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The Effects of Renewable Energy Projects on Employment: Evidence from Brazil

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This paper studies the employment impacts of renewable energy projects in Brazil. Between 2006 and 2017, Brazil's solar capacity increased from 0.001 GW to 1.01 GW, and wind capacity increased from 0.233 GW to 12.4 GW. Using detailed employment information from the universe of formal workers in Brazil, we analyze whether the development of renewable energy projects impacts employment in the local municipalities. Solar energy projects appear to have no significant impact on local economic activity. In contrast, we find that when new wind energy projects come online, total employment in a municipality increases by 15.95 percent, and the number of firms in a municipality increases by 14.84 percent. The number of jobs in the electricity sector increases by as much as 74.33 percent, 51.72 percent in the construction sector, and 22.54 in transportation. The employment increases appear to stem from growth of existing firms and growth of new firms. The effects persist and are even larger when we consider only municipalities that have not experienced expansions in their electricity grid. Proxying land lease income with municipal tax revenues, we do not find evidence that the effects are driven by windfall income from land leases.

KEYWORDS

labor impacts, renewable energy, energy policies

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Efectos en empleo de proyectos de energía removable: evidencia para Brasil

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Este artículo analiza los efectos laborales de los proyectos de energía renovable en Brasil. Se utiliza información detallada del universo de trabajadores formales en Brasil y cuantifica los efectos del desarrollo de proyectos de energía renovable en el empleo a nivel municipal. Los proyectos de energía solar no tienen efectos significativos en la actividad económica local. Sin embargo, se encuentra que cuando nuevos proyectos de energía eólica comienzan, el empleo total a nivel municipio aumenta en 15.95%, mientras que el número de negocios a nivel municipio aumenta en 14.84%. El empleo formal en el sector eléctrico aumenta 74.33%, así como 51.72% y 22.54% en los sectores de construcción y transporte, respectivamente. Los aumentos del empleo parecen deberse al crecimiento de negocios existentes y negocios recientemente creados. Los efectos duran y son mayores al considerar únicamente los municipios que no han experimentado expansiones eléctricas. Usando datos de ingresos fiscales municipales, no se encuentra evidencia para concluir que los efectos son causados por aumentos en el ingreso derivado de renta de terrenos.

KEYWORDS

Efectos en el empleo, Energía, Política energética

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1 | INTRODUCTION

One of the main policies towards reducing GHG emissions globally is the transition to renewable sources of energy. The development of renewable energy projects has the potential of reducing GHG emissions and also be a source of employment for many regions. In the US alone, the number of jobs in the wind energy sector increased three-fold between 2013 and 2019 and the number of solar energy jobs increased five-fold during the same period (Curtis and Marinescu, 2022). Fabra et al. (2023) find that in Spain, new solar energy projects increase firm-level employment in the municipality by 2.5 job-years per MW of installed capacity, whereas new wind energy projects do not generate employment effects.

Several studies have analyzed the potential of renewable energy development in increasing employment (Simas and Pacca, 2014; Zhang et al., 2017; Connolly et al., 2016). However, there is little causal evidence of the impacts of renewable energy projects on employment, especially in Latin America. The objective of this study is to analyze the impact of the development of renewable energy projects on local labor markets in Brazil. Brazil is the country with the highest installed wind and solar capacity in Latin America. Between 2003 and 2021, Brazil's solar capacity increased from 0.0007 GW to 13 GW, and wind capacity increased from 0.024 to 21.16 GW. While Brazil has increased renewable energy capacity, recent government policies have also supported the continuing operation of coal power plants. By understanding the employment impacts of renewable energy projects, our study quantifies the potential economic benefits of expanding the renewable energy sector in Latin America's largest economy.

We leverage detailed employment information from all formally employed workers in Brazil to study the impacts of renewable energy projects on labor outcomes. We use the Relação Anual de Informações Sociais (RAIS) dataset, which contains the universe of formal employment in Brazil. We have access to data from 2006 to 2017. The data details job characteristics like occupational code, location, and wage. We aggregate the individual information to municipality-year level outcomes and link this information to data on electricity generation. We observe the locations, types, and capacity of new electricity generation projects collected by the Agência Nacional de Energia Elétrica (ANEEL).

We analyze whether the increase in renewable energy generation translates into higher employment, higher total earnings, and a higher number of active businesses in municipalities that have experienced new solar and wind energy projects between 2006 and 2017 in Brazil. We then zoom in on electricity-related jobs, and jobs in construction and transportation as adjacent occupations.

Using the robust staggered DID design by De Chaisemartin and d'Haultfoeuille (2020), we find that wind energy projects have remarkable effects on employment at the municipality level. The opening of new wind energy projects increases total employment in a municipality by 15.95 percent and total earnings from employment by 18.44 percent. In electricity-related occupations, the number of jobs increases by 74.33 percent. The number of jobs in construction increases by 51.72 percent, and in transportation by 22.54 percent. The total number of employers increases by 14.84 percent. For the case of solar projects, we fail to find significant effects on employment, earnings, or business activity. We do suspect these null results for solar energy projects could be due to much lower variation for the study period, since the total solar capacity by 2017 was 1 GW, compared to 7 GW by the end of 2022.

We complement the analysis looking at heterogeneous outcomes by type of worker, areas with high solar and wind potential, and looking at tax revenues on the municipal level. We find higher employment effects among workers 45 or younger and we find larger wage increase for workers with High School or more.

Our paper contributes to a growing literature that analyzes the impact of renewable energy projects on employment (Curtis and Marinescu, 2022; Fabra et al., 2023; Zhang et al., 2017; Simas and Pacca, 2014). These papers find that renewable energy projects have increased in recent decades but their impacts are heterogeneous. Areas with high renewable potential might be more likely to benefit than others. By finding positive impacts of renewable energy development on local labor markets, our paper contributes to the growing literature that examines the role of the energy transition on employment outcomes. Our paper also contributes to a larger literature that examines the impacts of environmental policies on labor outcomes (Walker, 2013; Greenstone et al., 2012; Liu et al., 2017, 2021). This literature finds that environmental policy can lead to labor reallocation across sectors, which might potentially affect to the composition of the workforce and the long term outcomes of employed workers (Walker, 2013; Hafstead and Williams III, 2018).

The remainder of this article is structured as follows: Section 2 describes the data, Section 3 provides descriptive statistics of renewable energy in Brazil, Section 4 introduces our empirical specification, Section 5 presents the results, and Section 6 concludes.

2 | DATA

2.1 | Municipality-level Employment

We use the Relação Anual de Informações Sociais (RAIS), which contains the universe of Brazilian formal wokers and matches employer to employees. The dataset gather information on employment links, payroll, and the number of firms. The data contain the annual universe of formal employment in Brazil from 2006 to 2017. The primary unit of observation is a job observation. Job locations are observed at the municipality level. We observe a total of 5,568 municipalities in Brazil. Individuals are identified by a unique ID. We observe 90.1 million unique individuals in total between 2006-2017.

In each year, we observe all formal employment links. In 2015, the total labor force in Brazil comprised 101 million individuals, according to the World Bank[1]. In 2015, we observe 55.6 million individuals, thus 55.05 percent of the labor force is formally employed. For each job, we observe the start and end date, an identifier for the employing firm, the location, average monthly compensation, and precise occupational codes that allow us to identify electricity-related jobs and adjacent occupations. The occupational codes correspond to the newest iteration of the Classificação Brasileira de Ocupações (Brazilian Job Classification, CBO 2002) system. We use these occupational codes to identify occupations that are potentially connected to renewable energy projects.[2] We then aggregate these jobs at the municipality level per year. To measure the number of firms in a municipality, we count all unique firm IDs that employ workers in the respective municipality.

Table 1 shows the descriptive statistics for the full sample of municipalities in Brazil. The share of electricity-related jobs is 1.4% of total jobs and comprises 1.9% of the payroll per municipality. The average number of electricity jobs per municipality is 294, while the average number of jobs in the construction and transportation sectors are 975 and 707, respectively. Municipalities have on average 500 active employers per year.[3] Table 2 shows summary statistics on jobs and wages in new versus existing firms and firms that

[1]Source: https://data.worldbank.org/indicator/SL.TLF.TOTL.IN?locations=BR

[2]Currently this is an ad hoc manual assignment, using the higher-level CBO digits as a first filter for sectors and then revising job by job to infer whether a specific occupation could plausibly be connected to renewable energy projects. For example, related occupational codes are 214310 "electrical engineer", 300305 "electromechanical technician", etc.

[3]We are unable to link each individual firm to a sector since we classify sectors based on occupational codes. Therefore, we are only able to provide the total number of firms for the full sample, not by sector.

TABLE 1 Descriptive Statistics on Employment

	All jobs	Electricity	Construction	Transportation
Share jobs	1.000	0.014	0.075	0.069
	(0.000)	(0.020)	(0.072)	(0.043)
Share total payroll	1.000	0.019	0.072	0.070
	(0.000)	(0.027)	(0.067)	(0.046)
Total number of jobs	10,869	294	975	707
	(114,880)	(2,495)	(9,045)	(5,247)
Total monthly payroll	24.119	0.847	1.886	1.369
(in million 2017 R$)	(339.29)	(8.63)	(21.19)	(11.44)
Av monthly wage (in 2017 R$)	1,542	2,044	1,567	1,526
	(461)	(1,449)	(741)	(483)
Total number of firms	500			
	(3,995)			

Notes: The table shows the average and standard deviation (in parenthesis) of the labor outcomes of interest across municipality-years using the RAIS database 2006 to 2017.

TABLE 2 Descriptive Statistics on Firms per Municipality-Year

	(1)	(2)	(3)	(4)	(5)
	New firms	Existing firms	Renewable firms	Other firms	All firms
Total number of jobs	643	10,297	5,772	6,115	10,869
	(5,560)	(109,971)	(57,235)	(63,340)	(114,880)
Total monthly payroll	1.14	23.11	14.83	11.91	24.12
(in million 2017 R$)	(12)	(329)	(185)	(173)	(339)
Av monthly wage	1,314	1,550	1,820	1,398	1,542
(in 2017 R$)	(589)	(469)	(915)	(377)	(461)
Total number of firms	83.5	424.8	36.4	469.4	499.3
	(583)	(3,468)	(301)	(3,725)	(3,995)

Notes: The table shows the average and standard deviation (in parenthesis) of number of jobs, payroll, average wages, and the number of firms by type across municipality-years using the RAIS database 2006 to 2017. Firms are identified as "renewable" if they employ at least one worker whose occupation is potentially related to renewable energy projects.

employ "renewable" workers and firms that do not (other firms). Appendix Table A1 shows summary statistics for different demographic groups of workers.

Table 2 shows descriptive statistics for different types of firms. On average, 83.5 new firms are operating in each municipality-year and 424.8 existing firms. "New firms" are defined as firms that have started operating in a municipality in a given year. New firms employ on average 643 workers in a municipality-year, and existing firms employ 10,297 workers. In our data it is not possible to directly detect which firms are involved with the renewable energy projects we observe. To proxy for firms that might be involved, we define "Renewable firms" as firms that employ at least one worker in an occupation that we have defined as "potentially related to renewable energy projects" as described above. Notice that the columns for new and existing firms, as well as the columns for renewable and other firms do not add up exactly to the "all firms" column because they are averages across municipality-year observations, and some municipality-years do not contain any new firms or any renewable firms.

