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Evaluation of the impact of FDNE financing on the construction of wind farms and its effects on the labor market and economic indicators of municipalities in Sudene's area of operation

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ABSTRACT

In 2023, Brazil ranked sixth globally in installed capacity for onshore wind energy, with the Northeast leading production, accounting for 91.52% of the country's wind potential. Wind energy not only provides economic benefits but also fosters local and regional development. This study aimed to analyze the causal impacts of wind farm deployment in Northeastern municipalities benefiting from FDNE, focusing on the labor market and economic indicators such as per capita GDP and Gross Value Added (GVA) in the agricultural, services, and industrial sectors. Using data from 1999 to 2022 and employing the Difference-in-Differences (DiD) model, the results show that the construction of wind farms significantly increased employment, per capita GDP, and GVA in the industrial and services sectors, while causing temporary negative impacts on the agricultural sector, which dissipated after the completion of the wind farms.

Keywords: Impact evaluation; Wind Energy; Labor Market; GDP per capita; Sector GVA.
JEL: Q42; R58; O13

SUMMARY

1. INTRODUCTION

Wind energy is one of the main existing sources of renewable energy, mainly due to the high efficiency that can be achieved with the resources and technology currently available. In 2023, the world's installed wind power capacity reached 117 GW, bringing the total installed capacity to 906 GW, an increase of 13% compared to 2022 (Global Wind Report, 2024).

Brazil plays a leading role in the global wind energy production scenario. In 2023, it was among the top six[1] countries in terms of onshore installed capacity , with 30.45 gigawatts. By June 2024, installed capacity[2] had already increased by 4.8 GW, and the sector now has more than 1,000 wind farms in operation (Global Wind Report, 2024). At the same time, Agência Brasil (2024)[3] reported that wind energy had reached a 13.2% share of the national energy matrix, corresponding to 20% of the energy generation required.

In regional terms, according to the Annual Report of the National Electricity System Operator (ONS, 2023), the Northeast region stands out for having 91.52% of the country's wind potential, with a significant increase in the installation of new plants in recent years. In 2023, the region achieved record levels of wind power generation, especially in July, when wind power production reached 18.40 GW, representing 149.1% of the subsystem's demand.

The production of renewable energies, such as wind power, can offer various economic benefits, such as the possibility of local and regional development. Rural areas, often marked by high unemployment and low economic activity, can benefit from these projects, which require local labor, especially during the construction phase (Simas, 2012; BNDES, 2019). These projects promote training, create jobs, increase income and contribute to tax collection.

As the Northeast has historically been one of the most unequal regions in the country and has favorable conditions for wind power generation, the Northeast Development Fund's (FDNE) role in financing this sector could be important for boosting the labor market and municipal economic indicators.

The FDNE was created by Provisional Measure No. 2.156-5/2001 and regulated by Decrees No. 7.838/2012 and No. 6.952/2009. Its purpose is to finance economic and social development in the Northeast region, and in recent years it has directed large volumes of resources to financing the wind sector. Under the management of the Ministry of Integration and Regional

1 The main one is China, followed by the USA, Germany, India and Spain.

2 In November 2023, the Chamber of Deputies approved the legal framework regulating offshore energy generation, through Bill No. 11,247 of 2018.

3 For more details, see: https://agenciabrasil.ebc.com.br/economia/noticia/2023-04/capacidade-de-geracao-de-energia-eolica-deve-bater-recorde-neste-ano.

Development (MIDR), through Sudene the fund allocates resources to infrastructure projects, public services and productive initiatives, focusing on the potential for generating new activities and jobs, with actions aimed at sustainable growth in the Sudene area, covering the Northeast, the north of Minas Gerais and Espírito Santo.

Among its portfolio of projects, the FDNE includes a number of projects in the electricity sector, particularly in the wind power generation sector. To illustrate the priority given by the Fund to wind power generation projects, it should be noted that this sector has accounted for more than half of the projects supported (41), corresponding to 30% of the value of contracts since its creation.

In this context, the aim of this study is to measure the causal effects of the construction and installation of wind farms in municipalities in the northeast of Brazil, including those benefiting from the FDNE, on municipal labor market indicators such as the number of jobs, average pay and the wage bill, and economic activity indicators such as GDP *per capita* and Gross Value Added (GVA) in agriculture, services and industry. The analysis considers that the jobs are generated before the parks start operating, i.e. when the grant comes into force or the construction of the parks begins.

There are other studies that have also analyzed the causal impact of the presence of wind farms in municipalities in the Northeast on economic indicators, such as Rodrigues et al. (2019), Sampaio (2022) and Sampaio, Costa and Irffi (2023). However, this study differs methodologically in that it uses the year of the grant, one of the initial stages of authorization for construction, and the year of the start of construction of the wind farm as causal interventions. In addition, a broader period of analysis was used (2001 to 2022). Thus, these two aspects (the duration of the grant and the year construction began), together with a longer period, increase the precision of the measurement of the causal impact of wind farms on the economic indicators considered.

This report seeks to contribute to regional development in the Northeast by measuring and analyzing the causal effects of the construction and operation of wind farms in Northeastern municipalities, including projects financed by Sudene through the FDNE, on economic indicators such as GDP per capita and GVA in the industry, services and agriculture sectors. It uses the Differences in Differences (DiD) methodology proposed by Callaway and Sant'Anna (2021). It should be noted that it was not possible to measure the specific effects of the installation of wind farms financed by the FDNE due to the small number of municipalities benefiting from this funding. However, it was possible to capture the effect for the total number of wind farms installed and under construction between 2001 and 2022. Furthermore, based on the results found, the study contributes to the formulation of public policies and investment strategies in renewable energies.

In addition to this introduction, the study consists of four more sections. The second section presents a literature review on the effects of implementing wind energy on economic indicators. The third section shows the database and empirical strategy used in the research. The next section presents the descriptive statistics, the effects of the construction and operation of wind farms and the robustness analysis. Finally, the concluding remarks are presented.

2. LITERATURE REVIEW

The implementation of renewable energy initiatives, such as wind power, represents a source of job creation and a development option in agricultural regions, with the potential to boost the socio-economic development of rural areas (Río and Burguillo, 2008). Despite the sector's challenges in terms of poor transmission infrastructure (Diógenes et al., 2020), the literature highlights that wind energy offers significant economic benefits in Brazil and worldwide.

