**The importance of the electricity sector: a national and inter-regional input-output analysis**



A importância do setor de eletricidade: uma análise nacional e inter-regional de insumo-produto

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**Abstract:** This paper analyzes the structural evolution of the electric sector in Brazil between 2010 and 2019 using the Input-Output framework. National results show that the industry has above average production multipliers that follow Brazilian economic performance and is considered a key sector – especially due to its supply –, having linkages with all other activities that exceed the economy’s average. Given its importance, the paper analyzes the regional gains and spillovers from larger investments in the sector, revealing that the Northeast is the region with the most significant impact on production, taxes, employment, and salaries.

**Keywords:** Input-Output; Energy; Electricity; Investment.

**JEL Classification:** C67; H54; O18.

**Resumo:** Este trabalho analisa a evolução da estrutura do setor elétrico brasileiro entre 2010 e 2019 a partir da modelagem insumo-produto. Os resultados nacionais mostram que o setor possui multiplicadores de produção acima da média, os quais acompanham o desempenho da economia brasileira, e é considerado estratégico – especialmente pelo lado da oferta –, sendo que suas relações afetam todas as outras atividades acima da média da economia. Dada essa importância, o artigo investiga os ganhos e transbordamentos regionais de maiores investimentos no setor, o que revelou que o Nordeste é a região com os maiores impactos sobre produção, impostos, emprego e salários.

**Palavras-chave:** Insumo-Produto; Energia; Eletricidade; Investimento.

**Classificação JEL:** C67; H54; O18.

**1.** **Introduction**

The electrical sector[[4]](#footnote-4) is essential to the proper functioning of the economy, with a two-way causality between electricity consumption and economic growth (Apergis; Payne, 2011; Sarway; Chen; Waheed, 2017; Stern; Burke; Bruns, 2019). Thus, the unavailability of electricity can be a bottleneck for production and generate a series of adverse effects.

Given this strong relationship with economic performance, the analysis of the electricity sector and its dynamics provides important insights into the functioning of the economy. The paper’s goal is to examine data from 2010, 2013, 2016 and 2019 using the Input-Output framework to verify the importance of the electrical activity for the Brazilian economy. Therefore, the evolution of its production multipliers will be analyzed and its degree of connectivity with other productive sectors will be measured through linkage indexes – both traditional and pure –, coefficients of variation and fields of influence.

Adding to the relevance of electrical activity is the fact that the country has faced recurring threats of water crises during the 2010s, which harmed electricity generation due to Brazil's heavy reliance on hydroelectric sources (Brazil, 2020). To mitigate potential adverse effects, investments in the sector – especially in other renewable alternatives – is essential (Silva; Neto; Seifert, 2016); in a continental country like Brazil, however, the decision of *where* to invest is fundamental.

In order to support this policy, this paper examines in which region investment in the electricity sector generates the greatest economic impact, using an interregional input-output matrix estimated with data from the Electronic Invoice of 2013 (Oliveira, 2020). Such frameworks[[5]](#footnote-5) can be used to simulate investment shocks and other components of final demand and provide important guidance for planning and implementing public policies.

The national results show that the electricity sector has above-average production multipliers – evolving in line with the economy's performance in the 2010s – and that it can be considered strategic, with linkage indexes above one, which is more pronounced on the supply side. Furthermore, its supply and demand relationships influence all other activities in a way that is above the average of the economy.

The regional analysis, in turn, reveals that investments in the electricity sector in the Northeast generate the highest impact on production, taxes, employment and wages, which is consistent with the fact that the region is the most suitable for investments in renewable electricity sources. However, there are large spillover effects to other regions, especially to the Southeast, which concentrates a large part of the country's production.

The rest of the paper is organized as follows: Section 2 describes the Brazilian electricity sector and its evolution throughout the 2010s, as well as its relationship with the country's economic performance. Section 3 presents the theoretical framework of the national and regional input-output models, the results of which are in Sections 4 and 5, respectively. The concluding remarks are presented in Section 6.

**2. Overview of the Brazilian Electricity Sector**

 In Brazil, the Energy Research Company (*Empresa de Pesquisa Energética* - EPE) projects that electricity demand will increase by 31.3% between 2019 and 2026 (Brazil, 2017), from just under 500 terawatt-hours (TWh) to over 653 TWh. Following the trend of the 2010s, the rural and commercial classes should be the main channels for increased consumption, while the industrial category will see the smallest growth (Brazil, 2021).

To meet this demand and avoid negative impacts on economic activity, the country must have a robust, diversified and renewable generation capacity. It is well known that Brazil is not only one of the main producers of electricity, but also uses a quantity of renewable sources above the world average, as can be seen in Table 1.

Table 1: Comparison of electrical matrices – Brazil and World (% of the respective total)

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|   | **Hydro-electric** | **Biomass** | **Wind** | **Solar** | **Total Renewable** | **Non-Renewable** |
| *Brazil* | *World* | *Brazil* | *World* | *Brazil* | *World* | *Brazil* | *World* | *Brazil* | *World* | *Brazil* | *World* |
| **2010** | 78.2 | 16.6 | 6.1 | 1.8 | 0.4 | 1.7 | 0.0 | 0.2 | 84.7 | 20.7 | 14.0 | 79.4 |
| **2011** | 80.6 | 16.4 | 5.9 | 1.8 | 0.5 | 2.1 | 0.0 | 0.3 | 87.0 | 21.0 | 11.2 | 79.1 |
| **2012** | 75.2 | 16.8 | 6.3 | 1.9 | 0.9 | 2.4 | 0.0 | 0.5 | 82.4 | 22.0 | 15.8 | 78.1 |
| **2013** | 68.5 | 16.8 | 7.0 | 2.0 | 1.2 | 2.9 | 0.0 | 0.7 | 76.6 | 22.8 | 21.3 | 77.3 |
| **2014** | 63.2 | 16.8 | 7.6 | 2.1 | 2.1 | 3.2 | 0.0 | 0.9 | 72.9 | 23.5 | 24.8 | 76.6 |
| **2015** | 61.9 | 16.6 | 8.2 | 2.2 | 3.7 | 3.6 | 0.0 | 1.1 | 73.7 | 24.0 | 23.9 | 76.1 |
| **2016** | 65.8 | 16.8 | 8.5 | 2.3 | 5.8 | 4.0 | 0.0 | 1.4 | 80.1 | 25.0 | 17.6 | 75.2 |
| **2017** | 63.1 | 16.4 | 8.4 | 2.4 | 7.2 | 4.6 | 0.1 | 1.9 | 78.8 | 25.8 | 18.8 | 74.3 |
| **2018** | 64.7 | 16.4 | 8.6 | 2.4 | 8.1 | 5.0 | 0.6 | 2.3 | 81.9 | 26.6 | 15.7 | 73.5 |
| **2019** | 63.5 | 16.3 | 8.3 | 2.5 | 8.9 | 5.5 | 1.1 | 2.7 | 81.8 | 27.5 | 15.9 | 72.6 |

Source: 2020 National Energy Balance (BEN)[[6]](#footnote-6) and Energy Information Association.

*Note*: green highlights that the contribution of the respective source is greater in Brazil than in the world, and red indicates that the source has a greater weight in the generation of electrical energy in the rest of the planet.

