The impacts of wind power on Brazilian local labor market *

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Abstract

Renewable energy is a crucial element to mitigate the effects of climate change, and wind power is an important resource because of its lower production cost and sustainability. Beyond the environmental dimension, the implementation of wind farms may impact local development. Due to the weather conditions, Brazil emerges as one of the leading countries in the generation of wind power. Thus, this paper aims we estimate the impacts of wind farms on the Brazilian local labor market, aggregating information from several data sources into a panel from 2002 and 2016. We analyze the impacts on the formal employment and wage levels, considering different sectors, educational level, and firm size. We explore the staggered process of expansion of wind farms among municipalities through the staggered Difference-in-Differences (DiD) approach, and we apply the event-study framework to verify the effects of duration and pre-intervention trends. The results suggest that wind farms increase the total level of employment and wages in all economic sectors. The most significant impacts are found for the industry, construction and agricultural sectors. Also, we find positive effects on the total level of employment and wages of lower educated workers. These results suggest that wind power may generate significant social impacts through the labor market, providing local development and household welfare increase in developing countries.

Resumo

A energia renovável é um elemento crucial para mitigar os efeitos das mudanças climáticas, e a energia eólica é um recurso importante devido ao seu baixo custo de produção e sustentabilidade. Além da dimensão ambiental, a implantação de parques eólicos pode impactar o desenvolvimento local. Devido às condições climáticas, o Brasil surge como um dos principais países na geração de energia eólica. Assim, este trabalho visa estimar os impactos da presença de usinas eólicas no mercado de trabalho local brasileiro, agregando informações de diversas fontes de dados em um painel de 2002 a 2016. Analisamos os impactos nos níveis de emprego e salário formal, considerando diferentes setores, nível de escolaridade dos trabalhadores e tamanho das firmas. Exploramos o processo escalonado de expansão dos parques eólicos entre os municípios por meio da abordagem de *staggered Difference-in-Differences (DiD)* e aplicamos um *event-study* para verificar os efeitos de duração do efeito e das tendências pré-intervenção. Os resultados sugerem que os parques eólicos aumentam o nível total de emprego e salários em todos os setores econômicos. Os impactos mais significativos são encontrados para os setores industrial, de construção e agrícola. Além disso, encontramos efeitos positivos no nível total de emprego e salários dos trabalhadores com

*The views and opinions expressed in this study are those of the authors and do not necessarily reflect the position of EPE.

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menor escolaridade. Estes resultados sugerem que a energia eólica pode gerar impactos sociais significativos através do mercado de trabalho, proporcionando desenvolvimento local e aumento do bem-estar das famílias nos países em desenvolvimento.

Palavras-chave: Energia eólica, desenvolvimento local, staggered difference-in-differences, event-study.

Códigos JEL: Q42, C23, R58

Área: 7. Infra-estrutura, transporte, energia, mobilidade e comunicação.

1 Introduction

Debates on the importance of renewable energy arise in the context of climate change. The Kyoto Protocol, which was created in 1997 and came into force in 2005, was a relevant agreement to promote renewable energy sources as it set targets for reducing the greenhouse gas emissions. Under this agreement, countries have sought to implement renewable energy according to their characteristics and constraints (Moreno and Lopez, 2018[14]). In December of 2015, during the 21st United Nations Climate Change Conference (COP21), governments from around 190 countries presented their plans for reducing national greenhouse gas emissions. In this context, Brazil committed to reducing the emissions by 37% in 2025 and 43% in 2030, compared to 2005 levels (EPE, 2016[8]).

In this context, wind power is an important source of renewable energy. Although not widely adopted worldwide, wind energy could supply up to 20% of the world's electricity demand by 2050 (Edenhofer et al., 2011[7]). The wind power has grown exponentially in the world since the late 1990s, especially in the European Union and the United States. Wind energy is notable among renewable energy sources due to lower production costs, supply security, and environmental sustainability (GWEC, 2006[9]). In addition, this energy source has some specific advantages, such as: i) non-use of water and non-emission of greenhouse gases during operation; ii) no danger of fuel leakage; iii) allows the occupation of soil, by crop or pasture, in the perimeter of the wind farm; (iv) wind turbines occupy a relatively small area; and v) allows geographically isolated and off-grid regions to generate their energy without incurring high costs with transmission networks (Costa et al., 2009[5]).

In addition to environmental impacts, wind energy is relevant to local development. According to the International Renewable Energy Agency (IRENA), the wind industry has employed about 1,15 million people worldwide in 2017, including onshore and offshore segments. For Brazil, IRENA suggests that about 33,700 people work on the manufacturing of wind turbine components, tower construction and installation, and operation and maintenance of wind farms (IRENA, 2018[11]). Despite the existence of many studies focusing on the socioeconomic effects of renewable energy sources, the literature on the impacts of wind power is recent and still scarce.

Wei, Patadia, and Kammena (2010)[17] argue that wind farms create most jobs during the construction and installation stages. Rio and Burguillo (2008)[6] mention that the implementation of renewable energy projects can contribute to local development, especially in rural areas.

These authors argue that during the construction of a wind farm, the demand for goods and services increases, and local suppliers can benefit from a higher income and temporary jobs. Also, changes in the structure of communities may occur, such as improvements in public infrastructure, lower-cost energy supply, and so on. Blanco and Rodrigues (2009)[4] find that wind energy in some European Union countries creates a significant number of direct jobs, mainly in the wind turbines and components industry that tend to be supplied by local companies.

For Brazil, Simas and Pacca (2014)[16] find relevant local impacts during the construction of wind farms, but they conclude that jobs created in the maintenance and operation sectors are those that persist over time. Rintzel et al. (2017)[15] and Martini et al. (2018)[13] find positive impacts on the labor market and Brazilian GDP, respectively. Despite this evidence, the specific mechanisms and the potential of wind energy in increasing local welfare in developing countries is little know. Moreover, none of these studies conducted for Brazil is based on methodological approaches that allow controlling the effects of the implementation of wind farms on labor market outcomes of a locality.