International literature addresses the economic effects of the wind sector. In a study for the European Union, Blanco and Kjaer (2009) found that, in addition to the effects on the labor market, there is also industrial development, as the sector promotes the development of new technologies and their export, boosting competitiveness in the global market. Bianchini et al. (2019) examine the impact of wind energy on employment and regional development in European countries, finding significant positive impacts. Specifically, regions that invest in this energy source often receive infrastructure improvements and generate demand for skilled workers, boosting regional economic growth by attracting investment and increasing local activity.

In this context, Dvořák et al. (2017), Hondo and Moriizumi (2017) and Moreno and López (2008) examined the wind energy sector in relation to job creation and its other impacts in the Czech Republic, Japan and the Spanish region of Asturias, respectively. They identified that, in addition to the creation of new jobs, there is infrastructure development, regional GDP growth and an increase in economic activity in the region.

Brown, Pender, Wiser, Lantz and Hoen (2012) carried out an *ex-post* analysis of the impact of wind energy on counties in the United States, using a Difference-in-Differences model. The results indicated that the development of wind energy has generated positive and significant economic impacts. Specifically, the installation of wind farms is associated with an increase in *per capita* income, tax revenues, jobs and property value added.

In the national literature, in semi-arid regions, for example, the wells drilled for the construction of wind towers are subsequently used by the local population (Simas and Pacca, 2013). Munday et al. (2011) provide a detailed analysis of the benefits of wind farms in rural areas and their implications for local economic development, especially in relation to per capita income and economic development opportunities.

With regard to the impacts of these installations on municipalities, Simas and Pacca (2013); Aldieri, Grafström, Sundström and Vinci (2019); Rodrigues, Costa and Irffi (2019); Gonçalves, Rodrigues and Chagas (2020); Sampaio (2022) and Sampaio, Costa and Irffi (2023) examine the relationship between wind energy and job creation, highlighting the socio-economic benefits of this energy source. In general, the authors found that the installation of wind farms has a positive impact on the creation of direct and indirect jobs in municipalities.

Regarding the effects on economic activity, local development, infrastructure and economic development, the literature presents some relevant studies. Aldieri, Grafström, Sundström and Vinci (2019) note that regions where wind farms are installed often experience local economic growth, driven by increased economic activity and infrastructure development. These factors help to reduce regional disparities, providing greater job creation in rural and less developed areas.

In this same context, Simas and Pacca (2013) point out that the installation of wind farms in rural and less developed areas promotes local development, improving infrastructure and creating an economic chain based on job opportunities. Similarly, Gonçalves, Rodrigues and Chagas (2020) showed that investments in the wind sector have influenced economic development at both regional and national levels. These investments result in increases in *per capita* income, employment rates, the Human Development Index (HDI) and improvements in local infrastructure, promoting development in regions with fewer economic opportunities.

With regard to economic indicators, Sampaio (2022) identified positive impacts on GDP *per capita*, industry GVA, municipal tax revenues and tax collection, as well as a slight increase in the local labor market, represented by the *per capita* wage bill. In addition, Sampaio, Costa and Irffi (2023) also point out that the implementation of wind farms has significant positive impacts on various economic variables, such as *per capita* income, the creation of direct and indirect jobs, and the reduction of regional inequalities. In addition to these economic variables, Silva, Alves and Ramalho (2020) observed an increase in the purchasing power of the local population due to the greater inflow of capital into the economy.

3. METHODOLOGY

3.1 Database

To carry out this research, we used information on wind farms in operation and under construction in the Northeast region of Brazil available from the National Electric Energy Agency's Generation Information System (SIGA-ANEEL) and the National Institute for Space Research (INPE). These projects include those financed by the FDNE, according to the Fund's Management Report made available by Sudene.

For the treated group, only the northeastern municipalities with installed wind farms (built and under construction), according to information from SIGA-ANEEL, were kept in the sample. For the control group, the municipalities bordering[4] the municipalities without installed wind farms were used. For both wind farms under construction and wind farms in operation, the majority of the treatment was based on the year in which construction began. However, in cases where this information was not available, the start of the project's concession period was used, since wind farms can only begin construction once this concession has been granted.

To capture the effects on the local labor market, the number of active permanent jobs was taken into account, indicating the number of jobs. In addition to employment, we used the Wage Mass, which corresponds to the sum of all wages and can capture the effect on labor income. The volume of employment and the Wage Mass were obtained from data extracted from the Annual Social Information Report (RAIS) of the Ministry of Labor and Employment (MTE).

As the effects on economic indicators may be due to factors other than the installation of the wind farm, characteristics such as the size of the population (taken from the Brazilian Institute of Geography and Statistics - IBGE) and the general, educational, longevity and income Municipal Development Indices (HDI) (taken from the UN Atlas of Human Development - ADH-UN) are taken into account in the estimates. The weighting also takes into account whether the municipality is located in the semi-arid region, in the São Francisco river basin or in the Parnaíba river basin, variables taken from the Institute for Applied Economic Research (IPEA). All these characteristics, obtained for the year 2000, are used to calculate the weights that weight the characteristics of the municipalities, using the entropy balancing described by Hainmueller (2012), in order to compare the municipalities with the most similar characteristics

4 The bordering municipalities were constructed using QGIS software.

before treatment.

Population density and municipal typology, taken from the MIDR, and average wind speed, considered to be an important parameter for the installation of wind farms in municipalities, are used as covariates in the model. This annual frequency information includes the wind farms in the municipalities where they are installed from 2001 to 2022.

It should be noted that, as not all municipalities have information on average wind speeds, it was decided to consider the average wind speed for the stations closest to the municipalities in 2022. This was possible using information from the National Meteorological Institute (INMET). In addition, for information on the labor market, namely: active jobs, average remuneration and wage bill, jobs in the statutory sector and the Federal Public Administration were removed, keeping only non-public jobs in the analysis. Table 1 describes the variables used in the estimated models:

Table 1 - Variables used to estimate the models

Variable	Model 1 - Parks in Operation/Construction	Model 2 - Parks under construction
ln(Number of links)	Yes	Yes
ln (Wage bill)	Yes	Yes
ln (Average pay)	Yes	Yes
ln (GDP per capita)	Yes	Yes
ln (GVA - Services)	Yes	Yes
ln (GVA - Industry)	Yes	Yes
ln (GVA - Agro)	Yes	Yes
Population density	Yes	Yes
Average Wind Speed	Yes	Yes
Dummy stating that there is a park under construction in the municipality	No	Yes

Source: Prepared with survey data.