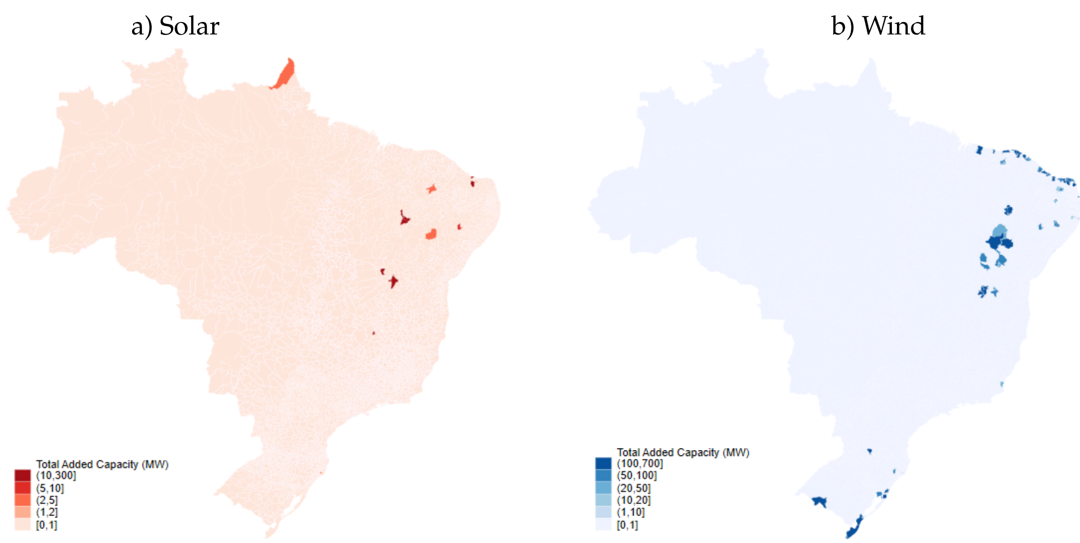
2.2 | Renewable Energy Projects and Electricity Grid Expansions

We obtained the energy-related projects that started operating between 2006-2017 from the Sistema de Informações de Geração da ANEEL (ANEEL Generation Information System) data. ANEEL provides information on all energy-related projects, their municipality, their start date, the date of last recorded generation, and their production capacity. Projects are dated according to their first energy generation date.

Some projects consist of multiple power plants, in which case we focus on the municipality of the main plant in the database. Figure 1 shows the total solar and wind energy capacity that was added throughout our study period in megawatts. Appendix Table A4 shows how generation capacity evolved between 2006 and 2017. By the end of 2017, around 1 GW of solar and 12.5 GW of wind energy generation had been added.

New electrical power sources need to be connected to the grid with new transmission lines, which is especially relevant if the new sources are located relatively far away from existing structures. We obtained data on the universe of electrical substations in Brazil from Empresa de Pesquisa Energética (Energy Research Office, EPE). EPE provides information on the substations' exact location and their start date. Substations are dated according to their first energy distribution date. We measure grid expansions as increases in the number of electrical substations that are operated in a municipality. Appendix Table A2 shows summary statistics separately for municipalities that experienced a grid expansion (column 1) and that have not experienced a grid expansion (column 2) in the electricity grid in our study period. Grid expansions are relatively rare events: 3.9% of municipalities experienced an expansion between 2006 and 2017, and they tend to occur in larger municipalities.

FIGURE 1 Total Added Capacity in Megawatts 2006-2017

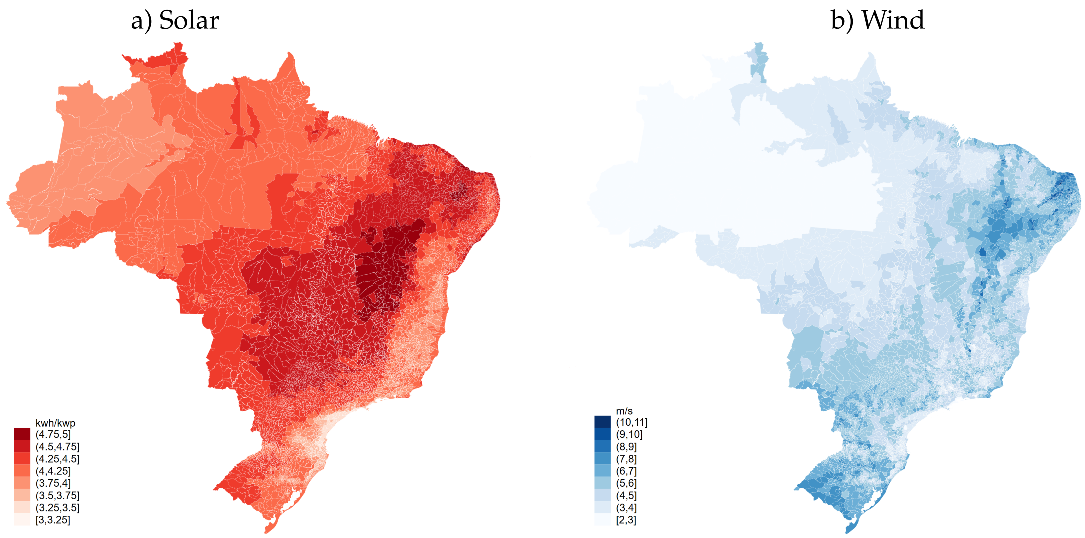


Notes: The figure shows the total solar (panel a) and wind (panel b) capacity in megawatts that was added throughout the 2006-2017 period at the municipality level.

2.3 | Wind and Solar Potential

We obtain solar and wind potential from the Global Solar Atlas and Global Wind Atlas, provided by the World Bank. The Global Solar Atlas provides the photovoltaic power potential of 1kWp free-standing PV system with cSi modules inclined at optimum tilt at a 1km $\times$ 1km resolution. The photovoltaic power potential varies by season, so the World

FIGURE 2 Solar and wind potential



Notes: The figure shows the annual average solar and wind potential at the municipality level. Solar potential is measured in kWh/kWp and wind potential is measured in m/s.

Bank offers monthly estimates. We obtained the average across months per municipality. We also generated two classifications: high and low solar potential, where high solar potential is defined as higher than 4.5 kWh/kWp. The Global Wind Atlas provides average annual wind speed at a resolution of 300m $\times$ 300m for a 100m height. We obtain the average wind speed per municipality and classify high wind potential as areas that have average wind speed higher than 5 m/s. With this classification, 57.2 percent of municipalities in Brazil have high wind potential and 29.9 percent have high solar potential. Figure 2 shows the solar and wind potential at the municipality level. The figures show great variation on solar and wind potential. The highest solar potential is located in the center of the country, while high wind potential areas can be found in both northern and southern areas of the country. Appendix Table A3 shows the summary statistics for our labor market outcomes of interest, focusing only on municipalities in high solar and high wind potential areas.

2.4 | Municipal Tax Revenues

We collected data on municipal tax revenues to examine whether renewable energy projects have detectable impacts on municipal tax revenues, which could either come from increases in business activity, or tax revenue from land leases for renewable energy projects.[4] We use data created by the National Treasury Secretariat, made available through their open-access database: Brazilian Finances (Finanças do Brazil, FINBRA). Wind farms tend to be located in rural areas, but second-order effects can be expected in the urban areas either through housing prices or service levels. Thus, in order to understand the impact of renewable energy projects on tax revenues, we use the total tax revenues obtained from FINBRA.

Appendix Table A5 shows summary statistics on municipal tax revenues by year. The average municipal tax revenue increased from 11.75 million R$ in 2006 to 18.42 million R$

[4] Municipalities can both impose and collect three main types of taxes: service taxes (Imposto Sobre Serviço, ISS), urban property taxes (Imposto Predial e Territorial Urbano, IPTU), and property transfer taxes (Imposto de Transmissão de Bens Imóveis, ITBI). Another important source of revenues for municipalities is the income tax collected at the source (Imposto de Renda Retido na Fonte, IRRF), which is directly collected on the wages and, despite being a federal tax, is kept by municipalities.

in 2017.

3 | ESTIMATION

We estimate the impact of renewable energy projects on employment by leveraging variation in the timing of new renewable energy projects, considering that municipalities experienced new projects at different times. We recover the average treatment on the treated by estimating the following equation:

$$y_{mt} = \beta \ \mathsf{Project}_{mt} + \gamma_m + \mu_t + \varepsilon_{mt} \quad (1)$$

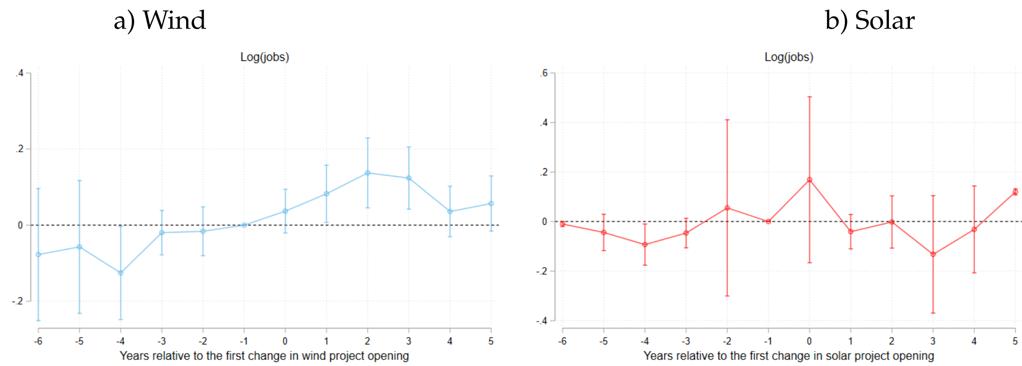
Where y_{mt} is the labor outcome of interest in municipality m in year t. Our main outcome variables of interest are: total number of jobs, total number of employers, total monthly payroll, and average monthly wages. We cluster the standard errors at the municipality level. $\mathsf{Project}_{mt}$ is an indicator for whether or not new generators with a total capacity of at least 1 MW came online in a municipality-year. We choose this cutoff to avoid noise from very small projects like individual rooftop solar projects. Individual rooftop solar projects can be as small as 0.2 KW. If however, total solar projects installed in a municipality-year exceed 1 MW in capacity, we count the municipality-year as treated. Similar to existing literature (Rico-Straffon et al., 2023; Sanchez et al., 2023), we estimate Equation 1 using De Chaisemartin and d'Haultfoeuille (2020) which result on time-specific average treatment on the treated (ATT) for each period since treatment, which is then averaged across treated units. We use De Chaisemartin and d'Haultfoeuille (2020) estimator as opposed to a two-way fixed effects estimator because two-way fixed effect estimators may yield misleading estimates if the treatment effect is heterogeneous between groups over time.

We first estimate the impact of renewable energy projects on overall employment and then zoom in on occupations related to electricity, construction, and transportation. We repeat the estimation of Equation 1 focusing only on jobs in these occupations, and add as outcomes of interest the share of jobs in these occupations among all jobs in the municipality and the share of payroll among total payroll in the municipality.

Figure 3 shows that new wind energy projects significantly increase total employment in a municipality, and that these effects persist over several years. Importantly, these figures also show that before treatment, not-yet treated and treated municipalities experienced similar outcomes, which is an important assumption for the validity of the De Chaisemartin and d'Haultfoeuille (2020) estimator. Figures A1 and A2 show the event-study graphs for other outcome variables across all occupations. The graphs show the instantaneous effect and the dynamic effects, which are the comparison between municipalities that experienced a new renewable energy project coming online and the municipalities that have not yet received a renewable energy project. These graphs test for the parallel-trends assumption under dynamic treatment effects, and this figure shows that before the introduction of the renewable energy projects, there were no statistically significant differences in energy sector labor outcomes between the municipalities that experienced renewable energy projects and the municipalities that did not experience them, accounting for dynamic treatment effects.

