

**WIND POWER AND THE LABOR MARKET IN THE BRAZILIAN NORTHEAST: A SPATIAL PROPENSITY SCORE MATCHING APPROACH\***

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**ABSTRACT:** Debates on the importance of renewable energy sources have arisen in the context of climate change. Wind power is a renewable and clean energy source with minimal environmental impact. Also, the existing literature indicates that the installation of wind farms can be an important channel for local development through job and income generation. In this context, this study aims to analyze the relationship between the presence of wind farms and the labor market outcomes of the municipalities of the Northeast region of Brazil, which contains around 80% of the installed capacity of this technology in the country. The database of this study is built from several public data sources. The methodological approach taken was a combination of propensity score matching and the estimation of the average treatment effect. However, we consider the existence of spatial dependence of the municipalities in the estimation of the propensity score. The results suggest that the presence of wind power plants is positively related to increases in the total wage of the municipalities, mostly in sectors such as construction, transportation, and logistics. In addition, the presence of these plants allows the shifting of resources to the agricultural sector.

**Keywords:** Wind energy; Spatial propensity score matching; Local development.

**JEL Codes:** Q42; C31; R58.

**ENERGIA EÓLICA E O MERCADO DE TRABALHO NA REGIÃO NORDESTE DO BRASIL: UMA ABORDAGEM DE PAREAMENTO POR ESCORE DE PROPENSÃO ESPACIAL**

**RESUMO:** O debate acerca do potencial da energia eólica surge no contexto das discussões sobre mudanças climáticas. A energia eólica é uma fonte de energia renovável, limpa e de baixo impacto ambiental. Além disso, a literatura indica que a implantação de usinas eólicas pode ser um importante canal de desenvolvimento local ao gerar empregos e renda. Nesse sentido, este estudo busca analisar a relação entre a instalação de parques eólicos nos municípios da região Nordeste do Brasil, a qual concentra cerca de 80% da capacidade instalada dessa tecnologia no país, e os resultados de mercado de trabalho da região. A base de dados deste trabalho é construída a partir de várias fontes de dados públicos. A metodologia empregada é o pareamento por escore de propensão, além do cálculo do efeito médio de tratamento nos tratados. Em decorrência da natureza espacial das unidades observadas, a existência de dependência espacial é considerada na estimação. Os resultados sugerem que a implantação de usinas eólicas pode elevar a massa salarial nos setores de construção, transporte e logística. Além disso, a presença dessas usinas pode deslocar recursos para o setor agropecuário.

**Palavras-chave:** Energia eólica; Pareamento por escore de propensão espacial; Desenvolvimento local.

**Classificação JEL:** Q42; C31; R58.

## 1. Introduction

The electricity sector is essential for the growth and development of any economy. For this reason, understanding the determinants of supply and demand in this sector is strategic in public policy formulation<sup>1</sup>. Debates on the importance of renewable energy sources have arisen in the context of climate change. The Kyoto Protocol, created at the United Nations Framework Convention on Climate Change (UNFCCC) in 1997 and came into force in 2005, was a relevant agreement in the promotion of the use of renewable energy. This agreement set targets for reducing greenhouse gas emissions, from which each country sought to implement the use of renewable energy according to its characteristics and potential (MORENO; LOPEZ, 2008). In December 2015, during the 21st Conference of the Parties in Paris (COP21), governments of around 190 countries presented their plans to reduce domestic greenhouse gas emissions. Brazil committed to reduce its emissions by 37% as of 2025 and by 43% as of 2030 from the 2005 levels (EPE, 2016).

Given this context, wind energy is deemed an important renewable source of energy since it has a high potential in reducing greenhouse gas emissions, although it is not equally distributed in space. However, this source of renewable energy is not widely used worldwide, notwithstanding that it could, theoretically, supply up to 20% of world electricity demand by 2050 (EDENHOFER et al., 2011). In addition to environmental impacts, some studies provide evidence demonstrating that advancing the production of renewable energy sources, especially wind energy, may be relevant to the local development of regions impacted by the installation of wind farms. Wei et al. (2010) argue that many local jobs can be generated, mainly at the construction and installation stages of such plants. Río and Burguillo (2008) also show that the implementation of renewable energy projects can contribute to local development, especially in rural areas. These authors further argue that during the construction phase, an increase in the demand for goods and services is expected, and local suppliers are benefited from increased income and temporary jobs, inside and outside the communities. In addition, changes in community structure can occur, such as improving public infrastructure, lower-cost energy supply, and more.

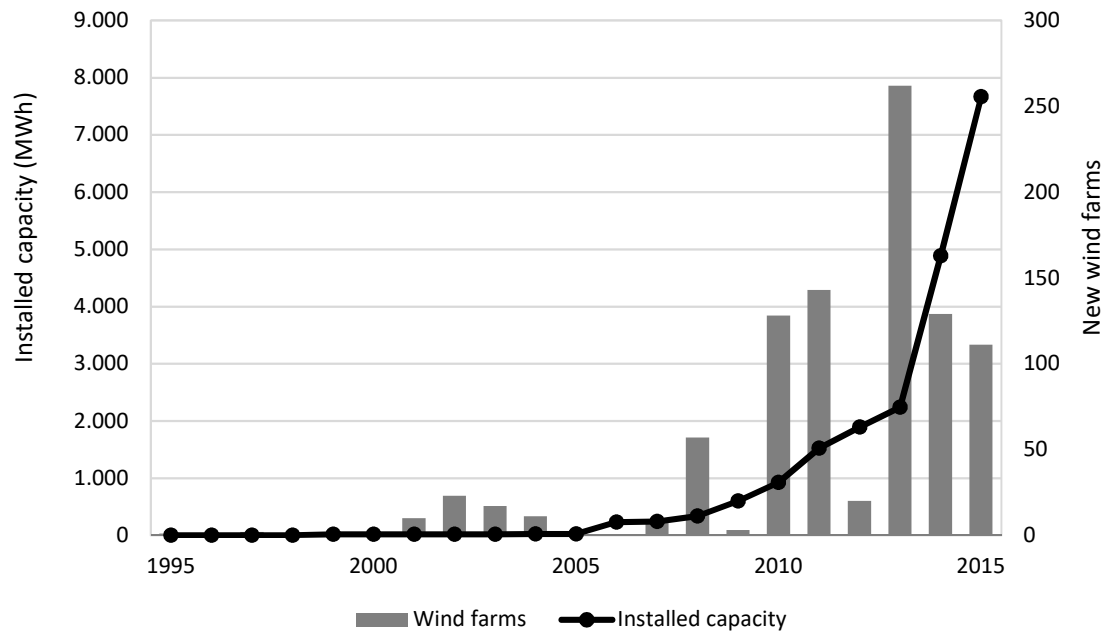
Despite the existence of many studies focused on the socioeconomic impacts of other renewable energy sources<sup>2</sup>, literature that specifically addresses the effects of wind energy on local development is merely recent and scarce. Blanco and Rodrigues (2009) showed that the deployment of wind energy in countries in the European Union creates a significant number of direct jobs, mainly in the wind turbine and component industry. Ejdemo and Söderholm (2015) have identified the impacts on employment in the Swedish construction sector. Concerning Brazil, Simas and Pacca (2014) have verified that the main contribution is in the construction phase and that, despite the low number of jobs created in operation and maintenance of the farms, these jobs have persisted over time.

