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Local Economic Impacts of Wind Power Deployment in Denmark

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Abstract

An argument sometimes used to support renewable energy is that it may contribute to job creation. On the other hand, these technologies often face local opposition. In the case of Denmark, the country with the longest wind power experience, we examine whether the installation of new turbines had local economic benefits. Using the Danish master data register of wind turbines and detailed data on the municipal budget, personal income and sectoral employment from Statistics Denmark, we build a panel covering 250 municipalities. We use a quasi-experimental set-up and exploit time and regional variations at the municipal level. We find that the deployment of wind power contributed to the increase in personal income for entrepreneurs and reduced dependence on social benefits. As municipalities received payments from wind investors ahead of the construction, the new wind revenues were also followed by increases in local public spending. We find only very minor effects on employment in some sectors, and the aggregate local employment does not change significantly. Heterogeneity analyses indicate that the increases in local entrepreneurial income are largely driven by small installations, whilst increases in municipal budget and reductions in the dependence on social benefits are induced by larger installations.

Keywords Wind power · Renewable energy · Climate policy · Co-benefits · Employment

JEL classification C23 · H23 · Q42 · Q48

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1 Introduction

As part of their energy and climate policies, nations develop schemes to support renewable energy (RE) deployment. Beyond the objective to reduce greenhouse gas emissions, RE may play a key role in reducing air pollution and increasing energy independence in the context of uncertainties regarding global market prices of energy carriers. In the case of wind power, new deployment often faces local opposition, known as the “not in my backyard (NIMBY) syndrome” due to the noise it creates, the visual impacts, and the consequences on real estate prices in the surroundings. On the other hand, policymakers often argue that energy deployment may contribute to local job creation in addition to the environmental benefits. With such a potential double dividend, RE would be a key element to enable growth to be green.

We quantify the local economic impacts of wind power deployment in the case of Denmark, the country with the longest experience with this technology. Exploiting a comprehensive panel that takes advantage of the availability of very detailed data at the municipality level, we aim to identify the effects throughout the revenue chain by exploiting regional and time variations. More specifically, we examine the impacts on the personal per-capita income at the municipal level, the local public budget, and employment, potentially taking into account spill-over effects on the various economic sectors.¹ We focus on the period from 1993 to 2002, which is when the extension of wind power was the largest in Denmark. This is interesting for the current context in which policies are developed to increase the share of renewable energy in power production significantly. To account for potential endogeneity concerns, we employ a quasi-experimental set-up, building on the generalized propensity score (GPS), introduced by Hirano and Imbens (2004) and constructed to allow for causal inference with observational data.

We find that one euro per capita of newly generated revenues from wind power deployment generates an increase in personal income growth of 84 cents per capita of personal income in the municipality in the first year (the effect is only significant at the 10% level though). Analyzing the results for more granular income categories, we see that increases in entrepreneurial income largely explain the positive impact. Our estimates suggest that local entrepreneurial income growth increases by 60 cents for every euro of new wind revenues in the first period after the turbine was connected to the grid. This is consistent with the observation that around two-thirds of the wind turbines in Denmark were owned by individuals, in which case the revenues could be reported as entrepreneurial income. Three years after the connection of new turbines, we detect a decrease in the growth of income from social benefits of 31 cents in the third year after the revenues were generated for the first time. This indicates that revenues from wind turbines help to reduce the reliance of persons in the municipality on social security payments by providing other sources of income. There is no additional income increase after the first year.

We also find a positive impact on the municipal budget. Our results suggest that one euro of new wind revenues per capita is associated with increased public spending of 38 cents (per capita) in the first year after the connection of new wind power capacity to the grid. This effect is mostly composed of additional health care spending (26 cents), increased

¹ Throughout the study, employment as an outcome variable refers to the number of employed individuals in full-time equivalents.

administrative spending (6 cents in the first year), and additional funding for infrastructure (13 cents).²

Interestingly, we find that the effects on local entrepreneurial income are largely driven by smaller installations, whilst the effects on public budget and social benefits arise from the deployment of larger, utility-scale wind parks.

In our data, there is no evidence of effect of additional wind power revenues on aggregate local employment. There are some minor effects on employment subcategories, but these compensate one another across sectors.