Therefore, this paper aims to contribute to this literature, estimating the impacts of this energy source on local wages and jobs, using a longitudinal database for the Brazilian municipalities and an identification strategy based on the staggered differences-in-differences. We intend to investigate this issue with a focus on some questions, such as i) Did the implementation of wind farms indeed help the local development in a developing country through increases in jobs and wages? ii) If so, are the largest effects of wind power found in indirect or direct jobs? iii) If so, was the increase in employment and wages concentrated among less skilled and disadvantaged workers? iv) If so, what are the periods in which we expect significant impacts - during the construction, implementation or operation and maintenance of wind farms? We address these issues to the best extent possible with the data currently available and provide evidence on the potential of wind power in increasing local development in Brazil.

Currently, Brazil has 600 wind farms. In 2018, according to Global Wind Energy Council (GWEC), Brazil ranked 8th in the global installed capacity and 5th in the ranking of new onshore installed capacity. Brazil ended 2018 with 14,71 GW of installed wind energy, representing an annual growth of 15.18% (GWEC, 2018[10]). In 2017, wind power generation accounted for 7.2% of all the energy injected into the National Interconnected System (SIN). Besides, wind power was able to supply about 22.4 million Brazilian households per month, which is equivalent to about 67 million inhabitants, which is larger than the entire population of the Northeast region of Brazil.

The wind conditions of Brazil - high speed and regular winds - are the primary determinant of the growth of this energy source in recent years. The Northeast region accounts for 80% of the wind energy generated in Brazil. However, the South and Southeast regions were also the focus of candidate projects presented in the last years and, except for the North region, the whole territory offers wind conditions for the development of this clean energy source.

Given the relevance of wind power in the national energy matrix, and its potential for the future, we estimate the local effects of wind farms on the levels of employment and wages in the formal labor market, considering different sectors (industry, construction, commerce, services, and agriculture), educational level (elementary, high school, and college), and firm size (small, medium and large). We explore the staggered process of expansion of wind farms in Brazilian municipalities through the staggered Difference-in-Differences (DiD) approach. Moreover, we apply the event-study framework to verify the effects of duration and pre-intervention trends on outcomes. We aggregate information's from several sources into a panel from 2002 to 2016, where the data from the labor market come from the Annual Social Information Report (RAIS) of the Brazilian Ministry of Economy, and the energy data come from Generation Information Data (BIG) and Georeferenced Information System of the Electric Sector (SIGEL) of the Brazilian Electricity Regulatory Agency (ANEEL).

The results of this study suggest that wind farms increase the level of employment and wages in all local economic sectors. The highest impacts are found for the industry, construction and agricultural sectors. Indeed, it is possible to observe positive and statistically significant effects of the implementation of wind farms on the employment and wages of workers with elementary and high school, which is an evidence that the expansion of wind power in Brazil could have relevant social impacts through labor market outcomes for the less skilled workers, providing local development geared towards increasing welfare and reducing inequality. In addition, the event-study carried out in the article shows a statistically significant increase in total employment for two periods prior to implementation, which is consistent with the phase of construction of the wind farm that lasts, on average, from eleven to eighteen months, and for two periods after the intervention, that can be explained by the indirect effects of wind energy on employment and wages spreading throughout the local economy, impacting the agriculture sector as well.

This article is structured into four sections, besides this introduction and bibliographical references. The second section consists of a brief review of wind energy in Brazil. The third presents the methodology and data description. Finally, the fourth section presents results and the fifth the final remarks and discussions.

2 Wind power in Brazil

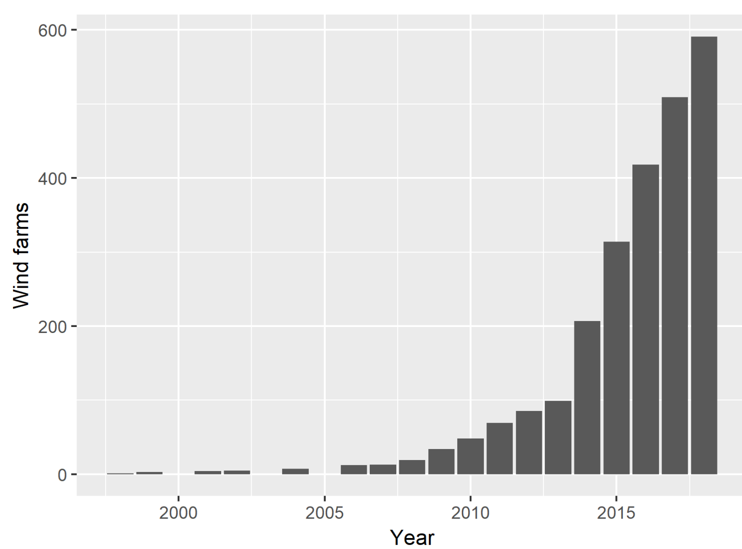
The first wind farm operated in Brazil was established in Fernando de Noronha island, Pernambuco State, in 1992. However, the Brazilian wind power potential only started to be commercially explored in 2002, with the Program for Incentive to Alternative Energy Sources (PROINFA), [1]. The program aimed to increase the share of alternative sources, such as wind energy, small

[1] PROINFA was launched in 2003 by Law 10,438 of April 2002, established by Law 10,762 of November 2003, and regulated in 2004

hydroelectric plants, and biomass, in the National Interconnected System (SIN) [2] through governmental incentives to independent producers. The PROINFA is designed to work in two phases. The first phase would take place between 2006 and 2008, and the second phase would begin after 2008. The wind power generated would be purchased by the government for twenty years. During the program, just 54 wind farms with a potential of 1.4 GW were implemented.

Before PROINFA, Law 10,848 established energy contracts through auctions in 2004. However, the first auction where wind power competed with other energy sources, including non-renewable ones, occurred only in 2008. After that, there was a significant surge of projects registered (wind power accounted for less than 10 % of projects registered in 2007 and increased to 54 % in 2018). Thus, the incidence of wind farms in Brazilian municipalities became more expressive from 2008, as shown in Figure 1. We observe a growing trend since 2006 in the number of installed wind farms, with the most significant growth occurring from 2014. Moreover, according to ANEEL (2014) [1], the installed capacity of wind power grew from 1 GW in 2010 to 14,71 GW in 2018 in the country.

Figura 1: Wind farms in Brazil 1998-2019



Source: ANEEL.