Table 1 shows that hydroelectric plants dominate the Brazilian electrical matrix – with a share of 63.5% in 2019, although this percentage has decreased over the decade –, and shows that wind energy – mainly generated in the Northeast (IBGE, 2016) – is becoming increasingly important on the national scene. This fact can be observed in Figure 1, which shows the growth rates in electricity generation from 2010 to 2019 for the different sources available in BEN (Brazil, 2020).

Figure 1: Growth in the Generation of Different Energy Sources[[7]](#footnote-7)



Source: Brazil (2020).

Considering that renewable sources account for around 80% of electricity generation, the Brazilian electrical matrix is ​​extremely clean when compared to the rest of the world. However, it is still largely dependent on hydroelectric sources, which has led to a number of concerns about the security of electricity supply over the last decade due to successive water crises (Silva; Neto; Seifert, 2016).

The diversification of Brazil's electricity matrix has been driven not only by strategic considerations, but also by the declining cost of other renewable sources (Roser, 2023), especially wind power. In particular, once transmission costs and externalities are taken into account, there is evidence that wind power is becoming the cheapest mean of generating electricity in Brazil (De Jong; Kiperstok; Torres, 2015).

In addition to the diversification of electricity generation, it is interesting to analyze its evolution throughout the 2010s. As shown above, electricity is an essential input for all productive activities, so blackouts or rationing can hinder growth. This relationship can be seen in Figure 2, which shows the real growth of production in the electricity sector[[8]](#footnote-8), the percentage change in electricity consumption in TWh (Brazil, 2021) and the real rate of change in Gross Domestic Product (GDP).

Figure 2: Relationship between Electricity Sector Growth and GDP

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Source: IBGE and Brazil (2021).

Figure 2 shows that during the period of economic expansion until 2014, energy production and consumption grew more than GDP, which was repeated during the recession of 2015 and 2016, when consumption and generation decreased more slowly. This trend continued during the economic stagnation experienced between 2017 and 2019. In fact, the analysis of consumption by class shows that the growth of all categories was greater between 2010 and 2013, and the downturn between 2013 and 2016 was driven by the industrial sector, which is the country’s main consumer of electricity (Brazil, 2021).

**3. Theoretical Framework**

**3.1. National Input-Product Matrix**

**3.1.1. Estimate of the National Input-Output Model**

In Brazil, Input-Output Tables (IOTs) are published every five years by IBGE considering the dimensions *product (m)* $×$ *sector (n)*[[9]](#footnote-9). The matrices collect data on the entire Brazilian productive structure and include information on both domestic supply and demand for national and imported products, in addition to considering indirect taxes net of subsidies, trade and transport margins and the value added of each product and activity.

However, the periodicity of official IOTs does not allow annual analysis to be carried out, which can be circumvented through estimates based on Uses and Resources Tables (TRUs) and other data sources. For this reason, this paper uses of the methodology proposed by Guilhoto and Sesso Filho (2005, 2010), which consists of reconciling the resource tables of goods and services[[10]](#footnote-10), valued at basic prices, with the table of uses of goods and services[[11]](#footnote-11), which uses data at consumer prices.

However, to avoid changes in relative prices and to make the matrices comparable over time, they must be deflated. Given the way in which IBGE publishes national accounts and TRUs – with values ​​at current prices and those of the previous year, enabling the construction of chained price indexes –, dividing by this price indexes results in non-additive matrices: in other words, the total deflated output is not equal to the sum of the deflated output of each sector/product.

According to Alves-Passoni (2019, p. 81-85), the nominal price change of a product is the result of a combination of two phenomena: general inflation and the change in relative prices. Therefore, the author proposes a two-step method. Initially, the matrices are deflated by the most aggregate deflator – in this case, the gross value of the economy's production –, which eliminates the inflationary effect. Then, the volume index is adjusted by the chained price indexes specific to each cell of the matrix, eliminating the change in relative prices.

In practice, the matrix of uses at basic prices was estimated following Guilhoto and Sesso Filho (2005, 2010) at both current prices and prices from the previous year, for each year between 2010 and 2019. After this process, the method described by Alves-Passoni (2019, p. 191-193) was applied to the TRUs at basic prices, using as the most aggregated deflator the one with respect to the gross production value of the economy.

Given the existence of inconsistencies in IBGE’s TRUs data[[12]](#footnote-12), the TRUs at basic prices from the previous year were adjusted using the procedure outlined in Appendix D of Alves-Passoni (2019). The GRAS method (Temurshoev; Miller; Bouwmeester, 2013) was applied to balance the system's tables, using as reference the vectors of supply and demand of products and sectors at basic prices from the previous year (before adjustments).

Once estimated and deflated, the IOTs were converted into sector *x* sector dimension tables using the industry-based technology assumption, where each sector has only one type of technology; in other words, each product represents a fixed proportion each activity’s output (Miller; Blair, 2009, p. 197).

It is worth noting that, although all estimated IOTs are of dimension 68, in order to facilitate visualization, the results presented in most of the graphs and indicators that appear throughout the article were made with the aggregation of these matrices to 25 activities, following the classification set out in the Appendix.

With the estimated, deflated and aggregated matrices, it is possible to follow the model designed by Leontief (1986) to analyze the intersectoral relations of the economy. Assuming that the production functions are of the Leontief type – that is, that the inputs are used in fixed proportions and without substitution – and with the additional assumption of constant prices, it is possible to define the matrix $A\_{n×n}$ of direct technical coefficients:

$$\begin{array}{c}A\_{n×n}=\left[\begin{matrix}a\_{ij}\end{matrix}\right]=\left[\begin{matrix}\frac{z\_{ij}}{x\_{j}}\end{matrix}\right],\#\left(1\right)\end{array}$$

where $z\_{ij}$ is the intermediate consumption that the sector $j$ demanded from the activity $i$ and $x\_{j}$ is the total production of the industry $j$. Thus, the matrix above shows the inputs directly requested from other industries by the $j$ sector in its production process. In terms of calculation and implementation, if $x\_{j}$ is 0, $a\_{ij}$ will also be 0.

This leads to the well-known inverse Leontief matrix equation:

$$\begin{array}{c}x\_{n×1}=\left(I-A\right)\_{n×n}^{-1}∙y\_{n×1}= B\_{n×n}∙y\_{n×1},\#\left(2\right)\end{array}$$

where $x\_{n×1}$ is the sectoral production vector, $I\_{n×n}$ is the $n$ order identity matrix and $y\_{n×1}$ is a vector containing the sum of all final demand components per sector. This equation allows us to determine, given exogenous demand shocks, how production will vary in the short term, considering both direct and indirect intermediate consumption in the productive sectors.

The Leontief model is useful not only for calculating the impact of exogenous shocks to final demand on output in the short run, but also for analyzing a series of indicators based on the IOTs, such as production multipliers ($M\_{j}^{prod}$).