The existing literature on the local economic impacts of RE deployment focuses mostly on the effects on employment and is not fully conclusive. It consists of studies using structural methods or empirical identification approaches. On the one hand, some positive effects are found in the RE sector or related sectors due to the local sourcing of components and services. The benefits seem to be detected mostly during the manufacturing and construction phases. The positive spill-overs in related sectors are observed only if a sufficient share of parts and services are supplied by local firms. On the other hand, negative impacts are identified as a consequence of increased costs of energy generation or the crowding out of alternative investments.

Our main contribution relies on the fact that we analyze the case of Denmark, a country that has been a pioneer in the deployment of wind power and that has the longest experience with this technology. Our analysis highlights the impacts of local revenue generation through renewable energy deployment, as opposed to solely focusing on impacts from the construction. The empirical approach in this paper allows us to capture all potential local impact channels. In addition, we use unique datasets combining detailed information on installed turbines and official statistical data at the municipal level. We do not restrict our analysis to employment but we also examine the effect on personal income and the municipal budget. We employ a statistical identification that allows us to fully capture spillovers on the other sectors of the economy, without having to impose the structural assumptions of input-output tables.

2 Literature Review

Studies on the economic impacts of renewable energy deployment have not always been conclusive. Using an input-output model, Loomis et al. (2016) show that the deployment of wind power in Illinois, United States, resulted in job creation, additional income for land-owners, and increased tax revenue. Employing an econometric identification as opposed to a structural input-output approach, Hillebrand et al. (2006) investigate the local economic impacts of increased RE deployment due to the compulsory compensation scheme for green energy in Germany. Particularly, they estimated the impacts of additional investment into renewable energies in monetary value. The study also considers two opposing effects: a spurred economic growth through potential local sourcing of components and services versus a potential local contractionary effect due to increased electricity costs. The authors argue that these may arise due to the high capital investment necessary for scaling up RE production and potential distortions due to the shifting of electricity production away from

²The cited subcategories do not add up as we only list the statistically significant results here, whilst the overall spending effect can include non-significant, but positive effects from other spending categories.

the efficient path as a consequence of public incentives. Whilst this effect is at the level of the electricity bidding zone, there can still be a local impact of these cost increases. They find that, over time, the increased energy costs offset the positive economic impacts. On the contrary, exploiting the variation in green energy policy across U.S. metropolitan areas, Yi (2013) finds that policies enhancing green energy deployment have a positive impact on local employment. The main explanatory variable they employ is a clean energy policy index measuring the intensity of renewable energy subsidies at the regional level. It is important to note that this analysis focuses specifically on employment effects in the electricity sector.

Hillebrand et al. (2006) find negative impacts on other sectors through higher electricity costs, sectors that Yi (2013) does not incorporate in his study. In the case of Portugal, Costa and Veiga (2021) use the number and capacity of newly installed turbines separately to estimate the impact of wind power investment on local unemployment. They find that wind power deployment has a short-term positive effect during the construction of turbines and a very small impact in the operation phase.

More recently, in the case of Spain, Fabra et al. (2024) find a positive impact of solar investments on local employment during the construction phase (effect that diminishes over time). Regarding wind power deployment, they find limited employment impacts but can detect increases in income and public spending. They suggest the skill profile for wind power is very specific, and hence that employment is not created locally, but with firms operating on larger regional scales with teams moving across building sites. Focusing on rural territories in Spain, Duarte et al. (2022) show that the positive effects of wind turbine deployment on income and employment are temporary and that jobs are generated during the manufacturing and construction phases, but no longer during the operation and maintenance phases. Confirming those findings, Scheifele and Popp (2024) employed a difference-in-difference approach in Brazil and observed small increases in employment only in the twelve months following the commission of wind turbines, whilst impacts on fiscal revenue persist. Stavropoulos and Burger (2020) provide a meta-analysis. They show that the applied methodologies at least partially drive the reported employment effects of renewable energy. However, in line with an earlier meta-analysis by Meyer and Sommer (2014), they find that studies generally find smaller employment effects for wind power compared to solar and hydropower. This observation was confirmed in the recent study by Fabra et al. (2024).