The Energy Research Office (EPE) of Ministry and Mines and Energy (MME) is responsible for analyzing and approving the projects for the Brazilian energy auctions. Before the auctions, the interested entrepreneurs present projects, which are analyzed based on some guidelines, such as i) three years of anemometric data on wind speed and direction in the locality of the project; ii) verification of the interference of wind turbines in neighboring areas; iii) a certification of the feasibility of connecting the wind farm to the energy transmission system; iv) environmental

[2] SIN is a set of facilities and equipment that enable the supply of electricity in the interconnected regions of Brazil: South, Southeast/Center-West, Northeast, and most of the North.

licenses; v) a certification of the land use rights and the georeferencing of the area. Therefore, the investor chooses the location of the wind power project, based on the possibility of meeting the criteria required to participate in an auction, and factors that maximize their chance of winning the auction, as well as the project's profitability. In other words, investors have the autonomy to decide where to implement its wind farm, and the main factor determining their choice are the wind conditions. Thus, the Northeast and South are the main regions to receive wind power projects. The prominence of these regions is also observed in the location of wind farms operating in 2018, as can be seen in Figure 2.

Figura 2: The location of wind farms in Brazil (2018)

Source: ANEEL.

In this paper, we focus on the impacts of wind energy on local development, analyzing the employment and total wages of municipalities with implemented wind farms. Wind energy can improve local welfare through a set of channels, such as i) job creation and income growth of individuals working in sectors directly or indirectly affected by wind energy; ii) growth of income of landowners due to land leasing for the implementation of wind farms; iii) the possibility of coexisting agricultural and livestock activities and wind farms.

Wind energy allows job creation mainly in the turbine industry and in the construction of the farms. It is estimated that for each megawatt of wind energy implemented per year, fifteen jobs are created - which may be direct or indirect, and in the wind turbine industry, supply chain or wind farm implantation (Costa et al., 2009[5]). However, the direct jobs created by the turbine industry are not necessarily allocated to local workers. Although this industry is increasing in

Brazil, wind turbines can come from factories distributed all over the Brazilian territory or from an international manufacturer. According to IRENA (2018)[11], the job creation dynamics of wind power are subject to geographic shifts in the production of equipment, and the requirements in some countries to source a certain percentage of local equipment, components and services are reshaping the industry. In Brazil, there is a trend towards compliance with a minimum of 60% nationalization of wind equipment and components.

Unlike the turbine industry, the operation of the wind farm does not require a large number of workers. It is estimated that 0.4 jobs are created for each megawatt of wind energy when the wind plant is in operation or maintenance. The highest number of jobs arise during the construction and implementation of a plant, which last, on average, from eleven to eighteen months. For example, in the construction of a wind farm with a capacity of 50 MW in the Northeast region of Brazil, about two hundred direct jobs were created in the construction, and only twenty jobs in the operation of the plant (Costa et al., 2009[5]).

We estimate the effects of wind energy on employment and wages in different sectors (industry, construction, commerce, services, and agriculture), as well as educational levels (elementary, high school, and college) and size of firms (small, medium and large). These analyses performed for economic sectors and considering the heterogeneity of workers and firms allow to inferring about the specific impacts that wind energy has on local development and the potential for improvements in local welfare and inequality.

In Figure 3, we see that employment and the real average wage of all sectors increase in Brazil from 2002 to 2013, and decrease after this period due to the Brazilian economic crisis. However, we also verify trends specific to each sector, such as construction which showed an increase in the number of workers of 150% from 2002 to 2013, but a 50% increase in the average wage over the same period. On the other hand, the agricultural sector has an increase of about 60% in the number of employed workers, but a growth of 150% in the average wage, also reflecting the improvement of productivity in this sector. It is essential to highlight that our data on employment and wages are based on RAIS, which presents only the register made by formal firms.

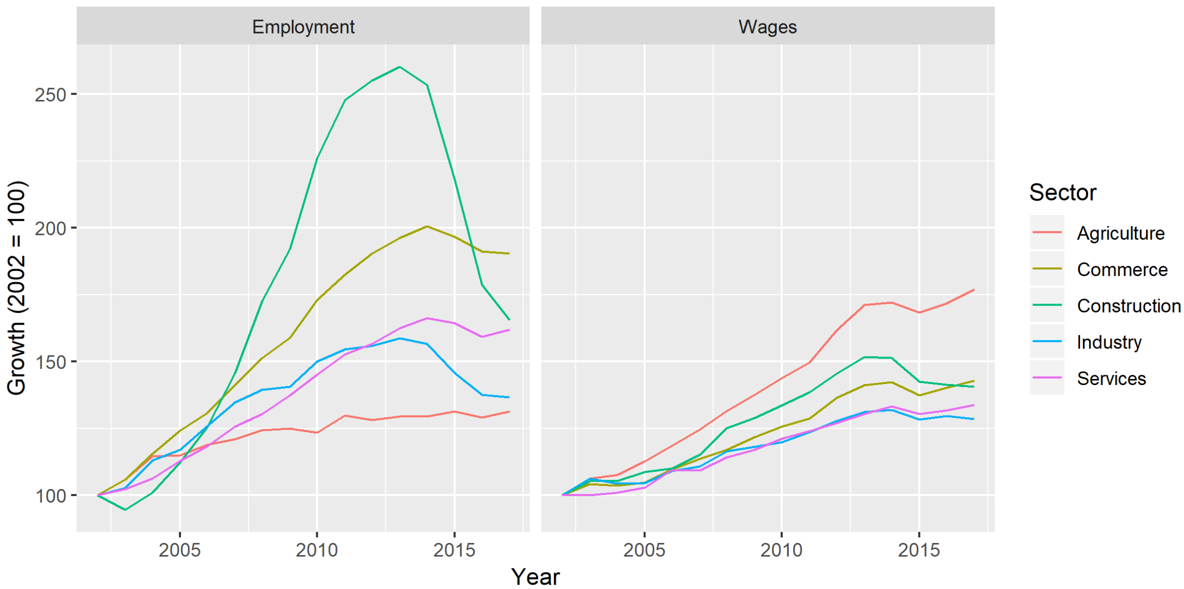
Finally, it is important to note that the dynamics of job creation related to wind energy are subject to geographic shifts in the production and installation of equipment, requirements to source a share of equipment, components and services locally, and a wide range of technical, economic and policy-driven factors.