According to data from the Brazilian Electricity Regulatory Agency (ANEEL), the installed capacity of wind energy in Brazil grew by approximately 430% between 2010 and 2014, from 927 MWh to 4,888 MWh. In addition, data from ANEEL indicate that wind farm records in Brazil began in 1995 and have grown significantly from 2010 (see Figure 1). According to the Global Wind Energy Council (GWEC) report, Brazil, in 2015, was the Latin American country with the largest installed capacity of wind power energy (5.96 MWh) and was ranked tenth in the global ranking for installed capacity, accounting for 2% of the global share of accumulated capacity this year (8.72 GW). In addition, Brazil was the country ranked fourth in the ranking of the new installed capacity of wind power generation (2.76 GW) in 2015.

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<sup>1</sup> For a literature review on the conditions of electricity demand in Brazil, see Uhr et al. (2017 and 2019).

<sup>2</sup> For a literature review on the potential of various renewable energy sources in creating jobs, see Wei et al. (2010) and Lehr et al. (2008).

**Figure 1 - Wind farms and the installed capacity of wind energy in Brazil**

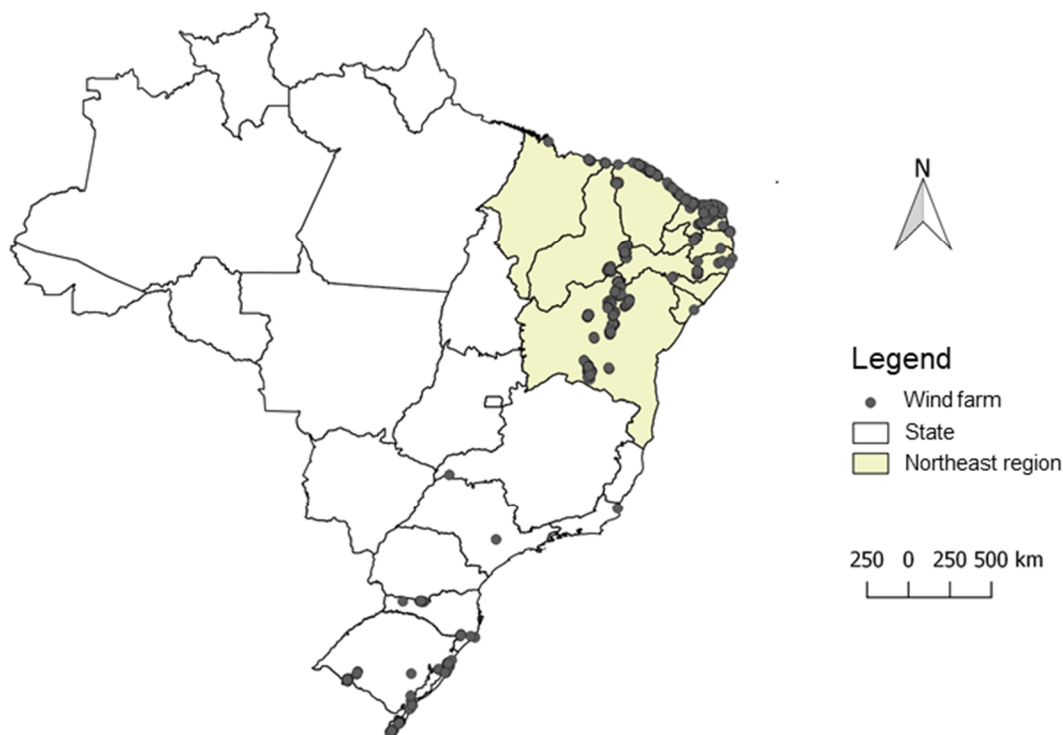
Source: Elaborated by the authors, based on data from ANEEL.

Given these facts and the small number of studies that have analyzed the impact of wind farms on local development, this article aims to understand the relationship between the implementation of wind farms and the labor market results of the municipalities of the Northeast region of Brazil, focusing on three main variables: (i) employment level, (ii) the total amount of wages, and (iii) the number of firms.

Brazil's Northeast region accounts for 54% of the country's wind potential. Moreover, in this region, the sources of wind and hydroelectric power are complementary, because the periods of drought, when the reservoirs of the dams are at the lowest level, coincide with the period of highest incidence and intensity of winds (COSTA et al., 2009). According to ANEEL, 80% of the municipalities with wind farms, in operation or under construction, are located in this region. Figure 2 shows the spatial distribution of wind farms in Brazil and illustrates this intense concentration in the Northeast region, highlighted in gray.

The main contribution of this paper is to relate the implementation of wind farms and the labor market outcomes of the municipalities, through the spatial propensity score matching method as well as the calculation of the average treatment effect on the treated. This methodological approach allows the determination of a control group of municipalities, statistically similar to the treatment group of municipalities, in terms of specific observable characteristics, with the presence of wind farms as the only factor that differentiates the groups. We considered the existence of spatial dependence in the estimate of the propensity score, due to the spatial nature of the units analyzed (CHAGAS et al., 2012).

We concentrated our analysis for the year 2013, and we built our database based on two ANEEL databases, the Georeferenced Information System of the Electricity Sector (SIGEL) and the Generation Information Data (BIG), in addition to the Annual Social Information Report (RAIS), from the Brazilian Ministry of Economy, and other variables from the Brazilian Institute of Geography and Statistics (IBGE) and the National Institute for Space Research (INPE).

**Figure 2 - Spatial distribution of wind farms in Brazil**

Source: Elaborated by the authors, based on data from ANEEL.

The results suggest that the total wages of the construction, transportation, and logistics sectors are higher in municipalities that have wind farms, either in operation or under construction. In addition, municipalities that have wind farms in operation or under construction contain more firms in the agricultural sector, suggesting that the presence of wind power plants can lead to the transfer of resources to the agricultural sector, boosting this activity in the local economy. For the number of jobs in the municipalities, no statistically significant results were found.

The article contains six sections, besides this introduction, appendices, and bibliographical references. The second section consists of a brief literature review on wind energy in Brazil. The third section presents the empirical strategy of the paper and the description of the sample. The fourth section shows the descriptive analyses we conducted. The fifth section presents the results of our study. Lastly, the last section contains our final considerations.

## 2. Wind farms and the local development

Wind energy has grown exponentially in the world since the late 1990s, especially in the European Union and the United States. Wind energy stands out among renewable energy sources due to its lower production costs, the security of supply, and environmental sustainability (GWEC, 2011).

Indeed, this energy source has some specific advantages: (i) the non-use of water and the absence of greenhouse gas emissions during the operation phase of wind turbines; (ii) the absence of danger of fuel leakage; (iii) the possibility of occupation of the land by agriculture or pasture, around the perimeter of the wind farm; (iv) the relatively small area occupied by wind turbines; and (5) the opportunity given to geographically isolated regions that have no available power grid but have strong winds, to generate energy without incurring high transmission costs (Costa, Casotti, and Azevedo, 2009)<sup>3</sup>.

<sup>3</sup> Disadvantages of wind power generation include: (i) the threat to the life of wild animals, especially birds; (ii) noise pollution; and (iii) visual pollution (Klick and Smith, 2010).

