CearaRGNorte	PEparaibAL	BahiaSE	RestSE	SaoPaulo	RestSUL	RGSul	CentroOest
1 OCC1	0,15	-0,17	-0,03	0,75	0,23	-0,14	-0,09	-0,06	-0,18	-0,53	-0,06
2 OCC2	0,07	-0,18	0,26	0,91	0,70	-0,09	0,04	-0,26	-0,32	-0,54	0,05
3 OCC3	-0,32	-0,03	0,39	0,86	0,80	-0,11	0,16	-0,29	-0,47	-0,53	0,21
4 OCC4	-0,64	0,17	0,57	0,84	0,87	-0,15	0,23	-0,24	-0,55	-0,44	0,25
5 OCC5	-0,57	0,09	0,57	0,82	0,96	-0,18	0,21	-0,23	-0,51	-0,38	0,15
6 OCC6	-0,55	0,05	0,54	0,74	0,97	-0,17	0,23	-0,18	-0,53	-0,47	0,10
7 OCC7	-0,91	0,16	0,80	0,77	1,25	-0,28	0,32	-0,16	-0,60	-0,64	0,18
8 OCC8	-0,80	0,13	0,71	0,81	1,14	-0,24	0,28	-0,15	-0,53	-0,59	0,11
9 OCC9	-1,08	0,18	0,90	0,86	1,40	-0,33	0,35	-0,13	-0,70	-0,71	0,20
10 OCC10	-0,91	0,25	0,86	0,81	1,43	-0,31	0,28	-0,19	-0,71	-0,58	0,11

Table 5. Realwage by destination and income group in case 1- % cumulative deviation (2016-2035).

CASE 1	RestNO	Para	MaranPiaui	CearaRGNorte	PEparaibAL	BahiaSE	RestSE	SaoPaulo	RestSUL	RGSul	CentroOest
1 OCC1	0,60	0,45	0,56	0,80	0,65	0,48	0,44	0,50	0,36	0,17	0,50
2 OCC2	0,58	0,28	0,59	0,74	0,61	0,30	0,19	0,20	0,11	0,03	0,33
3 OCC3	0,42	0,24	0,52	0,69	0,55	0,21	0,20	0,12	0,06	0,03	0,29
4 OCC4	0,28	0,19	0,46	0,61	0,50	0,14	0,18	0,09	0,04	0,02	0,21
5 OCC5	0,26	0,18	0,47	0,62	0,55	0,15	0,16	0,10	0,04	0,02	0,20
6 OCC6	0,25	0,17	0,43	0,57	0,55	0,15	0,16	0,12	0,06	0,03	0,19
7 OCC7	0,27	0,16	0,53	0,63	0,66	0,14	0,18	0,13	0,04	0,01	0,21
8 OCC8	0,24	0,15	0,45	0,62	0,60	0,12	0,17	0,12	0,05	0,01	0,17
9 OCC9	0,30	0,17	0,57	0,68	0,74	0,13	0,18	0,15	0,04	0,00	0,22
10 OCC10	0,33	0,17	0,59	0,66	0,76	0,14	0,18	0,12	0,02	-0,01	0,22

Table 6. Realwage by destination and income group in case 4- % cumulative deviation (2016-2035).

CASE 4	RestNO	Para	MaranPiaui	CearaRGNorte	PEparaibAL	BahiaSE	RestSE	SaoPaulo	RestSUL	RGSul	CentroOest
1 OCC1	2,49	1,88	2,29	3,42	2,66	2,10	1,79	2,10	1,51	0,78	2,07
2 OCC2	2,26	1,10	2,17	3,07	2,26	1,49	0,57	0,72	0,42	0,17	1,09
3 OCC3	1,53	0,86	1,79	2,77	1,91	1,14	0,51	0,33	0,27	0,18	0,74
4 OCC4	0,95	0,62	1,50	2,39	1,64	0,88	0,40	0,21	0,22	0,15	0,43
5 OCC5	0,95	0,62	1,65	2,47	1,98	1,08	0,41	0,30	0,21	0,13	0,53
6 OCC6	0,89	0,60	1,51	2,23	2,00	1,00	0,43	0,38	0,26	0,15	0,54
7 OCC7	0,94	0,58	1,98	2,52	2,47	1,17	0,48	0,41	0,23	0,10	0,63
8 OCC8	0,82	0,52	1,67	2,41	2,25	1,03	0,43	0,41	0,22	0,08	0,55
9 OCC9	1,04	0,62	2,14	2,75	2,81	1,19	0,48	0,49	0,23	0,08	0,67
10 OCC10	1,11	0,62	2,20	2,54	2,81	1,28	0,43	0,34	0,13	0,02	0,67

Table 7. Realwage by destination and income group in case 5- % cumulative deviation (2016-2035).

CASE 5	RestNO	Para	MaranPiaui	CearaRGNorte	PEparaibAL	BahiaSE	RestSE	SaoPaulo	RestSUL	RGSul	CentroOest
1 OCC1	0,32	0,25	0,28	0,51	0,36	0,25	0,27	0,29	0,22	0,10	0,27
2 OCC2	0,24	0,17	0,30	0,55	0,44	0,15	0,20	0,13	0,01	-0,06	0,21
3 OCC3	0,09	0,15	0,32	0,52	0,44	0,12	0,23	0,09	-0,10	-0,11	0,25
4 OCC4	-0,07	0,13	0,32	0,49	0,44	0,08	0,23	0,07	-0,17	-0,13	0,21
5 OCC5	-0,05	0,12	0,32	0,48	0,47	0,07	0,22	0,08	-0,15	-0,10	0,17
6 OCC6	-0,06	0,09	0,29	0,44	0,47	0,08	0,23	0,09	-0,16	-0,14	0,14
7 OCC7	-0,20	0,08	0,36	0,49	0,57	0,06	0,26	0,10	-0,22	-0,23	0,15
8 OCC8	-0,17	0,07	0,32	0,47	0,52	0,05	0,24	0,09	-0,19	-0,21	0,10
9 OCC9	-0,27	0,05	0,39	0,52	0,63	0,05	0,28	0,11	-0,25	-0,27	0,14
10 OCC10	-0,18	0,12	0,42	0,52	0,65	0,05	0,27	0,09	-0,26	-0,22	0,16