We explore heterogeneity in several dimensions. To check whether there are notable differences across different parts of the labor force, we repeat the estimations separately for workers above and below 45 years of age, and with and without a high school degree. Figure A3 and Figure A4 show the event-study graphs for workers above and below 45 years of age, and Figures A5 andA6 show the event-study graphs for workers with educational attainment "less than High School" and "High School or more". We also restrict the sample

FIGURE 3 Effect of New Wind and Solar Projects on the Log Number of Jobs in a Municipality



Notes: The figure shows year-specific effects of opening a renewable energy project using De Chaisemartin and d'Haultfoeuille (2020) estimator.

of municipalities to those with high solar and wind potential. Figures A7 and A8 show these event-study graphs.

In order to explore heterogeneous effects by sector, we obtain differential impacts for jobs that are in occupations related to construction, electricity, and transportation. Figures A9, A10, A11, A12, A13, and A14 show these event-study graphs.

Next, we analyze whether employment effects are driven by new firms or by growth of existing firms. We do so by estimating separately the impact of new renewable energy projects on the number of jobs and total payroll by new firms versus existing firms in a municipality.

We are interested in the channels through which renewable energy projects could affect local labor markets. Since wind and solar plants have to be located where wind and solar energy is available, transmission lines have to be built, which could generate electrification spillovers for local communities. To understand whether expansions in the electricity grid account for the effects we find, we repeat our estimations separately for municipalities that have experienced expansions of the electricity grid throughout our study period and for municipalities that have not. Finally, in remote locations with small economies, income from land leases to renewable energy projects might constitute a considerable positive income shock.[5] While there is no publicly available data on land lease incomes, we explore this channel using municipal tax revenues as a proxy. We estimate how tax revenues are impacted by the opening of new renewable energy projects.

4 | RESULTS

The results of the main specification in Section 3 are presented in Table 3. Overall, wind energy projects have a high impact on labor outcomes. The opening of a new wind energy project increases the average total number of jobs in the municipality by 15.95 percent and total payroll by 18.44 percent. Business activity, measured as total number of employers in a municipality, increases by 14.84 percent. In contrast to that, new solar projects do not appear to generate significant impacts.

The impacts of renewable energy projects might differ by age and education levels of the workers employed in the energy sector. Table 4 shows the impacts for workers younger

[5] Popular press reporting: https://g1.globo.com/economia/agronegocios/globo-rural/noticia/2019/08/25/producao-de-energia-eolica-garante-renda-e-investimentos-nas-comunidades-rurais-do-rn.ghtml

TABLE 3 ATT of New Wind and Solar Projects

	Av monthly wage	Log payroll	Log jobs	Log new jobs	Log no firms
Effect Solar	-27.98	.0809	.102	-.1997	.0181
	(81.0239)	(0.1498)	(0.1191)	(0.2041)	(0.0578)
N	116,783	116,783	116,783	116,464	116,783
Effect Wind	83.55	.1844	.1595	.2937	.1484
	(47.4333)	(0.0864)	(0.0417)	(0.1089)	(0.0355)
N	281,993	281,993	281,993	280,556	281,993

Notes: The table shows the coefficients in equation (1) using De Chaisemartin and d'Haultfoeuille (2020) estimator. The "Effect solar" row indicates the impact of a solar energy project and the "Effect wind" row indicates the impact of a wind energy project. The units of observation are municipality-years.

(Panel a) and older (Panel b) than 45. We find that job gains are larger for workers younger than 45. New wind projects increase employment by 17.72 percent and earnings by 20.15 percent. Among older workers, wind energy projects increase the number of jobs by 10.4 percent. Tables 5 show the impacts for workers with less than high school education (Panel a) and for workers with high school education or more (Panel b). For workers with less than high school education, new wind power projects significantly increase employment by 16.82 percent, and by 13.08 percent for workers with a high school degree or more. Earnings gains cease to be significant when the sample is split by either education or age.

Table 6 show impacts on jobs related to electricity (Panel a), construction (Panel b), and transportation (Panel c). In occupations related to electricity, the estimated coefficient of the impact of new wind energy projects on the log total number of jobs is as high as .7433. In construction and transportation related occupations, these coefficients are .5172 and .2254. In electricity-related jobs, total payroll increases at an even higher rate and average monthly wages increase by more than 50 percent. In construction and transportation related jobs, total payroll increases at similar rates compared to the number of jobs, and as a result, average monthly wages do not increase significantly.

To understand whether the earnings and job gains we find for wind projects are driven by the growth of existing firms or by the emergence of new firms, we estimate separately the impact of new renewable energy projects on new firms and existing firms. Table panel a) shows that the number of new firms increase by 21.2 percent after the opening of a wind energy project. Jobs and payroll at new firms do not increase significantly. Table panel b) shows that the number of jobs at previously existing firms, which are firms that have been active in a municipality for more than one year, increase significantly by 15.81 percent. Jobs and payroll at existing firms increase significantly, as does the number of existing firms. This is consistent with growth of existing firms as well as increased survival of new firms. In Panel c) and d) we split observations into municipality-year-firm groups that hire employees in "renewable energy" occupations and "other" occupations (non-wrenwable occupations). The number of "renewable" firms grows significantly. The number of firms that hire "Other" occupations also increase but the magnitude is lower. We interpret this as evidence that the impacts on local labor markets are quite broad and not limited to specific sectors or occupations.

In order to test for treatment effect heterogeneity by wind and solar potential, we restrict our analysis to areas with high wind and solar potential. 57.2 percent of municipalities are

TABLE 4 ATT of New Wind and Solar Projects, Workers Younger than 45

	Log jobs	Log payroll	Av monthly wage
	Panel a) Workers younger than 45		
Effect solar	.1188	.1182	9.8283
	(0.1282)	(0.1527)	(63.2662)
N	116,783	116,783	116,783
Effect wind	.1772	.2015	71.604
	(0.0476)	(0.0971)	(44.3176)
N	281,991	281,991	281,991
	Panel b) Workers older than 45		
Effect Solar	.0504	-.0482	-219.5468
	(0.1564)	(0.1654)	(141.989)
N	116,580	116,580	116,580
Effect Wind	.1035	.1209	96.9039
	(0.0593)	(0.0895)	(50.8542)
N	281,209	281,203	281,209

Notes: The table shows the coefficients in equation (1) using De Chaisemartin and d'Haultfoeuille (2020) estimator for all jobs for two types of workers: workers that are younger than 45 (Panel a) and workers that are older than 45 (Panel b). The effect solar row indicates the impact of a solar energy project and the effect wind row indicates the impact of a wind energy project.

classified as "high wind potential", and 29.0 percent are classified as "high solar potential". Table 8 shows the impacts of renewable energy projects on labor outcomes, focusing only on areas that have been identified as "high potential" for solar and wind energy projects. Here, we obtain significant and positive estimates for wind projects that are quite similar to the results for all municipalities in Table 3. For the case of solar projects, we also continue to find imprecise effects.

Table 9 shows the results estimating the effects of renewable energy projects on municipalities that have experienced an expansion of the electricity grid (Panel a) and the firms that have not experienced an expansion of the electricity grid (Panel b). Notably, in municipalities that have not experienced any grid expansions, we continue to find sizable and significant impacts of wind energy projects on the number of jobs, number of new jobs, total earnings, and number of firms. The effects on jobs and earnings are even larger than for the pooled estimation.

In order to understand whether new renewable energy projects constitute a windfall income for local communities in the form of land lease income, we examine the impacts on municipal tax revenues as a proxy. If individual land owners owe tax from their land lease income, this could be reflected in total municipal tax revenues. Table 10 shows the results. While there appears to be a positive effect of 27.1 percent from wind energy projects, the estimated results are not precise and thus we cannot conclude that municipal budgets experience boosts following the opening of new wind energy projects.

TABLE 5 ATT of New Wind and Solar Projects, Workers with Less than High School Degree

	Log jobs	Log payroll	Av monthly wage
	Panel a) Workers with less than High School		
Effect Solar	.1968	.1314	-92.3008
	(0.1697)	(0.2491)	(87.153)
N	116,481	116,471	116,481
Effect Wind	.1682	.1742	26.9608
	(0.0735)	(0.1082)	(38.0136)
N	281,001	280,989	281,001
	Panel b) Workers with High School or more		
Effect Solar	-.0042	-.0005	-11.2622
	(0.1195)	(0.1795)	(85.4264)
N	116,769	116,769	116,769
Effect Wind	.1308	.1601	105.5882
	(0.0499)	(0.0953)	(41.7874)
N	281,963	281,963	281,963

Notes: The table shows the coefficients in equation (1) using De Chaisemartin and d'Haultfoeuille (2020) estimator for all jobs for two types of workers: workers with less than High School (Panel a) and workers with High School or more (Panel b). The effect solar row indicates the impact of a solar energy project and the effect wind row indicates the impact of a wind energy project.

TABLE 6 ATT of New Wind and Solar Projects by Occupation

	Av monthly wage	Log payroll	Log jobs	Log new jobs	Share payroll	Share jobs
			Panel a) Electricity jobs			
Effect solar	565.8916	.4356	.1905	.2634	.005	.0045
	(564.3304)	(0.4742)	(0.2566	(0.619	(0.0076	(0.006
N	93,245	93,107	92,019	51,659	93,245	93,245
Effect wind	1322.158	1.1284	.7433	.8322	.0219	.0066
	(595.3284	(0.2575	(0.1598	(0.2271	(0.0057	(0.0022
N	216,182	215,858	213,275	146,701	216182	216,182
			Panel b) Construction jobs			
Effect solar	391.9249	.5301	.3188	-.0781	-.0057	-.0054
	(657.0721)	(0.4196)	(0.2347)	(0.2655)	(0.023)	(0.0206)
N	109,619	109,564	109,361	96,178	109,619	109,619
Effect wind	48.1222	.5046	.5172	.5815	.0096	.009
	(166.4753)	(0.1981)	(0.1726)	(0.2915)	(0.0159)	(0.0138)
N	261,609	261,475	260,961	226,400	261,609	261,609
			Panel c) Transportation jobs			
Effect solar	-.0933	.0549	.0423	-.015	-.0143	16.2309
	(0.3294)	(0.2156)	(0.1501)	(0.0138)	(0.0096)	(76.6192)
N	106,551	115,039	115,042	115,064	115,064	115,064
Effect wind	.3531	.249	.2254	-.0009	.001	58.9954
	(0.1561)	(0.1533)	(0.0972)	(0.0048)	(0.0036)	(88.7864)
N	250,410	275,072	275,039	275,155	275,155	275,155

Notes: The table shows the coefficients in equation (1) using De Chaisemartin and d'Haultfoeuille (2020) estimator for three types of jobs, classified by occupational codes: electricity jobs (Panel a), construction jobs (Panel b), and Transportation jobs (Panel c). The effect solar row indicates the impact of a solar energy project and the effect wind row indicates the impact of a wind energy project. The unit of observation is a municipality-year-occupation.