3.2 Identification strategy

The transmission mechanism is as follows: The construction of wind farms in municipalities in the Northeast significantly impacts local economies both directly and indirectly. The construction and operation of these farms generate direct and indirect jobs. According to LLera Sastresa et al. (2010), the jobs generated during the wind farm construction process are temporary. At this stage, there tends to be more local labor than from other surrounding municipalities. In addition, part of the jobs are taken up by construction workers, wind turbine installation technicians and crane operators, as well as occupational safety professionals (Simas, 2012).

Thus, there is an increase in the income of workers, as well as owners of leased land, which increases spending on local goods and services, resulting in higher tax revenues for municipalities, promoting the growth of economic sectors such as industry and services. The increase in local tax revenues allows municipal governments to increase spending on public services, such as education, and on local infrastructure[5] . Demand for local goods and services grows due to increased economic activity and employment, and real estate values can appreciate, increasing the wealth of local property owners. These combined factors promote a positive cycle of economic growth and higher GDP per capita in regions with wind farms (Slattery and Johnson, 2011; Brown et al., 2012; Brunner and Schwegman, 2022).

In this way, the installation of wind farms can be considered an important channel for local development, corroborating the PNDR logic model. As indicated in the previous section, the impact on labor market indicators (number of active jobs, average pay and wage bill), GDP per capita and GVA in the Industry, Services and Agriculture sectors is estimated, taking the start of construction of the wind farms as the intervention. However, for parks that are already in operation and do not have information on the start of construction, the start of the project's concession period is used.

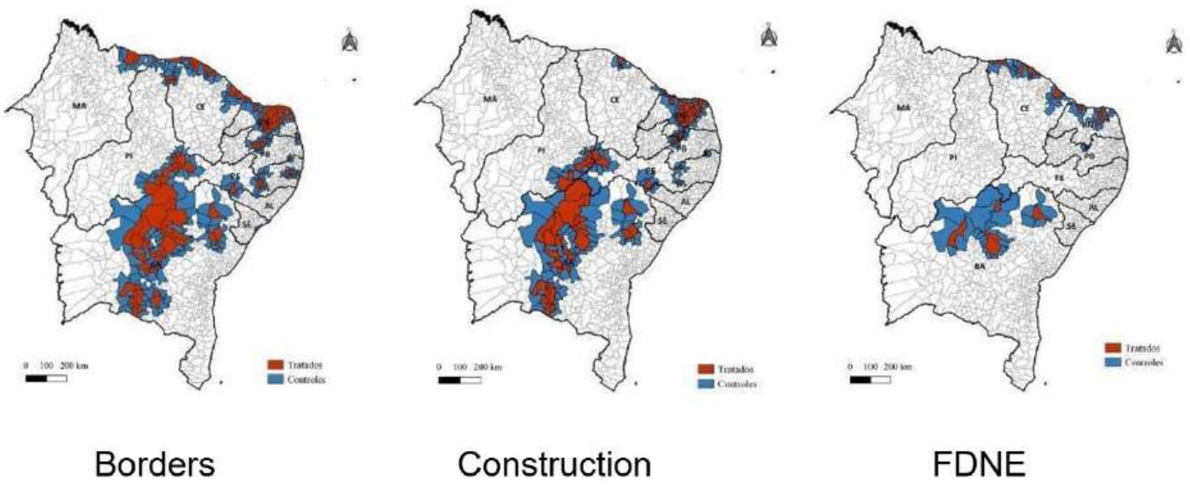
LLera Sastresa et al. (2010) expect there to be a larger workforce in the initial construction and installation phase of the parks and a smaller workforce in the operation phase. However, the workforce employed in the sector in the operational phase requires greater specialization, given its focus on maintenance. In this context, municipalities with wind farms in operation or under construction will be part of the treatment group. It should be noted that these are two separate analyses. The first includes municipalities with wind farms built and under construction (in aggregate), and the second considers only municipalities with wind farms under construction. In addition, the effects of labor market indicators, GDP per capita and GVA will be analyzed considering these municipalities and these two approaches.

The control groups for both cases are made up of municipalities that could receive such developments, but do not have wind farms. In addition, as the wind route is an important fac-

5 The authors are also analyzing the effects on tax revenues in another study.

tor for the installation of the farm, the control group was restricted to include municipalities immediately neighboring those with wind installations, as shown in Figure 1. The selection of the control groups, with neighboring municipalities, is based on the hypothesis that these municipalities have similar socioeconomic and climatic characteristics to those with wind farms (Rodrigues, Costa and Irffi, 2019; Sampaio, 2022; Sampaio; Costa; Irffi, 2023).

Figure 1 - Municipalities with wind farms in Sudene's area of operation



Source: Research data.

3.3 Econometric strategy

To achieve the proposed objectives, Callaway and Sant'Anna's (2021) staggered difference-in-differences (DiD) estimator was used, which makes it possible to estimate and infer the causal parameters of the effects of wind farm construction by taking into account multiple periods, variation in treatment time and heterogeneous effects.

Callaway and Sant'Anna (2021) classify the treated units according to when they started taking part in the treatment. In this way, it is possible to estimate the Average Effect of Treatment on the Treated for each group, "g", in each period of time, "t". In addition, the estimation can be carried out when there is a group of "never treated" units. If this group is not available or is very small, the group of units "not yet treated[6] " is used.

The authors propose a weighting that aims to bring treated and untreated units closer together in terms of their likelihood of participating in the program. This is done by estimating

6 Athey and Imbens (2006) and de Chaisemartin and D'Haultfoeuille (2018) also explore the use of "not yet treated" units as comparison groups in DiD procedures.

the following propensity score:

$$P_g(X) = P(G_g=1|X,G_g+C=1) \tag{1}$$

Where X is the set of observable variables; G_g is a binary variable that takes on a value of 1 if the company benefited in period *g*; and C is a dummy that takes on a value of 1 if the company belongs to the control group. Thus, the propensity score is estimated for each year of entry into the treatment, *g*, which generates greater flexibility in obtaining the similarity of characteristics between controls and each treatment group.