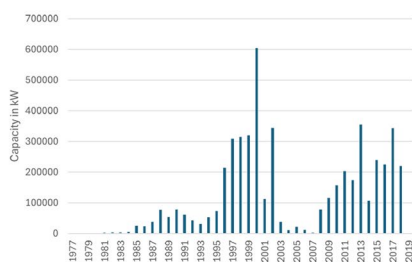
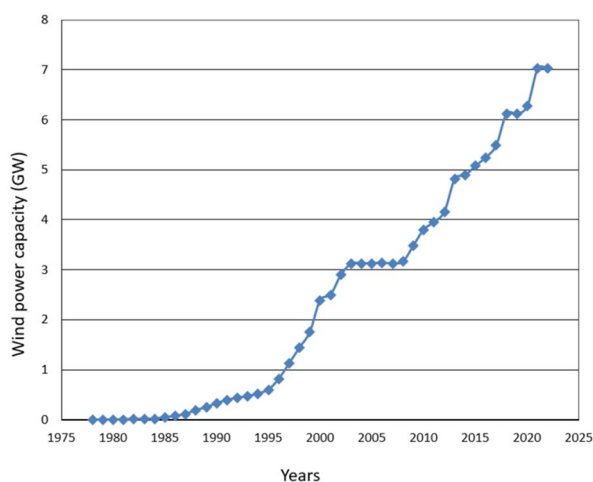
We contribute to the topic by analyzing the local economic impacts of wind power deployment in Denmark, using a comprehensive panel that takes advantage of the long Danish experience in wind power and the availability of very detailed data at the municipality level. Employing a generalized propensity score approach, constructed for causal inference with observational data, we aim to identify the impact on personal income, municipal budget, and employment by exploiting time and regional variations. This approach has advantages over the frequently employed input-output approach (we do not rely on the structural assumptions of input-output tables). As wind power deployment in Denmark is largely driven by private household investments, and given the granular disaggregation of the data, we can capture impacts throughout the revenue chain at the local level, potentially via fiscal multiplier effects and spill-overs to the various economic sectors. This analysis sheds light on the “not in my backyard” issue as we analyze the impacts on local agents potentially affected by RE deployment.

3 Institutional Background

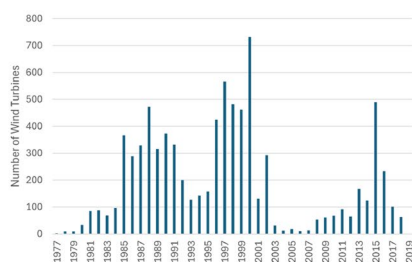
In Denmark on-shore wind power started to develop in 1976 (see Figs. 1 and 2). It was largely driven by private household investments, themselves supported by successive government policies: direct government support to the investment cost for building turbines, feed-in tariff, variable or fixed premium on top of the electricity market price.³ Utilities must buy the power produced from renewable energy sources (Helby 1998). The process of building turbines takes two to four years, including the time dedicated to the exploration of potential sites. To give some order of magnitude, the average capacity of a commissioned wind turbine was 250 kW in 1993 and 860 kW in 2000.⁴

A large share of Danish wind turbines are owned by individual entrepreneurs, e.g. farmers. Gorroño-Albizu et al. (2019) give the example of the Skinnerup installation, a 0.66 MW wind turbine installed by a farmer in Thisted Municipality in 2000. Shared ownership in the

Fig. 1 On-shore wind capacity in Denmark since 1976



(a) Annual added onshore wind power capacity (kW)



(b) Annual number of commissioned wind turbines

Fig. 2 Onshore wind power addition in Denmark between 1976 and 2018

³ A feed-in tariff is a constant price given to power producers for every unit (e.g. kWh) of electricity they produce.

⁴ Source: own calculation using data from the Master Data Register on Wind Turbines.

form of a partnership is also common.⁵ According to Johansen (2021) and Meyer (2007), until the start of the twentieth century, most Danish wind turbines were owned by cooperatives or individuals. The rest is owned by companies. In the case of partnerships, individuals jointly invest in the construction of the turbine and sell the power to the local utility. While the participation in a wind partnership was initially limited to individuals living close to the turbine site (Bolinger 2001), this constraint was progressively relieved.⁶ In parallel, the government imposed stricter siting guidelines for building turbines in the best wind areas.⁷ Individual wind power producers may use part of the electricity produced for the consumption of their own household (Bolinger 2001). In the example of the Skinnerup installation above, around 7% of the production is used for self-consumption and the rest is sold to the grid (Gorroño-Albizu et al. 2019). On the contrary, investors in a wind partnership have to sell the whole power production to the grid. In case of a partnership, the electricity produced by the wind turbine is taxed at the individual level, in proportion to the share the partner owns and according to his or her tax situation. Given possible tax exemptions, only a part of what is sold to the grid is taxed (Bolinger 2001).