In Brazil, the emergence of the Programme of Incentives for Alternative Electricity Sources (Proinfa) has also been identified as a contributor to the growth of wind farms in recent years. The main objectives of this program were: the diversification of the Brazilian energy matrix; the security of supply; the reduction of greenhouse gas emissions; and the exploration of regional and local characteristics and potentials, thereby generating employment and training for the workforce. This program was aimed at increasing the participation of electricity through incentives to independent producers, based on wind sources, small hydroelectric plants (PCHs), and biomass, in the National Interconnected System.

Thus, Proinfa can be regarded as a relevant milestone in the dissemination of wind energy in Brazil, with 44% of the implemented plants of the program are wind power plants. Several studies have highlighted the importance of public programs in the promotion of wind energy. Ohl and Eichhornb (2010) have stated that government policy is an essential step towards the implementation of renewable energy, including the development of wind energy. Bird et al. (2005), in turn, highlighted the role of financial incentives in terms of wind energy in Europe and the United States.

Government incentives and policies may be further justifiable if, in addition to environmental impacts, we take into account the effects of wind farms on the local development of regions affected by the installation of wind farms. Several studies have pointed to the generation of employment and mastery of technology as factors relevant to environmental preservation and energy security in terms of wind energy (MARTINS et al., 2008; SZARKA, 2006).

In this context, Blanco and Rodrigues (2009) have shown that many of the jobs generated by wind energy, especially those related to specialized services as well as the operation and maintenance of the plants, tend to be offered by local firms. These authors also determined that about 59% of direct jobs related to wind energy in Europe are in the component and turbine industries. They have also concluded that because much of the wind energy activity takes place locally (construction, operation, and maintenance), there is a positive relationship between the location of a wind farm and the number of new jobs.

On the other hand, Simas and Pacca (2015) found that, in Brazil, the jobs generated in construction correspond to about 55% of direct jobs and 40% of the total jobs created from the wind energy. They thereafter concluded that this is the stage of greater potential in terms of generating new jobs.

### 3. Empirical strategy

In this article, we use the propensity score matching (PSM) method. The existence of spatial dependence is taken into account in the estimates due to the spatial nature of the units analyzed (i.e., the municipalities).

#### 3.1. Propensity score matching

Matching methods seek to obtain a control group statistically similar to the treatment group in terms of specific observable characteristics. Thus, in comparing two groups of municipalities with the same observable characteristics, the only factor that differentiates them is the existence or the expectation of the presence of a wind farm in its territory.

According to Khandker et al. (2010), under the assumptions of conditional independence and common support, the *average treatment effect on the treated* (ATT), for a subsample with observable characteristics,  $X$ , can be written as:

$$ATT = E[Y(1)|T = 1, X] - E[Y(0)|T = 1, X] \quad (1)$$

where  $Y(1)$  is the potential outcome of the variable of interest under treatment and  $Y(0)$  is the potential outcome of the variable of interest in the absence of treatment.

The PSM method seeks to summarize the effects of different observable variables on a single index. Thus, treated and control municipalities with similar propensity scores are compared. Using the PSM, it is possible to construct a comparison group based on the probability of a municipality being treated ( $T$ ), conditioned on the observed characteristics  $X$  or the propensity score:  $P(X) = P(T = 1|X)$ . In this article, we estimated the propensity score using a *probit* model, such that:

$$P(T = 1|X) = \Phi(X\beta) \quad (2)$$

where  $\Phi$  is the cumulative distribution function (CDF) of the standard normal distribution and  $\beta$  is the estimated parameter vector.

However, as the unit of interest in this study consists of the municipalities of the Northeast region of Brazil, the sample has a geographical nature; thus, the units analyzed may not be randomly distributed in space. Hence, the possibility of spatial dependence between the observed units should be considered in the propensity score estimation through the implementation of a spatial propensity score. Based on Chagas et al. (2012), the spatial dependence can be inserted into equation (2) in two ways: through a regressor in the form of a spatially lagged dependent variable ( $Wy$ ) or in the structure of the error term ( $Wu$ ). Formally, the spatial model is represented by:

$$\begin{aligned} y &= \rho Wy + X\beta + u \\ u &= \lambda Wu + \varepsilon \end{aligned} \quad (3)$$

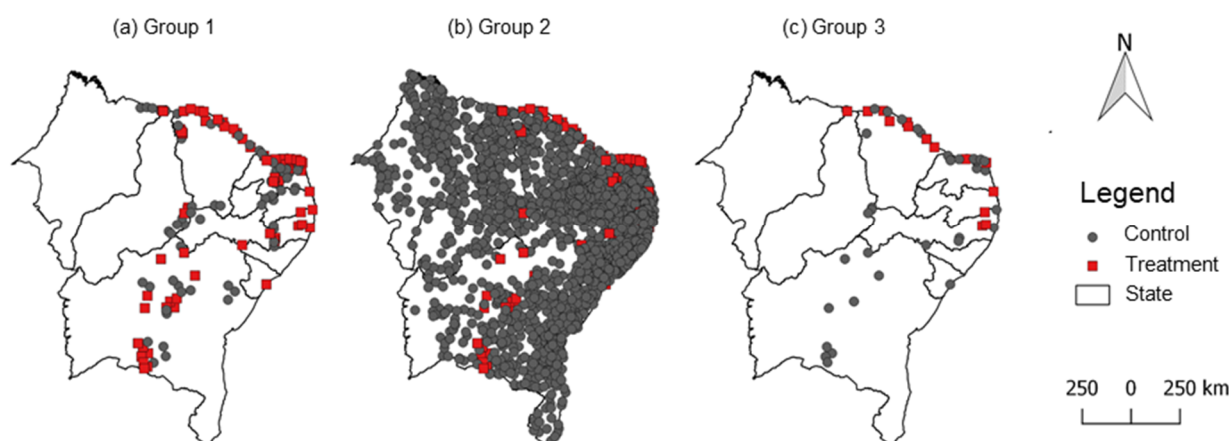
where  $y$  is the vector of the dependent variable,  $W$  is a spatial weight matrix that characterizes the type of neighborhood relationship between municipalities,  $\rho$  and  $\lambda$  are the spatial parameters, and  $\varepsilon$  is the error term. If  $\rho \neq 0$  and  $\lambda = 0$ , the specification is known as the *spatial autoregressive model* (SAR), and if  $\rho = 0$  and  $\lambda \neq 0$ , the specification is called the *spatial error model* (SEM)<sup>4</sup>.

### 3.2. Treatment and control groups

According to the Georeferenced Information System of the Electricity Sector (SIGEL) from ANEEL, wind power plants can be classified as: (i) operation; (ii) construction with grant; (iii) construction not started; (iv) winner of the auction; (v) disabled; and (vi) *Despacho de Requerimento de Outorga* (DRO). Municipalities with wind farms, either in operation or under construction, with a grant, already have the minimum required infrastructure in the area. On the other hand, the other municipalities have only the expectation of the installation of a wind power plant. Thus, to analyze the relationship between the presence of wind farms in the municipalities in the Northeast region of Brazil and the variables that capture local development, three analysis groups were defined.