Under these assumptions, the average treatment effect for group-time, including anticipatory behavior δ, can be identified semi-parametrically as:

$$ATT(g,t) = E\left[\left(\frac{G_g}{E[G_g]} - \frac{\frac{P_g(X)C}{1-P_g(X)}}{E\left[\frac{P_g(X)C}{1-P_g(X)}\right]}\right)\left(Y_t - Y_{g-\delta-1}\right)\right] \tag{2}$$

Where Y_t and $Y_{g-\delta-1}$ represent, respectively, the outcome variable at time t and at the time immediately preceding the receipt of the benefit by group g, considering the anticipation. Due to the presence of the dummies G_g and C in the first term between brackets in Equation (2), the difference $(Y_t-Y_{g-\delta-1})$ is calculated separately for each group g and its respective control group. In addition, estimators based on outcome regressions (Heckman et al., 1997, 1998), inverse probability weighting (Abadie, 2005) and doubly robust methods (Sant'Anna and Zhao, 2020) can be used to estimate ATT(g,t).

Therefore, this estimator proposed by Callaway and Sant'Anna (2021) is a weighting of the difference in results between the treated (G_g=1;C=0) and control (G_g=0;C=1), before and after the intervention, where the weights are:

$$w_g^G = \frac{G_g}{E[G_g]} \; e \; w_g^C = \frac{\frac{P_g(X)C}{1-P_g(X)}}{E\left[\frac{P_g(X)C}{1-P_g(X)}\right]} \tag{3}$$

This approach not only balances the observable characteristics between municipalities that have had and have wind farms built and under construction and those that do not have wind farms, but also controls for unobservable characteristics that remain constant over time. In addition, because it is a non-parametric estimator, ATT(g,t) makes it possible to identify the causal impact of wind farm construction without the need to impose specific functional forms, such as those used in traditional linear regressions in the differences-in-differences literature to control for observable characteristics.

In addition, the estimator makes it possible to test the hypothesis of parallel trends by calculating the ATT(g, t) for periods prior to treatment. Failure to reject the null hypothesis suggests that the control group is an adequate counterfactual for the treatment group. The null hypothesis of the test is:

$$H_0: E[X,G=1]-E[X,C=1] \; a.s. \rightarrow 0 \tag{4}$$

Finally, as presented by the authors, the assumption of parallel trends can be verified by means of graphical analysis, using a simultaneous 95% confidence interval.

Although the trend tests used in stepwise DiD models are a natural and intuitive check on the assumption of parallel trends, recent research shows some limitations. Even if pre-trends are exactly parallel, there is no guarantee that the assumption will be satisfied post-treatment (Kahn-Lang and Lang (2020). Another issue is that when there are pre-existing differences in trends, tests can fail to reject due to low power (Bilinski and Hatfield, 2018; Freialdenhoven et al., 2019; Kahn-Lang and Lang, 2020; Roth, 2022).

4. ANALYSIS AND DISCUSSION OF RESULTS

4.1 Descriptive Statistics

Table 1 shows the descriptive statistics for municipalities that already have wind farms in operation, and shows the averages and differences between the averages for the treated and control groups of municipalities. Information associated with the variables used to calculate the effect of the construction of wind farms on the municipalities and their borders is presented, after applying the filters outlined in the methodological section. The characteristics of the treatment groups are shown, before and after the municipalities that received the wind farms, and for the neighboring municipalities that did not receive wind farms. The year immediately prior to treatment (from 2000) and the last year after treatment (until 2022)[7] are considered , as a reference for comparing the groups.

The outcome variables used were the number of jobs, real average pay (deflated by the

7 The analyses for GDP and Value Added were carried out for the year 2021, as this is the last year available for these variables.

National Consumer Price Index - INPC), wage bill, GDP *per capita* and the aggregate value of agriculture, services and industry. Population density and average wind speed were used as control variables, i.e. as representative of the characteristics of the municipalities.

The results show that, in average terms, the number of jobs, the wage bill, the added value of agriculture and services, as well as population density, showed some differences between the municipalities, but these differences were not statistically significant in the pre- and post-treatment periods. Average earnings and GDP per capita were not significant in the pre-treatment period, however, after treatment this difference became positive and significant, suggesting a positive economic impact for those municipalities considered treated. The average wind speed, constant over the period considered (set at 2022, the last year of analysis), proved to be different and significant for the municipalities that have wind farms.

Table 1 - Means and mean differences of the variables for the groups of treated municipalities (T) and control municipalities (C) for the neighboring municipalities.

	Pre-intervention			Post-intervention		
Variable	Control	Treaty	T-Test	Control	Treaty	T-Test
Links	546	605	0.68	1605	2121	0.23
Average Remuneration	1.39	1.45	0.51	2.06	2.65	0.00*
Wage bill	833.44	1046.06	0.44	713.93	1270.49	0.15
GDP per capita	0.38	0.51	0.22	1.63	6.11	0.00*
GVA - Agro	1055.93	2215.10	0.05	79894.88	78956.62	0.94
GVA - Services	85848.76	93717.61	0.72	272962.00	396653.31	0.17
GVA - Industry	24511.04	49737.71	0.07	169520.15	537382.36	0.00*
Population density	40.50	35.41	0.35	46.877	44.404	0.74
Average wind speed	2.51	3.02	0.00*	2.507	3.024	0.00*
Obs	237	119		237	119	

Source: Prepared by the authors. Monetary values in thousands of reais. Note: * p-value < 0.05.

The average differences between municipalities in the groups of municipalities with and without wind farms were not statistically significant in the pre- and post-treatment periods in most cases, as can be seen in Table 2. This scenario was observed in the case of employment, wage bill, GVA - Agriculture, Services and Industry, as well as population density and average wind speed. However, it can be seen that the average salary, which had no significant difference in the pre-construction period of the wind farms, became positive after the treatment, highlighting the impact of the construction of wind farms on the average salary of these municipalities.

