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11023
2024

March 2024

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Fabian Scheifele, David Popp

CESifo

Impressum:

CESifo Working Papers
ISSN 2364-1428 (electronic version)
Publisher and distributor: Munich Society for the Promotion of Economic Research - CESifo GmbH
The international platform of Ludwigs-Maximilians University's Center for Economic Studies and the ifo Institute
Poschingerstr. 5, 81679 Munich, Germany
Telephone +49 (0)89 2180-2740, Telefax +49 (0)89 2180-17845, email office@cesifo.de
Editor: Clemens Fuest
https://www.cesifo.org/en/wp
An electronic version of the paper may be downloaded
· from the SSRN website: www.SSRN.com
· from the RePEc website: www.RePEc.org
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CESifo *Working Paper No. 11023*

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Abstract

Support from local citizens is important for the scale-up of renewable energy. We investigate the impact of utility-scale wind and solar parks on employment, GDP and public finances in Brazilian municipalities using a difference-in-differences design with matching. We find a positive employment impact of 1-1.5 jobs/MW in the 15 months preceding the commissioning of a solar park, when the park is under construction, but no impacts thereafter. For wind, we find no employment impacts during the construction phase and potentially a small impact of 0.2-0.25 jobs/MW in the 12 months following commissioning. In the year after commissioning, GDP increases 23% for an average sized solar park and 12% for an average sized wind project. The impacts only decrease slightly in the following years. We also find significant persistent fiscal revenue impacts in wind compared to only a one-time tax revenue increase in solar at the time of construction. Our results provide different implications for policymakers that want to advocate for renewable energy in their towns. While for solar, the main benefit constitutes a short-term increase in low-skilled employment and public revenues, wind energy provides more long-term financial benefits but less local employment opportunities.

JEL-Codes: Q520, O130, O140, E240, J210, H710.

Keywords: employment, renewables, local impact, difference-in-differences.

*Fabian Scheifele**
Technical University of Berlin / Germany
fabian.scheifele@tu-berlin.de

David Popp
Syracuse University / NY / USA
dcpopp@maxwell.syr.edu

*corresponding author

March 2024
We are grateful for comments received by participants of the Innovation Economics Seminar at the TU Berlin. Furthermore, we would like to thank Jorge Boeira and Mariano Gonzalez Serrano for their comments. We also would like to thank Sviatlana Nepeina for great research assistance. The views expressed in this paper are entirely those of the authors and do not necessarily represent the views of the World Bank and its affiliated organizations.

1 Introduction

The investments associated with the energy transition are assumed to generate large socio-economic benefits, such as net employment gains between 10 (IEA, 2023) and 14 million (IRENA, 2023) as well as positive GDP impacts (IEA, 2021). At the same time, there is often large opposition against renewable energy projects from local communities, who fear that their population will not benefit or even face negative consequences from having large solar or wind parks in their immediate surroundings. This opposition, which often delays and increases the cost of projects, is not only restricted to the Global North, but has also been observed in countries like India (Lakhanpal, 2019), Mexico (Martinez, 2020) or Brazil (Brown, 2011).

Despite the consensus that local support is crucial for the energy transition, there is so far little robust evidence on its local benefits. Employment benefits are mostly estimated at the country level with employment factors applied to capacity figures or input-output tables, both of which suffer from inaccuracies and recursive referencing. This leads to the repeated deployment of imprecise numbers (Cameron and Van Der Zwaan, 2015). Similarly, GDP impacts are mostly simulated using computable general equilibrium models in combination with large energy system models, but there is a lack of more granular and particular causal evidence on the impacts of sub-national entities such as states or municipalities.

In this study, we analyze the local impact of utility-scale solar and wind parks on a variety of socio-economic outcomes such as employment, wages, GDP and public revenues in the municipalities where they are built. We focus on 91 municipalities in Brazil that have received either a wind or solar park larger than 5 megawatts (MW) since 2007. This capacity threshold, employed by the Brazilian electricity regulator ANEEL, is used to separate decentralized micro-generation, which includes small rooftop installations or other forms of private generation by firms and is extensively used in solar, from larger utility-scale projects, which are expected to deliver broader socio-economic benefits. We use a wide range of publicly available data, such as employment data from the Ministry of Labor's RAIS database (Ferraz, Finan, and Szerman, 2015; Ulyssea, 2018), as well as data on public receipts and spending (Dahis et al., 2023) , power plant location and meteorology to construct two datasets, at the municipality-month and municipality-year level.

To estimate the causal impact of solar and wind parks on the above mentioned outcomes, we use a difference-in-differences design combined with matching. Since the timing of the treatment varies, we are using the power plant's commissioning date as the anchor for the relative timing of the treatment. To assure equal pre-trends and eliminate potential time-invariant or time-variant differences prior to the treatment, we match municipalities that receive a solar or wind park with a similar municipality from the same state. To provide granularity and separate direct and indirect employment, we use industry codes that distinguish firms into installation-related, operation & maintenance, components and unrelated sectors.

We find that solar parks have a significant but modest impact on installed-related employment during the construction phase, which begins around 15 months before the park is commissioned and begins to produce power and peaks at 1.5 jobs/MW around 6 months prior to commissioning. The impacts on employment in operations and maintenance are insignificant in solar. In contrast, we do not find any significant local employment impacts in wind energy during construction. However, in the first 12 months following commissioning, we find a small effect of around 0.25 jobs/MW in installation-related employment. Most of the impact identified in solar is concentrated among workers with primary or secondary education who are employed during the installation, while the impact on tertiary educated workers composes less than 5% of the overall treatment effect. The effects are primarily driven by municipalities that are second-adopters in their area, indicating that there may be learning effects about which jobs may be delivered by local firms. We find indications of spillover effects of similar magnitudes and timing in municipalities within a 20km radius of the solar park, but not beyond. The workers are primarily employed by existing firms, since there is no sizeable increase in local firm registration in the months preceding or following the installation.

Contrary to the modest local employment impact, we find sizeable impacts on municipal GDP and revenues and spending by the local municipalities. In the first year after commissioning, municipalities with solar and wind parks experience an increase of 1 million BRL/MW and 883,000 BRL/MW respectively. This translates into 23% increase for the average sized solar park and 12% for the average wind park compared to control municipalities. In solar this effect decreases over time, whereas in wind the GDP impact persists and even grows over time. Similarly, we observe a temporary increase of 128,000 BRL/MW (26%) in tax and fee revenues collected by the municipalities with solar parks but no impact on overall public receipts (incl. transfers from other levels of government). For wind we find a persistent impact on public revenues per MW for receiving municipalities ranging from 4% in year 2 to 15% five years after commissioning for the averaged sized wind park (51 MW). The growth is composed of local tax revenue increases during construction phase and of transfers from federal and state governments at later stages. We do not observe any spillovers of the GDP or revenue related impacts to neighboring municipalities, suggesting that the impacts remain do not lead to wider structural impacts in the region. The growth impacts on GDP and public revenues appear large but the recipient municipalities are mostly small towns (median size: 20,720 inhabitants) for whom the park is most likely one of the largest investments they received in many years.

The contributions of this paper are twofold. First, to the best of our knowledge, this is the first causal estimation of employment impacts of renewable energy in a developing country context, following similar studies in Spain (Fabra et al., 2023) and the United States (Gilbert, Gagarin, and Hoen, 2023). It confirms findings of Fabra et al. (2023) regarding significant local employment impacts in solar energy, but not in wind. Moreover, we enrich the literature on employment impacts by providing education and sector-specific estimates as well as by assessing geographical spillovers and heterogeneity with regards to the timing, both absolute and relative to other investments. Second, we provide causal estimates of the impacts on GDP and local public finance. While there is some ex-ante modeling of potential GDP impacts of renewable energy investment in Germany (Heinbach et al., 2014), our approach reveals the actually realized GDP and tax benefits compared to counterfactual municipalities and provides the spending categories of these gains.

Our findings also hold important policy implications. First, utility-scale solar parks can be an important absorber of local low to medium-skilled workers during the installation phase. While the impacts of around 60 to 90 additional jobs for a 60 MW solar park appear modest, they are often built in rural areas with low levels of formal employment for whom this may represent a substantial number. Since there are also further impacts when adjacent municipalities are building similar parks, adequate planning can shift these temporary jobs into medium to long-term employment. Second, both wind and solar parks provide significant fiscal returns for local governments, leading to increased public spending. As these effects are relatively large and persistent compared to the temporary employment impacts, they might be more effective arguments to advocate in favor of renewable investments and to overcome resistance by local citizens.

In the following section, we will provide a brief background on the potential benefits of renewable energy and the Brazilian context. This is followed by sections 3 and 4 on data and empirical strategy. Section 5 presents the results, followed by policy implications and conclusion (Sections 6 & 7).

2 Background & Context

2.1 Local benefits of utility-scale wind and solar parks

The potential benefits of wind and solar parks for the receiving communities can broadly be divided into three categories: (i) employment-related benefits; (ii) benefits due to increased economic activity during or after the installation and; (iii) income due to financial flows related to the project (Jenniches, 2018).

The majority of employment studies use multipliers for capacities, a jobs/MW rate which they multiply with the capacity installed, or sector multipliers based on input-output tables that provide employment estimates at the national level. The limitations of these studies is their lack of precision, due to very wide ranges of multipliers identified in the literature (Cameron and Van Der Zwaan, 2015), and that they are unable to distinguish where the employment impacts occur and whether these are net gains or merely substitutions. This has led to a call for more rigorous counterfactual based studies (Cameron and Van Der Zwaan, 2015). Two recent studies that respond to this and estimate local impacts econometrically are Fabra et al. (2023) and Gilbert, Gagarin, and Hoen (2023). Fabra et al. (2023) focuses on Spain and finds a positive impact between 1 and 2.47 jobs/MW between 2 years prior and 1 year after the installation but no impact on local employment for wind. Gilbert, Gagarin, and Hoen (2023) find a 3.6% increase in employment per 100 MW of capacity for firms within 20 miles of a wind park but no impact beyond this radius. Despite the differences in estimation, there is consensus that solar PV generally offers more jobs per MW in the receiving communities than wind and that operations & maintenance employment, while being more permanent, generally encompasses less than one-tenth of the employees needed during construction. In terms of skills, while a lot of local unskilled labor can be absorbed during construction, O&M employment opportunities for locals are lower as they tend to be higher skilled and are often done in multiple parks at once (Brown, 2011) .

A second avenue of positive local impact may occur via increased economic activities due to the influx of workers from other regions during the installation phase. The existing evidence comes from qualitative case studies and suggests that it remains restricted to benefits for local restaurants and hotel or home owners that rent out rooms to workers (Brown, 2011; Delicado, Figueiredo, and Silva, 2016). Existing evidence on long-term and more indirect effects on aggregate economic activity, usually measured in GDP, is restricted to modeling results (Lantz, 2008; Costanti, 2004).

Finally, private actors or the local government may benefit from financial flows related to the projects such as lease payments, property sales or by collecting public fees or taxes. While renewable energies often enjoy tax exemptions, including in Brazil, where the purchase of solar and wind energy components are VAT exempt in all 26 states, they may still generate tax revenues on electricity sales and through labor or land taxes. The few studies on this topic find positive tax impacts but estimate these effects ex-ante with input-output tables (Black et al., 2014) or through computable general equilibrium models (Heinbach et al., 2014). Due to the differences in tax regulations and levels of collections, these impacts may be highly country-specific. While the majority of taxes (by volume) collected in Brazil are at the federal level or the state level, there are still a number of taxes that are under municipal authority and whose revenues may be positively affected by these energy investments.

There are of course also numerous potential negative impacts of wind and solar parks on local communities in terms of environmental impacts or land access (Brown, 2011; Huesca-Pérez, Sheinbaum-Pardo, and Köppel, 2016). However, a discussion of these aspects is beyond the scope of this study. Nonetheless, by providing information on the potential benefits host communities may receive from wind and solar installations, our study informs debates local communities may have when considering whether to host such projects.

2.2 Case selection

We regard Brazil as a very suitable case for this analysis for three reasons. First, Brazil was an early adopter of wind energy in the Global South. The first wind parks were commissioned as early as 2006. The government promoted the deployment of wind and later solar energy, first through feed-in tariffs and since 2009 through technology-specific auctions. This support contributed to strong growth of wind energy. Since 2015, solar energy experienced growth from 42 MW in 2015 to 34,000 MW installed capacity in September 2023 (AB SOLAR, 2022). Furthermore, the government aimed to foster local capacities in the assembly of wind and solar equipment via local content requirements that developers must follow to qualify for a below market-rate loan from the national development bank BNDES (BNDES, n.d.). While the majority of the components are not produced close to the final site, this may have contributed to higher localization of the value chain that may be also reflected in the local communities.

A second peculiarity of Brazil is that both wind and utility-scale solar are primarily deployed in the Northern and Northeastern regions (see Figure 1), which are regions comparatively poor, with lower incidences of formal employment and less industrialized than the south of the country (Neri, 2022). This relative remoteness from other industrial activities and the fact that most parks are built in predominantly rural areas allows for a good isolation and identification of the impacts of these large investments. For example, it would be much harder to attribute the economic impact of a solar park built in the metropolitan area of Sao Paulo, where so much other and often related economic activity is occurring.

Lastly, Brazil has employment, GDP and public finance data available at very granular level allowing for an analysis at the municipal level (more details in the next section).

3 Data

This study combines a variety of public data sources, mostly accessed via the data repository Base dos Dados (Base dos Dados, n.d.). For employment, wage and firm data we use the public version of RAIS database of the Brazilian Ministry of Labor. RAIS contains the full population of formal employment in Brazil and firms declare both their end-of-the-year employment stock and the month in which they hired or dismissed a worker. We combine the end-of-the year value and the monthly net additions to a monthly time series of the employment stock at the municipality level. Since there are at times discrepancies between the monthly additions and the differences of the end-of-the year values reported by firms (Santos et al., 2018), the series is re-centered each December with the end-of the year value. We use month-year as well as municipality fixed-effects to control for any seasonal impacts that may arise from this adjustment (see Section 4). The wage data is transformed in similar fashion to represent the average annual wage, deflated to 2020 constant Brazilian Real (BRL), of the labor force that is active in the particular month. We use the worker's annual wage because this field is more constantly filled than monthly wages. We use sector codes in the Brazilian National Classification of Economic Activities (CNAE) at its most granular level (see Appendix Tables B1 and B2) to classify an employee's firm as relevant either for the production of components, the installation of the parks or the operation & maintenance.

Power plant data for our independent variable comes from the SIGA database of the energy regulator ANEEL (ANEEL, n.d.) and includes the day of commissioning (i.e. the day the plant begins to produce power), the name of the plant and the operator, the municipality and the capacity in MW. We aggregate this data at the municipality-month level for both solar and wind capacities and create a relative time variable which indicates the distance to the first commissioning in months. Since larger solar and wind parks are constructed in pieces ("lots") [1] which may get commissioned in different months, there are municipalities which get treated, i.e. receive new solar or wind capacity, in multiple months. However, most additional installations are occurring in the months directly following the first installation in month 0 (Figures A.1 and A.2). On average, in the first six months after the first commissioning, treated municipalities receive new installations in just 1.39 months and 1.63 months for wind. Thus, the majority of communities are only treated once (in month 0). We also match the names of power plants with loan data from the national development bank BNDES to identify parks funded by BNDES and hence needing to comply with local content requirements (BNDES, n.d.). Furthermore, we use data on solar irradiation from the Brazilian Solar Atlas (Bueno Pereira et al., 2017) and wind speed data from the Brazilian Institute of

1. In wind, certain tax benefits are restricted to parks below 30 MW, leading to a splitting of parks.

Meteorology (INMET, n.d.) for the matching process (see section 4). The irradiation data is cross-sectional and we transform the wind data into one average wind speed value per municipality, as both variables tend to be stable over time. We also use company registration data from the Ministry of Finance to identify the creation of new companies.

For data only available annually, we construct a second dataset in a similar manner. Data on annual public spending and public receipts such as taxes, fees and intergovernmental transfers comes from the SICONFI database of the Ministry of Finance (Secretaria do Tesouro, n.d.), ranging from 2000 to 2022, and GDP and population data come from the National Statistics Institute (IBGE, n.d.) and range from 2002 to 2021.

4 Sample selection & Empirical Strategy

For the monthly dataset our period of observation ranges from January 2007 until December 2021 because the sector classification that we use to separate direct and indirect employment was introduced only in 2006. Since the first wind parks were commissioned in 2006 and the first solar parks in 2015, this does not restrict our sample significantly. Our eligible treatment group consists of all municipalities that received a wind or solar power plant larger than 5 MW during our observation period and received no other power plant investment in the two years preceding or following the solar or wind power plant to avoid contamination of the treatment effect. We use this restriction because the sector codes mostly relate to activities that could also be employed in the construction of other power plants. While there are only 12 out 120 municipalities with wind parks smaller than 5 MW, there is a considerable amount of small generation in solar. 158 out of 209 municipalities have installations below 5 MW. We excluded these smaller plants because we expect ex-ante that local employment effects will be concentrated in large parks, but we also provide unmatched results that include all municipalities with any solar or wind capacity installed and results are consistent with our main specification (see section 5.5). We observe the treatment relative to the first time the municipality receives a wind or solar power plant, with the exception of two municipalities that received their first wind plant prior to 2007. For these, the date of treatment is their second investment, which occurred with sufficient distance from the pre-2007 investment.

We employ a difference-in-differences design with staggered adoption to estimate the causal treatment effect. The first threat to our identification is whether the control group is effectively untreated. We address this by including only municipalities that have not received any power plant investment larger than 5 MW during the observation period and that are at least 50km away from a municipality that received a power plant during this time as potential control units. The distance constraint assures that the control municipalities are not affected by potential spillover effects of neighboring municipalities that receive a power plant investment. The second and arguably most important aspect of a difference-in-differences design is whether the parallel trends assumption holds. That is, is it reasonable to assume similar trends in the dependent variable in the absence of any treatment? We do two things to ensure this: First, we provide pre-treatment estimates starting 36 months prior to commissioning. Second, we match each eligible treated municipality with one municipality from the pool of eligible controls to reduce pre-treatment differences and assure that the control group is similar in terms of geography and major socioeconomic characteristics.