TABLE 7 ATT of New Wind and Solar Project on Jobs and Payroll in Different Types of Firms

	Log no firms	Log jobs	Log payroll
		Panel a) New Firms	
Effect Solar	.0898	.2799	.1314
	(0.115)	(0.3852)	(0.787)
N	110,537	110,537	110,533
Effect Wind	.2119	.3456	.5557
	(0.0893)	(0.2829)	(0.2741)
N	232,086	232,086	232,055
		Panel b) Existing Firms	
Effect Solar	-.0034	-.0386	-.1146
	(0.0729)	(0.1035)	(0.1012)
N	11,6745	11,6745	11,6745
Effect Wind	.142	.1581	.1758
	(0.0354)	(0.0507)	(0.0926)
N	281,898	281,898	281,898
		Panel c) Renewable Firms	
Effect Solar	.155	.8231	.6465
	(0.2424)	(0.6441)	(0.497)
N	91,040	91,040	91,027
Effect Wind	.3892	.0952	.1786
	(0.0782)	(0.1964)	(0.1959)
N	211,066	211,066	211,028
		Panel d) Other firms	
Effect Solar	.0161	-.0288	.0058
	(0.0616)	(0.2806)	(0.3134)
N	116,774	116,774	116,774
Effect Wind	.1253	.2168	.2062
	(0.0365)	(0.1335)	(0.1383)
N	281,922	281,922	281,922

Notes: The table shows the coefficients in equation (1) using De Chaisemartin and d'Haultfoeuille (2020) estimator for four different types of firms: new firms (Panel a), existing firms (Panel b), renewable firms (Panel c), and non-renewable firms (Panel d). The effect solar row indicates the impact of a solar energy project and the effect wind row indicates the impact of a wind energy project.

TABLE 8 ATT of new solar projects in locations with high solar potential and effect of new wind projects in locations with high wind potential

	Av monthly Wage	Log payroll	Log jobs	Log new jobs	Log no firms
Effect solar	41.5277	.1593	.1447	-.0572	.0147
	(52.9081)	(0.2068)	(0.1485)	(0.188)	(0.0572)
N	19,953	19,953	19,953	19,852	19,953
Effect wind	61.1838	.1801	.1638	.2884	.1426
	(35.4196)	(0.0825)	(0.0479)	(0.1058)	(0.0299)
N	141,691	141,691	141,691	141,051	141,691

Notes: The table shows the coefficients in equation (1) using De Chaisemartin and d'Haultfoeuille (2020) estimator for all jobs for two types of locations: areas with high solar and high wind potential. The effect solar row indicates the impact of a solar energy project (in high solar potential areas) and the effect wind row indicates the impact of a wind energy project (in high wind potential areas).

TABLE 9 Results for municipalities that have versus have not experienced grid expansions

	Av monthly wage	Log payroll	Log jobs	Log new jobs	Log no firms
			Panel a) Have experienced grid expansion		
Effect Solar	-153.0412	-.0531	.0128	-.254	.0385
	(66.1614)	(0.1198)	(0.0876)	(0.3359)	(0.0632)
N	3,220	3,220	3,220	3,217	3,220
Effect Wind	42.002	.1251	.1223	.3176	.1558
	(57.2492)	(0.0846)	(0.058)	(0.119)	(0.0388)
N	7,978	7,978	7,978	7,941	7,978
			Panel b) No grid expansion		
Effect Solar	161.1521	.331	.2686	.0602	-.0537
	(53.0373)	(0.4047)	(0.4359)	(0.2007)	(0.063)
N	53,471	53,471	53,471	53,345	53,471
Effect Wind	93.318	.3422	.2404	.3486	.1146
	(40.9052)	(0.1156)	(0.0709)	(0.1587)	(0.0405)
N	213,208	213,208	213,208	212,190	213,208

Notes: The table shows the coefficients in equation (1) using De Chaisemartin and d'Haultfoeuille (2020) estimator for all jobs for two types of municipalities: municipalities that experienced a grid expansion (Panel a) and municipalities that experienced no grid expansion (Panel b). The effect solar row indicates the impact of a solar energy project and the effect wind row indicates the impact of a wind energy project.

TABLE 10 ATT of new solar and wind projects on municipal tax revenues

	Log tax revenue	Tax revenue
Effect solar	-2.1887	3.25e+07
	(1.3236)	(3.40e+07)
N	120,635	120,635
Effect wind	.271	2,371,727
	(0.2539)	(3,519,854)
N	266,768	266,768

Notes: The table shows the impacts of a new solar and wind project on municipal tax revenues. The coefficients in equation (1) using De Chaisemartin and d'Haultfoeuille (2020) estimator.

5 | CONCLUSION

This paper analyzes the impact of the opening of renewable energy projects on formal employment in Brazil. Using a robust dynamic treatment effect estimator, we show that wind energy projects have large positive impacts on local labor markets. We find that in years and municipalities where new wind energy projects come online, the number of firms increases by 14.84 percent, the number of jobs increases by 15.95 percent, and total earnings across all workers increase by 18.44 percent. Job gains and earnings gains are relatively larger for workers that are younger than 45 years of age, however, we find no significant differences in effects for workers with less than high school education versus those with a high school degree or higher education.

Looking at different sectors, we find that new wind energy projects increase earnings and jobs particularly among workers in occupations related to electricity, with gains in average monthly earnings by over 50 percent. In construction- and transportation related occupations, we also find above average gains in jobs. The number of construction-related jobs increases by 51.72 percent and the number of transportation-related jobs increases by 22.54 percent. Comparing effects among new firms versus existing firms, we find that jobs and payroll increase significantly at previously existing firms, as does the number of existing firms, which tells us that survival rates among new firms increase.

We consider whether the effects can be attributed to electrification and expansions in the electricity grid, but we find that effects persist and are even larger when we focus on municipalities that have not experienced expansions in the electricity grid throughout our study period. Finally, we do not find significant effects on employment or business activity from solar energy projects, however, in our study period the total installed capacity in solar energy projects totals only 1 Gigawatt, and we recognize that we might be under-powered in detecting effects.

Our results suggest that renewable energy projects have the potential of positively affecting economic activity and employment, and the effects are in the larger economy, not only among specialized workers in the electricity and construction sector. Our results may inform energy transition policies by showing that renewable energy projects can have considerable positive impacts on local economies. Importantly, our results do not focus on transitions between green and non-green sectors, which is an important question to examine and can have distributional implications for impacted workers (Curtis et al., 2023; Gilbert et al., 2023). Future work needs to understand the potential transition of workers from non-green to green sectors and their labor outcomes, both in the short and long run.

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APPENDIX TABLES

TABLE A1 Descriptive Statistics for Different Groups of Workers

	(1) Younger 45	(2) Older 45	(3) Less than HS	(4) HS or More
Total number of jobs	8,732	2,140	3,879	6,997
	(90,950)	(24,200)	(33,538)	(82,287)
Total number of new jobs	3,489	427	1,468	2,450
	(36,614)	(4,198)	(12,338)	(28,796)
Total monthly payroll (in million 2016 R$)	17.35	6.77	5.70	18.43
	(235.7)	(104.6)	(55.4)	(285.4)
Av monthly wage (in 2016 R$)	1,473	1,806	1,257	1,750
	(417)	(685)	(392)	(550)
Share jobs	0.781	0.219	0.413	0.587
	(0.067)	(0.067)	(0.155)	(0.156)
Share earnings	0.749	0.251	0.343	0.657
	(0.073)	(0.072)	(0.146)	(0.146)

Notes: Columns (1)-(4) show the average and standard deviation (in parenthesis) of the labor outcomes of interest using the RAIS database during 2006-2017 for different groups of workers.

TABLE A2 Descriptive Statistics in Areas that Have versus Have not Experienced an Expansion of the Electricity Grid

	(1) Grid expansion	(2) No expansion
Total number of jobs	108,562	6,888
	(536,965)	(39,782)
Total number of new jobs	38,710	2,497
	(190,242)	(14,235)
Total monthly payroll (in million 2016 R$)	285.4	13.5
	(1,625.9)	(95.9)
Av monthly wage (in 2016 R$)	1,883	1,528
	(653)	(446)
Total number of firms	4,115	353
	(18,415)	(1,496)
Share municipalities	0.039	0.961

Notes: Column (1) shows the average and standard deviation (in parenthesis) of the labor outcomes of interest in municipalities that have experienced an expansion in the electrical grid during 2006-2017. Column (2) shows these outcomes of interest for municipalities that did not experience an expansion.

TABLE A3 Descriptive Statistics in High Potential Areas

	(1) High solar potential	(2) High wind potential
Total number of jobs	8,179	9,216
	(65,095)	(51,704)
Total number of new jobs	2,976	3,313
	(23,200)	(18,561)
Total monthly payroll (in million 2016 R$)	16.5	19.3
	(162)	(135)
Av monthly wage (in 2016 R$)	1,490	1,549
	(472)	(480)
Total number of firms	396	456
	(2,510)	(2,093)
Share municipalities	0.299	0.572

Notes: Column (1) shows the average and standard deviation (in parenthesis) of the labor outcomes of interest using the RAIS and ANEEL databases during 2006-2017 for high solar potential areas. Column (2) shows the average and standard deviation (in parenthesis) of the labor outcomes of interest for high wind potential areas.

TABLE A4 Wind and Solar Generation Capacity between 2006 and 2017

Energy	Year	Added MW	Cumulative	N municipalities
Solar	2006	0.00	0.00	0
Solar	2007	0.00	0.00	0
Solar	2008	0.02	0.02	1
Solar	2009	0.03	0.05	1
Solar	2010	0.00	0.05	0
Solar	2011	5.16	5.21	8
Solar	2012	0.00	5.21	3
Solar	2013	4.45	9.66	1
Solar	2014	5.58	15.24	6
Solar	2015	11.48	26.71	7
Solar	2016	32.67	59.39	7
Solar	2017	947.82	1,007.20	15
Wind	2006	208.30	208.30	3
Wind	2007	10.20	218.50	1
Wind	2008	95.82	314.32	6
Wind	2009	264.83	579.15	5
Wind	2010	326.80	905.95	9
Wind	2011	596.35	1,502.30	6
Wind	2012	368.45	1,870.75	11
Wind	2013	350.56	2,221.31	9
Wind	2014	2,778.25	4,999.56	22
Wind	2015	2,652.78	7,652.33	25
Wind	2016	2,690.38	10,342.71	33
Wind	2017	2,153.57	12,496.28	28

Notes: The table shows the yearly added wind and solar generation capacity during the period 2006 and 2017.