Local communities may benefit from turbine installations as some wind project developers make payments or donations to municipalities ahead of the project development, in particular to promote local acceptance. Municipalities have some freedom to use this additional source of revenues, for example, to contribute to cultural and recreational activities.⁸

The deployment of wind power in Denmark is well explained by the different national support policies that were successively in place (see Table 9 in Appendix 1, based on Energinet 2011 and Jauregui-Naudin 2010). From 1984 to 2001, wind power producers received an electricity price corresponding to 85% of the local retail price of electricity excluding taxes. In 1991, a fixed price premium of 36 euros/MWh was added to this. It ended in 2001. Following the electricity market liberalisation (in 1999), existing turbines were covered by a feed-in tariff that provided an equivalent income to producers as under the previous scheme. In 2000, a feed-in tariff was introduced. Independently of the electricity market price, it provided the owners of new wind turbines 58 euros/MWh for the first 22,000 full load hours of electricity produced. This stayed in place for turbines built until 2002. In 2003, the feed-in tariff was replaced by a variable premium that was complementing the electricity market price.

⁵ Bolinger (2001) explains that one advantage of a partnership in comparison with a cooperative is that an individual in a partnership can deduct the interest on a loan for his share of a wind turbine from income taxes. Shares are computed as parts of the expected production. A share is usually 1000 kWh/year and costs about \$450 (assuming \$1000/kW project costs and 25% capacity factor).

⁶ Bolinger (2001) indicates that, according to the Danish Wind Turbines Manufacturers Association, the participation in a wind partnership was initially limited to individuals living within a radius of 3 km from the turbine site. The radius was extended to 10 km in 1985. In 1992, individuals living in neighboring counties could also participate. In 1996, individuals who had their job or their property in the borough were allowed to join a partnership. Finally, any person living in Denmark (from 1999 onwards) or in the entire European Union (from 2000 onwards) could participate.

⁷ Since 1999, a national directive has set detailed conditions (for example the distance to residential areas and requirements for installing groups of turbines) for designating the areas that are suitable for windmill installation (Pettersson et al. 2010). The regional planning of these areas has to comply with this directive. Projects of windmill installations at the municipal and local levels can only be completed in these zones.

⁸ Later in the history of wind power in Denmark, this support to municipalities where turbines are built was institutionalized in the form of the so-called “green scheme” (Danish Energy Agency 2009), itself succeeded by the “green fund” (Olsen 2022).

Figure 3 displays the geographical distribution of wind turbine installations in Denmark for two different time periods. The first figure displays the wind turbine installations with a commission date between 1993 and 1999, the second figure displays the number of wind turbine installations with the date of commission between 2000 and 2002. Both figures highlight that the greater country of Copenhagen (urban area) experienced little to no new wind turbine installations, regardless of the time period.

We decide to focus our analysis on the period 1993–2002. The first reason is that this is one of the periods where the deployment was the fastest. In 2003, the support policy was changed from a feed-in tariff to a premium on top of the electricity market price (Jaureguy-Naudin 2010; Gavard 2016). As a consequence, there was no change in wind power capacity in the following years. Second, this was before the change in municipality territorial definition which took place in 2007. The number of municipalities was then reduced from 240 to 90. Using the period with the larger number of municipalities allows for conducting a more granular analysis with a larger number of observations. We present the successive policies in place during that period in Table 9 in Appendix 1, based on Energistyrrelsen (2011) and Jaureguy-Naudin (2010). We use this information for the data preparation as explained in Sect. 4. Off-shore wind parks are not included in the dataset.