We use coarsened exact matching, requiring that the municipalities are from the same state and in the same bins for irradiation size (for solar) and wind speed (for wind)[2]. Since the municipalities differ substantially in size prior to match, we also match on average labor stock (for solar) and average population (for wind) [3] in the two to four years prior to installation using bin cutoffs at the 25th, 66th and 95th percentile. Fabra et al. (2023) document that employment effects do not start until 24 months before commissioning. Thus, matching on data points from these periods provides a reasonable assessment of pre-project conditions before being affected by the treatment. Since wind parks were built in Brazil as early as 2006, we use matching with replacement for wind to avoid losing too many treated observations of later cohorts for whom a lower amount of controls would be available. For solar, matching with replacement is not required because the first utility-scale solar plant only appeared in 2015 and the sample is smaller. We also provide unmatched results in section 5.5.

Tables 1 and 2 show the means and standardized differences for both the unmatched and matched solar and wind samples, respectively. On average, municipalities with solar parks are slightly larger in population but poorer in terms of GDP/capita, municipal revenues, and spending. For solar, even in the unmatched sample, most of the standardized mean differences are within the 0.25 standardized difference threshold that Rubin (2001) considers acceptable for balance, except for solar irradiation, municipal spending, receipts, as well as GDP. However, some differences in the unmatched sample are quite large and matching considerably improves the balance. Matching reduces the number of treated municipalities in the solar sample from 49 to 31. Wind municipalities are slightly smaller in population, workforce and also poorer in GDP/capita and municipal spending and revenues than the rest of Brazilian municipalities. While most of the unmatched mean differences are within acceptable ranges, with the exception of GDP/capita and municipal development index, some of the differences still appear quite large and matching again considerably improves

2. The irradiation cutoff is set at 5.4 kWh/m2/day and wind speed at 10th and 50th percentile

3. We used population rather than labor stock in wind purely because better balance could be achieved with this variable.

balance.

Figure 1 shows a map of the matched samples. Wind and solar farms are primarily built in the Northeast of Brazil, which is one of the poorest regions of the country, which also explains the lower means in GDP/capita and wages compared to control group in the unmatched samples. Requiring the control units to be in the same state (blue and grey dots), asssured that the geographical distribution of treatment and control samples are very similar.

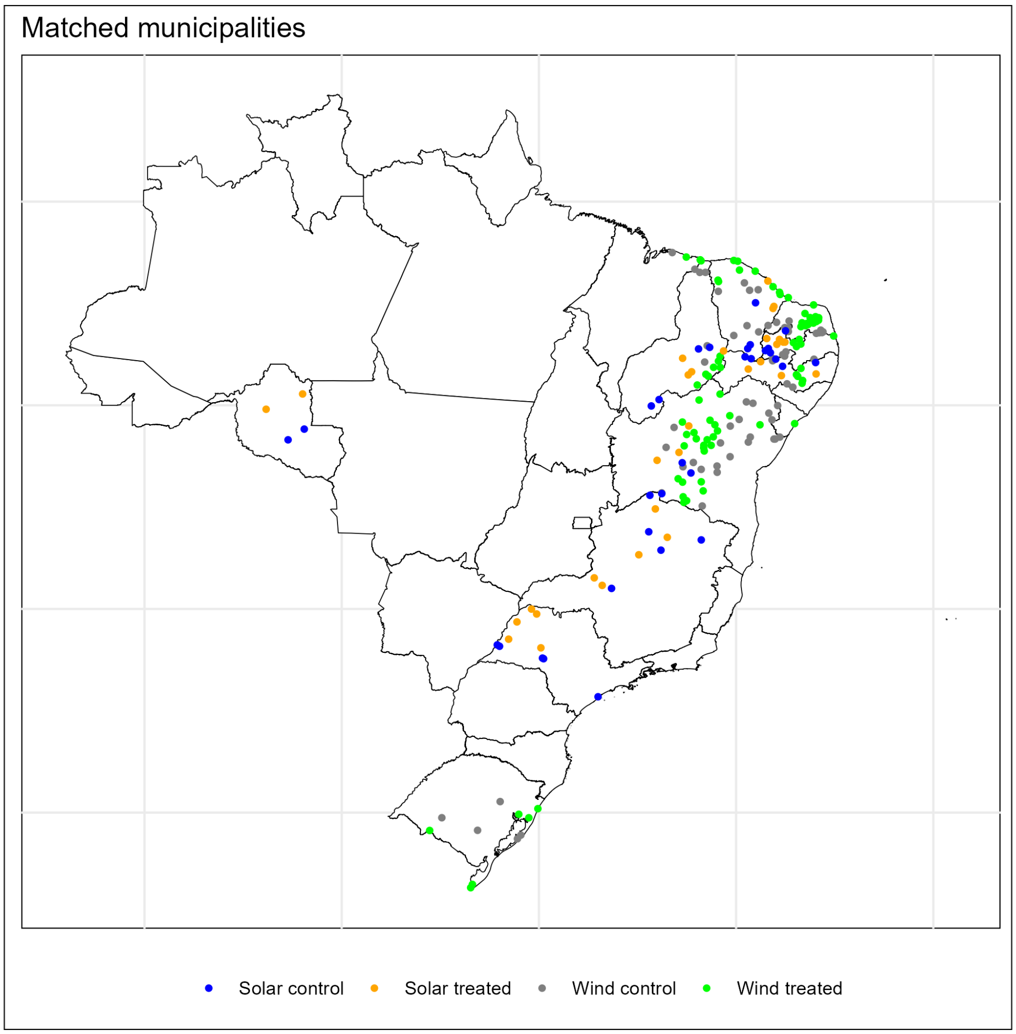

Figure 1: Municipalities with utility-scale wind and solar parks and respective controls

For our differences-in-differences estimation with differences in treatment timing, we use a two-way fixed effect regression with leads and lags of the capacity installed in the months relative to the first installation. The fact that we limit our control group to never-treated observation avoids the pitfalls of potential negative weights that may arise in such a setting (De Chaisemartin and D'Haultfœuille, 2020). We employ the test developed by De Chaisemartin and D'Haultfœuille (2020) and find that for wind none of 241 ATTs receive a negative weight and for solar just one out 42 ATTs receives a negative weight.

We estimate the following equation, as described in Sun and Abraham (2021), for both our monthly and annual dataset:

$$Y_{it} = \alpha_i + \lambda_t + \beta \cdot \sum_{l<-K} MW_{i,t}^l + \sum_{l=-K}^{J-1} \gamma_l MW_{i,t}^l + \sum_{l=J+1}^{L} \gamma_l MW_{i,t}^l + \mu \cdot \sum_{l>L} MW_{i,t}^l + \epsilon_{i,t} \quad (1)$$

whereby α_i and λ_t represent the municipality and month-year fixed effects (or year-fixed effects in the annual data set), respectively. K denotes the number of periods prior to the event and L the number of periods after the event, expressed as leads and lags l of the treatment indicator MW. We bin periods that are outside of our event window on both sides represented by coefficients β and μ (Schmidheiny and Siegloch, 2023). Our coefficients are normalized relative to the excluded relative time period J which is 36 months prior to the commissioning in the monthly data set or 3 years in the annual data. While the start of treatment might differ across different solar parks, 3 years prior to commissioning is well ahead of the start of construction and supported by Fabra et al. (2023), who find no employment effects until 24 months before commissioning. γ_l denote our coefficients of interest, namely the treatment effects in specific months preceding or following the commissioning of the solar or wind park. Our monthly panel has 180 month-years (Jan 2007-Dec 2021) and 62 and 136 municipalities in solar and wind respectively. The annual panel spans 19 to 23 years depending on the variable (see Section 3).

Variable	Mean C (Unmatched)	Mean T (Unmatched)	Std. Diff. (Unm.)	Mean C (Matched)	Mean T (Matched)	Std. Diff.(Matched)
Population	35,987.54	42,533.37	0.04	24,683.13	23,627.72	-0.05
No. of workers	8,747.72	5,740.56	-0.05	2,609.00	2,953.16	0.09
No. of workers with primary education	2,751.45	1,964.01	-0.05	711.04	884.20	0.15
No. of workers with secondary education	4,329.94	2,995.84	-0.04	1,392.58	1,573.39	0.08
No. of workers with tertiary education	1,666.33	780.71	-0.05	505.38	495.57	-0.02
Wage in 2020 BRL	1,905.36	1,828.36	-0.20	1,815.76	1,866.22	0.19
No. of firms	1,467.86	1,276.61	-0.02	700.99	751.60	0.06
No. of workers in solar-related sector	217.86	128.26	-0.05	16.66	41.10	0.32
Municipal spending p.c.	27,403.06	22,253.78	-0.35	26,149.90	27,026.87	0.09
Municipal receipts p.c.	28,702.97	22,289.47	-0.30	24,469.32	25,526.09	0.10
Municipal development index	0.66	0.64	-0.14	0.38	0.39	0.03
Municipal spending on energy	1,396,048.12	2,693,124.56	0.11	6,273,794.33	2,714,506.08	-0.57
Municipal spending on environment	5,213,675.23	1,988,359.36	-0.11	2,983,228.01	2,179,498.27	-0.17
Municipal spending on other infrastructure	87,360,996.58	59,402,598.36	-0.04	39,397,060.68	47,426,026.06	0.16
GDP (2020 BRL)	1,357,221,146.43	855,726,137.89	-0.05	373,490,140.11	470,610,792.07	0.18
GDP p.c. (2020 BRL)	24,876.32	17,390.51	-0.36	13,299.20	16,861.12	0.40
Growth in no. of workers (%)	9.82	12.92	0.05	0.34	-0.19	-0.04
No. of private-sector firms	1,242.04	1,037.44	-0.02	512.31	588.49	0.11
Irradition	5,030.18	5,648.98	1.52	5,538.29	5,597.03	0.13
N	5,513.00	49.00		31.00	31.00	

Table 1: Solar energy: Means and standardized differences of matched and unmatched sample, T= treatment group, C=control group, N denotes the number of municipalities

Variable	Mean C (Unm.)	Mean T (Unm.)	Std. Diff. (Unm.)	Mean C (Matched)	Mean T (Matched)	Std. Diff. (Matched)
Population	34,885.00	28,858.90	-0.04	21,274.74	24,677.71	0.12
No. of workers	7,415.50	2,606.79	-0.09	2,007.29	1,955.33	-0.01
No. of workers with primary education	2,572.97	998.45	-0.11	785.72	662.86	-0.06
No. of workers with secondary education	4,019.89	1,452.47	-0.09	944.11	872.49	-0.04
No. of workers with tertiary education	1,594.32	487.36	-0.07	279.84	279.33	0.00
Wage in 2020 BRL	1,660.68	1,569.78	-0.25	1,708.06	1,772.36	0.19
No. of firms	1,328.97	708.41	-0.08	556.22	581.16	0.02
No. of workers in wind-related sector	192.09	66.56	-0.09	11.65	43.78	0.20
Municipal spending p.c.	21,424.66	19,355.51	-0.12	21,125.50	20,533.70	-0.05
Municipal receipts p.c.	24,702.67	20,448.95	-0.15	22,701.30	22,196.70	-0.04
Municipal development index	0.48	0.43	-0.60	0.45	0.46	0.04
Municipal spending on energy	1,578,476.11	1,238,261.54	-0.05	941,627.24	895,108.30	-0.03
Municipal spending on environment	4,200,248.10	1,590,742.61	-0.13	1,019,566.82	1,475,346.45	0.14
Municipal spending on other infrastructure	69,207,925.40	36,085,368.01	-0.07	20,587,638.24	23,686,298.26	0.12
GDP (2020 BRL)	1,206,174,792.90	483,644,145.44	-0.08	268,067,571.59	292,307,139.77	0.05
GDP p.c. (2020 BRL)	22,588.06	15,823.38	-0.37	10,225.69	11,454.74	0.18
Growth in no. of workers (%)	18.11	15.54	-0.04	4.63	7.49	0.07
No. of private-sector firms	1,121.50	592.32	-0.07	449.57	479.07	0.03
Wind Speed	2.03	3.34	1.19	2.83	2.91	0.10
N	5,451.00	111.00		60.00	76.00	

Table 2: Wind energy: Means and standardized differences of matched and unmatched sample, T= treatment group, C=control group, N denotes the number of municipalities

5 Results

5.1 Employment & Wages

Figure 2 shows the treatment effect in additional jobs per MW for the 36 months preceding and 24 months following the commissioning of the first solar park for four different sectors. We observe that the differences to the control group are zero for all four groups until around 16 months before commissioning, indicating that the equal trends assumption holds. During the 15 months preceding commissioning we find significant job impacts in installation-related sectors, peaking at 1.5 jobs/MW created in the sixth month prior to commissioning. Given that the average installation size at month 0 is 64 MW, on average local firms in the municipalities with a park employ 96 additional workers in the peak month compared to the control group. While this may not appear a lot it actually represents a ten-fold increase in employment, as control municipalities only employ 9.8 people in these sectors in the same relative time period. After commissioning we see a second increase, which has however a very wide confidence interval and is hence not significant. In Section 5.5 we show that this second peak is driven by a single municipality.

For jobs related to operations & maintenance we observe a small increase in the months after the installation but the coefficients are insignificant and very small. Similarly, coefficients for local component production jobs are close to zero with a small, but insignificant increase between 13 to 9 months preceding the commissioning. In other sectors not directly related to solar or power generation we observe a slight upward trend in the 24 months following commissioning but since the confidence intervals also wide in the post-period and the effects are not significant at the 5% level we are reluctant in interpreting this as direct impact (Figure 2d).

Comparing employment impacts by a worker's education level, we observe significant impacts across all three education levels, but the majority of created jobs are occupied by workers with primary or secondary education (Figure 3). For these workers, employment effects have a peak impact of 0.8 jobs/MW and 0.68 jobs/MW respectively compared to only 0.05 for tertiary-educated workers. The tertiary educated jobs appear to peak slightly before the other two, which seems reasonable given that construction work is usually preceded by planning carried out by engineers.

In wind energy, we do not find any major impacts in related sectors. We find a small increase of installation-related jobs that peaks at 0.25 jobs/MW 9 months after commissioning but it is only significant at the 10% level. For the average size park (51.3 MW) this translates into 12.8 additional jobs or 52% more jobs compared to the control group. Based on discussions with industry experts, these effects may relate to smaller repair work

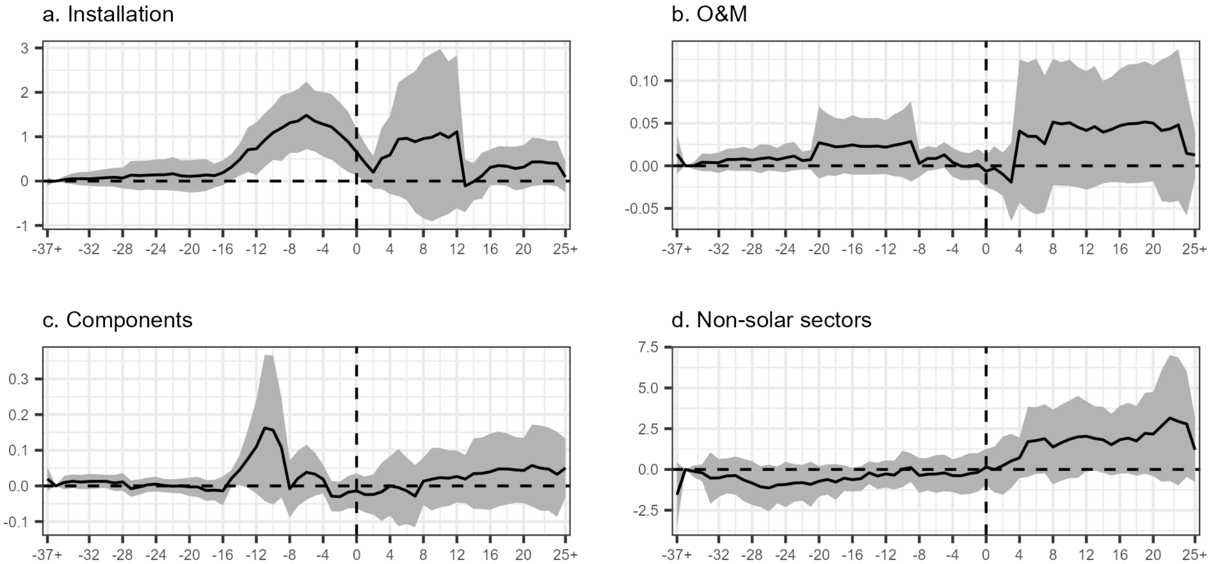

Figure 2: Employment impacts (Jobs/MW) of solar park by sector. Coefficient plot of TWFE regression: N (municipalities): 62, n (observations): 11160, ribbon: 95% confidence interval. Scales of y-axis differ by plot.