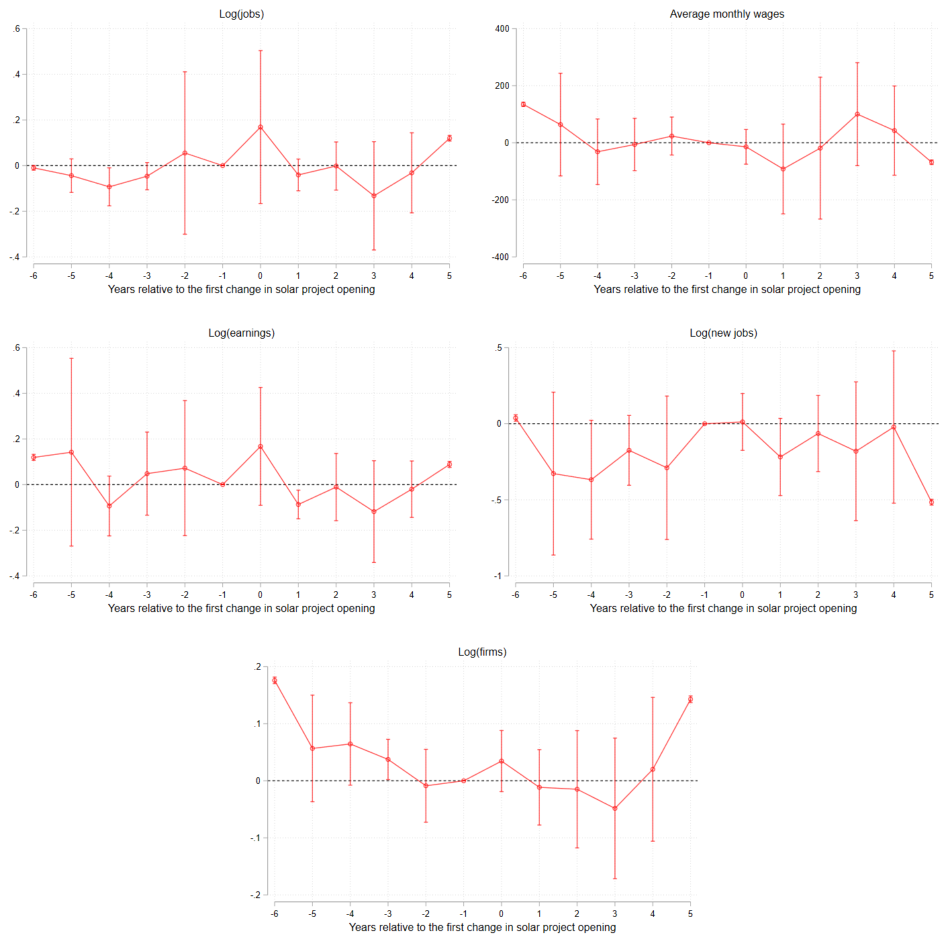
TABLE A5 Municipal tax revenues 2006-2017

Year	Median	Mean	Quantile_90	Quantile_95	Max
2006	0.78	11.75	8.28	22.81	15,045
2007	0.85	13.00	9.32	25.66	16,545
2008	0.97	14.41	10.60	28.43	17,426
2009	1.00	14.92	11.13	28.11	17,756
2010	1.14	16.83	12.89	32.91	20,272
2011	1.26	18.75	14.69	37.83	21,807
2012	1.40	21.07	16.94	43.36	24,123
2013	1.04	18.56	13.71	36.25	24,143
2014	1.08	19.83	14.54	39.42	25,088
2015	1.00	18.45	13.77	37.26	24,801
2016	0.98	17.98	13.56	37.15	24,270
2017	1.05	18.42	13.97	39.45	25,715

Notes: The table shows the average municipality tax revenues in million R$ during the period 2006-2017.

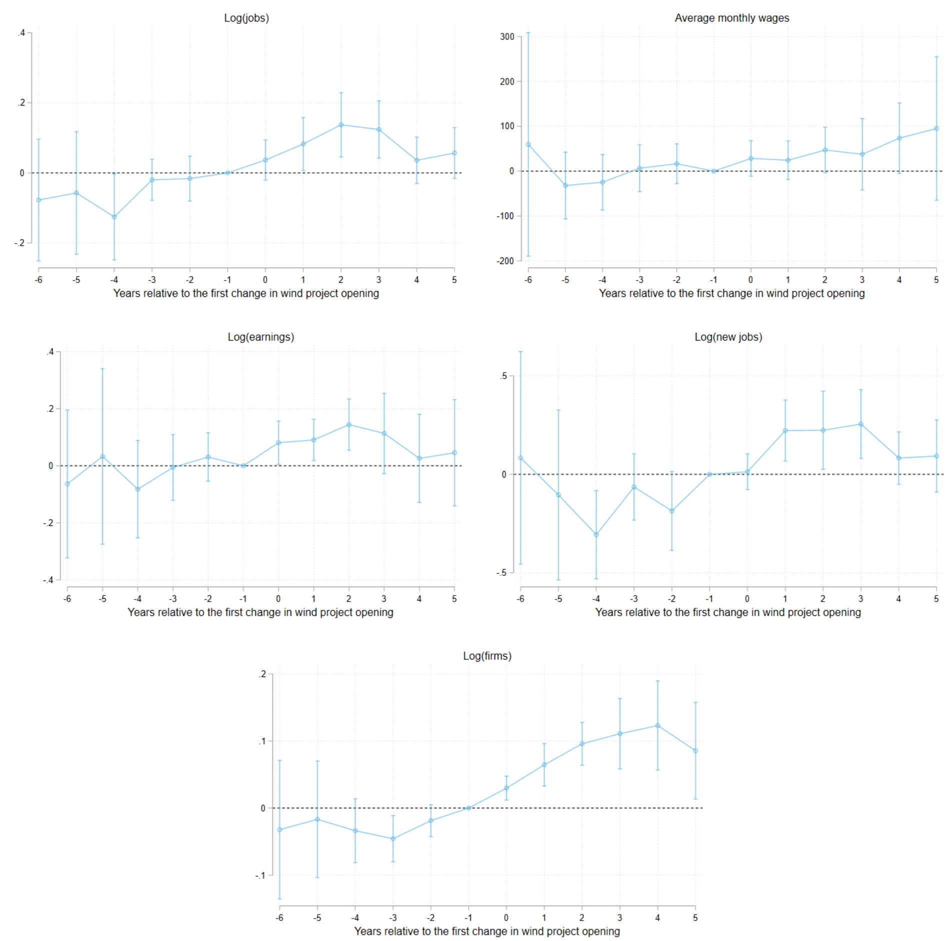
APPENDIX FIGURES

FIGURE A1 The Impacts of Solar Energy Projects on Labor Market Outcomes



Notes: This figure shows the impacts of new solar energy projects on labor market outcomes using robust dynamic De Chaisemartin and d'Haultfoeuille (2020) estimators. The unit of observation is a municipality-year.

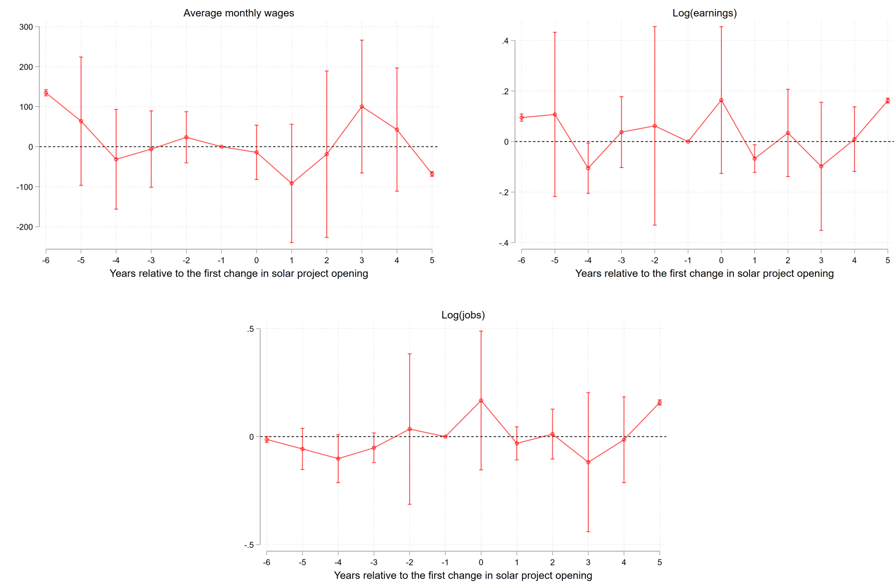
FIGURE A2 The Impacts of Wind Energy Projects on Labor Market Outcomes



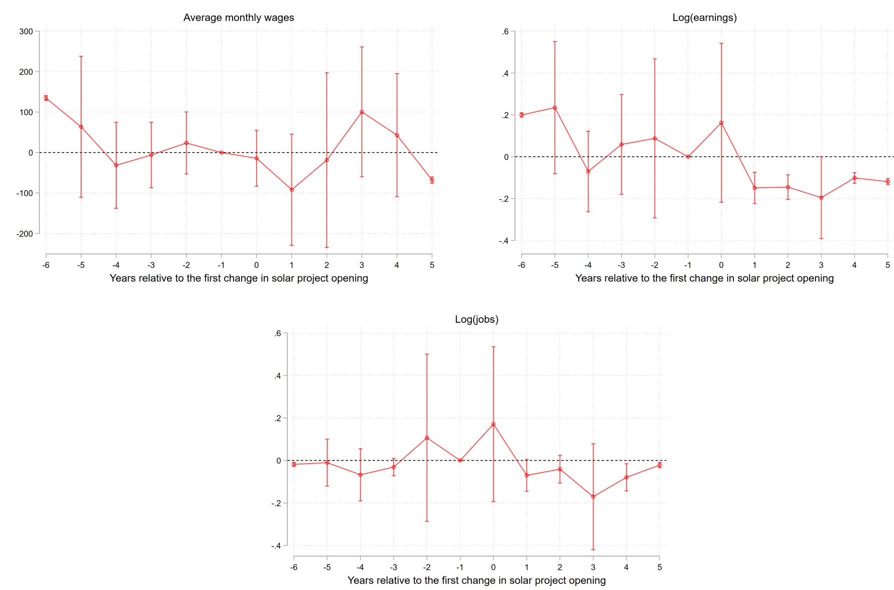
Notes: This figure shows the impacts of new wind energy projects on labor market outcomes using robust dynamic De Chaisemartin and d'Haultfoeuille (2020) estimators. The unit of observation is a municipality-year.

FIGURE A3 The Impacts of solar energy projects on labor market outcomes by age

Panel a) Younger than 45



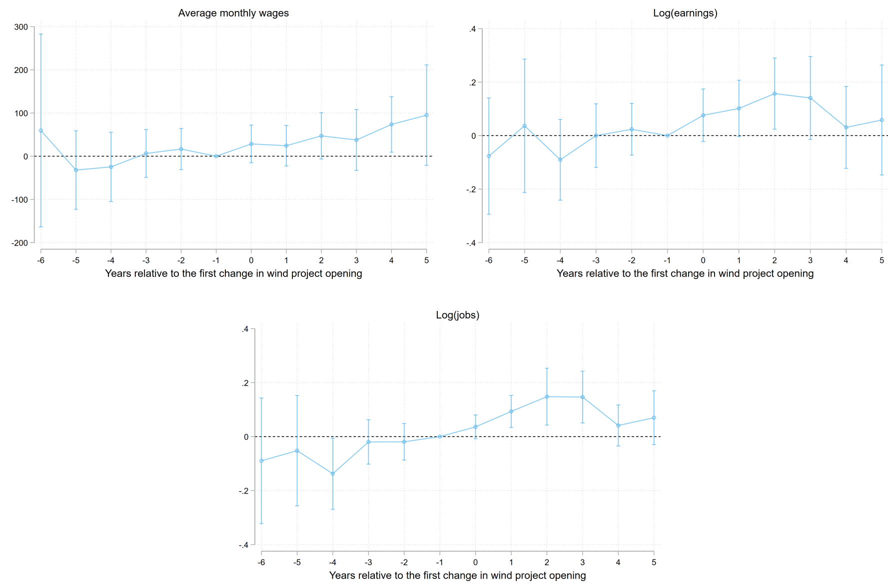
Panel b) Older than 45



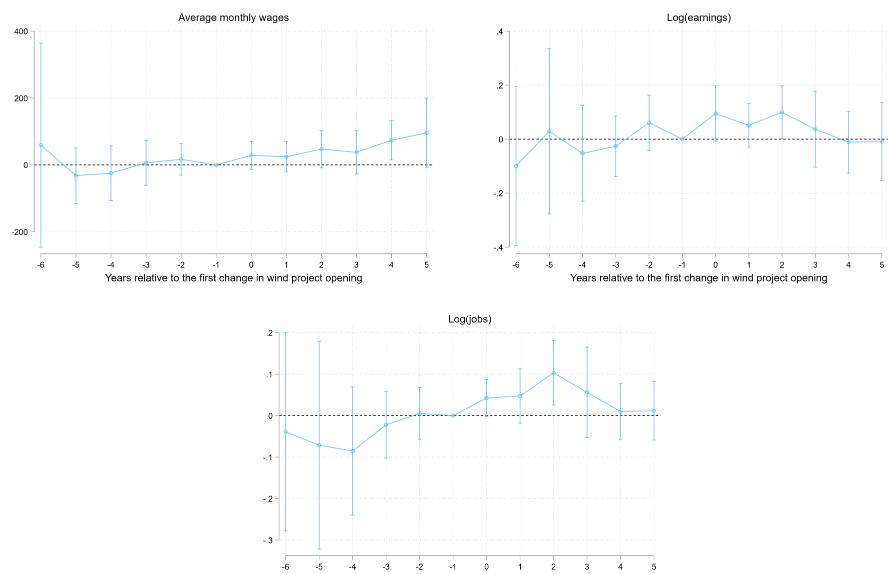
Notes: This figure shows the impacts of new solar energy projects on labor market outcomes by age using robust dynamic De Chaisemartin and d'Haultfoeuille (2020) estimators. The unit of observation is a municipality-year-age group.