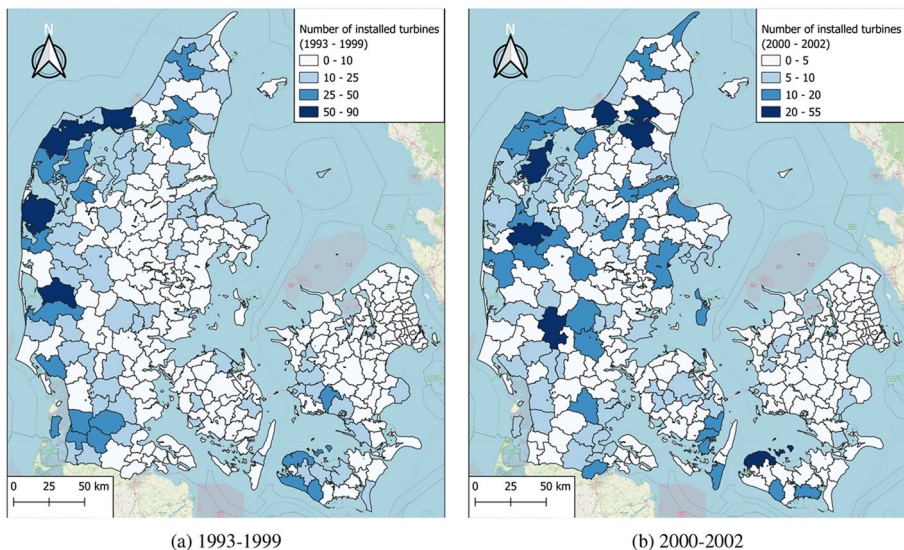


Fig. 3 Geographical distribution of wind turbine installations

4 Data

For the econometric analysis, we build a panel covering 250 municipalities from 1993 to 2002. This includes all Danish municipalities except those in the greater county of Copenhagen and the municipality of Christiansø.⁹ The panel contains municipality-level data on the new wind power revenues, i.e. the revenues from the new wind turbines connected to the grid in the municipality each year, as well as data on personal income, the municipal budget, and employment for the time period 1993–2002. The employment data is disaggregated by sector, and the budget data by category. The panel is balanced. We identify the municipalities according to their boundaries as of 2004.

4.1 New Revenues

Following Feyrer et al. (2017), we define the “new revenues” in municipality i in year t as the revenues from wind power production from the turbines connected to the grid in municipality i in year t . We consider the revenues from the first year of operation. We compute them based on the annual power production of each turbine, as well as the electricity price and the support policy when the turbine was built. The Master Data Register on Wind Turbines provides the power production of each turbine in each year. We find detailed information on the support policies in Energinet (2011). We use the electricity price data from Dansk Energi for the period 1985–1999 (before the electricity market liberalization). For the time period from 2000 onwards, we compute the weighted electricity price, based on the hourly wind power production and hourly prices from Energinet.¹⁰ Indeed when there is no wind, turbines do not receive any electricity price. In addition, turbines in different municipalities do not necessarily all produce electricity at the same time. However, electricity price data are not disaggregated at the municipal level. Using a simple average of the electricity price over each year would thus be inaccurate. We rather use a weighted average of the electricity price taking into account hourly wind power production, giving more weight to prices when wind power production is higher. The detailed calculations are provided in the code included in the supplementary material.

4.2 Municipal Budget, Personal Income, Employment

The data on the municipal budget, personal income, and sectoral employment come from Statistics Denmark. Figure 4 presents the disaggregation available for the personal income data.¹¹ The personal income is composed of the primary income and the current transfers.¹²

⁹We indeed identify, merge and exclude the 21 urbanised small municipalities that belong to the greater county of Copenhagen as this urban area is significantly different from the other municipalities. We also do not keep the municipality of Christiansø. It is outside of the geographical area of the study.

¹⁰Note that the data available to compute the new wind power revenues only provide the electricity sold to the grid. As individual owners may use part of the electricity for their consumption, we cannot take into account this additional implicit revenue. It is, however, a small part of the total wind power production (typically less than 10% of the wind capacity owned by individuals is used for their electricity consumption (Gorroño-Albizu et al. 2019)).

¹¹The personal income data are reported in the municipality where the person resides.

¹²The aggregate personal income data from Statistics Denmark also includes wealth-generated income (interest payments and return from stock investments) but the latter is not included in any of the subcategories.