For Group 1, the treatment consists of the municipalities where there is at least one wind farm in operation or under construction with a grant and the control group, the municipalities with wind power plants at the project stage, that is, wind farms with statuses of construction not started, winner of the auction or DRO. For Group 2, the control group is expanded to include all other municipalities of the Northeast region, that is, those with no expectation of implementation of wind farms. Finally, Group 3 contains the municipalities with operating wind farms that are part of the Proinfa program in the treatment group, and the municipalities with operating wind farms that are not participating in this program in the control group. Figure 3 shows the spatial distribution of municipalities according to these groups. The red dots on the map are the treatment group municipalities, and the green dots are the control group municipalities. For all analyses, the reference year is 2013.

<sup>4</sup> For more details on spatial models and spatial econometrics, see Anselin (2001), LeSage and Pace (2009), and Almeida (2012).

**Figure 3 - Spatial distribution of the treatment and control groups**

Source: Elaborated by the authors.

Note: Municipalities of the treatment group are in red color and municipalities of the control group are in gray color.

#### 4. Database and variables

We build the database by aggregating two ANEEL databases, SIGEL and BIG. SIGEL presents georeferenced information from all registered or projected wind power plants. The data extracted from these sources are the power of the wind farm, the project registration date at ANEEL, the implementation stage of the wind farm, and the municipality where the wind farm is located. BIG presents information on wind farms that are at least in the construction phase with a grant. Although SIGEL has more detailed information on wind farms, BIG contains the beginning of the wind farm operation, information relevant for our analysis.

It is noteworthy that we have disregarded deactivated wind plants and wind plants with an installed capacity of 100 kilowatts (kW) or less since these wind power plants are not implemented for commercial purposes (ANEEL, 2014). Thus, we used these data to build the database at the municipal level and to define the treatment and control groups described in Section 3.2.

The objective of this paper is to analyze the relationship between the implementation of wind farms and variables that capture the level of welfare and local development of the municipalities of the Northeast region of Brazil. Thus, in this paper, the outcome or dependent variables, for which the average treatment effect on the treated is calculated, are the employment level, the total wages, and the number of firms in the municipalities analyzed.

We used RAIS data from the Brazilian Ministry of Economy in constructing the dependent variables of employment, wages, and the number of firms. We focused on workers with active employment relationship as of December 31, 2013. In addition to the total level of employment and wages in municipalities, we computed for the estimates using disaggregation based on (i) two schooling level of workers – completed and not completed higher education<sup>5</sup>; (ii) economic sectors defined by the Brazilian Classification of Occupations (CBO) – Agriculture, Industry and Maintenance, and Services and Commerce<sup>6</sup>; and (iii) three subcategories of the Industry and Maintenance sector – Construction, Electricity and Gas, and Transport and Logistics<sup>7</sup>. For wages, we

<sup>5</sup> For this disaggregation, we use the filter for schooling after 2005 (IBGE), present in RAIS data.

<sup>6</sup> For this disaggregation, we use the filter for CBO 2002 Large Groups, present in RAIS data. Agricultural, forestry, and fishery jobs are aggregated to obtain the level of employment in Agriculture. Jobs from the production of industrial goods and services of repair and maintenance are aggregated to get the level of employment of Industry and Maintenance. Finally, jobs in administrative services, other services, salespeople in shops, and markets are aggregated to obtain the number of jobs in Services and Commerce.

<sup>7</sup> For this disaggregation, in addition to the filter for the categories of CBO 2002, we use the filter for the workers of the production of industrial goods and services among the groups of CNAE (National Classification of Economic Activities) 2.0. Jobs from transportation, storage, and mail are aggregated to get the number of Transport and Logistics.

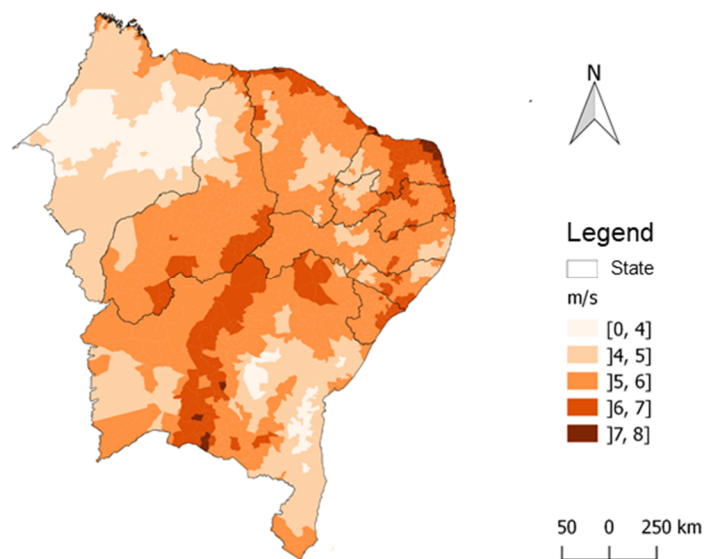


applied a natural logarithm. For the total number of firms, we used a different form of disaggregation, since firms are heterogeneous in terms of worker educational level. Another difference can be seen in the breakdown by economic sector, due to the number of firms, it is only possible to apply filters based on IBGE Groups. Thus, this procedure implies consolidating the Industry with the Construction sector.

The first step of the empirical strategy is the propensity score estimation, in which some explanatory variables are considered for the probability of the municipalities belonging to the treatment group. The explanatory variables are wind speed, the ratio of agricultural gross domestic product (GDP) to total GDP, area of municipalities, population, and a dummy variable for the metropolitan region.

The wind speed of a locality is the explanatory variable for which we expect a positive and high magnitude impact on the probability of having a wind farm, given that this is one of the main criteria evaluated by the Ministry of Mines and Energy (MME) for approval of participation in energy auctions of wind energy projects. This variable is considered at the municipal level, based on georeferenced information provided by the National Institute for Space Research (INPE), and is calculated as the average annual wind speed (in meters per second) at 50 meters in height<sup>8</sup>. Figure 4 presents the spatial distribution of this variable. The comparison of Figures 3 and 4 shows that the Northeast region of Brazil, in which most of the municipalities with wind power plants are concentrated, is also the area with the highest wind speed.

**Figure 4 - Average annual wind speed of the municipalities of the Northeast region of Brazil**



Source: Elaborated by the authors, based on data from INPE.

Note: Average annual wind speed in meters per second at 50 meters in height.

We used the natural logarithm of the number of inhabitants of the municipality as a population variable, obtained through data provided by IBGE. The inclusion of a control for the municipality size in terms of population density, which is highly correlated with the economically active population, improves the matching of the municipalities of the treatment and control groups in terms of economic dynamics. We used the municipal GDP data at current prices to calculate the ratio between the agricultural GDP and the total GDP of the municipalities. These data are available from IBGE. The inclusion of this variable seeks to capture the opportunity cost of land use for the presence

<sup>8</sup> According to Grubb and Meyer (1993), the density of the wind energy must be greater than or equal to 500 W/m<sup>2</sup> at the height of 50 meters for being considered technically usable, which requires a wind speed between 7 and 8 meters per second.



of wind farms, as one of the possible alternatives for land use in agricultural activities. Thus, a negative relationship is expected between this variable and the probability of existing wind farms in the localities. Another relevant explanatory variable is the total area of the municipality – in natural logarithm – whose inclusion aims to control for the availability of space for the construction of wind farms and allows the matching of the treatment and control municipalities with similar size. Therefore, we expect the relationship between this variable and the presence of wind farms in the localities to be positive. Finally, the inclusion of a variable that indicates whether the municipality is located in a metropolitan region aims to control for populational and economic dynamics, considering that urban areas have distinct characteristics from non-metropolitan areas.