Table 2 - Means and mean differences of the variables for the treated (T) and control (C) groups of municipalities bordering parks under construction

	Pre-intervention (construction)			Post-intervention (construction)		
Variable	Control	Treaty	T-Test	Control	Treaty	T-Test
Links	343	304	0.71	1210	1176	0.91
Average Remuneration	1.50	1.33	0.2	2.13	2.69	0.00*
Wage bill	556.55	465.84	0.59	3007.43	3065.24	0.95
GDP per capita	6.05	5.95	0.88	36.74	45.5514	0.21
GVA - Agro	16160.82	14532.35	0.53	76562.14	48956.27	0.07
GVA - Services	66550.75	64588.3	0.86	224610.25	204372.74	0.71
GVA - Industry	23860.24	31768.44	0.47	227413.39	284542.91	0.62
Population density	29.39	23.66	0.18	32.52	26.23	0.18
Average wind speed	2.69	3.02	0.09	2.69	3.02	0.09
Obs	161	75		161	75	

Source: Prepared by the authors. Monetary values deflated by thousands of reais. Note: * p-value < 0.05.

4.2 Effects of the Construction and Operation of Wind Farms

In order to verify the causal effect on the economic indicators of municipalities with wind farms built and under construction, their neighboring municipalities were considered as a control group. However, in order to validate the causal effects, municipalities with wind farms must follow the same trajectory as their neighboring municipalities in the absence of treatment. Thus, following Callaway and Santana (2021) and Callaway (2021)[8] , the parallel pre-trends test was carried out (Figure 2, Figure 3, Figure A1 and Figure A2), based on the study of events proposed by the authors[9] . The aim is to see if there is a systematic difference in the trajectory of

8 For more details, see: https://bcallaway11.github.io/posts/event-study-universal-v-varying-base-period

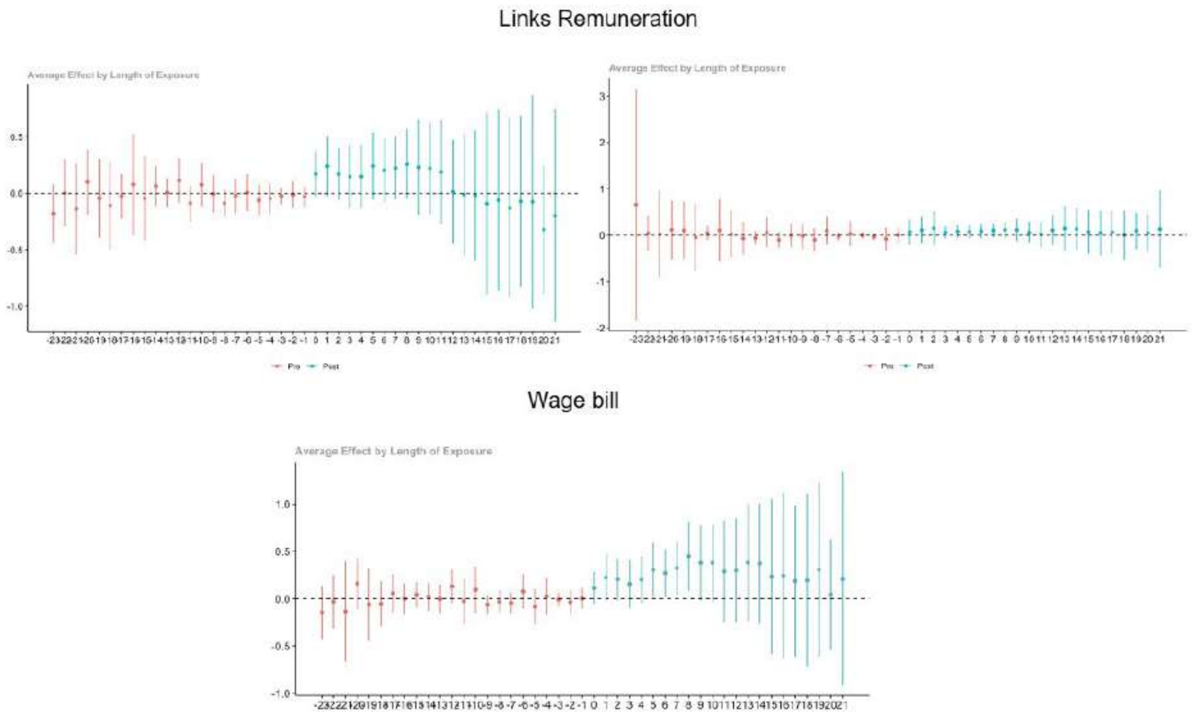
9 Callaway and Santana (2021) also argue that the group graph can be analyzed to check for parallel pre-trends. However, in this article we chose to use the Event Study, since according to the authors, even with caution, it can also be used.

the municipalities that have wind farms under construction or in operation with the neighboring municipalities before the construction of these farms.

The pre-treatment periods are used to validate the assumption of parallel pre-trends in the models, while the post-treatment periods show the dynamic effects of the treatment. It can be seen in Figure A1 in the appendix that for all estimates, the assumption of parallel pre-trends is valid.

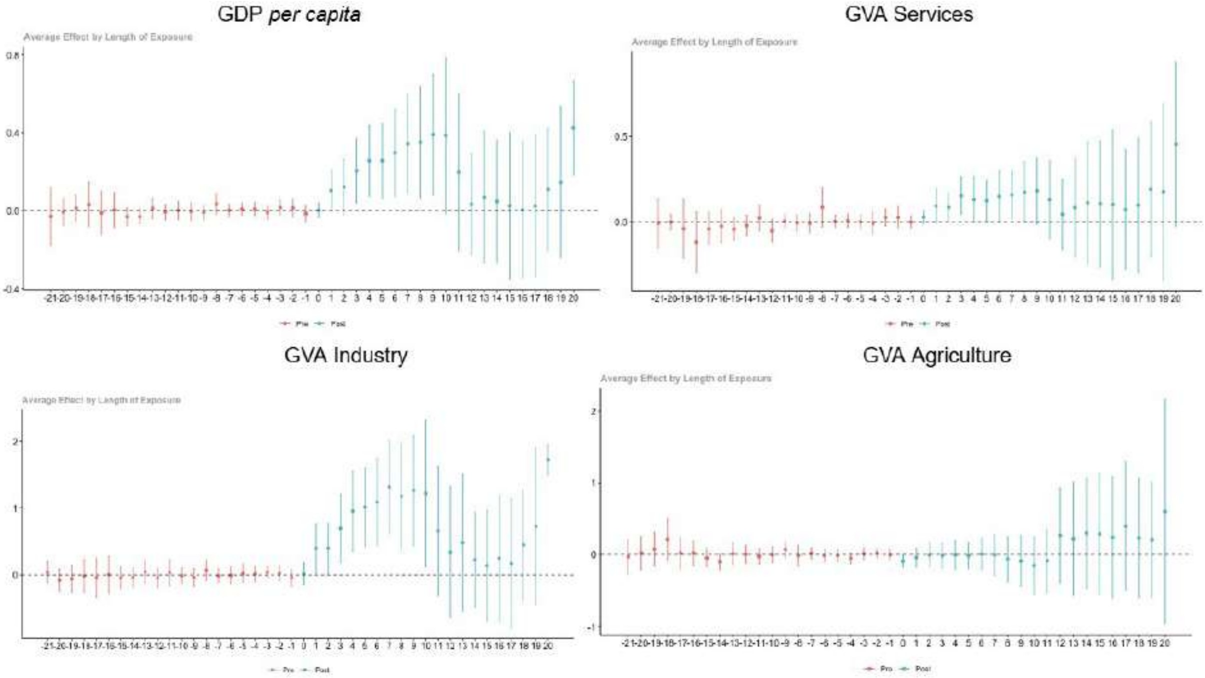
Thus, based on the results of the parallel pre-trend tests, it is possible to analyze the causal effects of wind farm construction on GDP per capita and GVA in industry, services and agriculture, using the Callaway and Sant'Anna (2021) estimator. However, even with the validation of the parallel pre-trend tests for almost all the estimates, the estimates found, both for the group average effect and for the dynamic effects, should be viewed with caution.