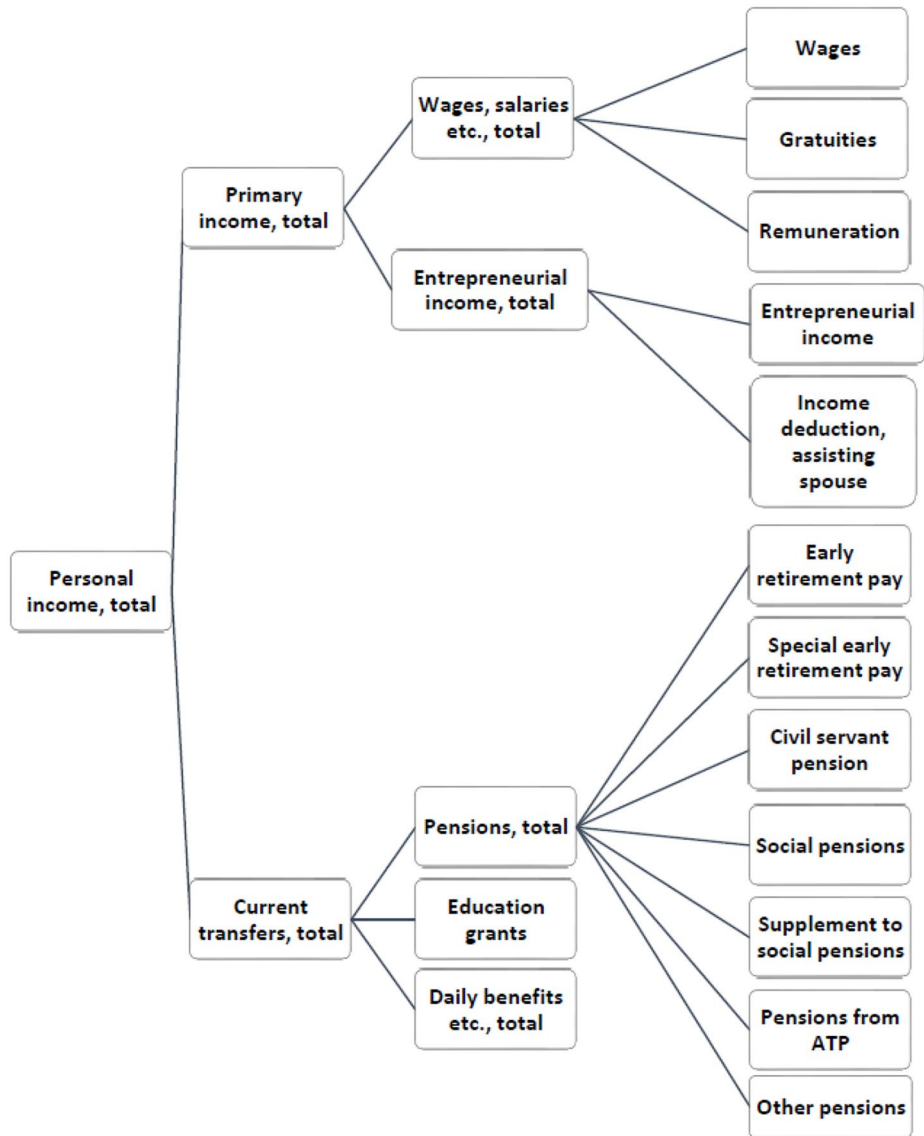


Fig. 4 Disaggregation in the personal income data

The primary income itself covers the entrepreneurial income, wages, and salaries. The wages and salaries are further split into wages, gratuities, and remuneration. The entrepreneurial income aggregates entrepreneurial income and income deductions.¹³ The current

¹³ According to Statistics Denmark, “Income deduction encompass expenses which taxpayers can subtract from their taxable income. For example, these include unemployment insurance, mileage allowance, and alimony, maintenance.” See: <https://www.dst.dk/en/Statistik/dokumentation/documentationofstatistics/personal-income-taxes/statistical-presentation>. This component is included in the category “entrepreneurial income, total” analysed and reported later in the paper.

Fig. 5 Personal income categories (shares)

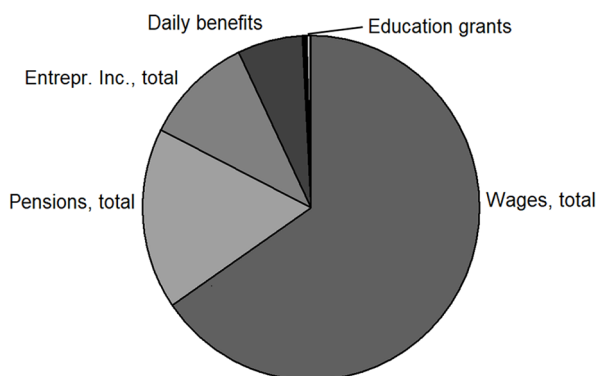
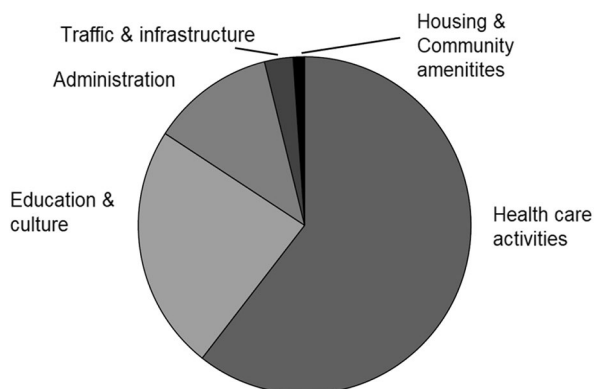