## 5. Descriptive analysis

The descriptive analysis presents t-tests for the differences between the means of the dependent variables of the municipalities of the treatment and control groups. The objective of these tests is to verify, in an unconditional analysis, the existence of statistically significant differences in the average of the variables for total employment, wages, and the number of firms, before performing the econometric estimation. We also perform the tests disaggregated by educational level of workers and economic sectors. Finding positive and statistically significant differences for the variables that capture the level of local development is the first evidence that the municipalities with wind farms – treatment units – could perform better in terms of these labor market outcomes.

Tables 1 to 3 show the mean variables for the treatment and control groups of municipalities – as described in section 3.2 – and the statistical significance of the tests. Comparing the results presented in these tables allows us to conclude the feasibility of using these treatment and control groups for estimates.

The comparison between the total level of employment in municipalities with wind farms under construction and operation and the municipalities with projects of wind power plants (Table 1) allows us to verify the statistically significant differences in terms of the average employment of the agricultural, electricity, and gas sectors. In contrast, when the other municipalities of the Northeast region of Brazil are added to the control group (Table 2), it is precisely the employment in these two sectors that no longer presents statistically significant differences, where all other employment variables are different between treatment and control groups. In the case of Group 3, in which the comparison is between municipalities with operating wind farms participating and non-participating in Proinfa, no differences are found for the total level of employment and employment of the sectors and subsectors analyzed (Table 3).

Regarding the level of wages, we observed that the municipalities with wind plants in operation and under construction present a higher level of wages for all sectors and subsectors analyzed, except in the electricity and gas sectors, in comparison to the municipalities with wind farms at the project phase (Group 1). This result evidences the possibility of an increase in the wages and welfare of workers in municipalities that have some wind farm operating or in construction. Statistically significant results are also found from the tests when we added the other Brazilian municipalities to the control group (Group 2). In this case, the differences also occurred for the total level of wages and the wages of sectors and sub-sectors, except in the electricity and gas sectors.

Also, when we compared the municipalities with operating wind farms participating and non-participating in Proinfa, we found significant results for the total level of wages, the wages of higher-educated workers, and the wages of the three sectors analyzed: agriculture, industry and maintenance, and services and commerce. This result serves as preliminary evidence showing that participation in this program could further reinforce the positive relationship between the presence of wind farms and local development. However, no differences are found when we disaggregated according to subsectors.

**Table 1 - T-test for the differences between the means of the dependent variables - Group 1**

Employment	Treatment (T)	Control (C)	Difference (T-C)	<i>t</i> -statistic
Total	15,934	2,282	13,652	-1.14
Completed higher education	2,918	496	2,422	-1.07
Not completed higher education	13,015	1,786	11,230	-1.15
Agriculture	231	104	127	-1.69 *
Industry and Maintenance	3,329	490	2,839	-1.16
Construction	977	70	907	-1.17
Electricity and Gas	7	1	6	-1.82 *
Transport and Logistics	270	20	250	-1.20
Services and Commerce	7,139	943	6,196	-1.13
<b>Wages</b>				
Total	14.7	14.1	0.6	-2.49 **
Completed higher education	13.5	13.0	0.5	-2.06 **
Not completed higher education	14.2	13.7	0.5	-2.38 **
Agriculture	10.7	9.6	1.2	-3.47 ***
Industry and Maintenance	12.4	11.8	0.6	-2.04 **
Construction	10.6	9.5	1.1	-2.26 **
Electricity and Gas	10.4	10.0	0.4	-0.54
Transport and Logistics	10.3	9.2	1.0	-2.00 **
Services and Commerce	13.5	13.0	0.5	-1.92 *
<b>Number of firms</b>				
Total	1,065	184	881	-1.15
Agriculture	20	9	11	-2.69 ***
Industry and Construction	197	25	172	-1.13
Construction	77	7	70	-1.14
Electricity and Gas	1	0	1	-1.63
Transport and Logistics	0	0	0	0.00
Services and Commerce	848	150	698	-1.15
Observations	65	69		

Notes: p-value < 0.10: \*, p-value < 0.05: \*\*, p-value < 0.01: \*\*\*; employment and number of firms are in levels; wages are in natural logarithm. The treatment group is composed of the municipalities in which there is a wind farm in operation or construction with a grant, whose base year is 2013, and the control group is composed of the municipalities with projects of wind farms, that is, with the status of construction not started, winner auction or DRO.

**Table 2 - T-test for the differences between the means of the dependent variables - Group 2**

Employment	Treatment (T)	Control (C)	Difference (T-C)	<i>t</i> -statistic
Total	15,934	4,564	11,370	-2.43 **
Completed higher education	2,918	806	2,112	-2.19 **
Not completed higher education	13,015	3,758	9,257	-2.48 **
Agriculture	231	173	59	-0.73
Industry and Maintenance	3,329	957	2,372	-2.64 ***
Construction	977	265	712	-1.97 **
Electricity and Gas	7	3	3	-0.88
Transport and Logistics	270	72	198	-2.29 **
Services and Commerce	7,139	2,063	5,075	-2.27 **
<b>Wages</b>				
Total	14.7	13.9	0.8	-4.36 ***
Completed higher education	13.5	12.7	0.8	-4.45 ***
Not completed higher education	14.2	13.5	0.7	-4.03 ***
Agriculture	10.7	9.9	0.9	-3.17 ***
Industry and Maintenance	12.4	11.5	1.0	-3.84 ***
Construction	10.6	9.9	0.7	-1.97 **
Electricity and Gas	10.4	10.8	-0.4	0.95
Transport and Logistics	10.3	9.4	0.8	-2.34 **
Services and Commerce	13.5	12.8	0.7	-3.81 ***
<b>Number of firms</b>				
Total	1,065	306	759	-2.77 ***
Agriculture	20	17	2	-0.42
Industry and Construction	197	43	154	-3.57 ***
Construction	77	17	60	-3.06 ***
Electricity and Gas	1	0	1	-4.64 ***
Transport and Logistics	0	0	0	0.00
Services and Commerce	848	245	603	-2.62 ***
Observations	65	1,729		

Notes: p-value < 0.10: \*, p-value < 0.05: \*\*, p-value < 0.01: \*\*\*; employment and number of firms are in levels; wages are in natural logarithm. The treatment group is composed of the municipalities in which there is a wind farm in operation or construction with a grant, whose base year is 2013, and the control group is composed of all other municipalities of the Northeast region of Brazil.