3 Methodology and data

3.1 Data

Despite the most substantial increase in wind power since 2010 in Brazil, we choose to explore the staggered process of expansion of wind farms in Brazilian municipalities from 2004 to 2014,

Figura 3: Employment and average wages in Brazil 2002-2018



Source: RAIS.
Notes: Deflated wages to 2002 base year, by the Extended Consumer Price Index (IPCA/IBGE).

through a staggered Differences-in-Differences approach (DiD), due to the unavailability of data for many control variables after 2014. Moreover, we chose to test a flexible coefficient approach through an event-study specification, which considers two lags and two leads of wind farm implementation, which implies having a database from 2002 to 2016.

Our database is built on the municipal level, the smallest administrative units in Brazil. We aggregate two ANEEL databases: the Georeferenced Information System of the Electricity Sector (SIGEL) and the Generation Information Data (BIG). We extract information on the capacity of the wind farms implanted, the date of registration of the wind farm in ANEEL, and the stage of implantation and location of the wind farm based on SIGEL data, which presents georeferenced information. The BIG data presents information about the start date of the operation of the wind farm. We only consider wind farms with operating status and exclude disabled wind farms and power plants with installed capacity less than or equal to 100 kilowatts (kW), since these plants are not implemented for commercial purposes (ANEEL, 2014[1]).

The aim of this article is to analyze the relationship between the timing of implementation of wind farms and labor market outcomes, variables that capture the welfare and local development. The outcome or dependent variables are the total levels of formal employment and the total level of wages in the municipalities under analysis. We use longitudinal and administrative data from the Annual Social Information Relation (RAIS) of the Brazilian Ministry of Labor and Social Security to build these labor market outcomes at the municipal level. The RAIS data is reported by firms only covers the entire Brazilian formal sector. In addition to the total level of formal employment and wages, used for the benchmark estimations, we construct formal employment and wage variables of i) different sectors: industry, construction, commerce, services, and agriculture, as defined by the groups of the Brazilian Occupational Classification (CBO); ii) three schooling levels of workers: elementary, high school and higher education; and iii) three different sizes of firms: small (firms with up to 49 employees), medium (firms with more than 49 and up to 499 employees) and large (firms with more than 499 employees). The employment and wage levels of these specific sectors and groups are used for analysis of heterogeneity.

We also extract data at the municipal level to construct control variables included in the most complete specifications. The first set of variables is composed of political controls, with the purpose of controlling the differences across the municipalities in terms of greater political effort, investment and resources allocation. We obtain data on the current net expenditures of municipalities from the Finances of Brazil (FINBRA/STN), and data on the mayor's political party, the education of the mayor, and the political party of the Brazilian president from the Brazilian Superior Electoral Court (TSE).

Other municipal characteristics are considered as control variables for changes that may occur simultaneously to the implantation of the wind farms in the analyzed period. The controlled socioeconomic characteristics are: population (from the Brazilian Institute of Geography and Statistics (IBGE)), as a control for the size of the economically active population; a proxy for the percentage of poor families at the municipal level, based on data from the beneficiary families of the Bolsa Familia Program (PBF) (Brazilian Ministry of Social Development), and the total number of households from IBGE; and a ratio between the gross added value of agriculture and the total gross added value from IBGE, to capture the opportunity cost of land use for the implementation of wind farms.

In addition, we use data on the average annual wind speed (in meters per second) at 50 meters of height, from the National Institute of Space Research (INPE), to estimate the propensity score of a municipality has at least one wind farm. This information is used in the robustness checks.

Finally, in the robustness checks, we analyze the possibility of impacts of the implementation of wind power beyond the boundaries of the municipality where the wind farm is located. Spillover effects may occur due to the migration of workers from neighboring municipalities, who become employed at the place where wind farms are implemented but continue to live in their cities. Another possibility already mentioned in the literature is that wind energy, which allows for local development, also increases the demand for goods and services, and local suppliers can benefit from higher incomes and temporary jobs. These benefits can surpass the boundaries of a municipality, generating welfare for more than one city.

In order to control these spillover effects, we construct distance measures from the location coordinates of the wind farms, and consider as treatment the municipalities whose administrative center is located within these buffers created based on the distance. Buffers are construted taking into account distances of 50km, 100km, 150km, and 200km. Appendix 1 shows the number of municipalities that are considered as treatment units by year and distance.

Despite the largest increase in wind power since 2010 in Brazil, we choose to explore the staggered process of expansion of wind farms in Brazilian municipalities from 2004 to 2014, due to the unavailability of data for many variables after 2014, and due to the choice of testing a flexible coefficient approach through an event-study specification, which considers two lags and two leads of the wind farm implementation in Brazil.

3.2 Empirical strategy

Our main interest is to study the relationship between the timing of implementation of wind farms and the local labor market outcomes. The adoption and implementation of wind power by municipalities in Brazil are still incipient, but the number of municipalities with at least one wind farm is increasing, especially after 2010, as shown in Section 2. Therefore, we explore the staggered nature of the sequential process of the wind farms implantation starting in 2004 and we use a Difference-in-Differences (DiD) strategy. Thus, we compare municipalities that receive a wind farm to those that did not receive it, before and after the intervention. This characteristic allows us to consider the same municipality as a unit of treatment in certain periods and a control unit in others. Therefore, our benchmark specification is as follows:

$$Y_{m,t} = \alpha + \beta WF_{m,t} + \gamma X_{m,t} + \theta_m + \mu_t + \varepsilon_{m,t} \tag{1}$$

where $Y_{m,t}$ indicates some labor market outcome of interest (total employment level or total wage level of the formal sector) for municipality m in year t; $WF_{m,t}$ is a dummy variable that identifies whether municipality m in year t has at least one wind farm; $X_{m,t}$ is a vector of municipal characteristics; θ_m is a fixed-effect of municipalities; μ_t is a year fixed-effect; $\varepsilon_{m,t}$ is a random term; and α, β and γ are parameters. The source of variation that allows identifying the effect of the wind farm is the distinct timing of implementation across municipalities. This strategy presents two main potential problems: the omitted explanatory variables and the dynamic endogeneity, that is, the implementation of a wind farm may respond to the conditions of the labor market within a municipality. We address the first concern, including control variables and a fixed-effect for the Brazilian States in the regressions, as well as adding interactions between the control variables and a linear time trend to capture trends specific to each municipality. In addition, the use of fixed-effects of municipalities and linear temporal trends are partial solutions to deal with the second source of concern, the dynamic endogeneity.