These indexes measure the effect of increasing the final demand of the $j$ sector on the production of all economic sectors, considering both its direct and indirect effects. Therefore, production multipliers are calculated from the sum of the rows in each column of the $B$ matrix, considering the direct and indirect impacts of demand expansion on output:

$$\begin{array}{c}M\_{j}^{prod}=\sum\_{i=1}^{n}b\_{ij}\#\left(3\right)\end{array}$$

**3.1.2. Linkage Indexes and Coefficients of Variation**

In addition to the impact analysis of the demand of the electricity sector, it is also interesting to analyze its structural relations with other economic activities. The Rasmussen-Hirschman linkage indexes (Rasmussen, 1957; Hirschman, 1961) allow the analysis of the most linked sectors within the economy – that is, those whose demand changes cause impacts above the economy’s average – both on the supply side (forward) and on the demand side (backward).

The backward indicators – which are also called dispersion power$ (PD\_{j}$) – are based on the $B=(I-A)^{-1}$ matrix, while the forward – dispersion sensitivities ($SD\_{j}$) – are calculated from the Ghosh matrix(Ghosh, 1958) in order to better capture the dynamics of the economy’s supply side, looking at production from the perspective of destinations (along the lines of the IOT). For a comprehensive review of the calculation and interpretation of these metrics, see Vale and Perobelli (2020, p. 80).

Therefore, if the indicator is greater than 1, the sector has a more intensive demand or supply impact than the economy's average. If both $PD\_{j}$ and $SD\_{j}$ are greater than 1, the activity is classified as a *key sector*.

However, above-average impacts do not imply a high number of links, as the demand or supply effects of a given sector may be concentrated in that sector and in a few other activities. To assess this dispersion, coefficients of variation ($CV$) are used (Vale; Perobelli, 2020, p. 81), which can also be calculated from a supply and demand perspective. The lower the coefficient, the more dispersed the impact of the sector, i.e. the greater the number of activities it affects. On the other hand, if $CV$ is high, the impact of its supply/demand is concentrated in a few industries.

Finally, although they provide an interesting analysis of the interconnectedness of the economy, traditional linkage indexes are sensitive to the size of each sector's output. To overcome these problems, we consider pure linkage indexes (Guilhoto et al., 1994). For a practical discussion of how to calculate these indicators, see Vale e Perobelli (2020, p. 91). Although mathematically complex, the indexes are intuitive to interpret:

* The normalized pure backward index ($\overline{PBL}\_{j}$) shows the impact of the sector's output value $j$ on the rest of the economy, excluding demand for its own products and returns from the rest of the economy to the activity. Thus, the index shows the relative importance of the sector's demand.
* The normalized forward index ($\overline{PFL}\_{j}$) shows the impact of the production of the rest of the economy on the $j$ sector, i.e. the relative importance of its supply.
* The normalized total pure index ($\overline{PTL}\_{j}$) is calculated from the average between the previous metrics and indicates the total impact or dynamism of the sector, relative to the economy's average. If the metric is greater than 1, the sector is considered key.

**3.2. Regional Input-Output Matrix**

Originally designed for applications at the national level, the input-output model can be used to analyze subnational units, given, for example, different technologies and production levels in each region and the greater importance of interregional flows for smaller economies, both with the rest of the country and with the international market (Miller; Blair, 2009, p. 69). In addition, as pointed out by Isard *et al*. (1998), the inter-regional system enables the existence of spillovers, in which increases in demand in a region affect the economic performance not only of itself, but also of other locations in the country.

The main difficulty in developing an inter-regional model is the need to estimate commercial transactions between regions, which can be difficult due to the scarcity of data and becomes exponentially more needed as the number of considered regions increases (Miller; Blair, 2009). To mitigate this problem, this paper uses the estimated regional matrix described in Oliveira (2020), calculated from a hybrid data method – i.e. with both census and sampled data – using data from the electronic invoice (Nota Fiscal Eletrônica - NFe) for the 27 Federation Units (*Unidades da Federação* - UFs), 128 products and 68 sectors in 2013.

The methodology of Oliveira (2020) is an extension of the Supply and Uses Interregional Tables (SUIT) method proposed by Guilhoto *et al*. (2019)[[13]](#footnote-13), with the advantage of allowing a more accurate estimation of state transactions using NFe data. Using a combination of methods such as location quotients and RAS, as well as bottom-up and top-down approaches, SUIT guarantees consistency of regional matrices with national ones and with data from regional accounts released by IBGE, but also preserves economic features of each state (Guilhoto *et al*., 2019).

Understanding this heterogeneity across regions is fundamental to the best design of public policies, since the allocation of resources has different effects depending on where they are invested. In the energy context, quantifying the magnitude and heterogeneity of these effects is crucial because investments in different locations have different economic consequences depending on where the sector's inputs come from and where the energy is sold. The strategy for doing so is described in more detail in Section 5.

**4. National Analysis**

This section presents the analysis of the indicators constructed based on the national IOTs estimated for the years 2010 to 2019. The graphs highlight the years 2010, 2013, 2016 and 2019. The section is divided into two parts: *(i)* the impact analysis, which deals with the production multipliers; and *(ii)* the structure analysis, which shows the traditional and pure linkage indexes, the coefficients of variation and the field of influence.

**4.1. Impact Analysis**

The analysis of the simple production multiplier, which measures the direct and indirect effect of a unit increase in the final demand of each sector on the marginal production of other economic activities, confirms the analyzes carried out in Figure 2 and shows how the impact of the electricity sector goes hand in hand with the Brazilian economy.

The results are shown in Figure 3, where the sectors are placed on the vertical axis and the multiplier on the horizontal axis. Each of the four panels represents a year analyzed (2010, 2013, 2016 and 2019); the dotted lines, in turn, were used to facilitate comparisons between the 25 activities and refer to the highest value observed for that year (gray dashed line) and the value of the electricity sector (in black).

Figure 3: Simple Production Multiplier



Source: Original work based on estimated IOTs.

As shown in the graph, there was a significant expansion in the value of the electricity sector multiplier between 2010 and 2013 – reaching a peak of 2.27 in 2014, the year prior to the onset of the economic crisis –, followed by a drop of 16% between 2014 and 2016 and relative stagnation until 2019. Thus, the results of the input-output approach are in accordance with the intimate relationship between economic activity and electricity generation, which is well documented econometrically in Brazil (Pao; Fu, 2013) and internationally (Apergis; Payne, 2011; Sarwar; Chen; Waheed, 2017).

Furthermore, apart from some subsectors that constitute the manufacturing industry (such as food and beverage manufacture, oil refining, metallurgy and automobiles and parts), the electrical sector presents one of the largest multipliers in the years analyzed, above the average of the economy, especially after 2010. Therefore, it is interesting to analyze how this industry is linked to the rest of the economy to identify if electricity is demand intensive, supply intensive, or both.

**4.2.** **Structure Analysis**

**4.2.1. Linkage Indexes and Coefficients of Variation**

Figures 4 and 5 show the evolution of the forward and backward indexes of the electricity sector over the decade. Since 2011, the electricity sector has been considered a key activity with above-average impacts on both supply and demand (forward and backward indexes greater than 1), confirming the results found in the 2011 analysis of Bertussi, Takasago and Guilhoto (2020). In particular, the authors find that the electricity sector has the highest forward linkage among the 14 activities analyzed in the paper.

The activity has a greater supply-side linkage, indicating that its production is very important as an input for other industries. Like the multipliers, both indexes evolve until 2014, declining during the recession. Since 2016, there has been a slight improvement, although there was a decline between 2018 and 2019.

**Figure 4: Linkage Indexes of the 68 Sectors per Year**



Source: Original work based on estimated IOTs.