FIGURE A4 The Impacts of Wind Energy Projects on Labor Market Outcomes by Age

Panel a) Younger than 45



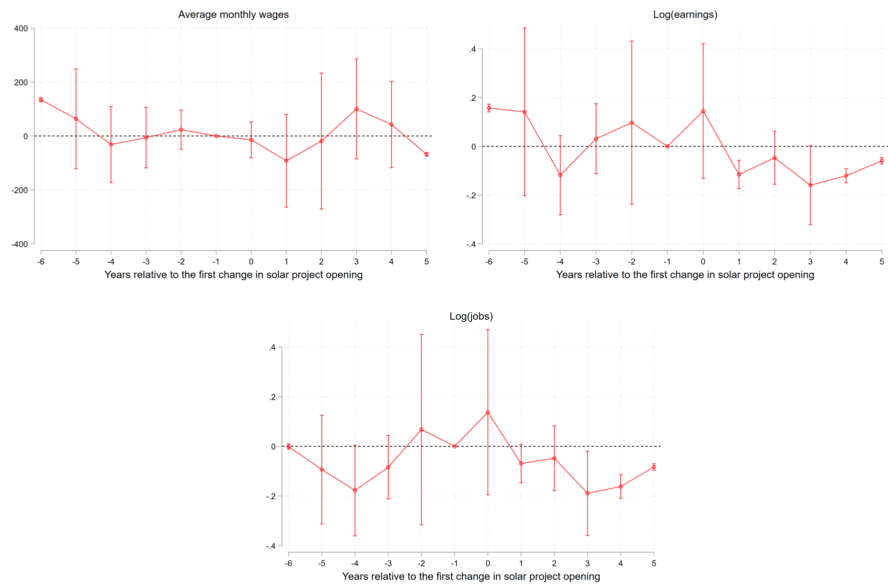
Panel b) Older than 45



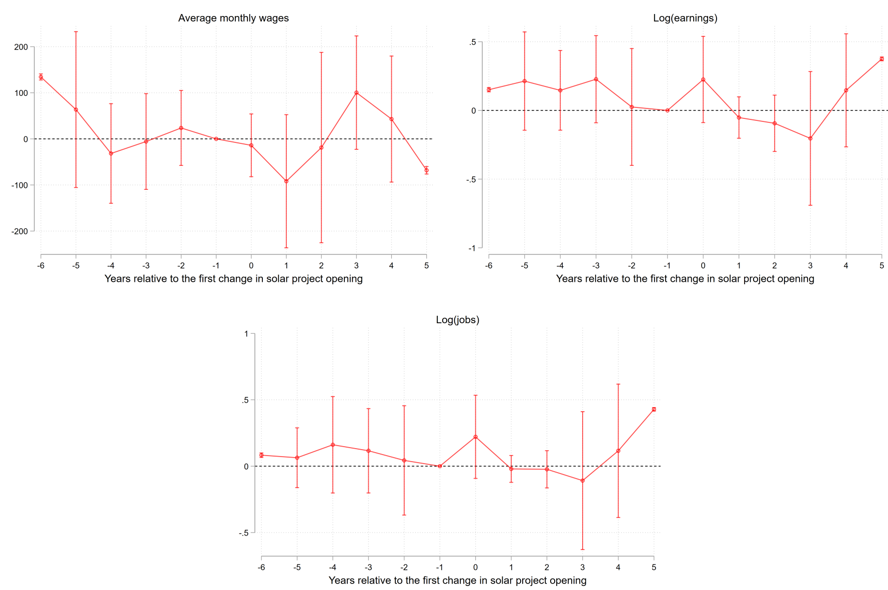
Notes: This figure shows the impacts of new wind energy projects on labor market outcomes by age using robust dynamic De Chaisemartin and d'Haultfoeuille (2020) estimators. The unit of observation is a municipality-year-age group. The unit of observation is a municipality-year-age group.

FIGURE A5 Impacts of Solar Energy Projects by Educational Attainment

Panel a) Less than High School



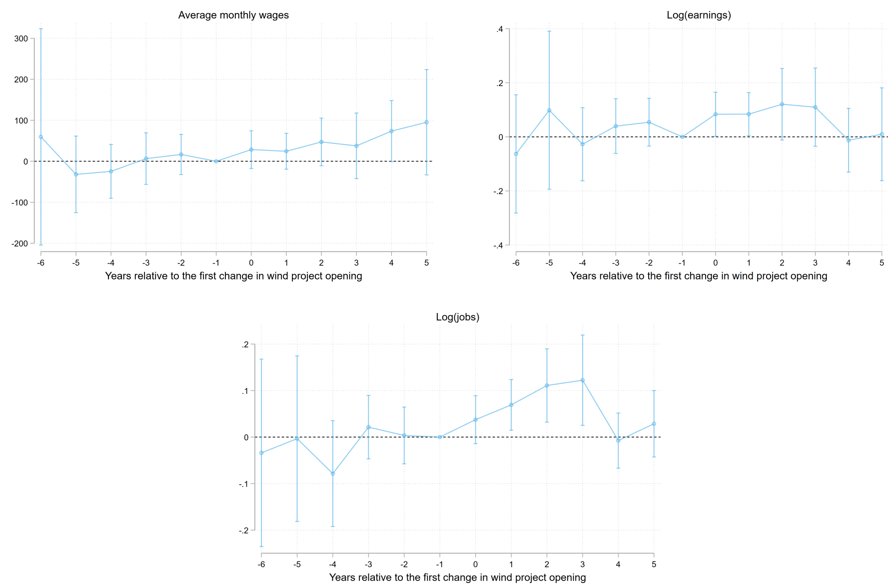
Panel b) High School or More



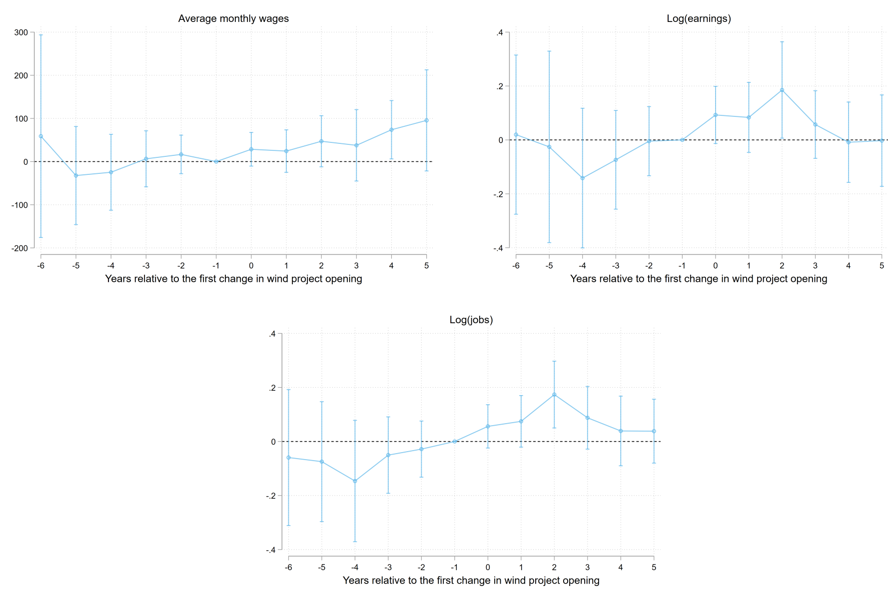
Notes: This figure shows the impacts of new solar energy projects on labor market outcomes by educational attainment using robust dynamic De Chaisemartin and d'Haultfoeuille (2020) estimators. The unit of observation is a municipality-year-educational group.

FIGURE A6 Impacts of Wind Energy Projects on Labor Market Outcomes by Educational Attainment