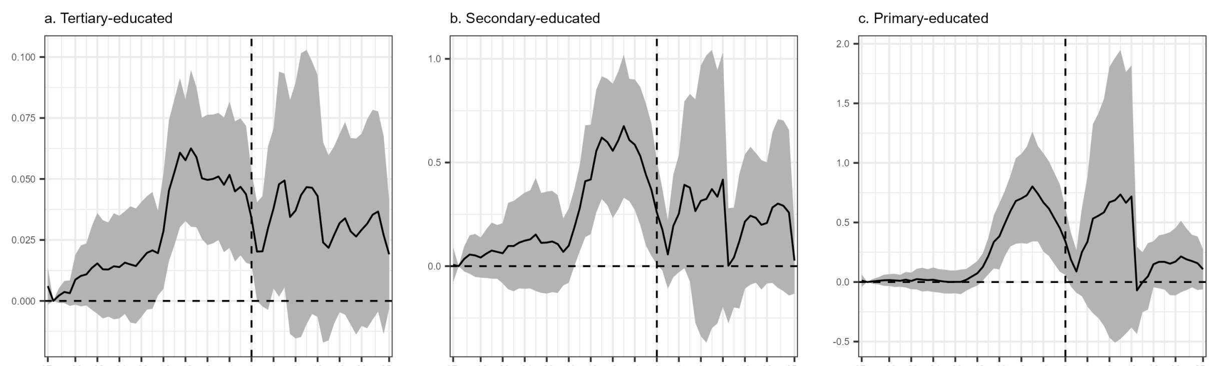

Figure 3: Employment impacts (Jobs/MW) of solar park by worker's education level. Coefficient plot of TWFE regression: N (municipalities): 62, n (observations): 11160, ribbon: 95% confidence interval. Scales of y-axis differ by plot.

that occurs in the first months after commissioning and are often carried out by local firms, which are registered under the same sector codes as companies active in the construction phase. In operation & maintenance (Figure 4b) we find no significant local impacts, which suggests that this work is done by firms not registered in the recipient municipality. There are no significant impacts on local jobs in component production. We observe an increase of employment in non-related sectors but since this is gradual and barely significant at the 5% level we would be reluctant to interpret this is as a direct effect of the wind park.

In terms of education, we observe similar patterns in wind as in solar energy. The small peak in local jobs in the first 12 months after installation mainly benefits workers

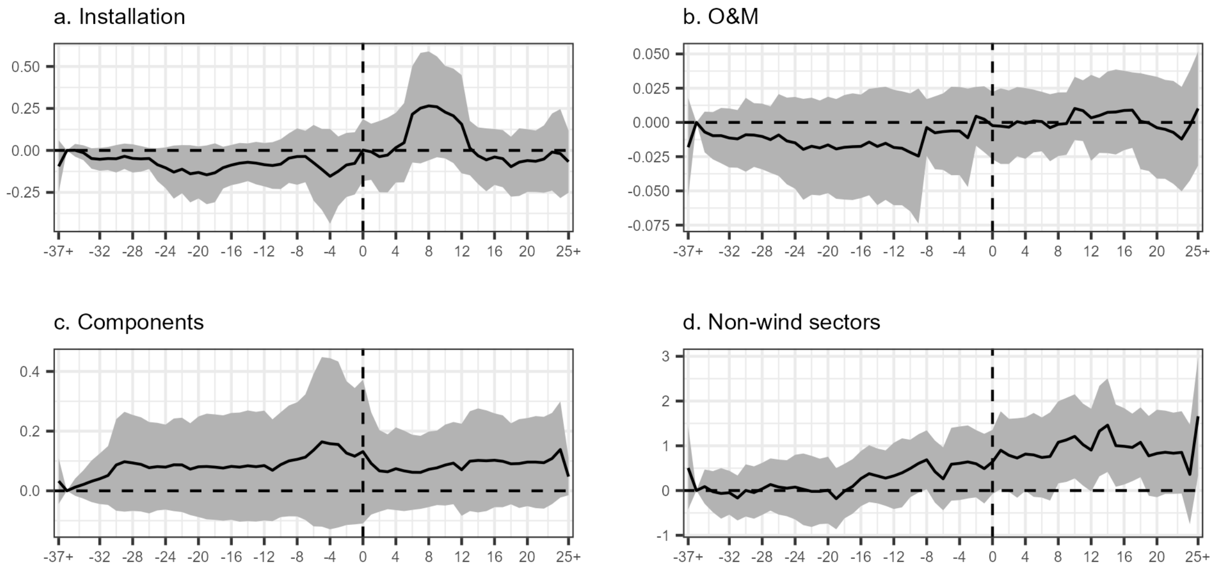

Figure 4: Employment impacts (Jobs/MW) of wind parks by sector. Coefficient Plot of TWFE regression: N (municipalities): 136, n (observations): 27360, ribbon: 95% confidence interval. Scales of y-axis differ by plot.

with primary and secondary education. There is no significant impact on tertiary-educated workers, except for a small increase peaking at 6 months following the commissioning.

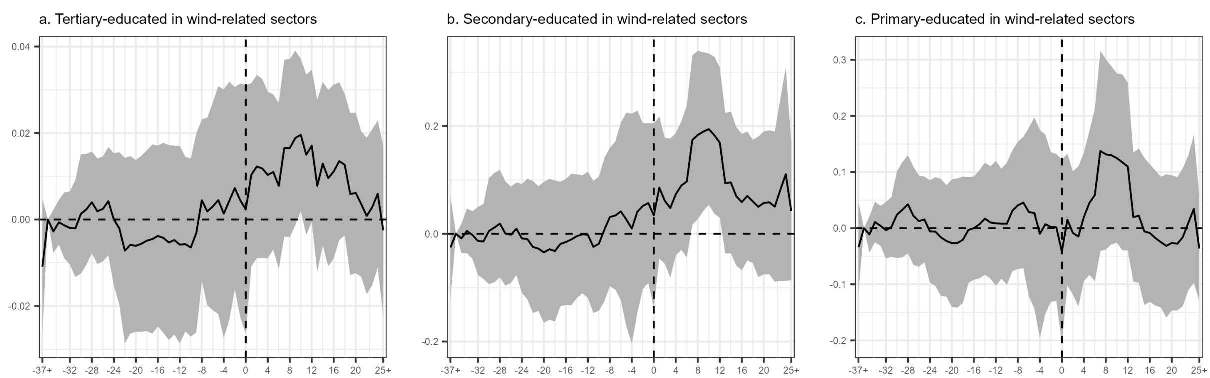

Figure 5: Employment impacts (Jobs/MW) of wind parks by workers' education level. Coefficient plot of TWFE regression: N (municipalities): 136, n (observations): 27360, ribbon: 95% confidence interval. Scales of y-axis differ by plot.

Figure 6 shows the impacts on the average wage level jointly in the three sectors (installation, component, operation & maintenance). In solar, we are unable to completely eliminate pre-treatment differences on wage levels between treatment and control, which can also be observed in the comparatively large standardised difference post-matching (0.2) in Table 1. This is why we observe an increase in wages between 36 and 16 months prior to the start of the commissioning, which is before the construction begins (Figure 6a). But we do not find any significant wage effects during the construction period itself, when demand for local workers is highest (Figure 2a). We do not observe any impact on average wages from wind projects.

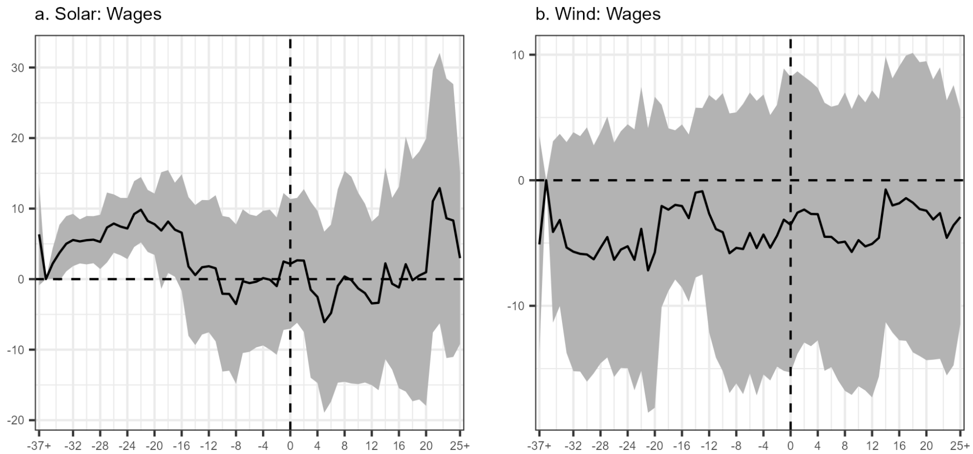

Figure 6: Wage impacts of solar and wind parks (2020 constant BRL/ MW) in sector-specific employments. Coefficient plot of TWFE regression: N (municipalities): 62 (Solar) and 136 (Wind), n (observations): 11160 (Solar) and 27360 (Wind), ribbon: 95% confidence interval. Scales of y-axis differ by plot.

5.2 Heterogeneity & Geographic Spillovers

To better understand the general employment impacts found in section 5.1, we analyze the heterogeneity of the treatment effect with respect to time and size of the parks as well as analyzing potential spillovers to the neighboring municipalities.

Figure 7 depicts the employment for municipalities that were the first within 50km to receive a solar or wind park against municipalities that were not the first within their radius. For both solar and wind, the local job impacts primarily occur among municipalities that are not the first to receive a park in the region. While we observe a small impact among first municipalities in solar, this impact appears to be in the very early part of the installation (15 to 9 months prior to commissioning) and very short-lived.

A second way of analyzing this is to separate the effects by absolute rather than relative time of adoption, using calendar years. There may be differences in local impacts if the wind or solar developers increased their cooperation with local firms over time or if regulations, like for example local content requirements, change the incentives to localize certain steps in the project delivery. For solar there appear to be no significant differences in the point estimates (Figure 8a), but due to the small number of solar plants prior to 2018 the confidence intervals are very large for this group. For wind, we have a much longer timespan of observations and parks built prior to 2015 do not exhibit any local job impacts, while there are small impacts for post-2015 parks 6 to 9 months after commissioning, albeit only significant at the 10%

Figure 7: Employment impacts (Jobs/MW) between "first-mover" vs. "second-mover" municipalities. Coefficient plot of TWFE regression with N (number of municipalities): Solar: (blue=24, grey= 38), Wind: (blue= 40, grey= 96) and n (number of observations): Solar: (blue=4,320 , grey= 6,840), Wind: (blue= 7,920 , grey= 19,440). Ribbons represent 95% confidence interval. Scales of y-axis differ by plot.

level (Figure 8b).[4]

Another reason for differences could be regulation as the local content requirements (LCR) were strengthened after 2012. However, Figure 9 suggests no significant differences between parks with and without LCR. In wind, municipalities with parks without LCR have slightly higher employment levels in related sectors, but since the difference between both samples stays constant over time we are reluctant to interpret this as a differential impact, but rather as a structural difference between both sub-samples.[5] Overall, the lack of local impact of LCR is not surprising since LCR are focused on the components and not on construction or maintenance services (BNDES, n.d.). These components may be built in Brazil, but not in the municipality where the equipment is installed, which is in line with our component-related employment results (Figures 2c and 4c). Overall, these results suggest some learning occurs among project developers about which jobs can be delivered by local firms, both during installation (in solar) and post-commissioning (in wind).

Secondly, we are interested in whether any economies of scale exist regarding the local

4. The samples were split based on "waves" of installation. Since in solar the first parks were commissioned in 2015, the first substantial number of parks was installed in 2017. In wind, there is a first phase of slower built-up until 2014, followed by a second phase with more installations per year.

5. Wind parks without LCR are smaller on average (43.9 MW) than parks with LCR (70.5 MW) and smaller parks show also slightly higher (non-significant) employment impacts (see Figure A.3).

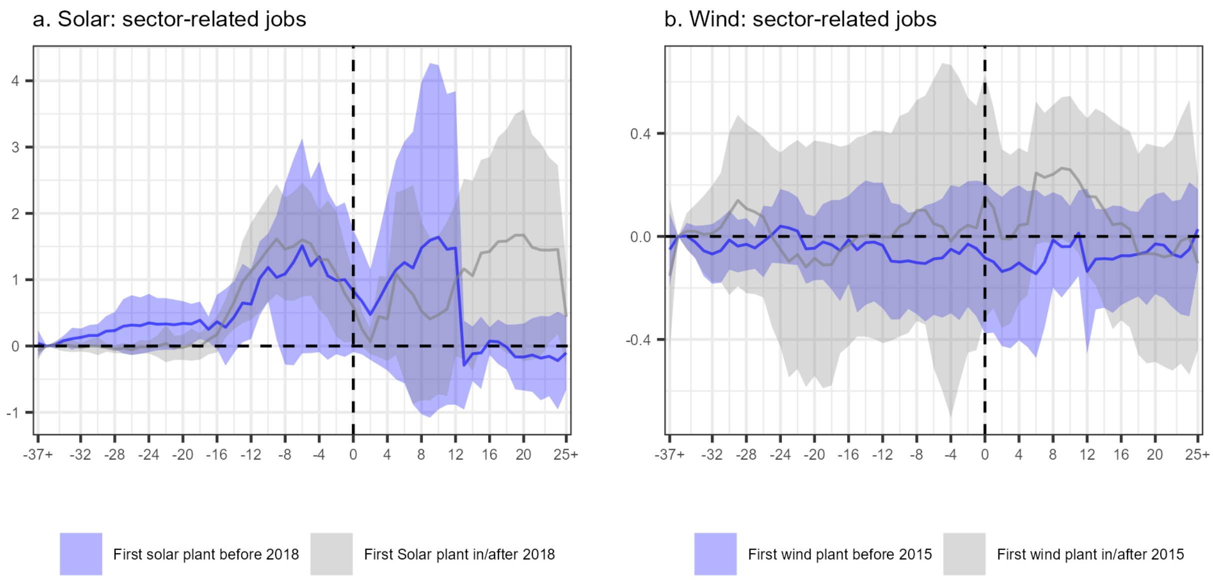

Figure 8: Employment impact (Jobs/MW) by time period. Coefficient plot of TWFE regression with N (no. of municipalities): Solar (blue =10, grey= 52), Wind (blue=31, grey=66) and n (no. of observations): Solar (blue= 1,800, grey=9,360), Wind (blue=5,760, grey=12,600)

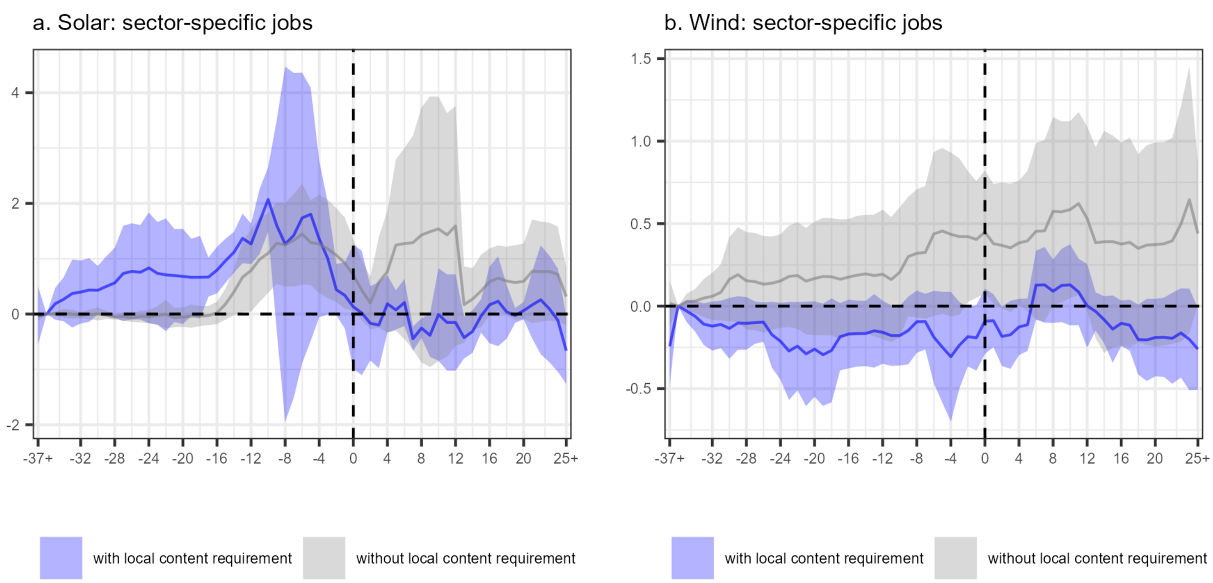

Figure 9: Employment impact (Jobs/MW) with or without local requirements. Coefficient plot of TWFE regression with N (no. of municipalities): Solar (blue =8, grey= 54), Wind (blue=41, grey=101) and n (no. of observations): Solar (blue= 1,440 , grey=9,720), Wind (blue=7,560, grey=19,800)

job creation. To assess this, we split both samples at their median size, installed in month 0. Figure A.3 shows no significant differences in the employment between solar parks smaller and larger than 60 MW. However, this result has to be interpreted with caution because the samples of both sub-groups are small, as can be observed by the larger confidence intervals. In wind, smaller parks are driving the job impacts as the impact for parks larger than 50MW is insignificant.

The third area of sub-analysis regards the presence of geographic spillovers, which we assess in two ways. First, we split the sample into municipalities which have other wind or solar investments occurring within a 50km radius and those who do not. In the case of solar (Figure A.4 a) we observe that municipalities with other parks built in their vicinity receive an additional employment boost after their own park is already built. For solar parks that do not have any other investments near by the employment effect remains restricted to the installation phase. This suggests that the increase in post-commissioning employment that we observe in the overall sample (Figure 2a) is driven by this group. In wind, the employments effects for both groups are not statistically significant but the point estimates are higher for municipalities with no other wind parks within 50km. Since we don't have identifiable labor data, we are unable to say whether workers are being re-employed in new locations in nearby communities in the case of solar energy, but this seems plausible given the small size of the municipalities and the granular sector classification of firms that we capture in the data. Second, we observe employment in solar and wind-specific sectors in the surrounding municipalities (Figure A.5), both within a 20km radius and within a ring of 20-40km distance from the treated municipality. We undertake the same matching procedure outlined in section 4. While the point estimates suggest some small spillover effects in municipalities within 20km of the solar park, the confidence intervals are too wide to provide conclusive evidence. Similarly in wind, effects are insignificant for both the 20km radius and the 20-40km ring, but the wider confidence intervals for the former suggest that some municipalities may experience increased employment activities in these sectors.