In addition to understand if the wind farm implementation could be effective in increasing local employment and wages, we intend to analyze to what extent and for how long this policy could be effective. Therefore, we implement a generalization of the DiD estimator and adopt a flexible coefficient approach through an event-study specification, as Jacobson et al. (1993)[12]. This specification allows the pre- and post-treatment estimation of the Average Treatment Effect (ATE) with binary time-varying treatment. The expanded outcome equation with contemporaneous treatment plus lags and leads can be written as:

$$Y_{m,t} = \alpha + \sum_{i=1}^{I} \beta_{pre,i} WF_{m,t+i} + \sum_{j=0}^{J} \beta_j WF_{m,t-j} + \gamma X_{m,t} + \theta_m + \mu_t + \varepsilon_{m,t} \qquad (2)$$

where $WF_{m,t-j}$ are year-specific indicators for whether the municipality m has received at least one wind farm in year $t-j$; and $WF_{m,t+i}$ indicates whether municipality m will receive wind farms i years in future periods. Following the usual strategy in event-study analysis, we test the significance of the coefficients $\beta_{pre,i}$, as there may be pre-existing trends in labor market outcomes. The inclusion of β_j allows a lag in the effects of the wind farm implementation and the heterogeneity of treatment by exposure time.

It is important to note that we cluster the standard errors at the municipality level to account for serially correlated and heterocedastic errors in all regressions (Bertrand et al., 2004[3]).

4 Results and discussions

4.1 General results

The first part of our results concentrates on general estimates focused on testing a set of control variables and fixed-effects. Table 1 presents the estimates of the relationship between the presence of wind farms and the total level of formal employment and wages for the period 2004 to 2014. These estimations are based on the specification (1), the staggered Differences-in-Differences approach.

In this subsection, we have tested seven specifications. The first column shows the results if no control variables are included. The second column takes into account control variables of local political and socioeconomic characteristics, since municipalities that receive a wind farm may also undergo other simultaneous changes during the implementation period, and the third column shows the results of a population-weighted regression, dealing with the fact that the variance of labor market outcomes may be related to population size. The fourth and fifth columns consider the fixed-effects for the Brazilian states and the economic areas defined by the IBGE, respectively[3]. In the sixth and finally, in the seventh column, we included a municipality-specific linear and non-linear time trends, respectively, controlling for any systematic differences and specific trend across locations.

The results indicate a positive and statistically significant relationship between the timing of implementation of wind farms and the total level of formal employment and wages of the municipalities. As the employment level and total real wages are in logarithmic form, coefficients can be interpreted as semi-elasticities. We observed that the inclusion of controls for the local

[3]In 2017, the IBGE established 510 economic areas (*Regiões Geográficas Imediatas*) that are structures from nearby urban centers to meet the immediate needs of populations, such as demand for durable and non-durable goods and services; job search; and provision of public and judicial services, among others (IBGE)

characteristics and fixed-effects for economic areas determine a considerable reduction in the coefficients. In addition, linear and non-linear trends causes the coefficients to fall and become statistically non-significant.

Point estimates suggest that wind farm implementation may be associated with increases of 39% in total local employment and 46% in total wages of the formal sector, using the specification (4) that takes control variables, population weights, and fixed-effects for states into account. We chose this specification as our benchmark, since in Brazil a broad set of public policies that could affect employment and wages are at least partially determined at the state level, and it is less expected that policies at the level of economic areas will occur because it would depend of regional integration of states. In addition, we deal with the pre-existing trends in the outcomes through the event-study analyses.

Tabela 1: General results for total employment and total wages

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Employment							
Wind Power	0.83768***	0.47783***	0.48452***	0.39076***	0.22914*	0.06577	0.07458
	(0.26003)	(0.16344)	(0.17930)	(0.14000)	(0.13023)	(0.06645)	(0.06577)
R-squared	0.01676	0.61735	0.64601	0.67825	0.72862	0.88261	0.87636
Wages							
Wind Power	0.96903***	0.50461***	0.50990***	0.45991***	0.27511*	0.10504	0.11462
	(0.27974)	(0.16940)	(0.18501)	(0.15834)	(0.14381)	(0.07416)	(0.07376)
R-squared	0.04384	0.64395	0.67042	0.69668	0.74601	0.89257	0.88662
Controls	NO	YES	YES	YES	YES	YES	YES
Population weighting	NO	NO	YES	YES	YES	YES	YES
FE States	NO	NO	NO	YES	NO	YES	YES
FE Economic Areas	NO	NO	NO	NO	YES	NO	NO
Linear trends	NO	NO	NO	NO	NO	YES	NO
Non-linear trends	NO	NO	NO	NO	NO	NO	YES
Observations	72,340	53,970	53,970	53,970	53,970	53,970	53,970

Notes: *** p<0.01, ** p<0.05, * p<0.1. Columns report Difference-in-Differences regressions and include municipality and year fixed-effects. Robust standard errors (clustered at the municipality level) in parentheses. Control variables (shown in the Appendix A2): percentage of poor families; ratio between the added value of agriculture and the total added value; dummy for political party of mayor equal to party of the president; schooling of mayor; and net expenditures of municipalities (log). Total employment and wages are log transformed.

4.2 Robustness

The first part of this section presents the results of robustness checks that deal with a major concern not addressed in the general results. The problem is the comparability of municipalities in the treated and control groups, that is, the absence of common support between treated and non-treated municipalities. To test samples with comparable control and treatment municipalities, we first estimated the specification (4) of Table 1 in three alternative samples and checked the sensitivity of the results to sample changes. The alternative samples are: i) we exclude municipalities that are state capitals, since the capitals are up to four times larger than the second largest municipality; ii) we exclude the municipalities located in the metropolitan areas (MAs), since these areas also present specific economic and demographic dynamics; and iii) we eliminate the municipalities located in the North region of Brazil, since this region has the lowest annual average wind speed and no project or implemented wind farm in 2018.