Fig. 6 Municipal budget categories (shares)



transfers category is composed of pensions, education grants, and daily benefits. The pensions can be further split into social pensions, special early retirement pay, pensions from the Arbejdsmarkedets Tillægspension (ATP), other pensions, and civil servant pensions. The daily benefits include unemployment benefits, temporary leave benefits, cash benefits, and other benefits.¹⁴

Figure 5 shows the share of the income categories (per capita) in the total aggregated personal income (the average is computed on all municipalities for the whole time period of study). We observe that wages represent the largest part (over 60%), followed by pensions (17%), entrepreneurial income (10%), and daily benefits (7%). The share of the primary income in the total income is hence over 70%.

The municipal budget data are disaggregated into five expenditure categories and one income category. Figure 6 shows the share of each expenditure category in the total expenses.¹⁵ We observe that the largest part of the municipal spending is devoted to health care activities (61% of the spending). This is followed by spending on education and culture (23%), administration (12%), traffic and infrastructure (3%), and, finally, housing and com-

¹⁴ Daily Benefits is the sum of “Unemployment benefits and the like”, “Temporary leave benefits”, “Cash benefits”, “Other benefits”. See: <https://www.statbank.dk/statbank5a/default.asp?w=1440>

¹⁵ Both Figs. 5 and 6 and refer to the whole of Denmark, except the greater county of Copenhagen and Christiansø.

munity amenities (1%). Besides these sources of expenses, municipalities also have income via their public utilities, for which we also have data available.

Table 1 shows the distribution of total employment in the various economic sectors, as reported by Statistics Denmark.^{16,17} The average is computed on all municipalities for the whole period of the study. In this time range, most people were employed in social institutions (11.5%), the manufacturing of basic metal products (8.5%), the construction sector (7%), agriculture (7%), education (6.5%), the trade and repair of cars (6.5%) and business activities (5.5%).¹⁸

Table 1 Share of employment categories

Employment Category	Percent
Social Institutions	11.5
Mfr. of basic metals	8.5
Construction	7
Agriculture	7
Education	6.5
Retail trade and repair work (no vehicles)	6.5
Business activities	5.5
Public administration	5.5
Wholesale trade (no motor vehicles)	5
Human health activities	4.5
Transport	4.5
Associations and culture	4
Mfr. of food, beverages and tobacco	4
Sale and repair of motor vehicles, sale of automobile fuel	3
Mfr. of wood products,	2.5
Hotels and restaurants	2.5
Finance and insurance	2
Mfr. of chemicals and plastic products	2
Mfr. of furniture	2
Post and telecommunications	1.5
Letting and sale of real estate	1.5
Mfr. of other non-metallic mineral products	1
Mfr. of textiles and leather	<1
Electricity, gas and water supply	<1
Activity not stated	<1
Fishing,	<1
Mining and quarrying	<1

¹⁶The employment data from Statistics Denmark are compiled according to the international guidelines from the International Labour Organization and follow the International Classification of Status in Employment. Employed persons are people who are working at least one hour in the week of reference. The employed are either employees, self-employed, or assisting spouses. Data represents employment in the municipality where the employee works.

¹⁷The table refers to the whole of Denmark, except the greater county of Copenhagen and Christiansø.

¹⁸The full description of the sectors is available in the Manual on Statistics of International Trade in Services (United Nations 2011). Another definition for social institutions is social work activities (both have the industry code 8539). For example, the retail trade and repair category is retail trade, except for motor vehicles and motorcycles; and repair of personal and household goods.