5.3 Mechanisms of employment impact

One key question is whether the observed impacts in solar energy are driven by existing or newly created firms. To analyze this, we use data from two sources, the Brazilian firm registry and the employment database. From the registration data, we find that there is a small but significant increase in firm registration under sector codes related to solar energy. An additional 0.007 firms/MW are registered between 24 and 22 months prior to commissioning (Figure A.6a). This translates less than 0.5 additional local firms set up for the average solar park, and the timing of registration suggests that these firms are being set up for installation-related activities that commence around 6-8 months later. The volatility of the data and the small coefficients also suggest that new firm registrations are rare occasions for most municipalities. Unfortunately, we cannot identify individual firms in the employment data to identify whether the job increases are driven by this new firm or by existing firms. We also assess the stock of firms that actively report employees in the RAIS system and find no difference between treatment and control municipalities in both wind and solar (Figure A.7). If anything, there may be a drop in the number of firms that report employees 3-5 years after the commissioning, but we would interpret these later coefficients with caution due to the wide confidence interval and the lower number of observations available for later years. While we are unable to identify individual firms in this second source, the combination of the small effect identified in the firm registration data and no differences on firms reporting to the annual employment registry suggests that the composition of the pool of local firms does not change significantly and hence most job impacts are occurring in incumbent firms.

A second issue that could explain the nonexistence of local impacts in the wind parks during the construction phase might be that firms registered elsewhere employ local workers without creating a local subsidiary in the municipality or bring in workers from outside the community. To investigate this, we use a specific field within the employment database for workers executing work in a municipality other than where their firm is registered. Hence, we focus on jobs where the firm is registered elsewhere but the job is executed in the municipality with the solar or wind park. Unfortunately, the data is missing for the years 2012-2017, but since most of the solar projects and the second wave of wind investments occur after these dates, the data are still useful. In the case of wind, we observe a positive tendency of both wind-specific as well as total employment starting 12 months prior lasting until 12 after the commissioning (Figure A.9c & d), but due to the wide confidence intervals the effects are only significant at the 5% level in the three months preceding commissioning. Furthermore, the peak point estimates of 0.06 jobs/MW in sector-specific employment and around 0.25 jobs/MW in total employment suggest that this effect is very small. In combination with the insignificant impacts of jobs from locally registered firms during the construction phase, this suggests that firms registered elsewhere are responsible for local job creation during the construction phase. While the effects are still comparatively small, ranging from 0.2 to 0.3 jobs/MW, this is as much as the impacts found for locally registered firms during the 12 months after commissioning. For solar, we find a small impact of outside-registered jobs in solar-related sectors that peaks at 0.12 jobs/MW three months prior to commissioning (Figure A.9a). During the operations & maintenance phase, we find slightly larger sector-specific (0.2) and total employment effects (0.75) but the large confidence intervals suggest that these results may not be spread uniformly across all treated units (Figure A.9b). However, overall the job effects from firms registered outside of the receiving municipality are smaller than the effects from the locally registered firms in the case of solar (see Figure 2). These findings are in line with information from industry experts indicating that installation is more complex in wind energy, requiring firms from outside, while installation of solar panels can be executed by local firms. However, the employment data does not tell us where workers live. Thus, we do not know whether this impact is driven by workers that moved from the municipality where their firm is registered to the project location or whether they already live near the project location. Furthermore, it is important to emphasize that the combination of these impacts and the main results from Section 5.1 do by no means represent the full picture of local employment as there may still be workers active at the project site, but who are not registered as workers with separate duty stations due to the short duration of their assignments.

5.4 GDP & local public finances

The second part of our analysis concerns the impact of solar and wind parks on economic activity, measured through municipality-level GDP and public revenues and spending. For GDP (Figure 10), we observe no impacts prior to commissioning and positive impacts of 1 million BRL/MW in solar in the first year following the commissioning. This translates into a 23% increase in GDP in year 1 for the average-size solar park compared to the control group mean in that year. The impact appears to decline in the later years, and the impact for years 2 and 3 is not significant at the 5% level. However, the imprecisely estimated decline may be due to the very small sample that we have in solar. GDP data are only available until 2021, and most solar parks were built in 2020 or later, meaning that we lack data for later years in these cases.

In wind, we also find significant GDP impacts ranging from 883,000 BRL/MW in year 1 to around 1.3 million BRL/MW in the long term, represented by the last coefficient (5+), which aggregates all effects for year 5 and beyond. For the average size wind park of 51 MW, this translates into a treatment effect between 12% (year 1) and 18% (year 5+) compared to the control group in the years following the commissioning of the park. In both cases, there are no differences in population over time (Figure A.8), indicating that these GDP impacts translated improvements in the per-capita income levels in the recipient municipalities.

In both wind and solar, GDP increases are solely driven by the value added from the industrial sector, which includes the sector of electricity generation (Figures A.10 a and A.11 a). This poses the question whether the GDP gains simply represent the value of additional electricity sales or whether there are spillovers to other industrial segments. While the GDP data are not available at a more granular level, we use auction price data from different years,

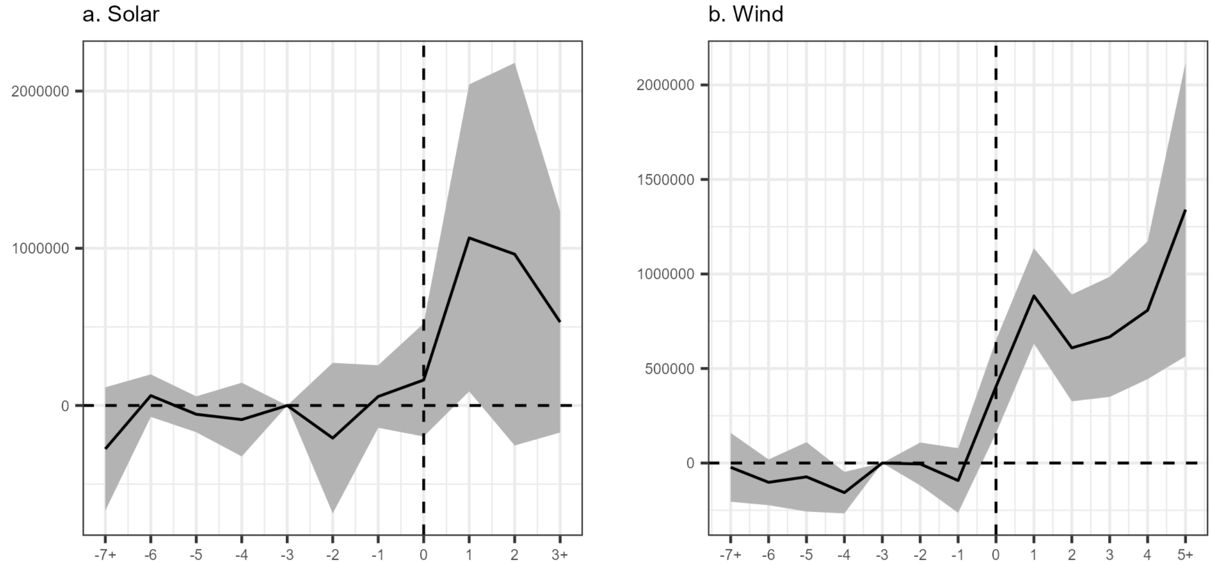

Figure 10: GDP impact (constant 2020 BRL/MW) at the municipal level
Coefficient plot of TWFE regression with N (municipalities): 62 (Solar) and 136 (Wind) and n (observations): 1,176 (Solar) and 2,887 (Wind)

deflated to real 2020 BRL to match the GDP data, and the average capacity levels of wind and solar parks from the grid operator to estimate annual electricity sales. The average-sized solar park (64 MW) generates around 30 Million BRL in annual sales.[6] The industrial GDP treatment effect for solar energy is 49 Million BRL in year 1 for the average-sized plant (64 MW) after commissioning and slightly decreases but remains statistically significant. In wind, the average sized park (51 MW) creates around 28.8 Million BRL [7] in annual sales and the GDP impacts on industrial value added range from 24 to 28 Million BRL.[8] Based on this back-of-the envelope estimation, GDP impacts to a large extent result from the sales of the new plant rather than of spillovers to other industrial firms. Furthermore, the fact that surrounding municipalities do not experience an increase in GDP, nor in industrial value-added (Figure A.12) also suggests that there is no wider form of regional structural change occurring. While other economic sectors (agriculture, services and public sector) also experience an upward trend in year 5 (Figures A.11 b-d), we interpret this with caution. The confidence intervals are wide and the number of municipalities with available data points declines for years further away from commissioning because the most recent wind parks are younger than five years.

6. 236.23 BRL/MWh*8760h*0.23*64MW
7. 174.2 BRL/MWh*8760h*0.37*51MW
8. 472,000 to 550,000 BRL/MW * 51 MW

Finally, we look for impacts on local public revenues and spending by the municipalities with solar and wind parks. In the case of solar, we do not find an overall impact on public revenues (Figure A.13a), nor is there an increase in transfers received by the federal or state government (Figure A.13c). There is a 11% increase in taxes and fees in the year prior to commissioning, and a 26% increase in taxes and fees during the year of commissioning for the average sized solar plant (64 MW). Around 1/5 of this impact is driven by the services tax, a local tax collected by the municipality (Figures A.13 b & d). Since these revenue impacts do not persist they are most likely directly related to taxes that are paid in connection with the commissioning of the plant. Moreover, they are not very big in absolute terms, as the impact on total public receipts remains insignificant. For wind, the fiscal impacts are more persistent than solar. While we observe the same short-term impacts on taxes (Figure A.14 b and d), we find a second long-term increase on total receipts that reaches 2 million BRL/MW for the final coefficient that captures effects 5 years and beyond (Figure A.14 a). This translates into a 15% increase for the average sized plant compared to the control group five years after commissioning. The additional revenue comes from both increases in tax collection and increases in transfers from the state and federal government (Figure A.14 b & c). This increase in receipts by wind energy municipalities is matched by an almost similar sized increase in spending (Figure A.15 a), whereof around one quarter is destined for infrastructure improvements or education (Figure A.15 c and d). Social assistance programs also receive more funding (Figure A.15 b) but the size of the impact (10,000 BRL/MW) is much smaller and only significant in the final period. We don't observe any spending effects in the case of solar (Figure A.16). In sum, we observe impacts on GDP and public finances in wind and solar investments but the impacts are more persistent for wind than for solar.

5.5 Robustness checks

We assess the robustness of our results in two ways. First, we test whether the results are stable to the exclusion of individual matching pairs. We observe that the identified employment impacts for wind, in the months following the commissioning, are not dependent on individual observations (Figure A.17b). The construction-related impact of solar parks in the 15 months preceding the commissioning is also consistent across all samples (Figure A.17a). However, the second increase, which had a positive point estimate but was insignificant due to large confidence intervals, appears to be driven by one specific municipality as the impact dissipates once this unit and its corresponding control are removed from the sample. We repeat this test on the GDP data in the annual dataset and also find that results are not driven by individual observations (Figure A.18).

Second, we also provide results without matching and without restricting treated municipalities to installations with more than 5 MW. The first observation is that the sector-specific employment results are in line with our main specification (Figures A.19 & A.20), which strengthens the external validity. This is particularly valuable for solar energy, where 160 out of 209 municipalities only have installations smaller than 5 MW. The per-MW job impacts during construction are very similar even when including these cases into the sample. One important difference to the matched results is that municipalities with wind parks have significantly higher employment levels in sectors not related to wind energy (Figure A.19d). This demonstrates that matching based on similar levels of pre-treatment population and employment was needed remove this bias. In the case of GDP, the tendency of the effects are also in line with our main specification, except for the earliest coefficient which however covers all periods 7 years or more before commissioning and therefore contains very distant periods (Figure A.21). Thus, our second observation is that matching is important, at least in some cases, to satisfy the identification assumption and improve the estimation. Furthermore, confidence intervals are also larger in the unmatched sample, due to the increased heterogeneity of municipalities. Overall, matching improves precision of the estimation as well as the credibility of the main identification assumption (i.e. equal trends in the absence of the treatment). However, based on these robustness checks, the results appear generalizable to the broader population of municipalities.

6 Policy implications & limitations

Our results provide several implications for policymakers. First, local job opportunities are more likely in solar than in wind parks and mainly occur in the installation phase. Whether these job impacts are a significant source of employment for the local population is highly dependent on the size of the park and the municipality and where the park is built. For example, a 60 MW solar park provides 60 to 90 jobs, which is 5-7% of the median formal workforce in these communities, as many people are still working in the informal sector and hence are not captured by the employment data. Hence, for a policy maker of a smaller municipality in a rural area with low levels of formal employment and many low-skilled workers it may still be worthwhile to advocate the job impacts as a way of garnering support for a local solar park. However, solar does not seem to provide many other local benefits expect for a one time effect in tax collection at commissioning. It remains unclear to us why the tax impacts are not persistent like in wind, as electricity sales continue. One explanation could be that more project firms may be registered in other municipalities but this should be investigated by further research.

For wind parks, while the immediate benefits for the local population in terms of employment are very low, municipalities with wind parks are actually much better of in the long-term, as suggested by the positive impacts on industrial GDP and fiscal revenues and spending. This can be a strong narrative for local policy makers, particularly in areas with relatively low fiscal revenues and insufficient funds to improve public infrastructure, as is the case for Northern and Northeast Brazil. Whether a 10% increase in annual public revenue and spending sufficiently compensates for negative impacts for the local population is difficult to establish. One aspect that we did not address here is which type of intergovernmental transfers are driving the receipts growth in wind municipalities and why these occur. Whether it is federal or state taxes or other public funds should be investigated by future research.

A third implication relates to the governance model of wind and solar park, which may be regulated by the government. In Brazil, many of the parks are owned by large international project developers but they create local project companies that are registered in the recipient municipalities. As observed, this provides them with additional tax revenues, which may otherwise occur in larger cities where these companies have their headquarters. Hence, if governments wish to redistribute the collection shares of local taxes more towards rural areas, requiring the creation of such local project firms may be good policy.

Finally, the comparison of our results with the Fabra et al. (2023) study of Spain suggests that the local employment impacts of solar energy are not necessarily larger in an emerging country context. Our employment impacts found during the construction phase of solar energy, with a peak of 1.5 jobs/MW, are smaller than the 2.47 jobs/MW found by Fabra et al. (2023). Only if we assume a large presence of informal workers in Brazil with similar magnitudes to our formal employment results (1-1.5 jobs/MW) would the magnitude of our estimates be similar to the magnitudes found by Fabra et al. (2023). Despite the lower magnitude, the fact that the results are similar in terms of timing, trajectory and significance of results for wind and solar increases the generalizability beyond our country context.

However, it is important to emphasize that our estimations are geographically limited to the concerned municipalities and their surroundings. There is additional employment in all three segments (components, installation and O&M) that might occur far away from the park locations which we are unable to capture due to unavailability of identifiable labor data. In particular, the impact on component manufacturing would be an interesting aspect to study in the Brazilian context, since the local content requirements targeted this aspect of the value chain and descriptive evidence suggests that the number of firms and employees in wind turbine production has increased constantly over the past 15 years (Figure A.22), which matches with qualitative evidence that argues that Brazil managed to build-up considerable local value chains in wind turbine manufacturing (Rennkamp and Perrot, 2016).

A second limitation regards the tenure and sequencing of employment. We are unable to observe how long workers are employed and whether they get re-employed when new projects get built in their vicinity. Our results show that employment rises again when surrounding municipalities built a solar park but we cannot say whether it is the same workers. This would be important information for policy makers because one criticism of solar-related employment is it temporariness, which could be addressed if regional expansion leads to coordinated and continuous built-ups.

7 Conclusion

Analyzing socioeconomic data at the municipal level in Brazil, we find that municipalities receiving a solar park larger than 5 MW experience a positive employment impact during the installation phase that starts around 15 months prior to commissioning and lasts until the park enters operation. The impact peaks at 1.5 jobs/MW half a year before the start date, and the created jobs primarily benefit workers with completed primary or secondary education. There are signs of geographic spillovers as treated municipalities see a second increase when another park is built in their vicinity. The impact on non-treated municipalities within 20km is insignificant, but large confidence intervals suggest this may be due to lack of power. In wind, we do not find any significant impacts on local jobs during the construction phase. However, a small impact of 0.25 jobs/MW in the 12 months following the installation suggests that local workers are used for repair work that often occurs during the start-up phase.

We find large and persistent increases in GDP in municipalities that receive wind and solar parks, but these seem to be to a large extent driven directly by the electricity sales. In wind, these GDP impacts are accompanied by permanent increases in local revenues, first driven by collected service taxes and later by increases in federal and state-level transfers. These revenue effects also lead to an increase in public spending on education and social assistance. In solar, we only find temporary increases in tax revenues in the year of commissioning itself but not beyond.

Overall, these results suggest that the local impacts of solar and wind parks are different in terms of their timing and duration, which carry different implications for policymakers advocating these benefits. While solar parks provide more direct short-term employment benefits, in particular for medium to low-skilled workers, the impacts of wind parks are more structural and long-term and lead to improved fiscal situations for the local communities.

Our analysis is restricted to the recipient municipalities and is unable to capture employment, GDP and revenue impacts that occur in municipalities outside the installation area. Future research with access to firm-level data should investigate how the increase in wind and solar impacts manufacturing employment for wind and solar equipment, which is an area where many developing countries provide policy support. Furthermore, the tenure of employment and the movement of workers across regions would be an interesting avenue for further research.