*Note*: the upper right quadrant of each panel presents the key sectors, and the Electricity and Gas sector is highlighted in black. Dotted lines refer to the index value equal to one.

Figure 5: Electricity Sector Linkage Indexes in 2010, 2013, 2016 and 2019



Source: Original work based on estimated IOTs

However, as explained in the methodology section, high connection rates do not necessarily imply a high number of connections with other sectors. To assess this dispersion, coefficients of variation are used ($CV$): the smaller the metric, the more dispersed the impact of the sector, i.e. the greater the number of activities affected by it. On the other hand, if $CV$ is high, the impacts of its supply or demand are concentrated in a few industries.

Figure 6 displays the average of the results found for the years 2010, 2013, 2016 and 2019[[14]](#footnote-14), and shows that the electricity sector has a more dispersed supply, i.e. its product is used as an input by many other industries. On the other hand, in 2019, more than half of the sector's purchases come from itself, resulting in a more concentrated demand compared to other economic activities.

In general, the linkage indexes and dispersion coefficients show that the electricity sector is strongly demanded by other activities in the economy and that the stimulus from its supply is comprehensive and uniform. On the demand side, its impacts are above the economy average, but are concentrated due to a high $CV$, which reflects the fact that the sector demands a lot from itself and consumes a high proportion of imported inputs (Montoya *et al*., 2015).

The results confirm the findings of Montoya *et al.* (2015) and Bertussi, Takasago and Guilhoto (2020) regarding the importance of the activity, the wide dispersion of its supply and the greater relative concentration of its demand. In addition, they show the evolution of the energy sector since 2002 (Firme; Perobelli, 2012) and 2005 (Guilhoto; Sesso Filho, 2010)[[15]](#footnote-15), when it was not considered a key sector.

Figure 6: Average Coefficients of Variation in 2010, 2013, 2016 and 2019



Source: Original work based on estimated IOTs.

**4.2.2. Pure Linkage Indexes**

Given the sensitivity of linkage indexes to the size of the producers in each sector, it is also interesting to look at the pure linkage indexes (Guilhoto *et al.*, 1994). The indexes, shown in Figures 7 and 8[[16]](#footnote-16), confirms the dynamism of the energy sector – considered a key sector every year – and its importance mainly on the supply side ($\overline{PFL}$), i.e. providing inputs to other industries. Furthermore, it is possible to observe that the decline in production due to the recession of 2015 and 2016 may have affected the indicators analyzed in this work, given the improvement in pure indexes – mainly those of supply – between 2013-2016 and 2016-2019.

Figure 7: Electricity Sector Linkage Indexes in 2010, 2013, 2016 and 2019



Source: Original work based on estimated IOTs.

Figure 8: Pure Linkage Indexes of the 68 Sectors in 2010, 2013, 2016 and 2019



Source: Original work based on estimated IOTs.

**4.2.3. Field of Influence**

Although linkage indexes show the importance of a sector in the economy as a whole, it is difficult to visualize the main linkages through which this occurs (Vale; Perobelli, 2020, p. 98). For this purpose, the field of influence is used.

This concept shows how changes in direct requirements – that is, in the matrix of direct technical coefficients ($A$) – are distributed across the economy, allowing the visualization of which intersectoral relationships are the most important among productive activities. Therefore, the field of influence can be calculated from the $A$ matrix and a matrix of increments $E\_{n×n}=\left(\begin{matrix}ε\_{ij}\end{matrix}\right)$. For each intersectoral relationship $(kl)$, $E$ is calculated as follows:

$$\begin{array}{c}ε\_{ij}=\left\{\begin{array}{c}ε, i=k, j=l\\0, otherwise\end{array}\right. \#\left(4\right)\end{array}$$

where $ε$ is a positive and small number – here, $ε=0,001$. Note that $E$ will always have only one element other than 0.

Thus, it is possible to create, for each intersectoral relationship $(k$, $l)$, a new matrix of total requirements $B(E)=[I-(A+E)]^{-1}$. The field of influence matrix $F$ for each relationship $(k$, $l)$ will be:

$$\begin{array}{c}F\left(ϵ\_{kl}\right)\_{n×n}=\frac{B\left(E\right)-B}{ϵ}\#\left(5\right)\end{array}$$

This process is repeated iteratively for all coefficients and relations present in the $A$ matrix of technical coefficients (always with isolated increments, obeying Equation 4).

Finally, it is possible to define the $S$ matrix, in which each element $(k$, $l)$ is the sum of the squares of the respective $F$ matrix. This makes it possible to see which technical coefficients have the greatest fields of influence – in other words, those with the greatest sensitivity to variations and, consequently, with the greatest potential for impact:

$$\begin{array}{c}S\_{n×n}=\left[\begin{matrix}s\_{kl}\end{matrix}\right]=\left[\begin{matrix}\sum\_{k=1}^{n}\sum\_{l=1}^{n}[F\left(ϵ\_{kl}\right)]^{2}\end{matrix}\right]\#\left(6\right)\end{array}$$

The results for the mean[[17]](#footnote-17) of the estimated matrices can be seen in Figure 9, where darker squares indicate a higher $s\_{kl}$, i.e. a strong link between sectors. For ease of comparison, Figure 9 classifies the values into four distinct categories, depending on their magnitude against the average and standard deviation (SD) of the economic linkages.

Reading across the rows relates to the sector's supply influence, while the columns show the demand influence. For example, if there are marginal changes in technical coefficients, Agriculture would buy between 1 and 2 SD more inputs from the Electricity and Gas sector than the variation in the economy's average demand. The most interesting aspect, however, is to analyze the overall performance of a sector as a supplier (line) or consumer (column) in comparison to all other activities: the darker the line/column, the stronger the influence of the sector's supply/demand.

Figure 9: Field of Influence (average of 2010, 2013, 2016 and 2019) – 25 Sectors



Source: Original work based on estimated IOTs.

According to Figure 9, among the 25 activities, the electricity sector has strong relations of both supply (lines) and demand (columns) with all sectors, second only to the oil refining and coke ovens industry. In fact, from both perspectives, both sectors are the only ones to have links with all other activities that are above the average for the economy. Bertussi, Takasago and Guilhoto (2020) also find that the electrical sector has a large field of influence, classifying it – along with Transportation and Manufacturing– as one of the most important in the Brazilian economy in 2011.

Therefore, the chain analysis carried out in the linkage indexes is complemented by the field of influence: not only is the electricity sector key for the country, but changes in technical coefficients in the electricity sector promote above-average changes in all economic activities, both on the supply and demand side.

**5. Inter-Regional Analysis**

The national analysis makes it possible to assess the importance of the electricity sector from both a demand and a supply perspective, highlighting its high degree of interdependence with other productive activities and its evolution over the last decade. The imminent threat of water and energy crises that Brazil has experienced in the last further highlights that new investments in the sector are needed to expand and diversify its energy distribution and generation capacity.

However, in a continental country with increasing budget restrictions like Brazil, it is necessary to decide in which state or region to invest. To answer this question, we will use the 2013 Inter-Regional IOT, estimated from NFe data obtained from the Federal Tax Service for 27 UFs and 68 sectors (Oliveira, 2020).