Next, we restrict the control and treatment groups to municipalities with an average annual wind speed above 3.5 m/s, which is established as the minimum for the operation of a wind turbine. Also, we implement a Propensity Score Matching (PSM) approach, estimating a probit model for the probability of presenting at least one wind farm, in which we include, as explanatory and exogenous variables, the average annual wind speed and the area of municipalities. This strategy aims to ensure that the trajectory of the labor market outcomes of the treated municipalities is similar to that of the municipalities belonging to the control group in the pre-treatment period. Finally, we restrict the period analyzed for 2010-2014, since this is the period with the most substantial increase in the implementation of wind farms, thus reducing the weight of a long baseline period with a low number of wind farms.

The Table 2 presents the results of this first set of robustness checks and allows us to verify whether our results are sensitive to alternative samples. We observe that the results with the exclusion of municipalities in the North region and with annual wind speed below 3.5 m/s, and the results for 2010-2014 are similar to the results under the benchmark specification (column 4 of Table 1). On the other hand, the exclusion of municipalities that are state capitals and located in metropolitan areas, that is, dynamic and well-populated cities, affects more significantly the estimated coefficients. The relationship between the timing of implementation of wind farms and labor market outcomes remains positive and statistically significant, but the effects fall to approximately 29 % for employment, and to 34 % and 30 % for total wages, excluding, respectively, capitals and MAs.

The results become statistically non-significant, although they remain positive, when we establish the common support between treated and control municipalities, weighting the regression by the propensity score of presenting at least one wind farm.

In this second part of the robustness checks, we intend to analyze another source of concern not addressed in the general results, the spillover effects, i.e., the possibility of the impact of the implementation of wind power beyond the boundaries of the municipality where the wind farm is located.

In order to control these spillover effects, we construct distance measures from the location coordinates of the wind farms, and consider as treatment the municipalities whose administrative center is located within these buffers created based on the distance, as detailed on the Subsection 3.1. Table 3 presents the results for estimates considering this expansion of treatment units based on distance buffers and spillover effects. The benchmark result is again the specification (4) of Table 1. We found that this new definition of treatment units establishes lower effects of wind

Tabela 2: Sample selections

	w/o Capitals	w/o MAs	w/o North	Wind > 3.5	Matching	2010-2014
Employment						
Wind Power	0.28965***	0.28478***	0.40597***	0.39972***	0.05684	0.39582***
	(0.10663)	(0.10690)	(0.13832)	(0.13929)	(0.17076)	(0.14572)
R-squared	0.67021	0.60814	0.68402	0.68443	0.64261	0.66660
Wages						
Wind Power	0.34186***	0.29602***	0.47692***	0.46947***	0.10138	0.43858***
	(0.11648)	(0.10878)	(0.15695)	(0.15753)	(0.17571)	(0.15986)
R-squared	0.69164	0.63174	0.70231	0.70183	0.66033	0.67981
Observations	53,970	53,970	53,970	53,970	53,970	53,970

Notes: *** p<0.01, ** p<0.05, * p<0.1. Columns report Difference-in-Differences regressions and include municipality, year and state fixed-effects. Robust standard errors (clustered at the municipality level) in parentheses. Control variables (not shown): percentage of poor families; ratio between the added value of agriculture and the total added value; dummy for political party of mayor equal to party of the president; schooling of mayor; and net expenditures of municipalities (log). Total employment and wages are log transformed.

energy on employment and wages. Considering the buffer of 50 km, we verify an impact of about 22% on employment and 25% on wages. The effects are maximal at a distance of 100km, and begin to decrease from this buffer, reaching impacts of 8% and 10%, respectively, for employment and wages.

Tabela 3: Spillover effects: treatment units based on distance

	Benchmark	50 km	100 km	150 km	200 km
Employment					
Wind Power	0.39076***	0.14186***	0.22162***	0.15639***	0.07815***
	(0.14000)	(0.05204)	(0.03326)	(0.02783)	(0.02493)
R-squared	0.67825	0.67836	0.67889	0.67918	0.67879
Wages					
Wind Power	0.45991***	0.16947***	0.25431***	0.18994***	0.09669***
	(0.15834)	(0.05617)	(0.03546)	(0.02935)	(0.02646)
R-squared	0.69668	0.69676	0.69732	0.69768	0.69723
Observations	53,970	53,970	53,970	53,970	53,970

Notes: *** p<0.01, ** p<0.05, * p<0.1. Columns report Difference-in-Differences regressions and include municipality and year fixed-effects. Robust standard errors (clustered at the municipality level) in parentheses. Control variables (not shown): percentage of poor families; ratio between the added value of agriculture and the total added value; dummy for political party of mayor equal to party of the president; schooling of mayor; and net expenditures of municipalities (log). Total employment and wages are log transformed.

Also, we combined some sample selections shown in Table 2 as the exclusion of the North region, capitals, and municipalities with wind speed below 3.5 m/s, with control for spillover effects, using the 100km buffer. Thus, we improved the comparability of municipalities in the treated and control groups and considered the impact that extends beyond the borders of cities. The results are presented in Table 4 and allow to observe similar effects to that shown in the third column of Table 3.

Tabela 4: Combining sample selections and spillover effects

	Benchmark	Sample selection	Sample selection & spillover
Employment			
Wind Power	0.39076***	0.30779***	0.21967***
	(0.14000)	(0.10483)	(0.03024)
R-squared	0.67825	0.67765	0.67843
Wages			
Wind Power	0.45991***	0.36128***	0.25266***
	(0.15834)	(0.11444)	(0.03176)
R-squared	0.69668	0.69857	0.69935
Observations	53,970	48,906	48,906

Notes: *** p<0.01, ** p<0.05, * p<0.1. Columns report Difference-in-Differences regressions and include municipality and year fixed-effects. Robust standard errors (clustered at the municipality level) in parentheses. Control variables (not shown): percentage of poor families; ratio between the added value of agriculture and the total added value; dummy for political party of mayor equal to party of the president; schooling of mayor; and net expenditures of municipalities (log). Total employment and wages are log transformed. Sample selection: exclusion of the North, capitals, and municipalities with wind speed below 3.5 m/s. Spillover effects measured through 100km buffer.

4.3 Heterogeneity

In this subsection, we verify the local impact of the implantation of wind farms on the levels of employment and wages of formal workers in different sectors (industry, construction, commerce, services, and agriculture), educational levels (elementary, middle and higher education) and size of firms (small, medium and large). Observing the heterogeneity of workers and firms allows us to infer about the specific impacts of wind energy on local development since improving the situation of disadvantaged groups could also imply changes in social welfare and inequality. The Table 5 shows the results of the heterogeneity for employment and the Table 6 for wages. The estimated equations follow the specification of the last column of Table 4, in which we combine some sample selections with control for spillover effects.