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Appendix

A Figures

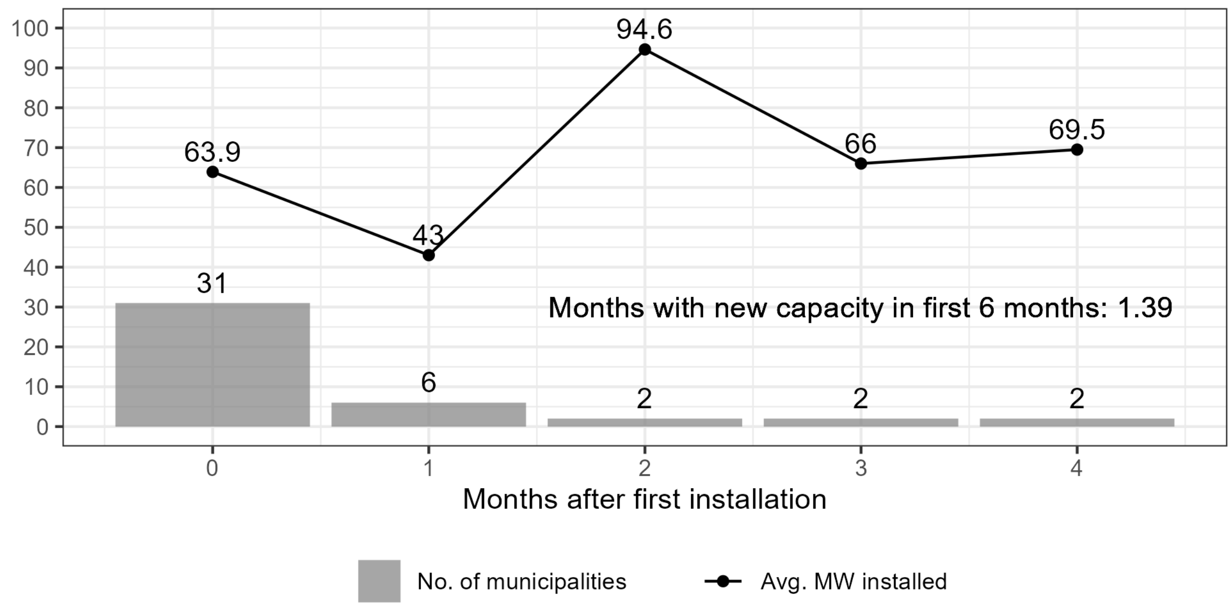

Figure A.1: Number of municipalities and average MW of solar commissioned

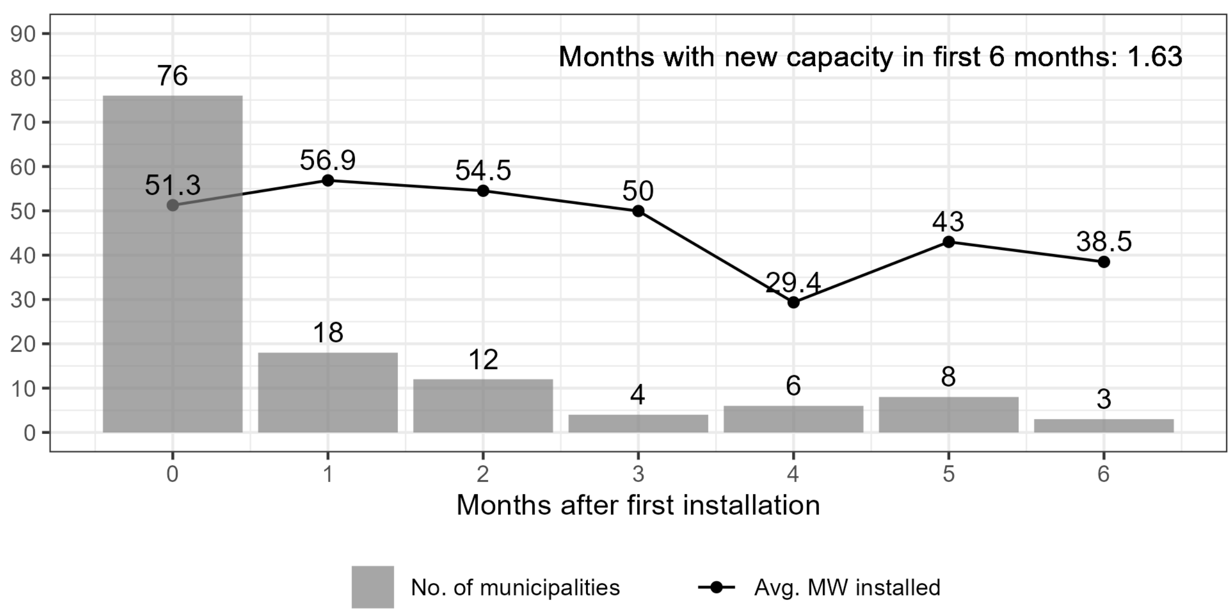

Figure A.2: Number of municipalities and average MW of wind commissioned

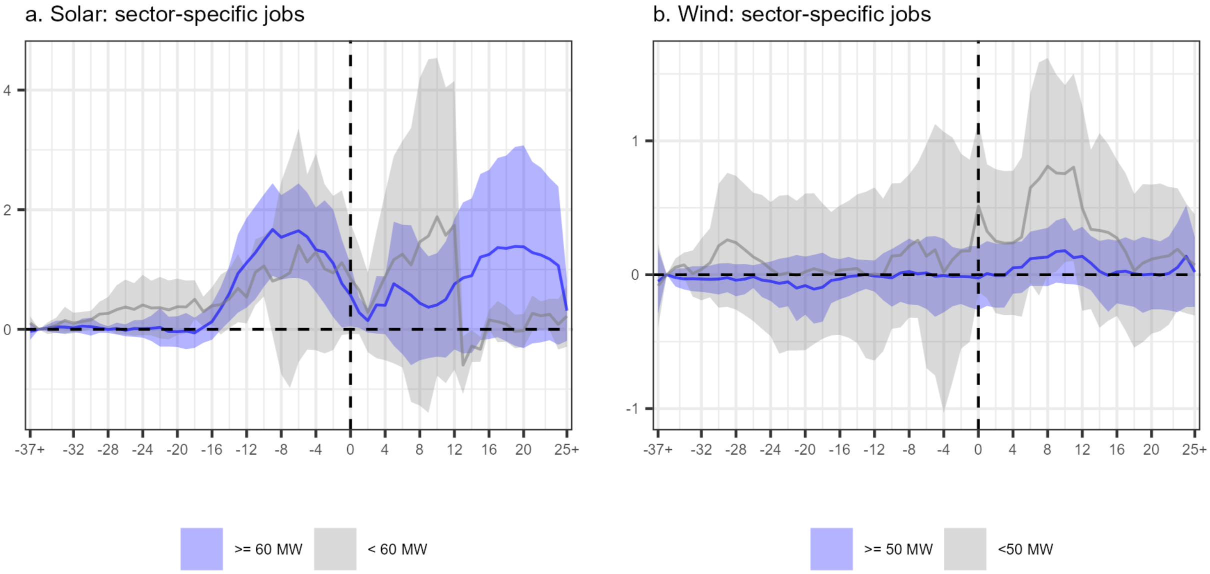

Figure A.3: Employment impact (Jobs/MW) by size of wind and solar park.
Coefficient plot of TWFE regression with N (municipalities): Solar (blue =30, grey= 32), Wind (blue=61, grey=80) and n (no. of observations): Solar (blue= 5,400, grey=5,760), Wind (blue=13,140 , grey=17,100). Ribbon: 95% confidence interval. Scale of y-axis differs by plot.

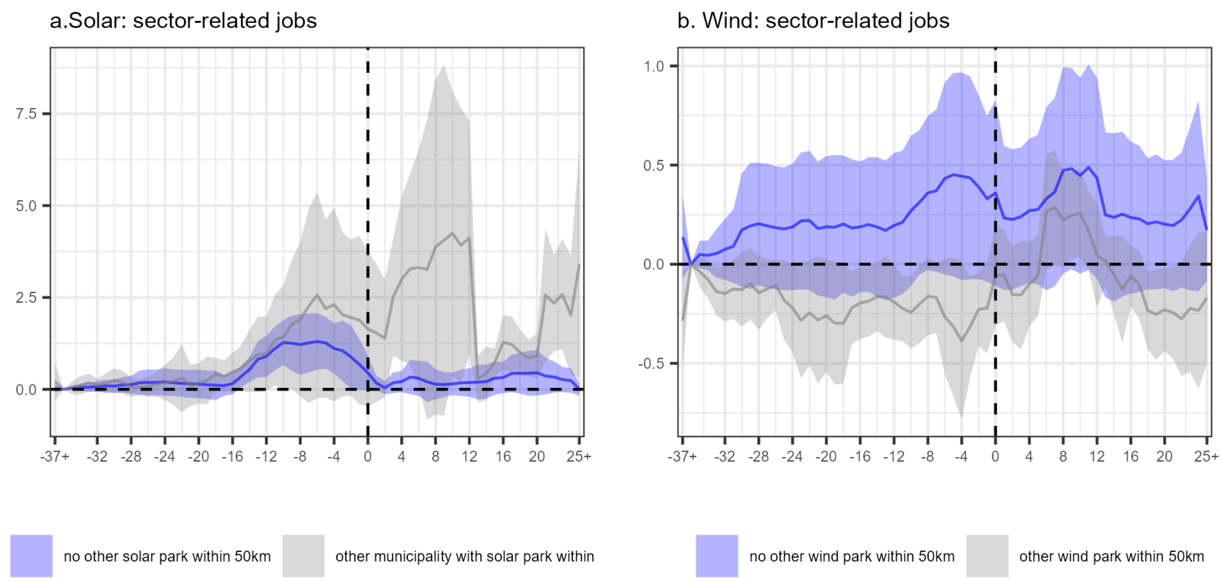

Figure A.4: Employment impact by occurrence of additional wind/solar investment in vicinity
Coefficient plot of TWFE regression with N (municipalities): Solar (blue =44, grey= 18), Wind (blue=77, grey=64) and n (no. of observations): Solar (blue= 7,920, grey=3,240), Wind (blue=14,400 , grey=12,960). Ribbon: 95% confidence interval. Scale of y-axis differs by plot.

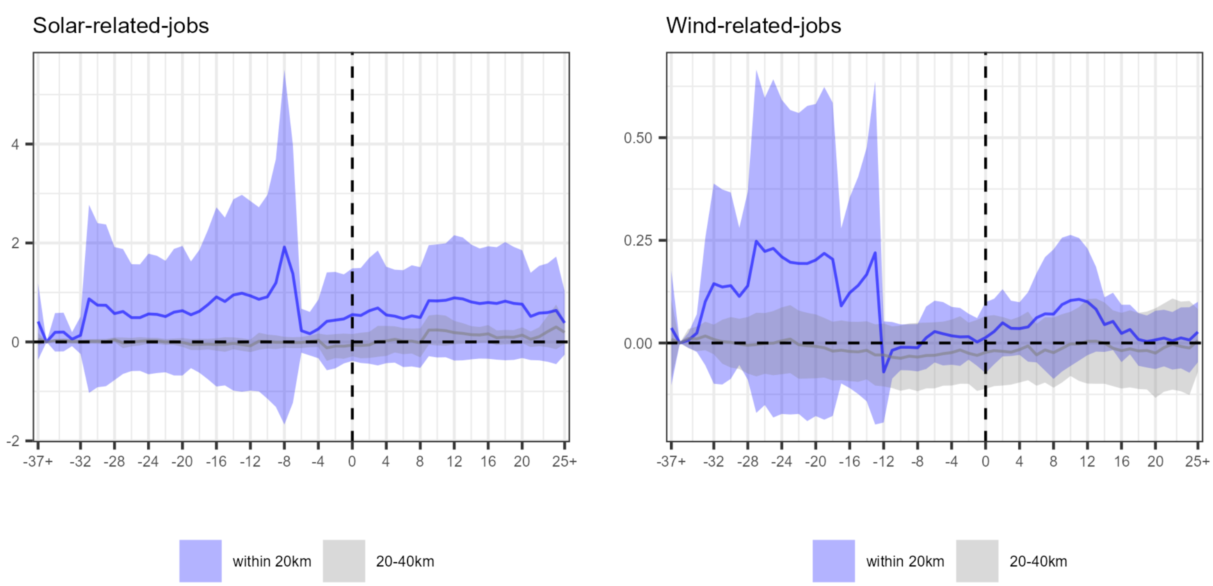

Figure A.5: Employment impact in neighboring municipalities.
Coefficient plot of TWFE regression with N (municipalities): Solar (blue =96, grey= 313), Wind (blue=144, grey=377) and n (no. of observations): Solar (blue= 17,280, grey=56,340), Wind (blue=25,920, grey=67,860). Ribbon: 95% confidence interval. Scale of y-axis differs by plot.

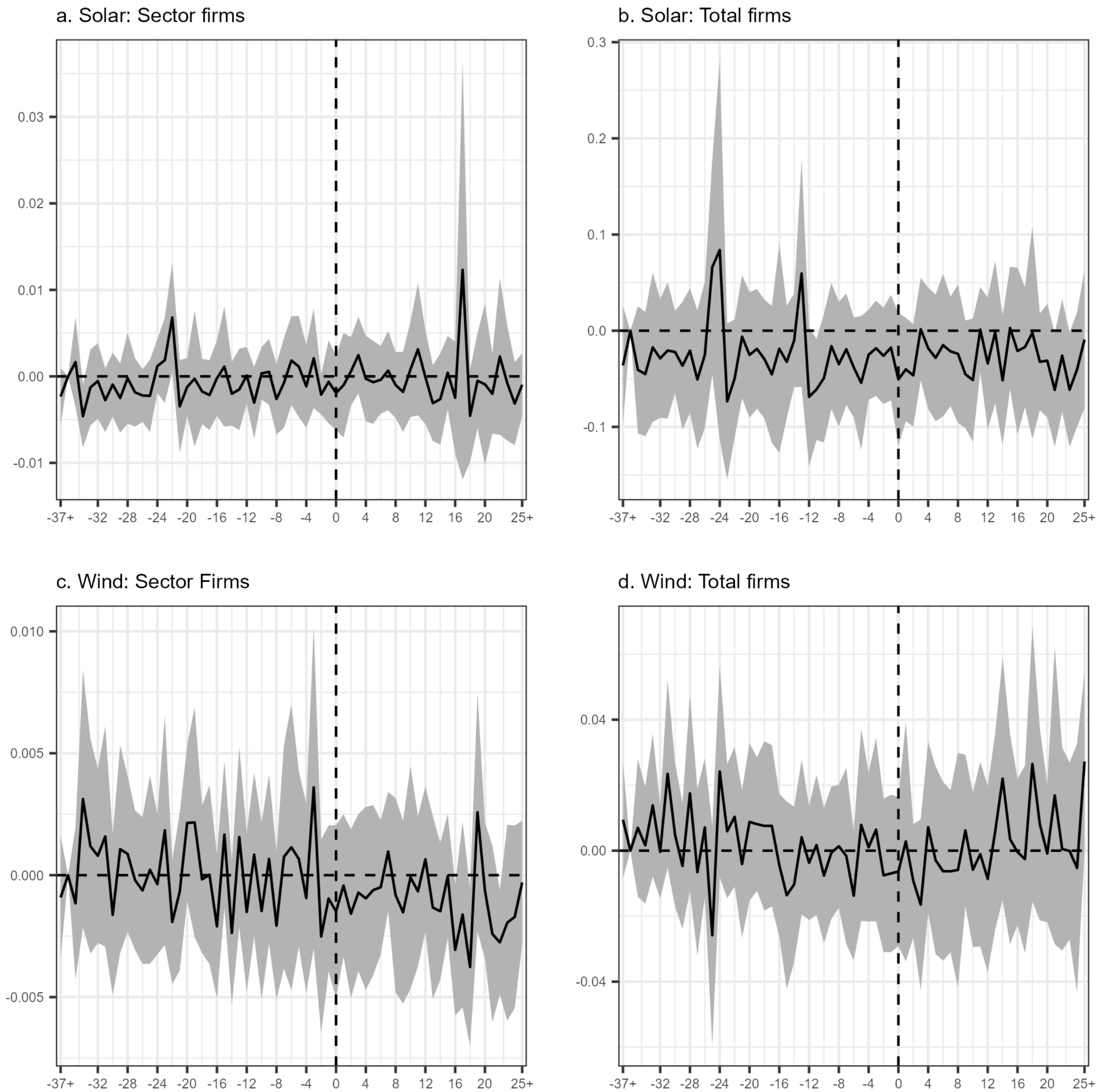

Figure A.6: Number of new firm registrations per MW.
Dependent variable refers to the legal registration of a new establishment in the public registry. Coefficient plot of TWFE regression with N (municipalities): 62 (solar) and 136 (wind) and n (observations): 10,850 (solar) and 25,786 (wind). Ribbon: 95% confidence interval. Scale of y-axis differs by plot.

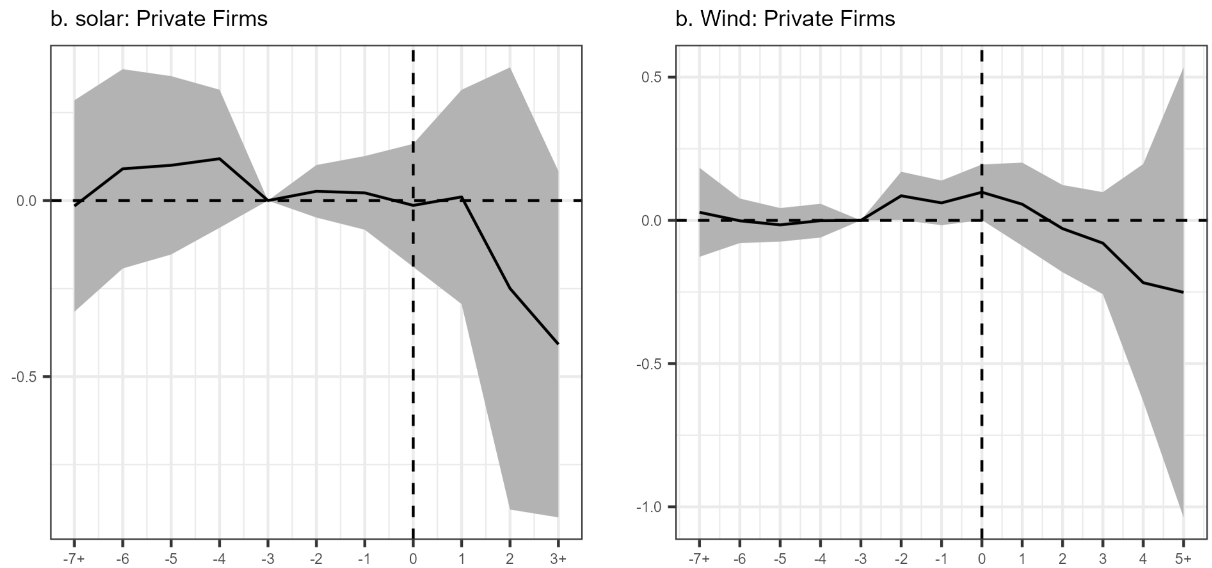

Figure A.7: Effect on active firms (No./MW).
Active firms are those that report at least one employee at the end of the calendar year to the employment registry RAIS. Coefficient plot of TWFE regression with N (municipalities): 62 (solar) and 136 (wind) and n (observations): 1,357 (solar) and 3,337 (wind). Ribbon: 95% confidence interval. Scale of y-axis differs by plot.