The objective of this section is to analyze how investment shocks in the electricity sector propagate when applied separately in different regions. The aim is to identify which regions have the highest potential impact and most significant spillovers, i.e. the largest effects on output and economic activity in other states.

This question is relevant given the great heterogeneity among Brazilian regions, since, as shown Oliveira (2020), isolated shocks in different locations in the country have very different effects on production and on the components of value added. Therefore, the aim of this section is to consider these differences in order to discuss the most effective investment strategies, guiding public policies towards places that have the greatest economic impacts and the greatest effects on reducing inter-regional inequalities.

In addition, the interconnectedness of sectors in different states and regions implies that the impact of shocks in a given location is spread throughout the country, given the dependence on inputs and goods and services from elsewhere, known in the literature as spillover effects. Thus, the simulated shocks seek to analyze the regional and national impacts of the increase in investment in the electricity sector, as well as evaluate its spillovers to other Brazilian locations and verify the costs and benefits of regional diversification of its investments and production.

First, it is important to analyze the subnational structure of the electricity sector. From a regional perspective, more than a third of the country's electricity generation in 2013 was concentrated in the Southeast, followed by the South (27.4%), Northeast (14%), North (12.6%), and Midwest (12.1%) (Brazil, 2021). This composition is also reflected in the estimated values ​​for the 2013 IOT shown in Table 2, in which the Southeast region, being also the main consumption hub, has an even greater weight in relation to the total, concentrating 52.4% of the Gross Fixed Capital Formation (GFCF) and 43.4% of production and final demand.

Table 2: Regional Composition of Investment, Production and Final Demand of the Electricity Sector in the Inter-Regional IOT 2013 (BRL Million in 2013)

| **Region** | **GFCF** | **%** | **Production** | **%** | **Final Demand** | **%** |
| --- | --- | --- | --- | --- | --- | --- |
| North | 28 | 8.0% | 17,016 | 9.4% | 5,027 | 9.0% |
| Northeast | 59 | 17.2% | 33,535 | 18.5% | 11,362 | 20.4% |
| Southeast | 180 | 52.4% | 77,806 | 43.0% | 24,205 | 43.4% |
| South | 52 | 15.3% | 35,709 | 19.7% | 10,328 | 18.5% |
| Midwest | 24 | 7.1% | 16,820 | 9.3% | 4,869 | 8.7% |
| **Total** | **343** | **100%** | **180,886** | **100%** | **55,791** | **100%** |

 Source: Original work based on the 2013 Regional IOT.

We highlight the process of generation diversification between 2010 and 2013 om Figure 10. During this period, Northeast increased its importance in the composition of the national electrical matrix by about 3%, and its energy generation increased by more than 30% – nearly three times the rate of the country as a whole (10.6%) (Brazil, 2021).

In fact, in 2014, the Northeast concentrated 76% of all installed wind and solar power (IBGE, 2016, p. 76), the sources with the highest growth rate in the country, as can be seen in Figure 1. Figure 10 shows the variation in energy generation by region between 2010 and 2013, illustrating the rapid growth in the Northeast and some stagnation in the Southeast (Brazil, 2021).

Figure 10: Variation in Electricity Generation by Region



Source: Brazil (2021).

**5.1. Structural Analysis**

The inter-regional matrix allowed the simulation of five regional shocks in GFCF amounting to BRL 34.3 million – 10% of the estimated GFCF for the electricity sector in 2013[[18]](#footnote-18) – in the five major regions of the country (North, Northeast, Southeast, South and Midwest).

This amount has been distributed within each region following the same proportion of the estimated investment for the activity that characterizes the electricity sector in the inter-regional IOT: Electricity and Gas. Take for example the Northeast region which was responsible for BRL 58.89 million of the BRL 343 million invested by the electricity sector in 2013. Since Bahia claimed 28.5% of the GFCF of the electricity sector in the Northeast (BRL 16.8 million), its Electricity and Gas activity will also receive 28.5% of the shock of BRL 34.3 million.

In general, let $I^{R}$ is the total investment in the electricity sector in the region $R$, $I^{UF}$ the investment of activity at a UF and $c\_{\left(27⋅68\right)×1}$ the vector of the monetary shocks to be applied to the final demand of the inter-regional matrix. The elements $c\_{UF,i}$ (shock in the sector $i$ of the state $UF$) will only be different from 0 if the activity is Electricity and Gas ($EG$) and the UF in question belongs to the shock region. Therefore, the elements $c\_{UF,i}$ are as follows:

$$\begin{array}{c}c\_{UF,i}=\left\{\begin{array}{c}34.3 ⋅\frac{I^{UF}}{I^{R}},  i=EG \&\&\&\&and UF \in \{R\}\\0, otherwise\end{array}\right.\#\left(7\right)\end{array}$$

The shock vector is then multiplied by the regional Leontief matrix – obtained in a similar way to the national model –, so that is possible to find the variation in production $Δx\_{\left(27⋅68\right)×1}$ in each sector of each UF due to the increase in investment in the Electricity and Gas activity in each region. The expression is given by:

$$\begin{array}{c}Δx\_{\left(27⋅68\right)×1}=B\_{\left(27⋅68\right)×\left(27⋅68\right)}⋅c\_{\left(27⋅68\right)×1}\#\left(8\right)\end{array}$$

Similarly to the national model, one can multiply the vector of variation in production by the coefficients of wages, employment and taxes to find the impact of the shock on these variables in each sector of each state, always assuming that the production functions are of the Leontief type. The process described in Equations 7 and 8 is then repeated separately for each of the five major regions of the country, and the results of the shocks are disaggregated to the state level.

Intuitively, the results show, given the inter-regional sectoral structure estimated for 2013, the potential growth of the economy due to the increase in investment in the electricity sector and the pressure from other productive sectors for a greater volume of energy.

Extending the national work of Takasago, Mollo and Guilhoto (2017), impacts were calculated on production, gross operating surplus (GOS), wages and total income[[19]](#footnote-19), as well as on the collection of indirect taxes and, in particular, the tax on the circulation of goods and services (*Imposto sobre Circulação de Mercadorias e Serviços*
 - ICMS). The results for investment shocks in the electricity sector in the five main regions can be seen in Table 3, where the darker cells make it easier to see the largest impacts[[20]](#footnote-20).