Figure 2 - Events study for parks built and under construction: Labor Market



Source: Prepared by the authors.

Figure 3 - Events study for parks built and under construction: Economic indicators



Source: Prepared by the authors.

Looking at the estimates for the average group effect, there is evidence that wind farms financed with FDNE funds have a positive effect on the labor market. Table 3 shows that the impact is 23.41%[10] on the creation of new formal, permanent jobs, when considering the municipalities with wind farms built and under construction. The effects on the wage bill also show an increase of 27.51% for municipalities with wind farms in operation and/or under construction. Wind farms under construction also have positive effects, with an average increase of 19.40% in the number of jobs. And in relation to the wage bill, there was an increase of 25.43%. However, there was no effect on the average wage.

10 Since the estimates were derived from a log-linear model, the causal effect is calculated as [100 x (exp(β) - 1)%].

Table 3 - Estimates of wind farm construction on economic indicators

	Parks in Operation/Construction				Parks under construction			
Effects	ATT	EP	IC		ATT	EP	IC	
Links	0,2103 *	0,0598	0,0931	0,3276	0,1773 *	0,0626	0,0547	0,3000
Wage bill	0,2430 *	0,0637	0,1182	0,3679	0,2266 *	0.0842	0,0615	0,3918
Remuneration	0,1462	0,1030	-0.0558	0.3481	0,1660	0,1636	-0,1547	0,4868
GDP *per capita*	0,1897 *	0,0384	0,1144	0,2651	0,0606 *	0,0267	0,0082	0,1129
GVA - Services	0,1024 *	0,0228	0,0577	0,1471	0,0137	0,0271	-0,0395	0,0668
GVA - Industrial	0.7190 *	0,1146	0,4943	0,9436	0,2796 *	0,0883	0,1065	0.4539
GVA - Agro	-0,0702	0,0398	-0,1482	0,0078	-0,0934 *	0,0289	-0,1501	-0,0367

Source: Prepared by the authors. * p-value < 0.05.

Based on these results, it can be said that the presence of wind farms boosts the local economy by creating new jobs. However, despite the increase in the number of jobs, the average salaries of workers have not changed substantially, i.e. the new jobs are paid similarly to those that already exist in the region. On the other hand, although there is no significant impact on average pay, the growth in the number of jobs indicates a general increase in the aggregate income (wage bill) of the local population.

Analyzing the results of wind farms on the GDP *per capita* of municipalities in Sudene's area of operation, it can be seen that they generated an increase of approximately 20.89% in the GDP *per capita* of municipalities, when considering municipalities with wind farms built and under construction, and 6.25% for those municipalities with wind farms still under construction. These results indicate that wind farms already in operation have a greater and immediate impact on GDP *per capita* compared to farms still under construction. The greater effect for wind farms that have already been built can be attributed to the generation of energy and, consequently, revenue from the farms in operation, as well as the continued employment of workers, while the farms under construction are in the initial phase of investment.

With regard to the effects on sectoral GVA, it can be seen that the services sector is not impacted by parks that are under construction, unlike parks that have already been built, where there is an increase of 10.78%. This result is possibly due to the temporary nature of construction activities, which do not require many local services, except those necessary for direct construction support. However, once they start operating, the parks generate a continuous demand for maintenance services, logistics and other services related directly or indirectly to energy generation, which results in a significant increase in the GVA of the services sector.

In the case of industry GVA, there is a positive effect in both situations, with an increase of 105.24% for parks already built and under construction and 32.26% for those still under construction. In addition to the indirect effects, the industrial sector has a positive impact in both phases, with a greater effect for parks already built and under construction. This scenario possibly occurs as follows: during construction, there is demand for building materials, equipment and engineering services, benefiting local industry. When the parks come into operation, there is an ongoing need for maintenance, repairs and possible expansions, which continues to boost the industrial sector.

On the other hand, the GVA of the agricultural sector shows a negative effect of (-8.92%) in municipalities that still have wind farms under construction, indicating that the sector is negatively impacted during the construction phase of wind farms. No effect was identified when considering wind farms already built and under construction. This result can be explained by the vacating of agricultural land during the construction period, which interferes with the sector's activities and results in economic losses. However, once the farms start operating, they do not significantly affect the agricultural sector, suggesting that the negative impacts are temporary and restricted to the construction period.

With regard to dynamic effects, the estimates for parks built and under construction (Figure 2) indicate that the positive effect occurs in the third year after construction begins and continues for up to ten years for GDP *per capita*, suggesting a strong, medium-term effect. For Industry and Services GVA, the positive effect occurs in the first year after construction and lasts until the ninth year. When analyzing GVA for Services, a similar effect is observed. Finally, the GVA for Agriculture showed a negative effect in the first year after construction of the parks began. Figure 2 also shows a dynamic effect in period 20 for GDP and Industry GVA.