**Table 3 - T-test for the differences between the means of the dependent variables - Group 3**

Employment	Treatment (T)	Control (C)	Difference (T-C)	<i>t</i> -statistic
Total	5,454	26,020	-20,566	0.57
Completed higher education	1,131	4,737	-3,606	0.53
Not completed higher education	4,323	21,283	-16,960	0.58
Agriculture	335	240	95	-0.55
Industry and Maintenance	1,091	5,499	-4,408	0.60
Construction	242	1,650	-1,408	0.61
Electricity and Gas	7	9	-2	0.18
Transport and Logistics	61	461	-400	0.64
Services and Commerce	2,544	11,632	-9,088	0.55
<b>Wages</b>				
Total	15.5	14.6	0.9	-1.79 *
Completed higher education	14.6	13.5	1.1	-2.14 **
Not completed higher education	15.0	14.2	0.8	-1.55
Agriculture	12.1	10.4	1.6	-2.88 ***
Industry and Maintenance	13.6	12.4	1.2	-1.92 *
Construction	10.4	11.1	-0.7	0.76
Electricity and Gas	10.1	10.8	-0.7	0.84
Transport and Logistics	9.9	10.8	-0.9	0.97
Services and Commerce	14.4	13.4	1.0	-1.82 *
<b>Number of firms</b>				
Total	485	1,679	-1,194	0.52
Agriculture	32	18	13	-1.42
Industry and Construction	66	324	-257	0.56
Construction	22	128	-105	0.57
Electricity and Gas	1	1	0	0.05
Transport and Logistics	0	0	0	0.00
Services and Commerce	388	1,338	-950	0.52
Observations	14	36		

Notes: p-value < 0.10: \*, p-value < 0.05: \*\*, p-value < 0.01: \*\*\*; employment and number of firms are in levels; wages are in natural logarithm. The treatment group is composed of the municipalities with operating wind farms that are part of the Proinfra program, and the control group is composed of the municipalities with operating wind farms that are not participating in this program.

## 6. Results

The results are divided into two parts. In the first part, we present the propensity score estimates, and we discuss the possibility of spatial dependence and the existence of common support (i.e., the overlap between treatment and control groups). In the second part, we present the relationship between the implementation of wind farms and the local development of the municipalities, by calculating the average treatment effect on the treated.

### 6.1. Spatial propensity score

The propensity score for the probability of the municipality presenting at least one wind farm is estimated using equation (2). Under the evidence of spatial dependence, identified by Moran's I

statistic, spatial elements are incorporated into the estimates according to the spatial characteristics of the data, that is, the spatial propensity score is estimated.

Five spatial weight matrices are considered in verifying the existence of spatial dependence in the observed units: 100, 200, 300, 400, and 500 kilometers. These distances are calculated by geographical coordinates of the administrative center of the municipality, available from IBGE. Thus, the proper strategy for choosing the appropriate spatial weight matrix for each model is to identify the distances associated with the highest spatial correlation using Moran's I statistic<sup>9</sup>. Such an indicator measures the spatial autocorrelation based on the product of the deviations of a variable to its average (Anselin, 2001). Moran's I statistic is calculated for the dependent variable and for the residual of the estimation of equation (2), whose result is presented in Table 4. The choice of the estimation method for the propensity score is based on the existence of spatial dependence of the dependent variable and the residuals of equation (2).

**Table 4 - Moran's I statistic for spatial correlation**

Distance	Dependent variable					
	Group 1		Group 2		Group 3	
	Moran's I	p-value	Moran's I	p-value	Moran's I	p-value
50 km	-	-	-	-	-	-
100 km	-	-	0.098	0.000	-	-
200 km	0.027	0.120	0.049	0.000	-	-
300 km	0.005	0.269	0.027	0.000	0.100	0.023
400 km	0.009	0.162	0.014	0.000	0.089	0.012
500 km	-0.008	0.519	0.007	0.000	0.077	0.004
Distance	Residual					
	Group 1		Group 2		Group 3	
	Moran's I	p-value	Moran's I	p-value	Moran's I	p-value
50 km	-	-	-	-	-	-
100 km	-	-	0.033	0.000	-	-
200 km	-0.002	0.426	0.009	0.000	-	-
300 km	-0.008	0.509	0.008	0.000	0.010	0.306
400 km	0.004	0.237	0.005	0.000	0.015	0.227
500 km	-0.008	0.517	0.003	0.001	0.019	0.141

Note: p-value < 0.10: \*, p-value < 0.05: \*\*, p-value < 0.01: \*\*\*.

We can, therefore, observe that there is no evidence of spatial dependence of the dependent variable for Group 1. For Group 2, it is not possible to reject the null hypothesis regarding the absence of spatial dependence for all cases considered. The 100-kilometer matrix has the highest value for Moran's I. Finally, for Group 3, there is evidence of spatial dependence only in considering the spatial lag in the dependent variable, where the matrix with the highest value for Moran's I is of 300 kilometers.

Table 5 shows the results of propensity score estimates. We found no evidence of spatial dependence for the dependent variable and residuals of the estimation for Group 1. Thereafter, the non-spatial probit model is estimated. For Group 2, which presents evidence of spatial dependence

<sup>9</sup> Stakhovych and Bijmolt (2009) point out that there are several procedures for identifying spatial dependence on data and the most common for spatial correlation are Moran's I statistic, the Kelejian-Robinson test, and the Lagrange Multiplier (LM) test. We adopt one of these tests (Moran's I), recognizing that each test has its advantages and disadvantages.

on both the dependent variable and the residuals of equation (2), the SAR probit and SEM probit models are estimated. For Group 3, which presents spatial dependence only for the dependent variable, the SAR probit is likewise estimated. The model specification includes the entire set of variables available that could be correlated to the presence of wind farms in the localities.

**Table 5 - Results of the propensity score estimations**

Group 1	Probit		SAR Probit		SEM Probit	
	Coefficient	SD	Coefficient	SD	Coefficient	SD
Constant	-6.373***	2.048	-	-	-	-
Wind	0.602***	0.201	-	-	-	-
Area	-0.174	0.137	-	-	-	-
Population	0.382**	0.152	-	-	-	-
GDP ratio	-0.396	1.412	-	-	-	-
MR	0.043	0.540	-	-	-	-
Rho	-	-	-	-	-	-
Lambda	-	-	-	-	-	-
Observations	134		-		-	
Akaike Inf. Crit.	181		-		-	
Group 2	Probit		SAR Probit		SEM Probit	
	Coefficient	SD	Coefficient	SD	Coefficient	SD
Constant	-12.287***	1.157	-9.482***	1.712	-1.363***	0.22652
Wind	1.246***	0.123	0.921***	0.193	0.137***	0.02121
Area	0.108	0.071	0.057	0.066	0.011	0.00843
Population	0.285***	0.079	0.300***	0.100	0.033***	0.01047
GDP ratio	-0.775	0.869	-0.707	0.841	-0.065	0.0901
MR	-0.562*	0.302	-0.535*	0.321	-0.075**	0.03656
Rho	-	-	0.359*	0.209	-	-
Lambda	-	-	-	-	0.068	0.14522
Observations	1,792		1,792		1,792	
Akaike Inf. Crit.	388		-		-	
Group 3	Probit		SAR Probit		SEM Probit	
	Coefficient	SD	Coefficient	SD	Coefficient	SD
Constant	-2.608	3.536	-2.411	3.629	-	-
Wind	-0.209	0.348	-0.238	0.354	-	-
Area	-0.427*	0.252	-0.439*	0.255	-	-
Population	0.552**	0.241	0.566**	0.236	-	-
GDP ratio	4.811**	2.454	5.024*	2.584	-	-
MR	-1.147	0.903	-1.322	0.849	-	-
Rho	-	-	0.128	0.404	-	-
Lambda	-	-	-	-	-	-
Observations	50		50		-	
Akaike Inf. Crit.	60		-		-	

Note: p-value < 0.10: \*, p-value < 0.05: \*\*, p-value < 0.01: \*\*\*.