**Table 3: Impacts of the Shock of BRL 34.3 million (10% of the National Value) on Investment in the Electric Sector**

|  |  |
| --- | --- |
| **Effect of the shock in the region** | **Region of origin of the shock** |
| **North** | **Northeast** | **Southeast** | **South** | **Midwest** |
| **Value added\*** | North | 18.9 | 1.0 | 0.9 | 0.6 | 0.8 |
| Northeast | 0.7 | 12.7 | 0.6 | 0.6 | 0.6 |
| Southeast | 6.2 | 8.9 | 21.6 | 7.9 | 7.6 |
| South | 0.6 | 0.8 | 1.4 | 15.6 | 0.7 |
| Midwest | 1.0 | 1.3 | 1.1 | 1.5 | 17.9 |
| **Total** | **27.2** | **24.7** | **25.6** | **26.3** | **27.5** |
| **Occupations\*\*** | North | 93.4 | 7.7 | 6.3 | 4.8 | 5.9 |
| Northeast | 14.3 | 140.6 | 9.6 | 10.3 | 9.5 |
| Southeast | 60.4 | 74.2 | 153.3 | 62.3 | 62.3 |
| South | 11.2 | 13.7 | 12.6 | 103.0 | 10.3 |
| Midwest | 8.1 | 9.2 | 6.4 | 8.5 | 71.1 |
| **Total** | **187.4** | **245.5** | **188.2** | **188.8** | **159.1** |
| **Total income\*** | North | 17.2 | 0.9 | 0.8 | 0.6 | 0.7 |
| Northeast | 0.6 | 11.4 | 0.6 | 0.6 | 0.5 |
| Southeast | 5.5 | 8.0 | 19.5 | 7.1 | 6.9 |
| South | 0.5 | 0.7 | 1.2 | 14.2 | 0.6 |
| Midwest | 0.9 | 1.1 | 1.0 | 1.4 | 16.3 |
| **Total** | **24.7** | **22.2** | **23.0** | **23.8** | **25.0** |
| **GOS\*** | North | 13.2 | 0.7 | 0.6 | 0.4 | 0.5 |
| Northeast | 0.3 | 7.6 | 0.3 | 0.3 | 0.3 |
| Southeast | 3.3 | 5.2 | 13.1 | 4.7 | 4.4 |
| South | 0.2 | 0.4 | 0.9 | 10.4 | 0.4 |
| Midwest | 0.6 | 0.8 | 0.7 | 1.0 | 12.5 |
| **Total** | **17.7** | **14.6** | **15.6** | **16.9** | **18.1** |
| **Wages\*** | North | 3.8 | 0.2 | 0.2 | 0.1 | 0.2 |
| Northeast | 0.2 | 3.4 | 0.2 | 0.2 | 0.2 |
| Southeast | 1.9 | 2.5 | 5.7 | 2.2 | 2.1 |
| South | 0.2 | 0.3 | 0.3 | 3.4 | 0.2 |
| Midwest | 0.3 | 0.3 | 0.2 | 0.3 | 3.5 |
| **Total** | **6.3** | **6.7** | **6.6** | **6.2** | **6.2** |
| **Taxes\*** | North | 2.4 | 0.2 | 0.2 | 0.1 | 0.1 |
| Northeast | 0.1 | 3.4 | 0.1 | 0.1 | 0.1 |
| Southeast | 0.8 | 1.2 | 3.9 | 1.1 | 1.1 |
| South | 0.1 | 0.1 | 0.1 | 2.1 | 0.1 |
| Midwest | 0.1 | 0.2 | 0.1 | 0.2 | 1.7 |
| **Total** | **3.5** | **5.0** | **4.4** | **3.7** | **3.2** |
| **ICMS\*** | North | 2.0 | 0.1 | 0.1 | 0.1 | 0.1 |
| Northeast | 0.1 | 2.7 | 0.1 | 0.1 | 0.1 |
| Southeast | 0.3 | 0.5 | 2.3 | 0.5 | 0.5 |
| South | 0.0 | 0.0 | 0.1 | 1.5 | 0.0 |
| Midwest | 0.1 | 0.1 | 0.1 | 0.1 | 1.2 |
| **Total** | **2.4** | **3.5** | **2.7** | **2.3** | **2.0** |
| **Production** | North | 48.0 | 3.2 | 2.8 | 2.0 | 2.5 |
| Northeast | 1.9 | 49.5 | 2.1 | 2.2 | 2.0 |
| Southeast | 14.5 | 21.2 | 61.9 | 19.4 | 19.2 |
| South | 1.5 | 2.1 | 3.3 | 42.4 | 1.9 |
| Midwest | 2.3 | 3.0 | 2.4 | 3.4 | 38.2 |
| **Total** | **68.3** | **79.0** | **72.5** | **69.4** | **63.8** |

Source: Original work based on the 2013 Regional IOT.

*Notes*: \*BRL million; \*\*Number of jobs.

As observed, isolated shocks of 10% of the GFCF of the electricity sector in each region produce very heterogeneous effects depending on the analyzed component. In terms of value added, GOS and total income, the region with the greatest total impacts was the Midwest, despite its electrical sector presenting the lowest production and final demands in the inter-regional matrix and the lowest generation capacity in TWh (Brazil, 2021).

Much of this result can be attributed to the fact that the simulated shock in the region generates a large amount of GOS for the Midwest electricity sector itself[[21]](#footnote-21) – BRL 11.6 million (64.3% of the total). This value, among the five simulations, is second only to the one generated in the electricity sector in the North region (BRL 11.8 million). However, in the inter-regional matrix, the electricity activity in the Midwest appears to have strong links with the electrical sector and with the oil and gas extraction industry in the Southeast, where BRL 3.4 million in GOS are generated (20% of the total), which is the determining factor for the EOB generated in Brazil as a whole to exceed that of the region North.

Despite a high-income generation capacity – which stems mainly from the GOSs mentioned above – the shock in the Midwest produces the smallest impact on production, considering both the economy as a whole and the effects retained in the region and in the regional electricity sector itself. In fact, in terms of energy generation, the central area of ​​the country is mainly composed of Small Hydroelectric Plants (SHP)[[22]](#footnote-22) (IBGE, 2016, p. 67). Despite playing an important role in inter-regional energy transmission – because it is in Brazil’s geographic center –, the low installed capacity of the Midwest region leads to low production gains, which places it in last place in terms of refers to energy generation. In this regard, the Northeast region appears as the most attractive.

In addition to the shock generating good results in the northeastern electrical sector, it is also what most boosts the production of Electricity and Gas activities most throughout the nation (in order, Northeast, Southeast, North and Midwest and South), which corresponds two-thirds of the effects of the shock considering the entire country and all industries. That said, the production gain due to the investment shock in the Northeast is 9% greater than that observed in any other region.

We attribute this result partly to its wind and solar generation capacity, which accounted for 76% of the country's total capacity in 2014 (IBGE, 2016, p. 76). In this context, Pao and Fu (2013) show that a 1% increase in electricity consumption from renewable sources increases real GDP by 0.2%, so that investments in the electrical sector in the region of countries with the greatest potential for renewable generation tend to encourage more economic activity.

Due to the greater production, the Northeast is also the most attractive in terms of indirect taxes and, particularly, ICMS, given the higher tax rates paid by the electricity sector. ICMS gains in all regions (BRL 3.5 million) cover more than 10% of the value of the simulated investment of BRL 34.3 million and are at least 30% greater than those observed for shocks in other regions[[23]](#footnote-23). Even considering only the impact on the region itself (the diagonal of each subpanel), the value is still 16% higher than observed in any other simulation.

Moreover, the Northeast also turned out to be the most attractive region when analyzing the impacts of the shock on occupations and wages, indicating that the investments in the region would have the greatest capacity to generate income from work, which is mainly due to the gains of employment and income in tertiary sectors – notably, commerce, other administrative activities and complementary services and land transport –, which exceed those observed in any other region of the country.

The conclusions recorded so far are based on the national effects of the shock in each region, considering all spillovers. Another relevant analysis – which will be carried out below – consists of observing the impacts that are restricted to the region itself, i.e. disregarding the effects on the rest of the country.