For parks that are still under construction (Figure A1), there was no dynamic effect for GDP per capita or GVA in services. On the other hand, there was a positive effect for the first year after the start of construction for industry GVA, and a negative effect for the first and eighth year after the start of construction only for agricultural GVA. This dynamic effect corroborates the average group-time treatment effects for this sample, with the exception of the GDP *per capita* estimate.

Therefore, the results obtained from the analysis of event studies show that the construction of wind farms has varying impacts on different economic sectors over the years of operation. While some sectors, such as industry and services, benefit positively from the start of construction, agriculture, for example, experiences negative effects in the short term. Furthermore, by indicating a positive impact on the local economy, this study corroborates the studies by Río and Burguillo (2008), Blanco and Kjaer (2009), Munday et al. (2011), Simas (2012), Simas and Paccas (2013), Aldieri et al (2019), Sundström and Vinci (20190, Rodrigues, Costa and Irffi (2019), Sampaio (2022) and Sampaio, Costa and Irffi (2023).

4.3 Robustness Analysis of Results: Clean Controls

The use of impact assessment models to measure the causality of a given intervention often fails to mitigate self-selection bias. In this study, the bias is due to the fact that municipalities bordering municipalities with parks may also have facilities in similar areas. Thus, it is possible that not participating in the treatment is due to some unobserved characteristic, which may be related to the outcome variables.

To mitigate this bias, a robustness test is carried out using as a control group municipalities that receive wind farm construction in later years within the period analyzed. It is believed that because these municipalities also received the treatment at some point in time, they are more similar to the treated municipalities, including in terms of unobserved characteristics that may influence their receipt of the treatment.

This group is commonly reported in the literature as "not yet treated", as discussed by Callaway and Santana (2021), Athey and Imbens (2006), and Chaisemartin and D'Haultfoeuille (2018). These authors explore the use of "not yet treated" units as control groups in DiD approaches. By using this group, the aim of the robustness analysis is to verify the consistency of the estimates, thus confirming their validity.

Table 4 - Robustness of the results.

	Parks in Operation/Construction				Parks under construction			
Effects	ATT	EP	IC		ATT	EP	IC	
Links	0.2244*	0.059	0.1088	0.3401	0.1807*	0.0672	0.049	0.3124
Wage bill	0.2620*	0.06	0.1445	0.3796	0.2344*	0.0864	0.065	0.4038
Remuneration	0.1333	.0926	0.0481	0.3147	0.1686	0.1663	-0.1574	0.4946
GDP *per capita*	0.1807 *	0.035	0.1122	0.2493	0.0563 *	0.0281	0.0011	0.1114
GVA - Services	0.095 *	0.0206	0.0548	0.1353	0.013	0.0279	-0.0417	0.0677
GVA - Industrial	0.7149 *	0.1215	0.4767	0.9531	0.2636 *	0.1013	0.0651	0.4621
GVA - Agro	-0.0751	0.0404	-0.1542	0.004	-0.092 *	0.0298	-0.1503	-0.0337

Source: Prepared by the authors. * p-value < 0.05.

Table 4 shows the average treatment effects by time-group for those "not yet treated". The robustness estimates reveal that the construction and operation of wind farms are largely consistent with the results in Table 3, especially with regard to GDP per capita and industrial GVA, both of which show positive and significant impacts. With regard to services GVA, the positive and significant effects are restricted to wind farms in the operation or construction phase. Agricultural GVA, on the other hand, shows negative impacts during the construction phase in both analyses, with statistical significance for parks under construction. Therefore, these results indicate that the construction and operation of wind farms generate positive economic effects on GDP per capita and on the industrial and services sectors, but can have a negative impact on the agricultural sector during the construction phase.

5. STRATEGIES TO BOOST RESULTS

The construction of wind farms in northeastern Brazil has had a positive impact on the labor market and on municipal economic indicators. However, with a view to guaranteeing the long-term economic benefits generated by the implementation and operation of wind farms, as well as boosting these results, measures can be added, such as incentives to train local workers in wind energy jobs, which can ensure that the local population remains in the formal labor market (Simas and Paccas, 2013; Munday et al., 2011).

Infrastructure development can also be boosted with the installation and construction of wind farms (Aldieri, Grafström, Sundström and Vinci, 2019). Investment in infrastructure can help generate and attract new investment. In addition, fostering local economic development can extend the benefits that already exist with the creation of wind farms, and this can happen through PNDR instruments, such as credit lines from the constitutional fund (FNE).

Due to its dynamic existence, the wind sector is constantly developing technologies. Investment in R&D can increase the efficiency of wind farms, reduce costs and open up market opportunities for local companies, strengthening the region's competitiveness in the renewable energy sector (Blanco and Kjaer, 2009).

It is also important to highlight sustainability policies in order to minimize environmental impacts and the health of communities living near the parks (Wang and Wang 2015).

Finally, the results show that there is a negative impact on the agricultural sector during the construction phase of the parks, so it is important to develop programs to support this sector in order to minimize the negative impacts generated by the construction of the parks.

6. FINAL CONSIDERATIONS

The FDNE is one of the instruments of the PNDR, which focuses on promoting public policies to reduce regional inequalities and, to this end, finances projects that are to be implemented, expanded, modernized or diversified in Sudene's area of operation, with a focus on sectors such as infrastructure, which have up to 20 years to repay the financing.

To this end, this article assesses the impact of FDNE funding on the construction of wind farms in relation to labor market indicators (employment, average income and wage bill) and economic indicators (GDP per capita and sectoral GVA - Services, Industrial and Agricultural) in the municipalities of the Sudene region.

The effects are estimated using the scaled difference-in-differences model, given that the financing and construction of wind farms, as well as the start of energy generation, take place in sequential stages over the years. For this reason, the use of the Callaway and Sant'Anna (2021) estimator is appropriate for evaluating this policy.

The results show evidence of an increase in GDP per capita and growth in GVA in the industrial and services sectors, despite a negative effect on agricultural GVA. It can therefore be inferred that wind farms can be an important tool for regional economic development.

Municipalities with wind farms show an increase in GDP per capita. Specifically, these municipalities with wind farms in operation or under construction showed a significant increase in their economic variables. These positive effects are attributed to the generation of energy and revenue from the farms in operation, as well as possibly to the employment and investments associated with the construction phase.