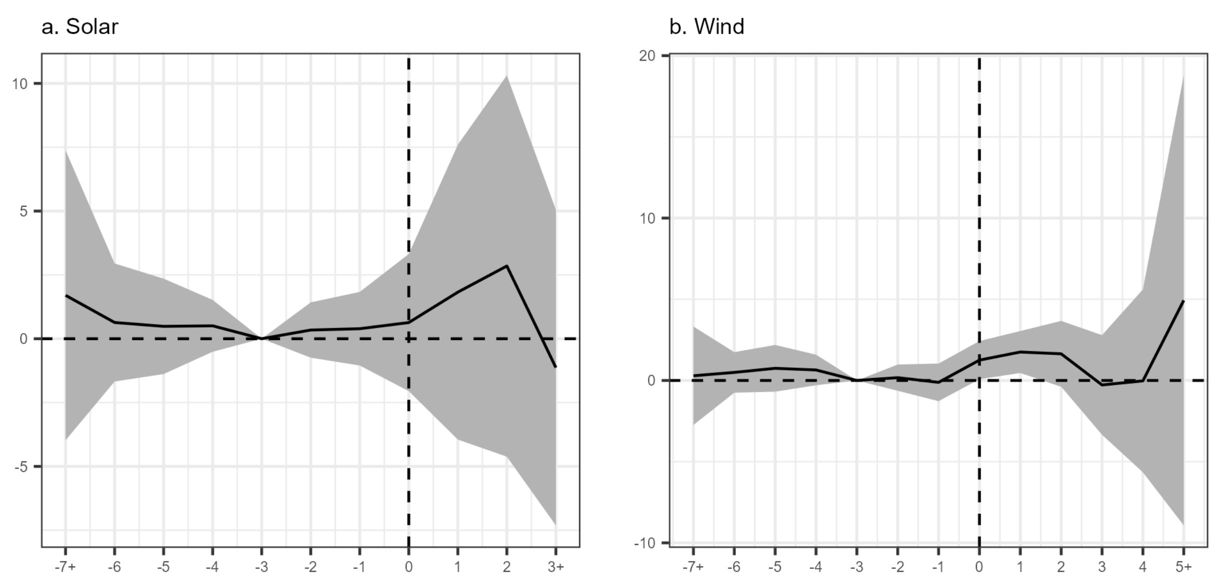

Figure A.8: Effect on population (Jobs/MW).
Coefficient plot of TWFE regression with N (municipalities): 62 (solar) and 136 (wind) and n (observations): 1,357 (solar) and 3,337 (wind). Ribbon: 95% confidence interval. Scale of y-axis differs by plot.

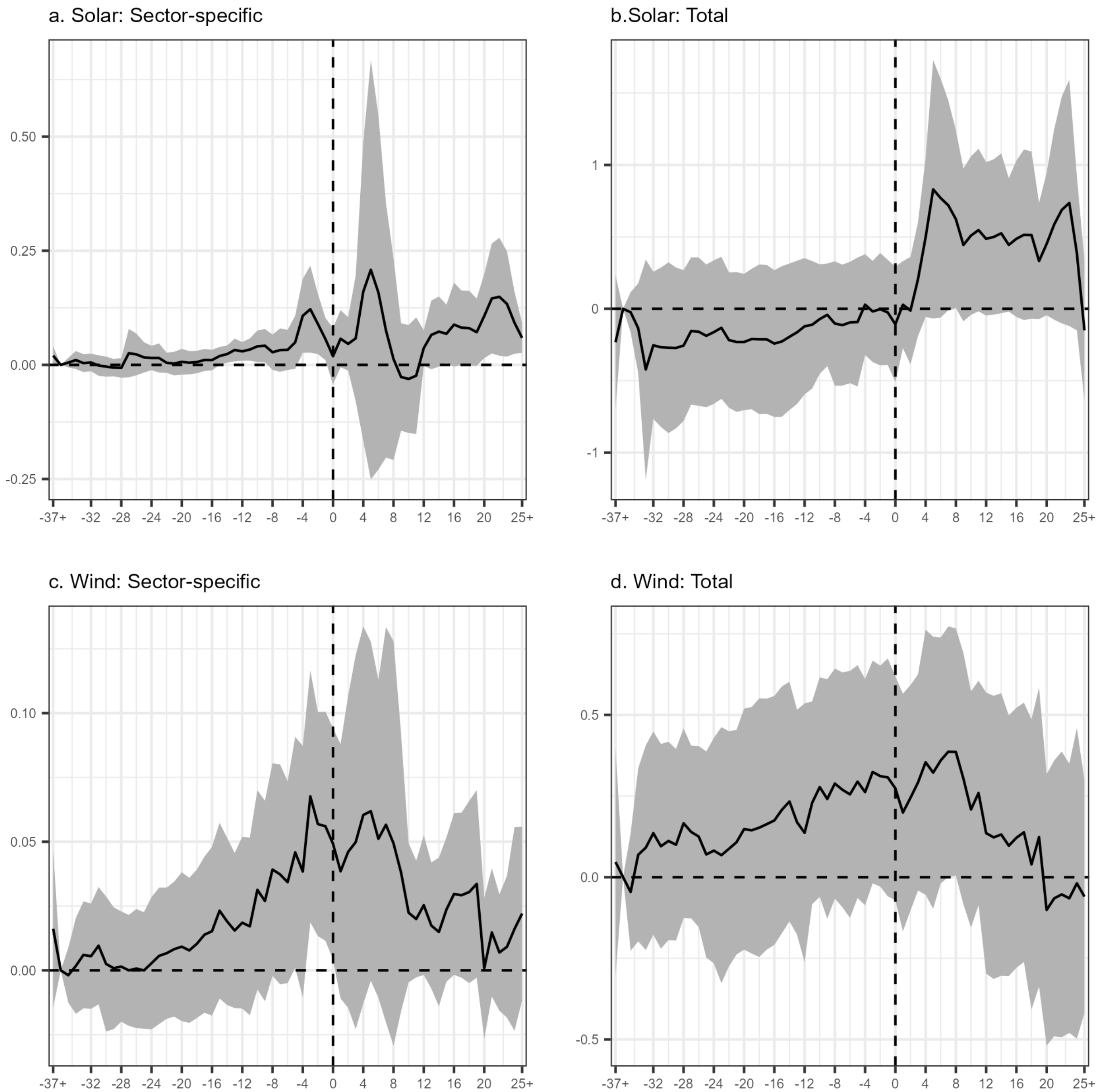

Figure A.9: Employment effect (Jobs/MW) of jobs in registered in other municipalities but executed in municipalities with wind or solar park.
Coefficient plot of TWFE regression with N (municipalities): 62 (solar) and 135 (wind) and n (observations): 6,696 (solar) and 16,308 (wind). Ribbon: 95% confidence interval. Scale of y-axis differs by plot.

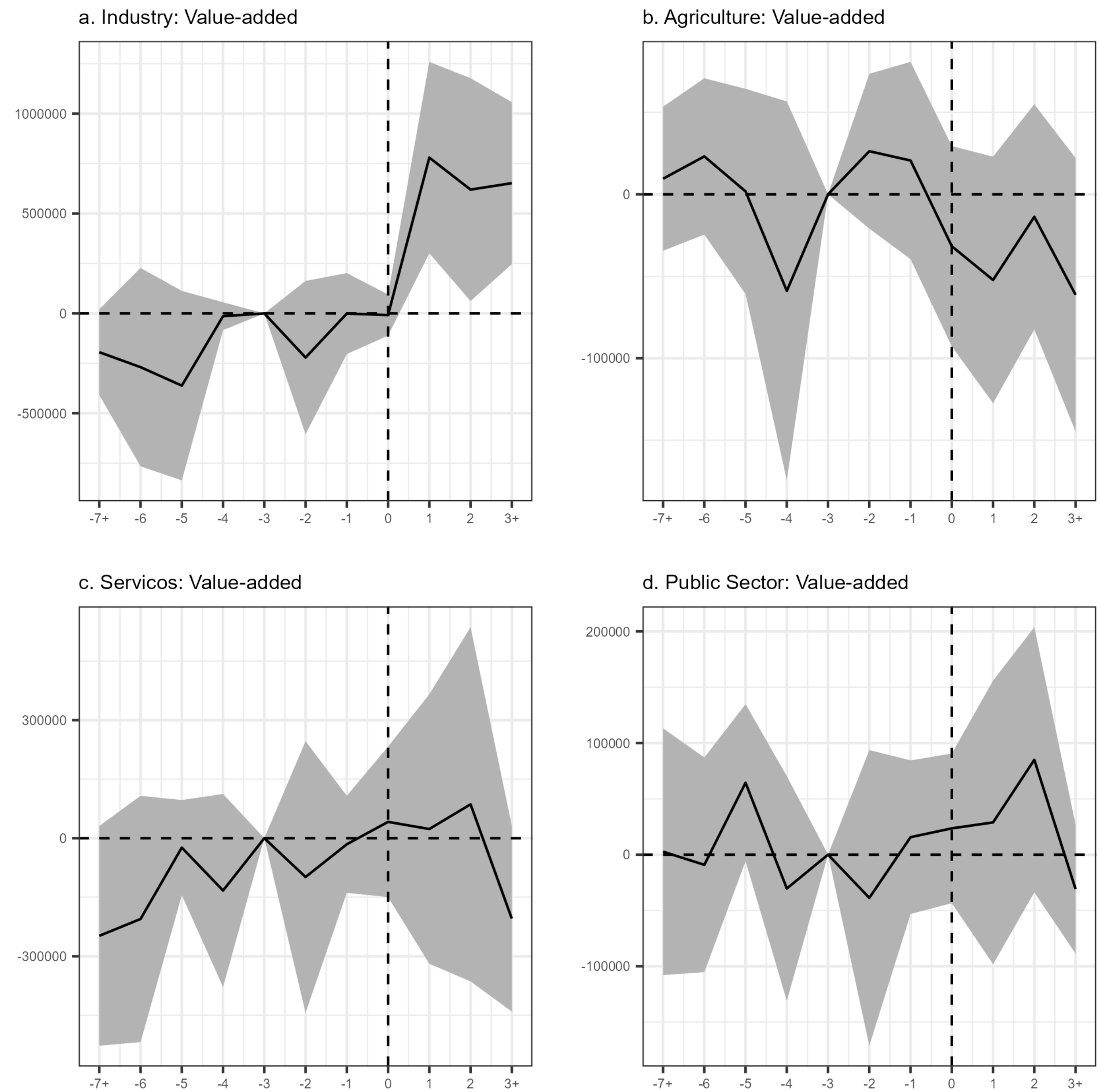

Figure A.10: Solar: GDP effect (constant 2020 BRL/MW) in value-added by 4 sectors. Coefficient plot of TWFE regression with N (municipalities): 62 and n (observations): 1,176. Ribbon: 95% confidence interval. Scale of y-axis differs by plot.

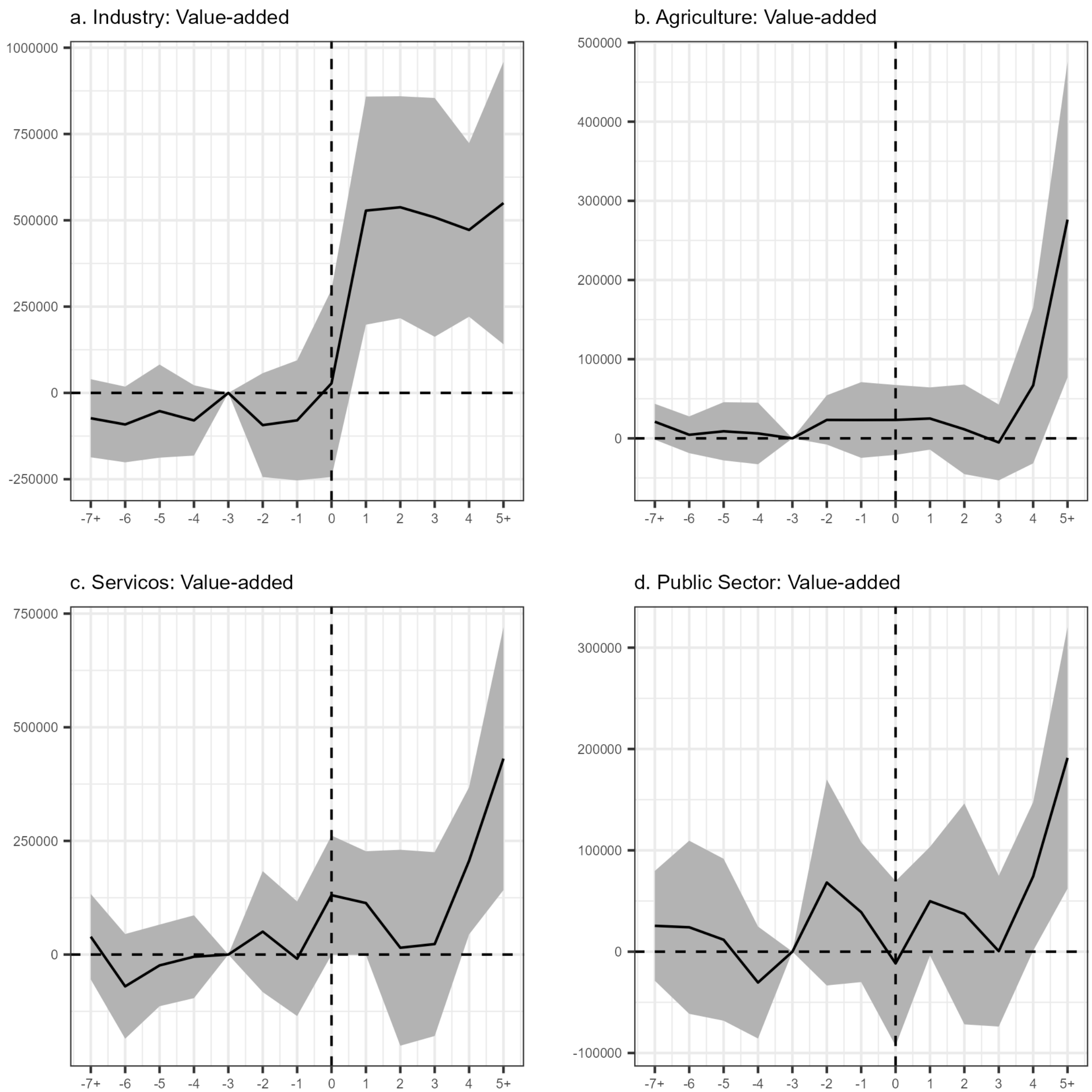

Figure A.11: Wind: GDP effect (constant 2020 BRL/MW) in value-added by 4 sectors. Coefficient plot of TWFE regression with N (municipalities): 136 and n (observations): 2,887. Ribbon: 95% confidence interval. Scale of y-axis differs by plot.