**5.2. Spillover Effects**

In addition to shocks, spillovers were analyzed in each region – in other words, the percentage of impact caused by the increase in final demand in the electricity sector that occurs in other areas of the country and not in the region of origin. The calculation was made for production and for various components of value added and the payments sector.

Thus, grouping the vector $Δx$ at a regional level – which gives rise to five values $Δx^{R}$, one for each region –, and $Δx^{NAC}$ being the national variation in production as a result of the shock, the spillover effects for each region $R$, interpreted in percentage terms of the total impact of the shock, are given by:

$$\begin{array}{c}SE=\frac{Δx^{NAC} - Δx^{R}}{Δx^{NAC}}\#\left(9\right)\end{array}$$

Therefore, the greater the “degree of retention” of the impact of the shock in the region, the smaller the spillover effect. Thus, large spillovers into developed regions can be seen as positive from a regional development perspective. On the other hand, spillovers in less developed locations show that the effects of a shock are not felt mostly in the region, which can occur, for example, through the purchase of inputs or the import of labor.

The main diagonals in Table 3 show that, in all the analyzed variables, except for GOS in the North and ICMS in the Northeast, the Southeast region has the largest impact when the spillover effects of the shocks are not considered.

The contrast in results when considering the total effects is due to the fact that the Southeast region is the largest importer of energy from other locations – almost 50% of its final consumption (Brazil, 2016), thus absorbing the impacts of shocks in other regions. In addition, the Southeast concentrates most of Brazil's industrial production – almost 54% in 2017, despite a decentralization movement (CNI, 2021) –, which means that the region exports inputs to other Brazilian areas. As a result, the investment made elsewhere is used in part to purchase inputs in the Southeast, which in turn generates income and employment in Brazil's most economically developed region.

Furthermore, Table 4 shows that, within the input-output framework, its domestic spillovers are small, which contributes to preserving the effects of the shock and is consistent with other results that simulate final demand shocks in all sectors of the economy and that point to the Southeast as the most self-sufficient region in the country (Haddad; Júnior; Nascimento, 2017; Guilhoto *et al.,* 2019).

**Table 4: Spillover effects of the GFCF shock in the electricity sector**

|  |  |
| --- | --- |
|   | **Region of origin of the shock** |
|   | **North** | **Northeast** | **Southeast** | **South** | **Midwest** |
| **VA** | 30.7% | 48.6% | 15.3% | 40.7% | 35.1% |
| **Occupations** | 50.1% | 42.7% | 18.5% | 45.5% | 55.3% |
| **Total income** | 30.2% | 48.5% | 15.4% | 40.5% | 34.8% |
| **GOS** | 25.1% | 48.0% | 16.0% | 38.2% | 30.9% |
| **Wages** | 40.6% | 49.2% | 14.0% | 45.4% | 43.3% |
| **Taxes** | 31.4% | 32.6% | 12.6% | 42.1% | 46.4% |
| **ICMS** | 18.6% | 22.2% | 13.4% | 34.8% | 38.9% |
| **Production** | 29.7% | 37.3% | 14.6% | 38.8% | 40.2% |

Source: Original work based on the 2013 Regional IOT.

The table can be interpreted as follows: the value of 30.7% for Value Added (VA) in the North region means that 30.7% (BRL 8.4 million) of the BRL 27.2 million generated from VA occur outside the region. Thus, the table displays the percentage of gains for each variable generated outside the region of origin of the shock.

Thus, in any variable analyzed, the spillovers of the shock in the Southeast are the smallest, indicating that the region retains most of the effects of its shock. In addition, the joint analysis of Tables 3 and 4 reveals that the richest region of the country is also the most benefited by investment shocks in the electricity sector in other locations, since, as the largest industrial producer in the country, it exports large quantities of inputs and materials to other locations.

**6. Concluding Remarks**

The 2010s can be clearly divided into two periods in terms of Brazil’s economic performance. Until 2014, there was a relatively stable economic growth, a situation that changed with the recession that began in 2015. Since 2017, however, the country has been experiencing stagnation with many economic and social consequences that put it in a delicate situation even before the Covid-19 pandemic. The electricity sector cannot be detached from this context, as its generation and production multipliers follow, to a large extent, the trajectory of the Brazilian GDP.

The analysis of both traditional and pure linkage indexes revealed that the electrical sector can be considered strategic for the economy, with larger linkages and more dispersed relationships across the supply side and a more concentrated demand, but with connections still above the economy average. The field of influence, in turn, showed that changes in the sector's requirements cause above-average impacts on all other industries, which corroborates its importance for the country's economic performance and productive activity.

Given this importance, it is crucial to decide where to invest in order to achieve the greatest impact and reduce regional disparities, as stated in article 3 of the 1988 Federal Constitution. To support this planning, an estimated inter-regional input-output matrix was used based on data from the NFe for 2013.

The results reveal that the Northeast region is the most attractive for investment policies in the electricity sector. This is due to the major impacts on production, occupations, wages and indirect tax collection, in addition to the region's electrical sector being interconnected with that of other locations in the country and being a development hub for sustainable energy sources such as wind and solar[[24]](#footnote-24), which have high returns on investment and will become even more of a priority in post-pandemic economic growth and in the fight against global warming. In fact, the International Energy Agency (IEA, 2021) projects that renewable sources will correspond to 95% of the increase in installed energy generation capacity by 2026. This puts the Northeast in a privileged position.

However, a large part of these effects leaks to other locations in Brazil, given that the Northeast has, in general, the largest spillovers among all regions. Disregarding these leaks, the region whose shock has the greatest impact on itself is the Southeast, which concentrates more than 40% of production and 50% of the sector's investment in the inter-regional IOT estimated for 2013. Furthermore, as it is the largest energy consumer hub and the largest industrial producer in the country, the Southeast imports half of its electricity consumption and exports inputs and materials to other locations, making it the largest beneficiary of spillovers from other Brazilian regions.

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**Appendix**

As mentioned in the paper, all estimated national IOTs come from official TRUs and IOTs containing 128 products and 68 sectors, which produces square matrices of order $n=68$. However, to simplify visualization and analysis, the industries were aggregated to a number of 25 activities, in order to preserve equality between supply and demand in each sector, as well as maintain the consistency of the GDP calculated from the three perspectives (expenditure, income and product). Table A1 below presents this aggregation.