Panel a) Less than High School

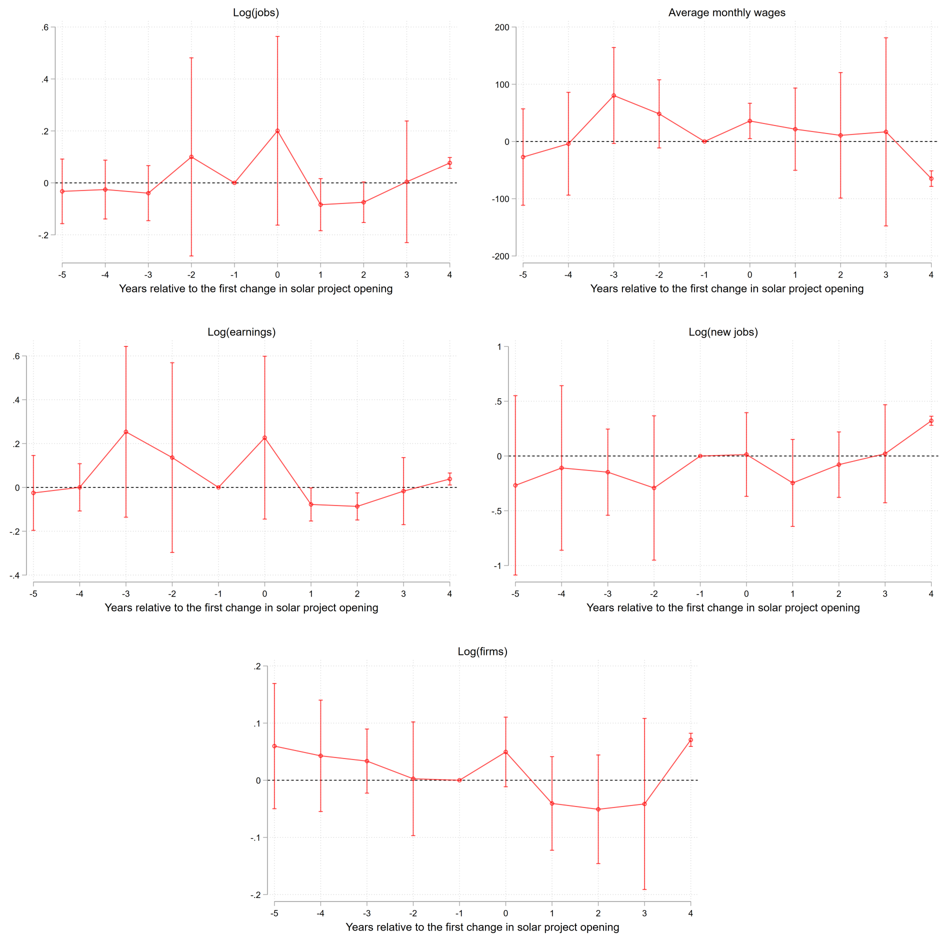


Panel b) High School or More



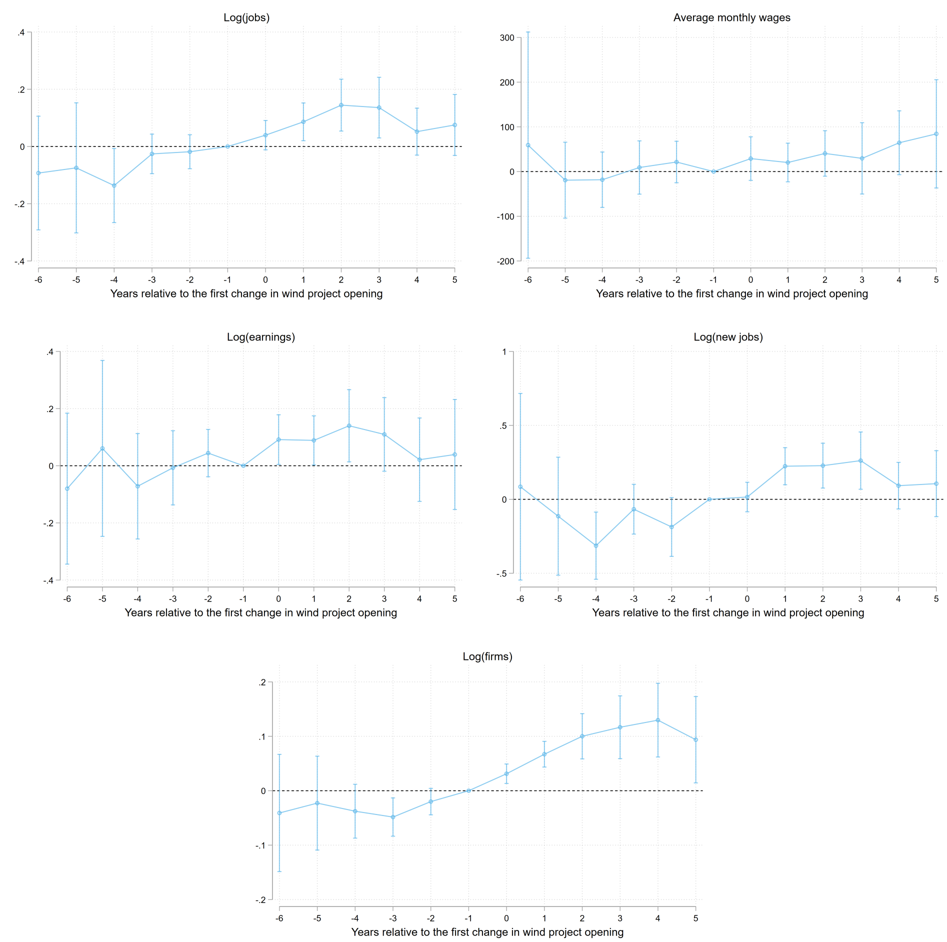
Notes: This figure shows the impacts of new wind energy projects on labor market outcomes by educational attainment using robust dynamic De Chaisemartin and d'Haultfoeuille (2020) estimators. The unit of observation is a municipality-year-educational group.

FIGURE A7 Impacts of Solar Energy Projects on Labor Market Outcomes in High-Solar Potential Areas



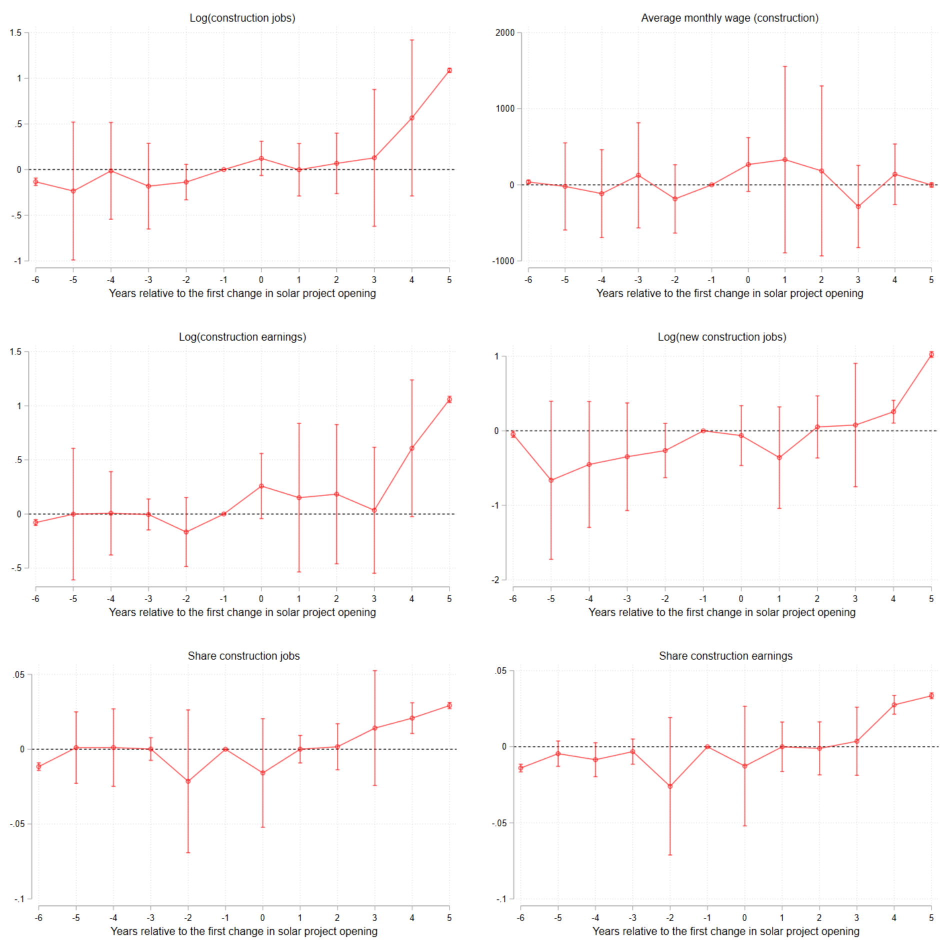
Notes: This figure shows the impacts of new solar energy projects on labor market outcomes focusing only on areas with high potential for solar energy using robust dynamic De Chaisemartin and d'Haultfoeuille (2020) estimators. The unit of observation is a municipality-year.

FIGURE A8 The Impacts of Wind Energy Projects on Overall Labor Outcomes in High-Wind Potential Areas



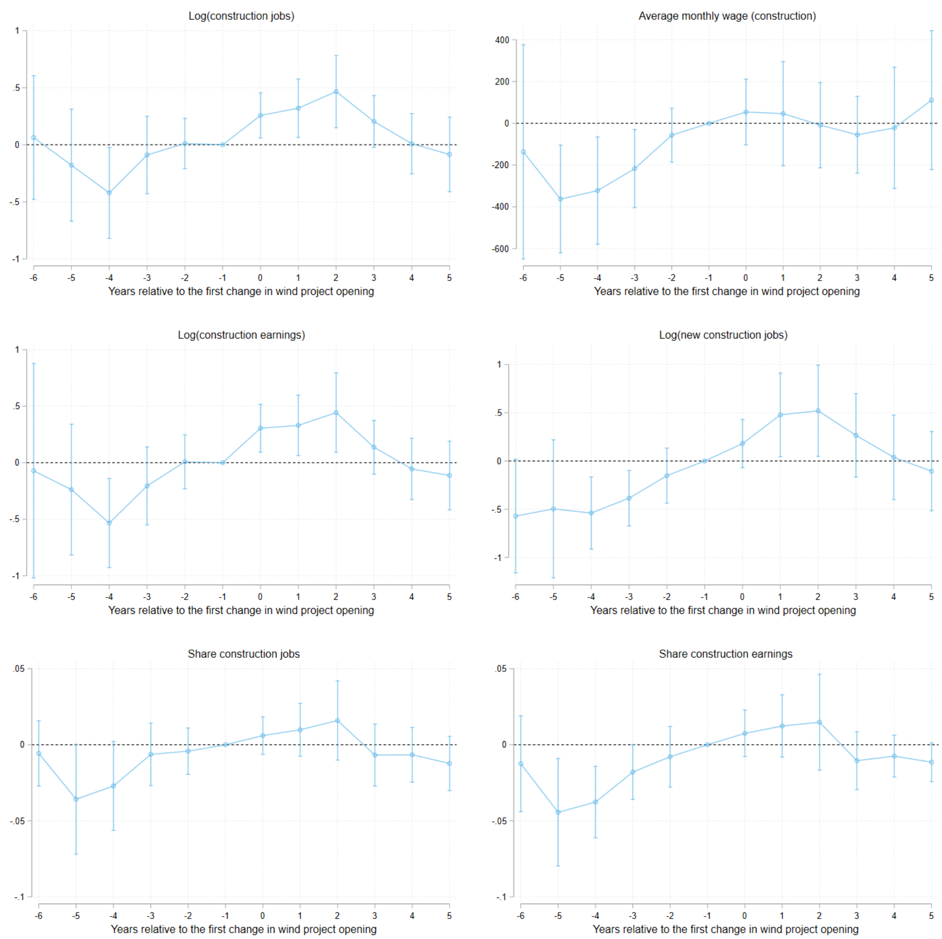
Notes: This figure shows the impacts of new wind energy projects on labor market outcomes focusing only on areas with high potential for wind energy using robust dynamic De Chaisemartin and d'Haultfoeuille (2020) estimators. The unit of observation is a municipality-year.

FIGURE A9 Impacts of Solar Energy Projects on Labor Outcomes in Construction



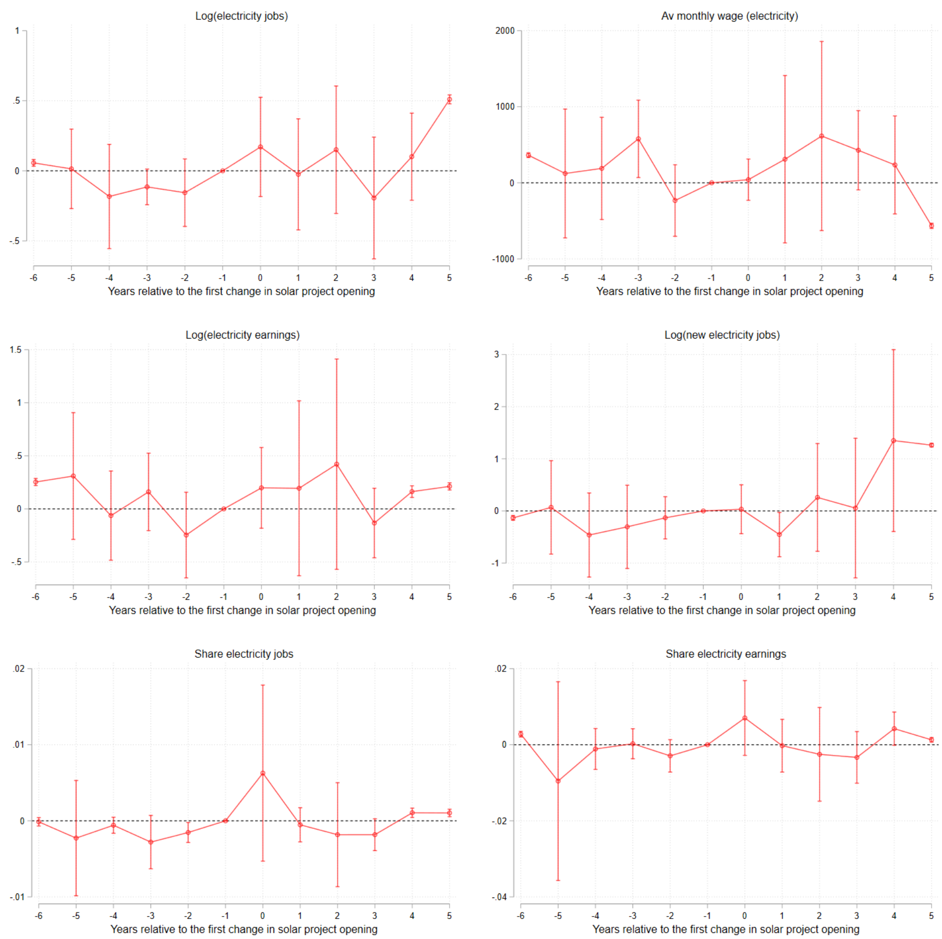
Notes: This figure shows the impacts of new solar energy projects on construction labor outcomes using robust dynamic De Chaisemartin and d'Haultfoeuille (2020) estimators. The unit of observation is a municipality-year-occupational group.