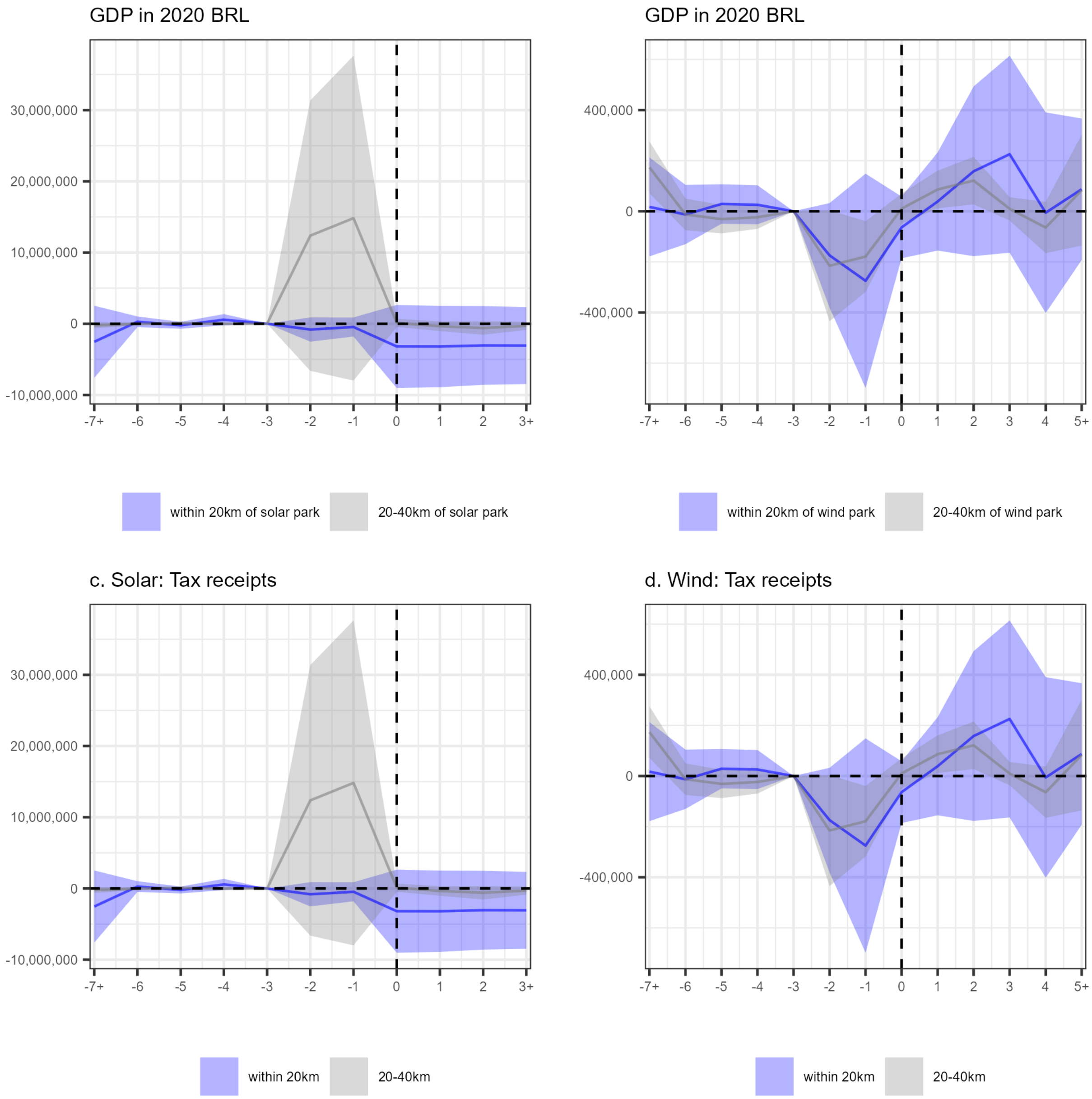

Figure A.12: Geographic spillover of GDP and Public Revenues (constant 2020 BRL/MW) Coefficient plot of TWFE regression with N (municipalities): Solar (blue =96, grey= 314), Wind (blue=144, grey=378) and n (no. of observations): Solar (blue= 1,722, grey=5,628), Wind (blue=2,586, grey=6,787). Ribbon: 95% confidence interval

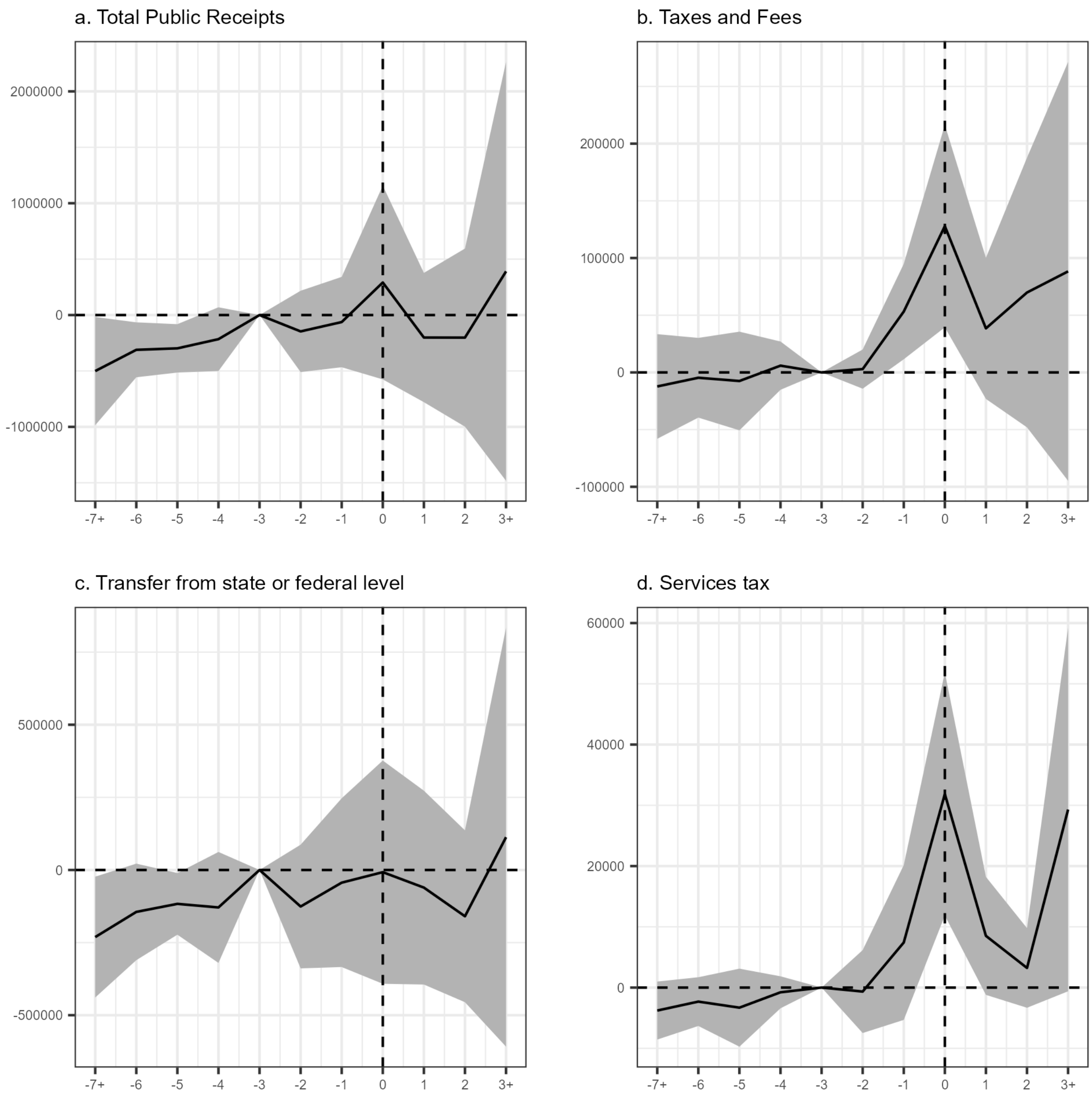

Figure A.13: Solar: Public revenue effect (constant 2020 BRL/MW) by category.
Coefficient plot of TWFE regression with N (municipalities): 62 and n (observations): 1,393. Ribbon: 95% confidence interval. Scale of y-axis differs by plot.

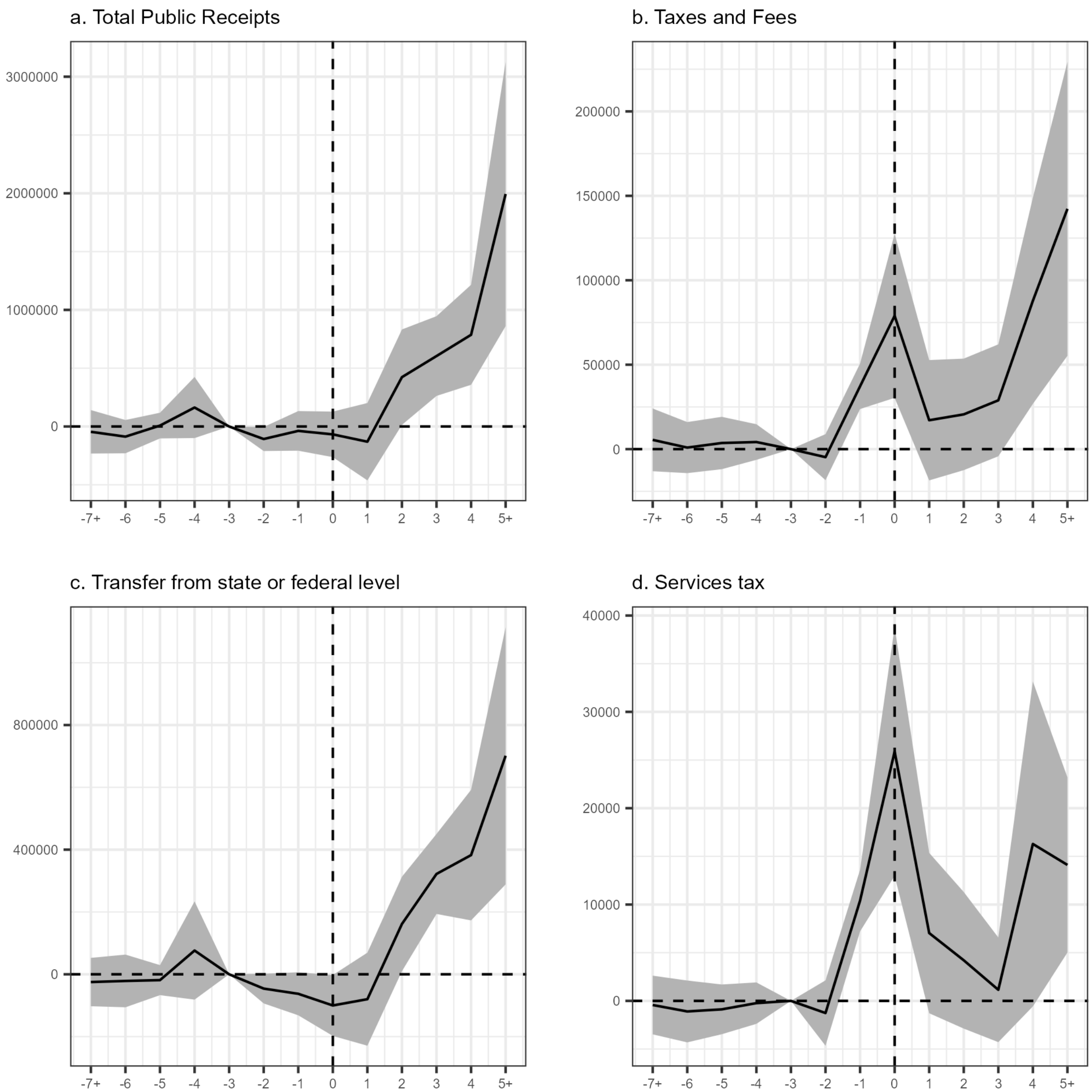

Figure A.14: Wind: Public revenue effect (constant 2020 BRL/MW) by category.
Coefficient plot of TWFE regression with N (municipalities): 136 and n (observations): 3,375. Ribbon: 95% confidence interval. Scale of y-axis differs by plot.

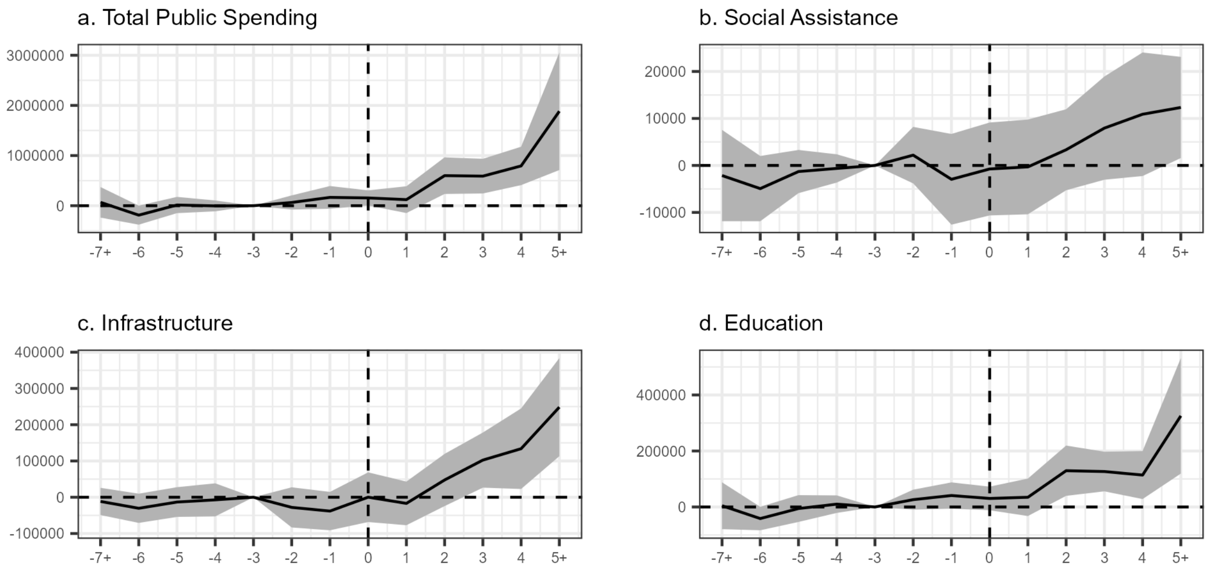

Figure A.15: Wind: Public spending effect (constant 2020 BRL/MW) by category.
Coefficient plot of TWFE regression with N (municipalities): 136 and n (observations): 2,781. Ribbon: 95% confidence interval. Scale of y-axis differs by plot.

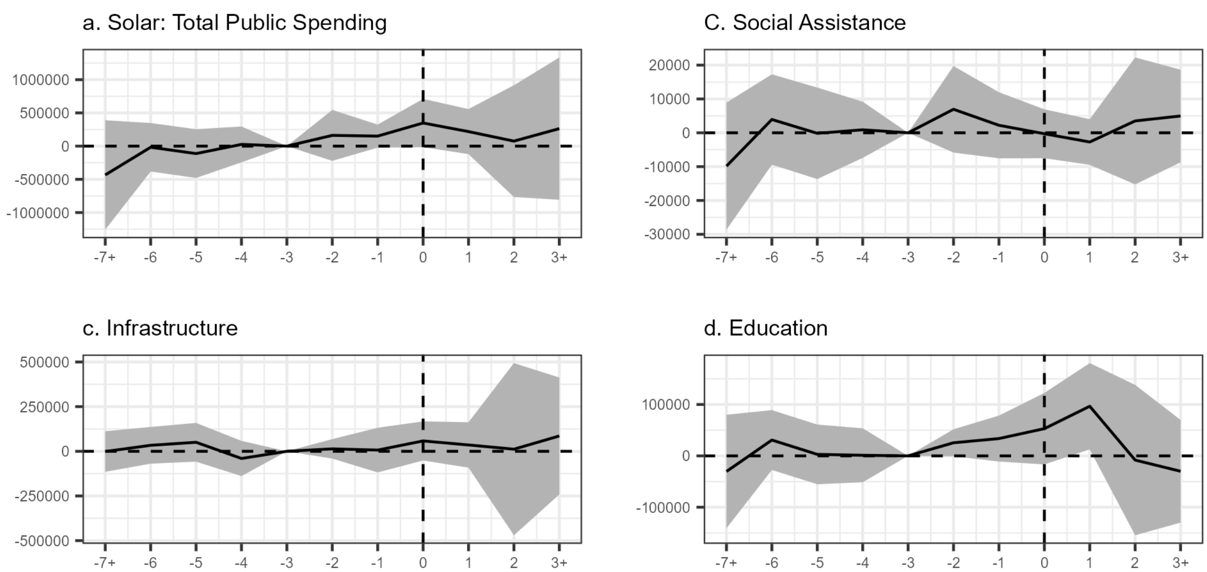

Figure A.16: Solar: Public spending effect (constant 2020 BRL/MW) by category.
Coefficient plot of TWFE regression with N (municipalities): 62 and n (observations): 729. Ribbon: 95% confidence interval. Scale of y-axis differs by plot.

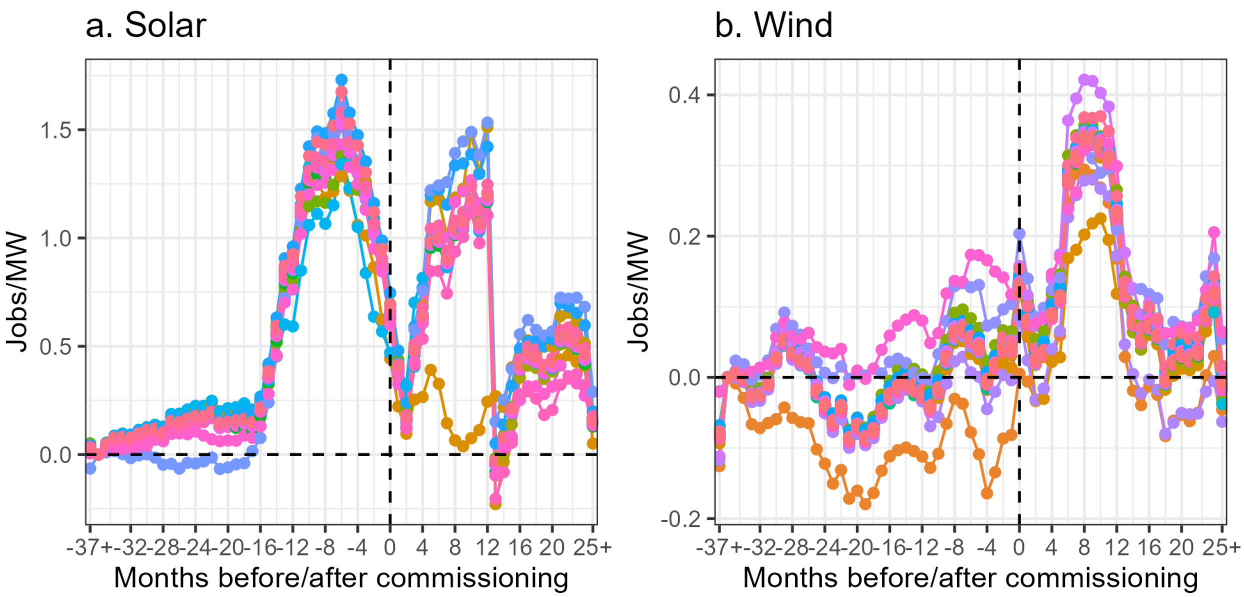

Figure A.17: Coefficients of employment effect (Jobs/MW) of TWFE regressions, leaving out 1 matched pair at a time.
Scale of y-axis differs by plot.