**Table A1: Aggregation of Activities by Level**

| **Level 25** | **Level 68** |
| --- | --- |
| Agriculture, livestock, forestry production, fishing and aquaculture | Agriculture, including support for agriculture  |
| Agriculture, including support for agriculture |
| Forest production, fishing and aquaculture |
| Extractive industries | Extraction of mineral coal and non-metallic minerals |
| Oil and gas extraction and supporting activities |
| Extraction of iron ore, including processing and agglomeration |
| Extraction of non-ferrous metallic minerals |
| Food and beverage manufacturing | Slaughter and meat, dairy and fish products |
| Sugar manufacturing and refining |
| Other food products |
| Beverage manufacturing |
| Textiles, clothing and accessories | Manufacturing of textile products |
| Production of clothing items and accessories |
| Manufacture of shoes and leather goods |
| Manufacture of wood, cellulose and paper products | Manufacturing of wood products |
| Manufacture of pulp, paper and paper products |
| Oil refining, coking plant and biofuels | Oil refining and coking plant |
| Biofuel manufacturing |
| Chemicals, disinfectants, paints, cleaning products and pharmaceuticals | Manufacture of organic and inorganic chemicals, resins and elastomers |
| Manufacture of pesticides, disinfectants, paints and chemicals  |
| Manufacture of cleaning, cosmetics/perfumery and personal hygiene products |
| Pharmochemical and pharmaceutical products |
| Manufacturing of rubber and plastic products |
| Metallurgy and steelmaking | Manufacture of products from non-metallic minerals |
| Production of pig iron/ferroalloys, steelmaking and seamless steel tubes |
| Non-ferrous metallurgy and casting |
| Metal products, except machinery and equipment |
| Electronic and mechanical equipment | Computer equipment, electronic and optical products |
| Manufacture of electrical machinery and equipment |
| Manufacture of mechanical machinery and equipment |
| Car and parts manufacturing | Car and parts manufacturing, except parts |
| Manufacture of vehicle parts and accessories  |
| Other industrial activities | Manufacture of tobacco products |
| Printing and reproduction of recorded media |
| Manufacture of other transport equipment, except motor vehicles |
| Manufacture of furniture and products for various industries |
| Maintenance, repair and installation of machines |
| **Electricity and Gas** | **Electricity, natural gas and other utilities** |
| Water, sewage and waste management activities | Water, sewage and waste management |
| Construction | Construction |
| Trade and repair of motor vehicles and motorcycles | Trade and repair of motor vehicles |
| Wholesale and retail trade, except vehicles  |
| Transport, storage and mail | Land transport |
| Water transport |
| Air transport |
| Storage, auxiliary transport and mail activities |
| Accommodation and food | Accommodation |
| Food |
| Information and communication | Print-integrated publishing and editing |
| Television, radio and cinema activities |
| Telecommunications |
| Development of systems and other information services |
| Financial, insurance activities | Financial intermediation, insurance and pensions  |
| Real estate activities | Real estate activities |
| Services provided to companies | Legal, accounting, consultancy activities, etc. |
| Architecture, engineering and R&D services |
| Other professional, scientific and technical activities |
| Non-real estate rentals and intellectual property asset management |
| Other administrative activities and complementary services |
| Surveillance, security and investigation activities |
| Public administration, defense and social security | Public administration, defense and social security |
| Education | Public education |
| Private education |
| Human health and social services | Public health |
| Private healthcare |
| Other services | Artistic, creative and performance activities |
| Membership Organizations and Other Personal Services |
| Home Services |

Source: Original work.

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4. The Energy/Electric sector will be analyzed considering the “Electricity and Gas” sector in IBGE's 2010 System of National Accounts (*Sistema de Contas Nacionais* - SCN). *Instituto Brasileiro de Geografia e Estatística* (IBGE) is the Brazilian Institute of Geography and Statistics, the main provider of statistical data on the Brazilian economy, society, and geography. [↑](#footnote-ref-4)
5. The estimation of complete inter-regional matrices for Brazil has only recently been developed, in the sense of subdividing Brazil into its 27 federation units (UFs) and the 68 sectors disclosed by IBGE (Haddad; Júnior; Nascimento, 2017; Guilhoto *et al.*, 2019). Previous studies generally comprised only one macro-region (Guilhoto *et al.*, 2010), made a comparison between a single state and the rest of Brazil (Carvalho; Perobelli, 2009) or analyzed a smaller number of productive sectors (Perobelli *et al.*, 2010). [↑](#footnote-ref-5)
6. In addition to the renewable and non-renewable division, BEN presents a 3rd category (“Others”, with approximately 2% of the total) which is not shown in Table 1. Therefore, the sum of the percentages of renewable and non-renewable generation for Brazil is less than 100%. [↑](#footnote-ref-6)
7. The solar source was omitted because it represented only 1% of the national matrix in 2019 and had high growth rates, which distorted the scale. Despite the great generation potential in Brazil, the production of solar electricity still suffers from relatively high costs and a lack of government incentives, especially compared to those aimed at wind energy (Silva; Neto; Seifert, 2016). [↑](#footnote-ref-7)
8. Production in the Electricity & Gas sector was first deflated to 2010 Reais (BRL) based on a price index vector constructed based on information from Tables 1 and 3 of the Uses and Resources Tables (*Tabelas de Recursos e Usos* - TRUs), which contains data at current prices and to values ​​from the previous year. [↑](#footnote-ref-8)
9. Currently, IOTs are published in three dimensions: $12×12$, $20×20$ and $128×68$. In addition, in the 2010 SCN, IBGE also published retropolated TRUs up to the year 2000, with 107 products and 51 sectors. [↑](#footnote-ref-9)
10. The resource matrix shows the output of the economy at the level of sectors and products. [↑](#footnote-ref-10)
11. The uses matrix presents the total demand of the economy, i.e., intermediate consumption and final demand. [↑](#footnote-ref-11)
12. For example, IBGE rounds demand/production values ​​lower than BRL 500,000 to 0. As a result, a cell may show positive values at current prices but zero at prices from the previous year, or vice versa. [↑](#footnote-ref-12)
13. The paper provides an overview of inter-regional estimation methods – with a focus on SUIT –, as well as presenting the evolution of the literature over time and a series of national and international applications. [↑](#footnote-ref-13)
14. The average of the coefficients was chosen because there were no significant changes over the decade. [↑](#footnote-ref-14)
15. Both articles use a broader notion of “energy sector” with more aggregated matrices. [↑](#footnote-ref-15)
16. As it is an arithmetic mean, $\overline{PTL}$ can be written as $0,5⋅\left(\overline{PBL}+\overline{PFL}\right)$. Thus, a sector is considered a key sector ($\overline{PTL} > 1$) when $\overline{PBL}+\overline{PFL}>2$, that is, $\overline{PBL}>2-\overline{PFL}$, which justifies the negatively inclined dotted line in the graphs. [↑](#footnote-ref-16)
17. As in the case of coefficients of variation, there were not many changes throughout the decade. [↑](#footnote-ref-17)
18. This value was calculated from the sum of the electricity sector GFCF in all states in the inter-regional IOT. It should be noted that the relative conclusions obtained would be the same with any shock value following the same distribution of this paper. [↑](#footnote-ref-18)
19. Defined here as the sum of wages (excluding taxes), GOSs and mixed income, i.e. the income of self-employed individuals. [↑](#footnote-ref-19)
20. The color scale is different for each analyzed component (such as value added and occupations). [↑](#footnote-ref-20)
21. Since they are extensive, the results of the shocks detailed by variable, sector and region were not included as tables in the paper but are available upon request. [↑](#footnote-ref-21)
22. A SHP is defined as one that generates power within the range of 3 to 30 Megawatts (MW). A hydroelectric plant, on the other hand, is defined as having a power output exceeding 30 MW. [↑](#footnote-ref-22)
23. Data from the National Council for Financial Policy (*Conselho Nacional de Política Fazendária* - Confaz) from 2018 show that the Northeast has the largest share of ICMS in the electricity sector in total tax collection, which is more pronounced in the states of Piauí, Ceará and Maranhão. [↑](#footnote-ref-23)
24. As seen in Table 1, these sources have grown in importance in the energy matrix throughout the decade, so the impacts found may be larger when looking at more recent regional matrices. [↑](#footnote-ref-24)