The results suggest that the implementation of wind farms in municipalities increases the total level of employment and wages in all economic sectors. We found the greatest impacts for employment in the agricultural (81%), industrial (60%), and construction (29%) sectors. These results are in agreement with the literature since Blanco and Rodrigues (2009)[4] found that wind energy creates a significant number of direct jobs, mainly in industry; Simas and Pacca (2014)[16] showed important local impacts during the construction of wind farms, for Brazil. Also, the results follow Bergmann et al. (2006)[2] that found the greatest socioeconomic benefits

Tabela 5: Heterogeneity: Employment

Sector	Total	Industry	Construction	Commerce	Services	Agriculture
Wind Power	0.21967***	0.60369***	0.28584***	0.27168***	0.11189***	0.81066***
	(0.03024)	(0.07431)	(0.06021)	(0.04927)	(0.02759)	(0.07706)
R-squared	0.67843	0.62659	0.57178	0.65626	0.63924	0.49004
Schooling	Total	Elementary	High school	College		
Wind Power	0.21967***	0.23744***	0.23782***	0.11729***		
	(0.03024)	(0.03823)	(0.03259)	(0.03427)		
R-squared	0.67843	0.62629	0.68057	0.63223		
Firm size	Total	Small	Medium	Large		
Wind Power	0.21967***	0.32640***	0.52804***	0.38941***		
	(0.03024)	(0.04486)	(0.08045)	(0.10406)		
R-squared	0.67843	0.67201	0.38290	0.50546		
Observations	48,906	48,906	48,906	48,906		

Notes: *** $p<0.01$, ** $p<0.05$, * $p<0.1$. Columns report Difference-in-Differences regressions and include municipality and year fixed-effects. Robust standard errors (clustered at the municipality level) in parentheses. Control variables (not shown): percentage of poor families; ratio between the added value of agriculture and the total added value; dummy for political party of mayor equal to party of the president; schooling of mayor; and net expenditures of municipalities (log). Total employment and wages are log transformed. Sample of municipalities: exclusion of the North region, capitals, and municipalities with wind speed below 3.5 m/s, and considering spillover effects with the 100km buffer.

of renewable energy sources in rural areas. Moreover, as argued in Section 2, wind energy can improve local welfare also by increasing the income of landowners due to land leasing for the implementation of wind farms and the possibility of coexistence of agricultural and livestock activities and wind farms. Therefore, the greatest impacts of wind power in this sector are expected.

Indeed, it is possible to observe positive and statistically significant effects of the implementation of wind farms on employment and wages of formal workers at all educational levels, but we find the greatest impacts to workers with elementary and high school. This result could evidence that the expansion of wind power in Brazil could have additional implications through labor market outcomes for less-skilled workers, providing local development oriented to increasing welfare and reducing social inequality.

The last part of Table 5 shows the heterogeneity of the effects of the wind farm implementation in terms of the size of firms in which the workers are employed. We find positive and statistically significant coefficients in the estimates for all sizes, which is in agreement with other studies, such as Rio and Burguillo (2008)[6], who argue that during the construction of wind farms, demand for goods and services increases and all local suppliers can benefit from higher incomes and temporary jobs. However, we observe the largest effects on medium and large-sized firms, which may be related to the fact that the industrial and construction sectors are more concentrated

Tabela 6: Heterogeneity: Wages

Sector	Total	Industry	Construction	Commerce	Services	Agriculture
Wind Power	0.25266***	0.97589***	0.59566***	0.33277***	0.16292***	1.64896***
	(0.03176)	(0.13425)	(0.13535)	(0.06310)	(0.02918)	(0.14233)
R-squared	0.69935	0.52109	0.46689	0.60847	0.65702	0.49110
Schooling	Total	Elementary	High school	College		
Wind Power	0.25266***	0.26950***	0.27441***	0.18313***		
	(0.03176)	(0.04056)	(0.03409)	(0.03978)		
R-squared	0.69935	0.62705	0.69728	0.62480		
Firm size	Total	Small	Medium	Large		
Wind Power	0.25266***	0.29949***	0.97153***	0.68113***		
	(0.03176)	(0.04584)	(0.15465)	(0.19932)		
R-squared	0.69935	0.67719	0.31093	0.48015		
Observations	48,906	48,906	48,906	48,906		

Notes: *** p<0.01, ** p<0.05, * p<0.1. Columns report Difference-in-Differences regressions and include municipality and year fixed-effects. Robust standard errors (clustered at the municipality level) in parentheses. Control variables (not shown): percentage of poor families; ratio between the added value of agriculture and the total added value; dummy for political party of mayor equal to party of the president; schooling of mayor; and net expenditures of municipalities (log). Total employment and wages are log transformed. Sample of municipalities: exclusion of the North region, capitals, and municipalities with wind speed below 3.5 m/s, and considering spillover effects with the 100km buffer.

and with a greater proportion of large-sized firms.

Finally, the heterogeneity results for wages are very similar to those observed for employment. We found positive and statistically significant impacts for all sectors, all educational levels, and firm sizes, but especially for: agriculture, industry, and construction; elementary and high school educational levels; and medium and large-sized firms.