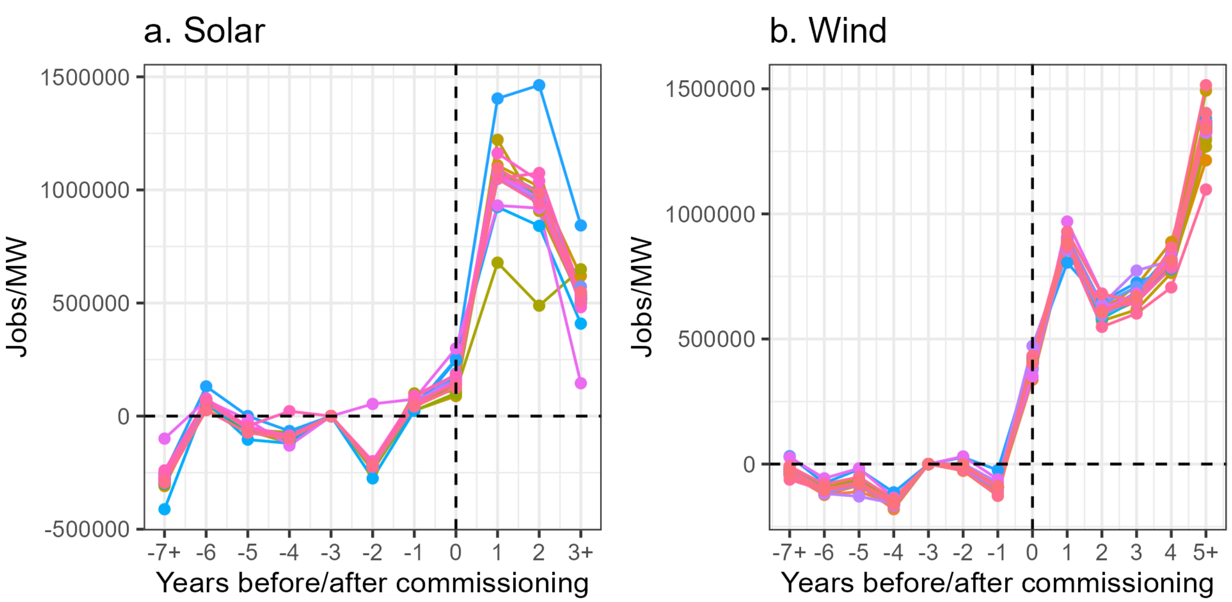

Figure A.18: Coefficients of GDP effect (constant 2020 BRL/MW) of TWFE regressions, leaving out 1 matched pair at a time.
Scale of y-axis differs by plot.

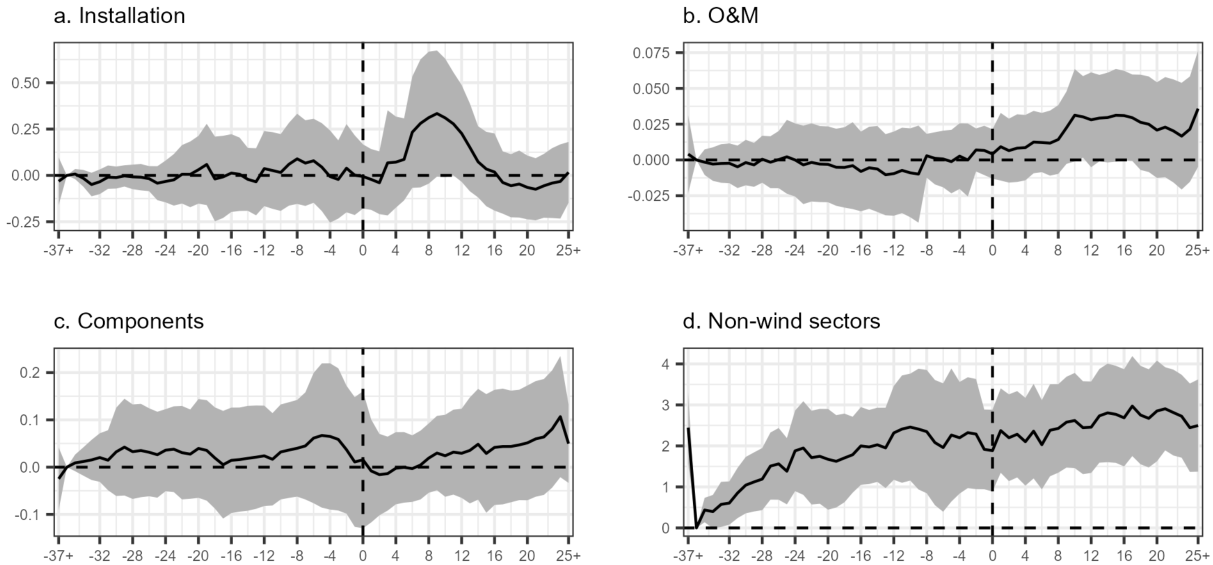

Figure A.19: Wind: Employment results (Jobs/MW) in unmatched sample.
Coefficient plot of TWFE regression with N (municipalities): 5561 and n (observations): 1,000,980. Ribbon: 95% confidence interval. Scale of y-axis differs by plot.

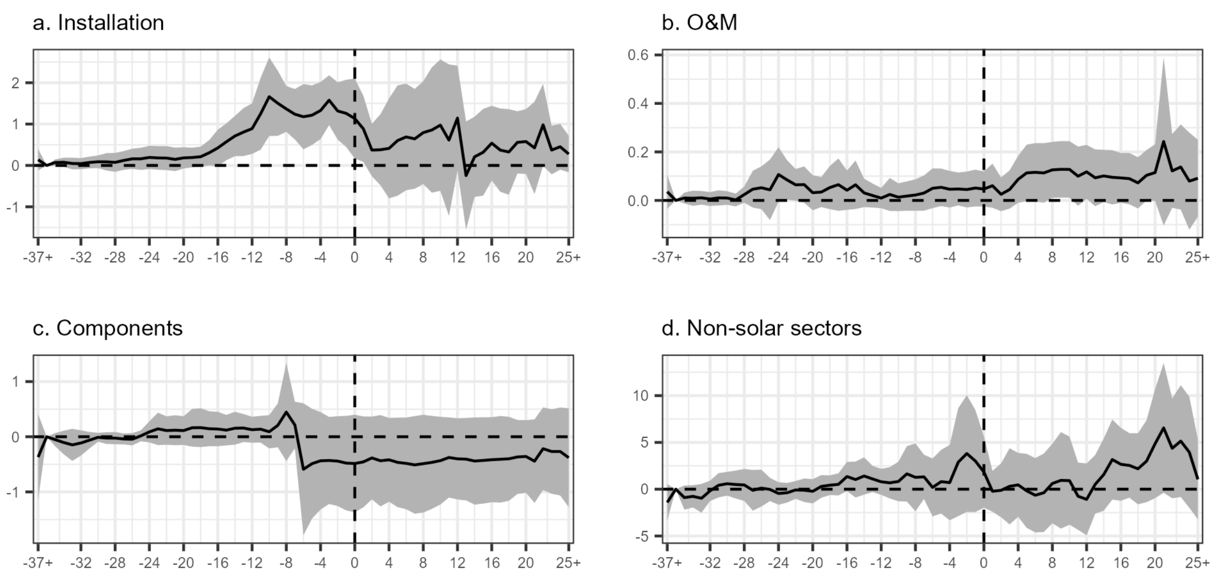

Figure A.20: Solar: Employment impact(Jobs/MW) in unmatched sample.
Coefficient plot of TWFE regression with N (municipalities): 5561 and n (observations): 1,000,980. Ribbon: 95% confidence interval. Scale of y-axis differs by plot.

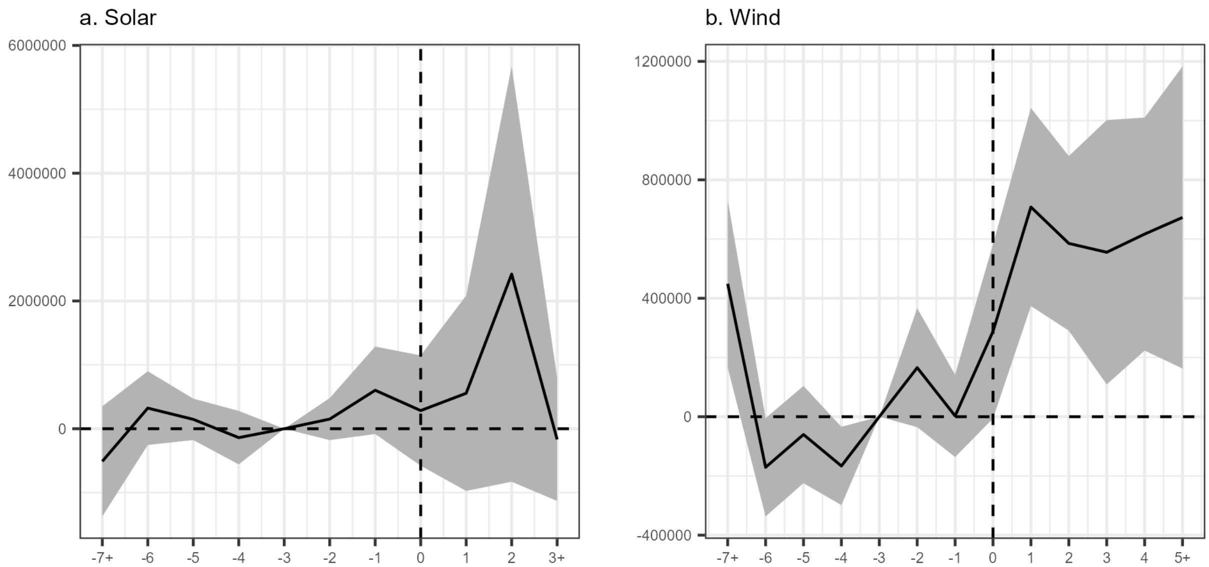

Figure A.21: GDP (constant 2020 BRL/MW) impacts in unmatched sample.
Coefficient plot of TWFE regression with N (municipalities): 5562 and n (observations): 105,656. Ribbon: 95% confidence interval. Scale of y-axis differs by plot.

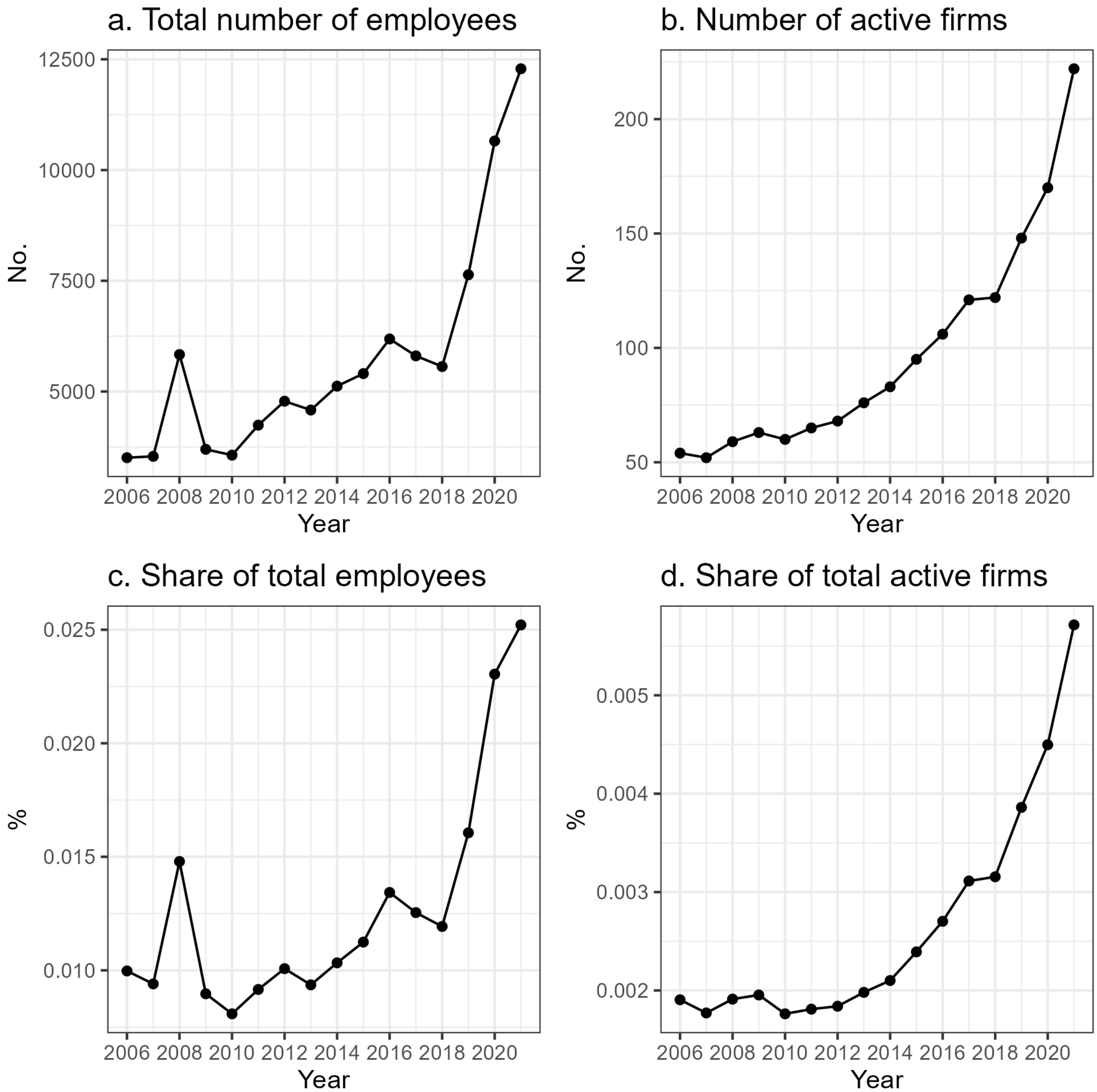

Figure A.22: Number of employees and firms in the sector of manufacturing of electrical generators (in absolute numbers and as share of the total population). This sub-sector (CNAE No. 2710401) also includes firms active in manufacturing of other electrical generators beyond wind turbines, but represents the lowest level of aggregation. Scale of y-axis differs by plot.

B Tables

cnae	description english	phase
2511000	Manufacture of metal structures	components
2599399	Manufacture of other metal products not specified above	components
2610800	Manufacture of electronic components	components
2651500	Manufacture of measurement, testing and control devices and equipment	components
2710401	Manufacture of direct and alternating current generators, parts and accessories	components
2710402	Manufacture of transformers, inductors, converters, synchronizers and similar equipment	components
2710403	Manufacture of electric motors, parts and accessories	components
2731700	Manufacture of apparatus and equipment for electricity distribution and control	components
2733300	Manufacture of wiring, cables and insulated electric conductors	components
2790201	Manufacture of electrodes, contacts and other carbon and graphite articles for electrical purposes	components
2790299	Manufacture of other electrical equipment and apparatus not specified above	components
4669999	Wholesale of other machinery and equipment not specified above; parts and pieces	components
3321000	Installation of industrial machinery and equipment	installation
4221901	Construction of dams and reservoirs for electricity generation	installation
4221902	Construction of electrical energy distribution stations and networks	installation
4221903	Maintenance of electricity distribution networks	installation
4292801	Assembly of metallic structures	installation
4292802	Industrial assembly works	installation
4321500	Electrical installation and maintenance	installation
7112000	Engineering services	installation
7739099	Rental of other commercial and industrial machinery and equipment not specified above, without operator	installation
3313706	Maintenance and repair of machinery, apparatus and equipment for heating installations	operations
3313901	Maintenance and repair of generators, transformers and electric motors	operations
3313999	Maintenance and repair of electrical machinery, apparatus and equipment not specified above	operations
3511501	Electric power generation	operations
3511502	Coordination and control activities for the operation of electric power generation and transmission	operations
3512300	Transmission of electric power	operations
3513100	Wholesale of electricity	operations
3514000	Distribution of electric power	operations
8299701	Electricity, gas and water consumption measurement	operations

Table B.1: Sector codes used for solar energy

cnae	description english	phase
2330301	Manufacture of precast reinforced concrete structures, in series and on request	components
2511000	Manufacture of metal structures	components
2599399	Manufacture of other metal products not specified above	components
2651500	Manufacture of measurement, testing and control devices and equipment	components
2710401	Manufacture of direct and alternating current generators	components
2710402	Manufacture of transformers, inductors, converters, synchronizers and similar equipment	components
2710403	Manufacture of electric motors, parts and accessories	components
2731700	Manufacture of apparatus and equipment for electricity distribution and control	components
2733300	Manufacture of wiring, cables and insulated electric conductors	components
2790201	Manufacture of electrodes, contacts and other carbon and graphite articles for electrical purposes	components
2790299	Manufacture of other electrical equipment and apparatus not specified above	components
2811900	Manufacture of engines and turbines, parts and accessories, except for aircraft and road vehicles	components
4669999	Wholesale of other machinery and equipment not specified above; parts and pieces	components
3321000	Installation of industrial machinery and equipment	installation
4221901	Construction of dams and reservoirs for electricity generation	installation
4221902	Construction of electrical energy distribution stations and networks	installation
4221903	Maintenance of electricity distribution networks	installation
4292801	Assembly of metallic structures	installation
4292802	Industrial assembly works	installation
4321500	Electrical installation and maintenance	installation
7112000	Engineering services	installation
7739099	Rental of other commercial and industrial machinery and equipment not specified above, without operator	installation
3313901	Maintenance and repair of generators, transformers and electric motors	operations
3313999	Maintenance and repair of electrical machinery, apparatus and materials not specified above	operations
3314701	Maintenance and repair of non-electric power tools	operations
3511501	Generation of electricity	operations
3511502	Coordination and control activities for the operation of electric power generation and transmission	operations
3512300	Transmission of electric power	operations
3513100	Wholesale of electric energy	operations
3514000	Distribution of electric power	operations
8299701	Electricity, gas and water consumption measurement	operations

Table B.2: Sector codes used for wind energy