The results for the propensity score estimation suggest that wind and population are the main variables correlated with the presence of wind farms when using both Group 1 and Group 2. Wind

speed is positively associated with the presence of wind farms in the localities, as expected. Population size is also positively related to the presence of wind farms in the municipalities, indicating that the presence of these wind power plants is more likely to occur in denser areas. For Group 2, the binary variable for the metropolitan regions (MR) is also significant, but it negatively affects the probability of presenting wind farms. In the estimates for Group 3, in addition to the population, the area and the ratio between agricultural GDP and total GDP were deemed relevant variables explaining the probability of presenting at least one wind farm. The higher the participation of agricultural activities in the municipality's economic activities, the greater the opportunity cost of land use to set up a wind farm, and the lower the likelihood that the locality will have wind farms. On the other hand, unlike expected, the area of municipalities – an indicator of area availability to implement wind power plants – is negatively correlated with the presence of wind power plants.

The spatial parameter of the SAR probit model associated with Group 2 is statistically significant, thereby corroborating the spatial nature of the sample, as indicated already by Moran's I. Therefore, in the matching step, for Groups 1 and 3, the propensity score is estimated by the standard probit and, for Group 2, by the SAR probit.

In the matching step, for the three treatment and control groups analyzed, the existence of common support is verified. We found common support for all groups, and we excluded some observations out of support in the second estimation step of the paper. It is noteworthy that in the matching performed for Group 2, there was a higher concentration of control units found in lower propensity score values. Indeed, based on the definition of this group, the treatment group is the municipalities with wind farms in operation or construction, while the control group is broad and includes the municipalities with wind farm projects and other municipalities in the Northeast region of Brazil. It should also be noted that the matching procedure for the three groups analyzed ensures that the mean propensity score was not different for treated and non-treated municipalities<sup>10</sup>.

## 6.2. Average treatment effect on the treated

This paper aims to analyze the relationship between the implementation of wind power plants and the local development of municipalities. We estimated this relationship by calculating the average treatment effect on the treated (see Tables 6 to 8). Table 6 presents the results for the total level of employment and the employment of the sectors and subsectors analyzed. Tables 7 and 8 show the results for the natural logarithm of wages and the number of firms, respectively.

In Table 6, we were not able to verify any statistically significant result for the relationship between the implementation of wind farms and the level of employment in the municipalities, for any of the defined treatment and control groups. The lack of statistical significance for this relationship contradicts the results found in the literature, given that Blanco and Rodrigues (2009) found a positive relationship for employment in the industry and Simas and Pacca (2015) and Ejdemo and Söderholm (2015) identified a positive relationship for the employment of the construction sector. The difference in the results of our paper and the cited studies may be due to estimation methods, degree of robustness of each method, or the definition of the sample of localities.

Table 7 shows that wages in the construction and transportation and logistics subsectors are higher in municipalities that have wind farms in operation or construction (Group 1). This difference accounts for approximately 11% for the construction subsector and 9% for the transportation and logistics subsector. We found a negative correlation between the presence of wind power plants and the total level of wages for the electricity and gas subsectors when we added the other municipalities of the Northeast region of Brazil to the control group (Group 2). This result is counterintuitive since the demand-side effects of labor in this subsector should pressure and raise wages. However, in this paper, we obtained employment and wage data based on RAIS data for employee-employer matching; thus, we focused on the equilibrium results of the labor market. Thus, this expected increase in wages in the electricity and gas subsectors, through increased demand for labor in this subsector, could be

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<sup>10</sup> The table presenting the t-tests performed before and after the matching procedure is in the Appendix of the paper.



offset by an increase in labor supply in the subsector, which could, in turn, decrease average wages per worker and total level of wages.

**Table 6 - Results for the level of employment in the municipalities of the Brazilian Northeast**

Group 1	Treatment	Control	Difference	
			Mean	SD
Total	15,933	2,863	13,069	12,384
Completed higher education	2,918	615	2,303	2,345
Not completed higher education	13,015	2,248	10,766	9,701
Agriculture	231	233	-2,18	134
Industry and Maintenance	3,329	627	2,701	2,620
Construction	976	82	894	915
Electricity and Gas	6,52	0,57	5,95	3,69
Transport and Logistics	270	22,15	247	230
Services and Commerce	7,138	1,122	6,016	5,133
Observations	65	69		
Group 2				
Total	15,934	14,519	1,414	13,965
Completed higher education	2,918	2,722	196	2,410
Not completed higher education	13,015	11,797	1,218	8,932
Agriculture	231	408	-176	132
Industry and Maintenance	3,329	2,920	409	2,593
Construction	977	954	22	735
Electricity and Gas	6,52	12,49	-5,97	5,97
Transport and Logistics	270	223	47	239
Services and Commerce	7,139	6,865	273	6,272
Observations	65	1,729		
Group 3				
Total	5,453	103,622	-98,169	77,870
Completed higher education	1,131	19,339	-18,209	13,424
Not completed higher education	4,323	84,283	-79,960	59,899
Agriculture	335	506	-171	276
Industry and Maintenance	1,091	21,032	-19,942	20,442
Construction	242	6,609	-6,367	5,047
Electricity and Gas	7,21	26,53	-19,31	30,05
Transport and Logistics	61,21	1,783	-1,722	1,331
Services and Commerce	2,544	47,114	-44,560	46,474
Observations	14	36		

Note: p-value < 0.10: \*, p-value < 0.05: \*\*, p-value < 0.01: \*\*\*; level of employment in absolute numbers.

**Table 7 - Results for the level of wages in the municipalities of the Brazilian Northeast**

Group 1	Treatment	Control	Difference	
			Mean	DP
Total	14.69	14.44	0.24	0.20
Completed higher education	13.50	13.27	0.23	0.25
Not completed higher education	14.23	14.02	0.22	0.21
Agriculture	10.74	9.97	0.77	0.52
Industry and Maintenance	12.45	12.34	0.11	0.26
Construction	10.62	9.46	1.16 **	0.57
Electricity and Gas	10.40	9.86	0.54	0.42
Transport and Logistics	10.25	9.35	0.90 *	0.50
Services and Commerce	13.48	13.31	0.17	0.22
Observations	65	69		
Group 2				
Total	14.69	14.62	0.06	0.19
Completed higher education	13.50	13.34	0.15	0.21
Not completed higher education	14.23	14.22	0.01	0.29
Agriculture	10.74	10.35	0.40	0.30
Industry and Maintenance	12.45	12.43	0.02	0.32
Construction	10.62	10.52	0.10	0.50
Electricity and Gas	10.40	11.29	-0.90 *	0.52
Transport and Logistics	10.25	10.17	0.09	0.47
Services and Commerce	13.48	13.50	-0.02	0.21
Observations	65	1,729		
Group 3				
Total	15.51	15.15	0.36	0.81
Completed higher education	14.59	13.96	0.63	0.78
Not completed higher education	14.95	14.70	0.25	0.88
Agriculture	12.08	11.15	0.94	0.78
Industry and Maintenance	13.59	12.71	0.88	1.03
Construction	10.36	11.01	-0.65	1.61
Electricity and Gas	10.11	12.24	-2.13 *	1.17
Transport and Logistics	9.89	12.68	-2.79 **	1.40
Services and Commerce	14.36	14.12	0.23	0.87
Observations	14	36		

Note: p-value < 0.10: \*, p-value < 0.05: \*\*, p-value < 0.01: \*\*\*; wages are in natural logarithm.