FIGURE A10 Impacts of Wind Energy Projects on Labor Outcomes in Construction



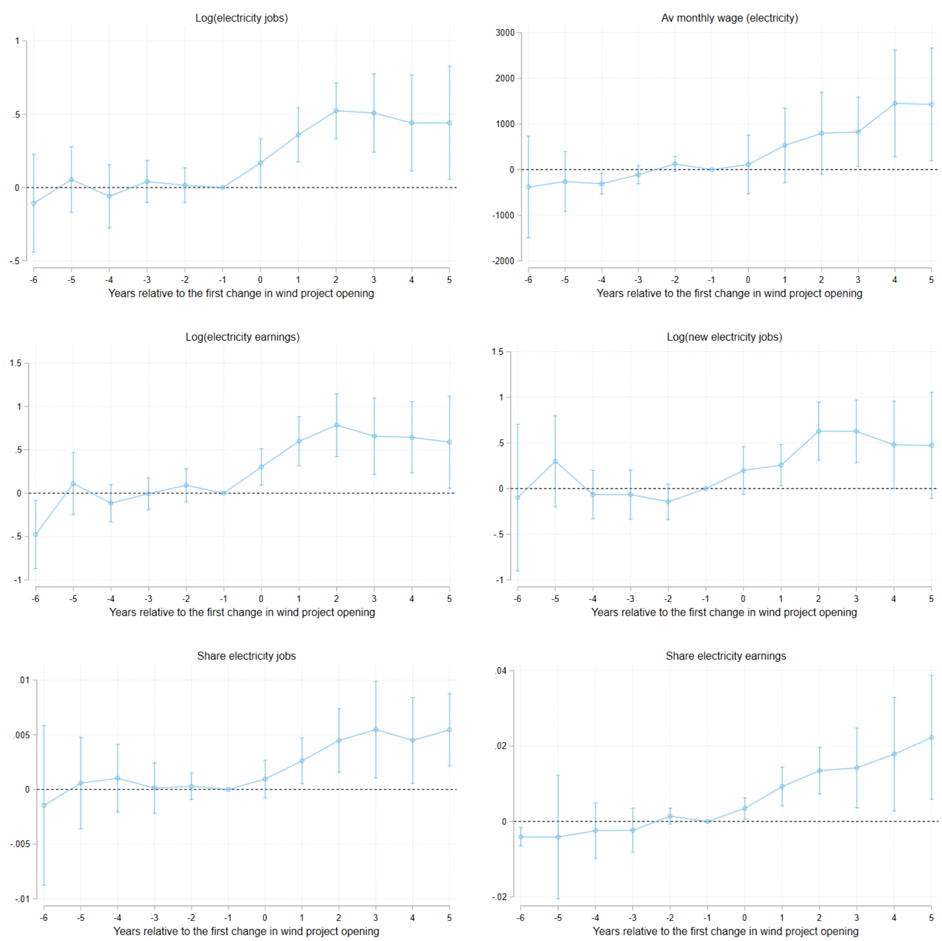
Notes: This figure shows the impacts of new wind energy projects on construction labor outcomes using robust dynamic De Chaisemartin and d'Haultfoeuille (2020) estimators. The unit of observation is a municipality-year-occupational group.

FIGURE A11 Impacts of Solar Energy Projects on Labor Outcomes in Electricity



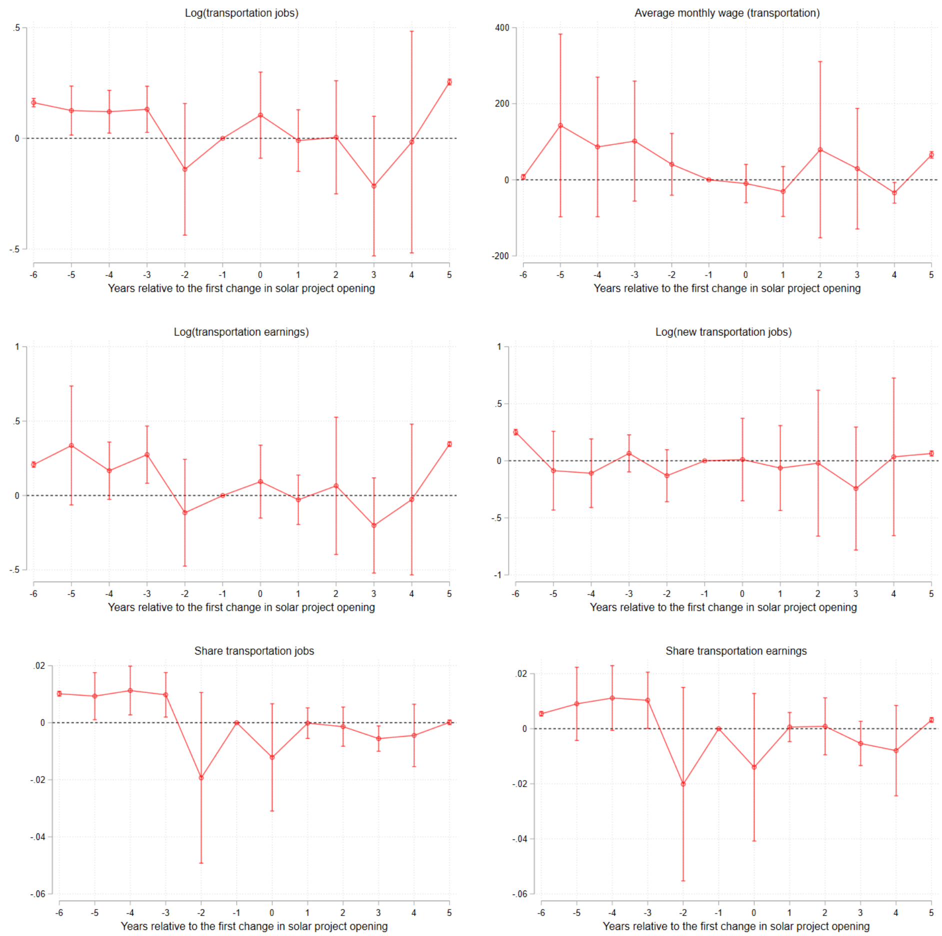
Notes: This figure shows the impacts of new solar energy projects on transportation labor outcomes using robust dynamic De Chaisemartin and d'Haultfoeuille (2020) estimators. The unit of observation is a municipality-year-occupational group.

FIGURE A12 Impacts of Wind Energy Projects on Labor Outcomes in Electricity



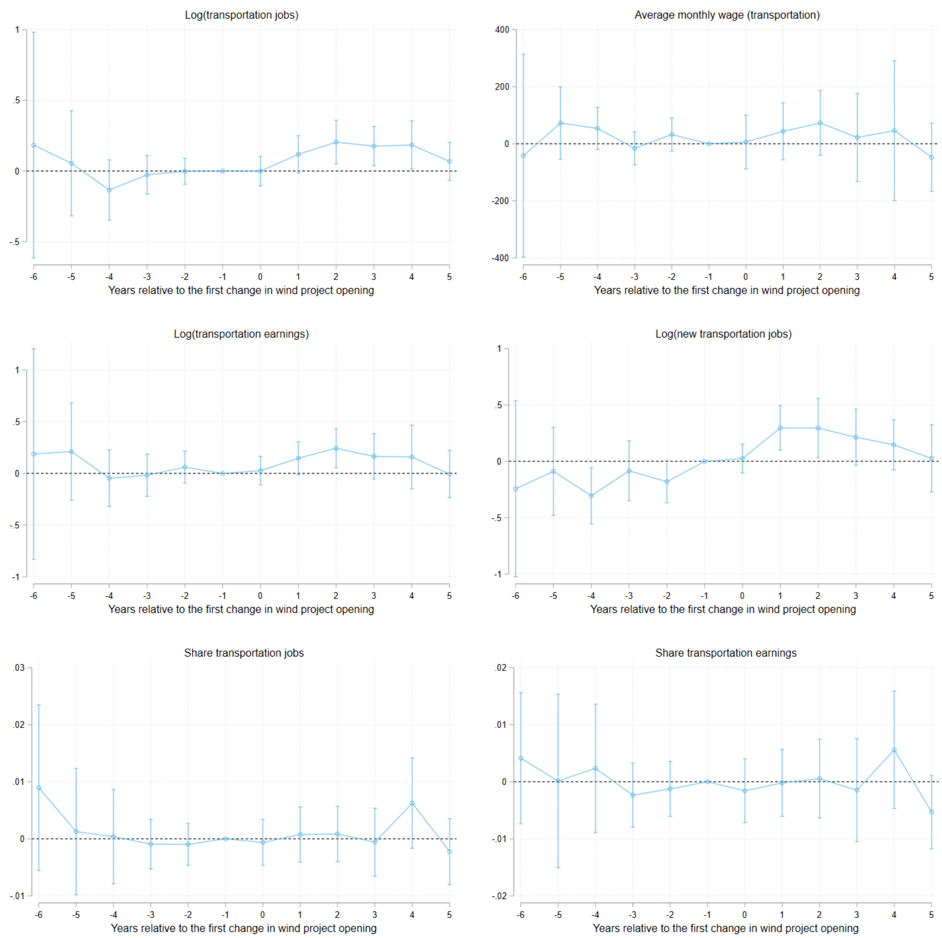
Notes: This figure shows the impacts of new wind energy projects on transportation labor outcomes using robust dynamic De Chaisemartin and d'Haultfoeuille (2020) estimators. The unit of observation is a municipality-year-occupational group.

FIGURE A13 Impacts of Solar Energy Projects on Labor Outcomes in Transportation



Notes: This figure shows the impacts of new solar energy projects on transportation labor outcomes using robust dynamic De Chaisemartin and d'Haultfoeuille (2020) estimators. The unit of observation is a municipality-year-occupational group.

FIGURE A14 Impacts of Wind Energy Projects on Labor Outcomes in Transportation



Notes: This figure shows the impacts of new wind energy projects on transportation labor outcomes using robust dynamic De Chaisemartin and d'Haultfoeuille (2020) estimators. The unit of observation is a municipality-year-occupational group.