In addition, wind farms have had a positive impact on the GVA of industry and services. In the industrial sector, there was a significant increase when comparing municipalities with wind farms already built to municipalities with wind farms under construction. The services sector also benefited, with an increase in GVA in municipalities with wind farms in operation.

The construction of wind farms has a positive impact on the industrial and service sectors, but the agricultural sector has shown negative effects during the construction phase of wind farms. This can be explained by the temporary eviction of agricultural land needed to build the farms. However, once construction is complete, the negative impacts tend to dissipate, and no effects were observed in municipalities with wind farms that are already operational.

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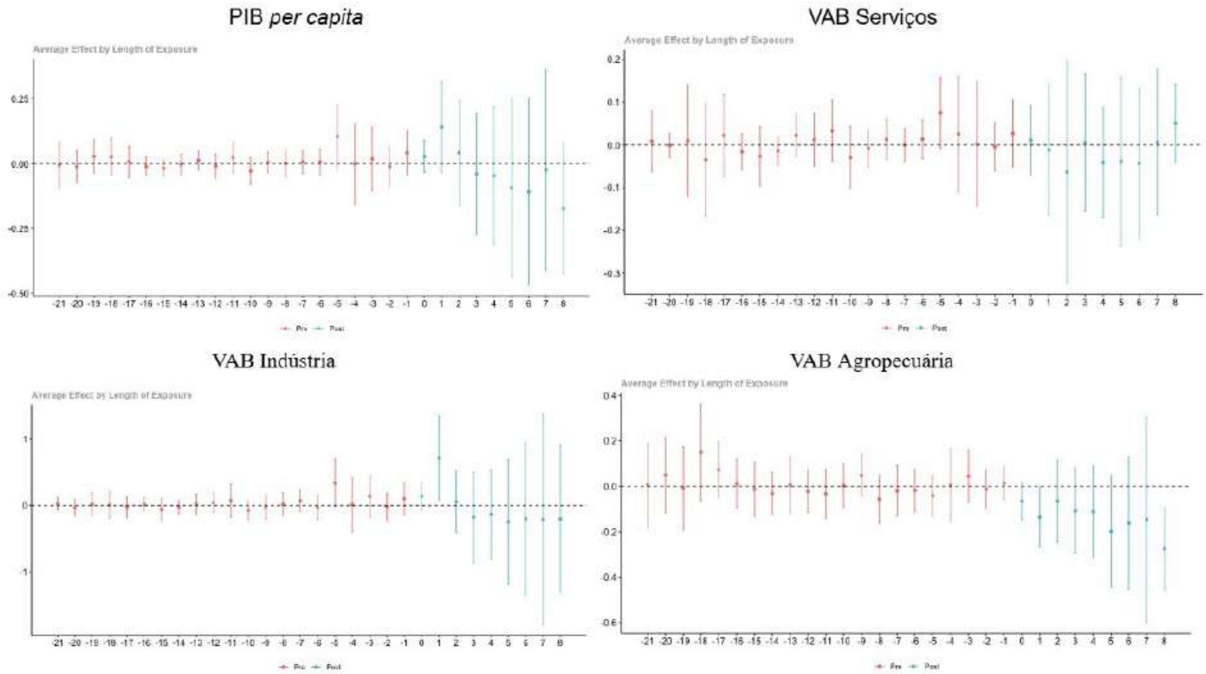
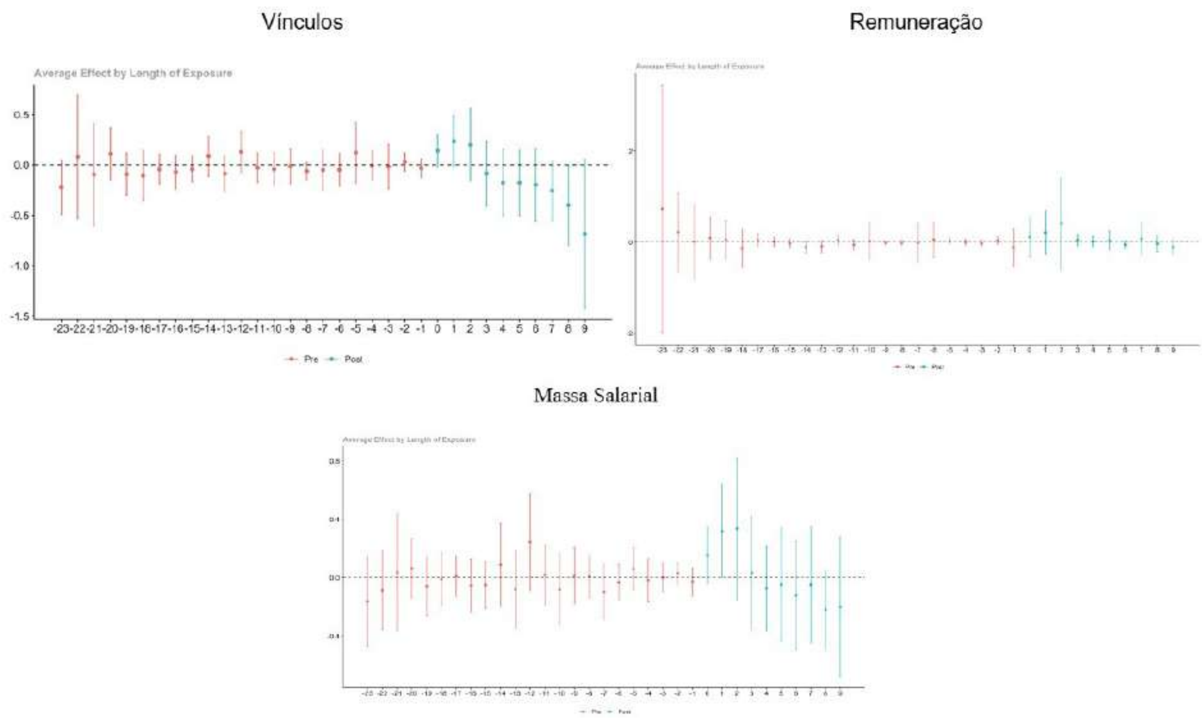
APPENDIX

Figure A1 - Events Study for parks under construction: Economic Indicators



Source: Prepared by the authors.

Figure A2 - Events study for parks under construction: Labor Market



Source: Prepared by the authors.