**Table 8 - Results for the number of firms in the municipalities of the Brazilian Northeast**

Group 1	Treatment	Control	Difference	
			Mean	DP
Total	1,065	222	843	631
Agriculture	19	10	9 **	4
Industry and Construction	197	31	166	166
Construction	77	8	68	62
Electricity and Gas	1	0	1	1
Transport and Logistics	0	0	0	0
Services and Commerce	848	181	667	649
Observations	65	69		
Group 2				
Total	1,065	971	94	1,061
Agriculture	19	30	-11	9
Industry and Construction	197	147	50	147
Construction	77	70	7	62
Electricity and Gas	1	1	1	0
Transport and Logistics	0	0	0	0
Services and Commerce	848	793	54	766
Observations	65	1,729		
Group 3				
Total	485	6,607	-6,122	4,771
Agriculture	31	31	1	19
Industry and Construction	66	1,312	-1,246	1,151
Construction	22	529	-507	435
Electricity and Gas	1	4	-3	4
Transport and Logistics	0	0	0	0
Services and Commerce	388	5,264	-4,876	3,970
Observations	14	36		

Note: p-value < 0.10: \*, p-value < 0.05: \*\*, p-value < 0.01: \*\*\*; total of firms in absolute numbers.

In the estimates for Group 3 – treatment group is the municipalities with operating wind farms participating in the Proinfa program, and the control group is formed by the other municipalities with operating wind power plants – we also found a negative relationship for wages of the subsectors of electricity and gas and transportation and logistics. However, in this case, the results are not out of line, as it would be possible for municipalities with operating wind farms, but not participants in Proinfa, to have better outcomes for the labor market after the implementation of the wind farms. We also verified that the level of wages is about 21% higher for electricity and gas and 28% for transportation and logistics in municipalities not participating in Proinfa.

In Table 8, we observed that the municipalities having wind farms in operation or construction present 48% more firms in the agricultural sector, and this is the only statistically significant result that we found regarding the number of firms. This positive result for the number of firms in the agricultural sector may be related to the possibility of land leasing in the implementation of a wind

farm project in a locality. This mechanism allows the continuity of agricultural activities in the land and can strengthen the local development.

Therefore, the results of this paper suggest that the presence of wind farms in operation or construction may be related to a higher level of wages in the construction and transportation and logistics subsector. Moreover, the results suggest that the presence of wind power plants may shift resources to the agricultural sector, boosting this activity in the local economy. This latter result is in line with the study of Bergmann, Hanley, and Wright (2006) for Scotland, which shows that the most significant socioeconomic benefits of implementing renewable energy sources, especially wind energy, occur in rural areas.

Finally, regarding the Proinfa program, the results indicate that the effects of the program on employment, wages, and the number of firms can be limited since the presence of wind farms out of the program is related to a higher level of wages in the electricity, gas, transportation, and logistics subsectors.

## 7. Concluding remarks

This study aims to analyze the relationship between the implementation of wind farms and local development in the municipalities of the Northeast region of Brazil in 2013. We focused on labor market outcomes, such as employment, wages, and the number of firms. The main contribution of this article is to relate the presence of wind farms to the labor market outcomes through the use of the spatial propensity score matching method and the calculation of the average treatment effect on the treated.

We found that the total level of wages in the construction, transportation, and logistics sectors are higher in municipalities that have wind power plants in operation or construction. This difference accounts for about 11% in the construction subsector and 9% in the transportation and logistics subsectors. Also, municipalities that have wind farms in operation or construction contain 48% more firms in the agricultural sector, thereby suggesting that the presence of wind power plants leads to the shifting of resources to the agricultural sector, boosting this activity in the local economy.

In addition, wages are higher in the electricity and gas and transportation and logistics subsectors in municipalities with operating wind farms but not participating in the Proinfa program. This result serves as evidence that the impacts of this government program may have been limited in the case of wind farm implementation. Finally, no statistically significant results were found regarding the relationship between the presence of wind farms and the total level of employment.

The results of this paper suggest that the presence of wind farms may generate positive impacts on the local development of Brazilian municipalities. Thus, given the natural conditions of the country, especially in its Northeast region, it could be expected that the expansion in the number of projects of this type of renewable energy will contribute to the increase of the local welfare. We can also expect that once auctions for renewable energy projects continue to take place, as a process of transition to an increasingly cleaner energy matrix, these positive impacts can be even higher, thereby positively affecting jobs, income, and the number of firms in the region.

It is noteworthy that, despite the relevance of the correlations found in this paper, it is not the purpose of the study to identify and estimate the isolated effect of wind energy. For this purpose, it would be necessary to use longitudinal data and econometric panel methods or other methods, allowing achieving robustness of the effects

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## Appendix

Table A1 - T-tests for the explanatory variables (prior and after the matching)

Group 1 Variables	Prior the matching			After the matching		
	T	C	<i>t</i> -statistic	T	C	<i>t</i> -statistic
Wind	6.35	6.05	-2.82 ***	6.22	6.19	-0.26
Area (log)	6.36	6.52	0.92	6.33	6.60	0.86
Population (log)	10.05	9.76	-1.67 *	9.88	9.99	0.42
Ratio Agriculture and total GDP	0.10	0.10	0.33	0.12	0.09	-1.34
MR	0.09	0.04	-1.13	0.04	0.04	0.03
Observations	65	69		65	69	
Group 2 Variables	Prior the matching			After the matching		
	T	C	<i>t</i> -statistic	T	C	<i>t</i> -statistic
Wind	6.35	5.17	-12.41 ***	6.59	6.57	-0.15
Area (log)	6.36	6.11	-1.75 *	6.50	6.44	-0.16
Population (log)	10.05	9.60	-3.67 ***	10.24	10.34	0.25
Ratio Agriculture and total GDP	0.10	0.14	2.76 ***	0.08	0.10	0.89
MR	0.09	0.08	-0.33	0.06	0.14	0.76
Observations	65	1,728		65	1,728	
Group 3 Variables	Prior the matching			After the matching		
	T	C	<i>t</i> -statistic	T	C	<i>t</i> -statistic
Wind	6.34	6.47	0.70	5.82	6.04	0.57
Area (log)	6.14	6.36	0.69	6.04	5.89	-0.11
Population (log)	10.51	10.05	-1.25	10.48	12.43	0.83
Ratio Agriculture and total GDP	0.13	0.08	-1.83 *	0.23	0.17	-0.32
MR	0.07	0.14	0.65	-	-	-
Observations	14	36		14	36	

Note: p-value < 0.10: \*, p-value < 0.05: \*\*, p-value < 0.01: \*\*\*. T-tests after the matching are performed for one of the blocks generated in the PSM. As this matching procedure ensures that the mean propensity score is not different for the treatment and control groups, the selection criterion for blocks was the maximum number of observations in each group.