4.4 Event-study

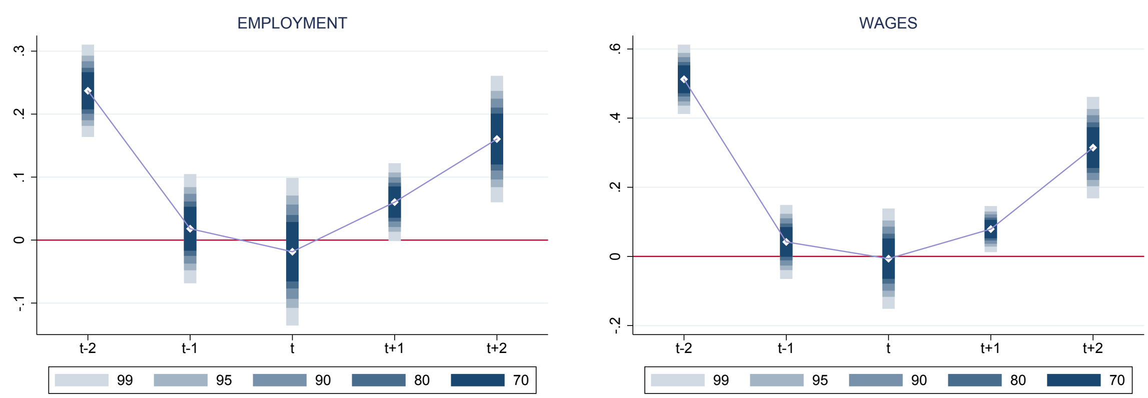
In the last part of this section, we focus on dealing with pre-existing trends in labor market outcomes of municipalities and the duration effects. Therefore, we implemented a generalization of the DiD estimator that allows the pre- and post-treatment estimation of the Average Treatment Effect (ATE) with binary time-varying treatment. We explored the staggered process of expansion of wind power across municipalities and used an event study framework, selecting two pre- and post-intervention periods, as we have some data restrictions detailed in Section 3, in order to understand the extent to which and for how long wind energy can have impacts on local development.

We present the main results of the event-study carried out in a graphical form, plotting the estimated pre- and post-intervention coefficients, $\beta_{pre,i}$ and β_j, based on the estimates of equation (2), in the same figure. We estimate equation (2) under the most basic specification, without controls, fixed effects, or sample selections. Then, we take into account the benchmark specification, with population weights, controls, and fixed effects for States, and we established a sample with the selection of municipalities outside the North region, which are not capitals, and with wind speed above 3.5 m/s, besides the sample selection, we consider spillover effects under the 100km buffer.

Figure 5 and Figure 6 illustrate the pre- and post-treatment effects of wind farm implementation on employment and wages of municipalities, under the most basic specification, and under the complete specification. These figures show the pre- and post-treatment effects for confidence intervals ranging from 70-99%. Considering a confidence interval of 99%, in both specifications, we verify impacts two periods before and after the wind farm implementation, with the highest levels of effects occurring two periods after the beginning of the operation of the wind farm.

This result for two periods prior to the wind farm implementation is consistent with those found in previous sections, since one of the sectors most affected is the construction and this phase lasts, on average, from eleven to eighteen months. Impacts in two post-intervention periods, which are lower than the pre-intervention effects, can be explained by the indirect effects of wind energy on employment and wages spreading throughout the local economy, impacting the agriculture sector as well. For this sector, we could expect the greatest impacts since landowners' income increases due to land leasing, and the possibility of coexistence of agricultural and livestock activities and wind farms, as seen in the results shown previously

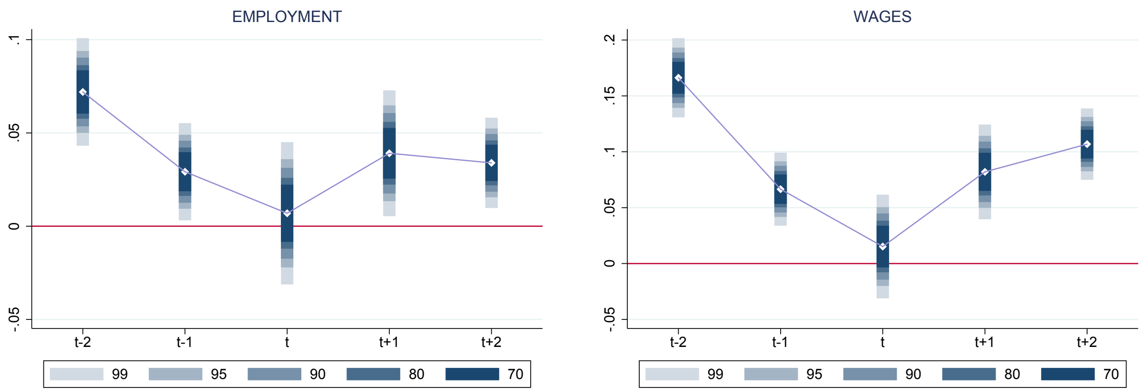
Figura 4: Event-study analysis: No controls, sample selections or spillover effects



5 Final remarks

Renewable energy is key to mitigate the effects of climate change. In December 2015, during the 21st United Nations Conference on Climate Change (COP21), governments from over 190 countries presented their plans for reducing national greenhouse gas emissions. In this context,

Figura 5: Event-study analysis: Benchmark specification, with sample selections and spillover effects (100km)



Brazil committed to reduce emissions by 37% in 2025 and 43% in 2030, compared to 2005 levels (EPE, 2016[8]).

Wind power is an important source of renewable energy, as it could supply up to 20% of the world's electricity demand by 2050, but is still not widely used worldwide (Edenhofer et al., 2011[7]). In addition to the environmental impacts, some studies show the relevance of this energy source for the local development of regions impacted by the installation of wind farms. Despite the existence of many studies focusing on socioeconomic impacts and comparison between different renewable energy sources, the literature on the effects of wind power on local development is recent and still scarce.

This study aims to estimate the impact of wind farms on the local labor market of Brazilian municipalities. We analyze the local impacts on formal employment and wages of workers in different sectors, educational levels, and size of firms. We explore the staggered process of expansion of wind farms in Brazilian municipalities from 2004 to 2014, using a staggered Difference-in-Differences (DiD) approach. We also used an event-study framework as an additional analysis to verify the effects of duration and pre-intervention trends on outcomes.

The results suggest that wind farms increase the total level of employment and wages in all local economic sectors. The highest impacts are found for the industry, construction, and agricultural sectors. Indeed, it is possible to observe positive and statistically significant effects of the implementation of wind farms on the employment and wages of workers with elementary and high school, which is an evidence that the expansion of wind power in Brazil could have relevant social impacts through labor market outcomes for the less skilled workers, providing local development geared towards increasing welfare and reducing inequality. In addition, the event-study carried out in the article shows a statistically significant increase in total employment for two periods prior to implementation, which is consistent with the phase of construction of the wind farm that lasts, on average, from eleven to eighteen months, and for two periods after the intervention, that can be explained by the indirect effects of wind energy on employment and wages spreading throughout the local economy, impacting the agriculture sector as well.

These results suggest that wind power may generate significant social impacts through the labor market, providing local development and household welfare increase in developing countries.

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