As explained in Sect. 5, we follow Feyrer et al. (2017) and scale our variables by the one-year lagged employment to deal with the fact that the same increase in new revenues can have a significantly different impact on municipalities of different sizes.¹⁹

In Appendix 1, we present the summary statistics for key variables at the municipal level (Tables 10 and 11), differentiating municipalities where wind turbines were installed in the period of our study and municipalities where that was not the case. We checked the *t*-statistics of differences in means across groups. The differences are not significant (see Table 12 in appendix).

4.3 Control Variables

Our controls include data on the unemployment rate, the average wind density for each municipality, and the stock of already installed wind turbines. We calculate the unemployment rate out of unemployment and employment data from Statistics Denmark. The data on the average wind density for each municipality is deduced from the Global Wind Atlas with the use of geographic information system (GIS) tools.²⁰ The data on the stock of installed wind turbines is from the Master Data Register of Wind Turbines from Energistyrelsen. These controls are used to compute the generalized propensity score, as explained in Sect. 5.

5 Methodology

We analyze the local economic impacts of wind power deployment. More specifically, we look at the effect of the revenue generated from newly installed turbines in a given year on personal income, the public budget, and employment at the municipality level. The effect of a given total capacity of new turbines is expected to depend on the size of the municipalities where they are installed: the same total capacity of new turbines installed in a small municipality will not have the same impact as in a large municipality. To address this, we follow Feyrer et al. (2017) and normalize the treatment as well as the outcome variables by the lagged total employment at the municipality level.²¹

5.1 Identification

We aim to identify the impact on personal income, municipal budget, and employment by exploiting regional variation and variation over time on the municipal level. We expect the choice of locations for the installation of new turbines to be largely driven by favorable wind conditions and topological features, which are unlikely to be correlated with the outcomes of interest. Still, wind power deployment might be correlated with regional economic conditions and unobservable political efforts to attract wind power investment. For example, municipalities with low employment levels might politically work towards facilitating

¹⁹ In the following, all references to per capita values refer to the values scaled by the lagged total employment.

²⁰ Data are downloaded in a GeoTiff format and then transformed into municipal-year data with the use of QGIS and Stata.

²¹ The mentions to per capita variables in the rest of the paper refer to the outcome variables after normalization by the lagged total employment at the municipal level.

construction permits to attract wind power deployment into their jurisdiction. These incentives for wind power producers to build turbines on their land are not observable, and could be a source of endogeneity to the extent they are correlated with our outcomes of interest.

To address this potential endogeneity concern, we employ the generalized propensity score (GPS) approach, provided by Hirano and Imbens, 2004. Employing the GPS-covariate adjustment instead of using the variables as direct controls allows for a richer potential functional form of the impact of the controls used to calculate the GPS. In the direct regression approach, the effect of the controls is imposed to be linear, whereas the GPS-calculation routine of Hirano and Imbens (2004) tests and selects the best fit.

It is important to note that this estimator exploits variation in treatment intensity across treated units and over time to identify the treatment effects (Bia and Mattei 2008). We hence run the estimation only on observations with positive treatment levels, since keeping non-treated units in the sample can introduce a bias in the GPS estimation (Bia and Mattei 2008). Our estimator exploits the variation in treatment intensity across municipalities where different levels of new revenues were generated, but which had the same ex-ante expected treatment level, based on the covariates. The different levels of revenue arise either from an uneven deployment of capacity or from variations in the wind conditions, which drive the revenue potential of the installed turbines.

5.2 The Generalized Propensity Score

Adapting standard propensity score methods for binary treatments, Hirano and Imbens (2004) provide a framework to use potentially confounding covariates to estimate the distribution of a continuous treatment. The result is a generalized propensity score. This allows us to model the expectation of the outcome variable depending on the treatment level and GPS. As opposed to controlling for the covariates directly, the GPS-covariate adjustment improves the estimation precision by decreasing the dimensionality of the estimation problem and is effective in addressing all biases introduced by the covariates used to estimate the GPS (Austin 2008).

Originating in epidemiological literature, the generalized propensity score method has been proposed for use in regional economics by Mitze et al. (2012). They apply this method to analyze the regional impacts of an infrastructure subsidy program in Germany. Arguing that regional economics can benefit from the quasi-experimental approaches pioneered in other economic disciplines, they find that endogeneity arising from differences in district characteristics, impacting both subsidy inflow and outcomes, can be addressed convincingly using the proposed generalized propensity score method. Subsequent applications include the analysis of the effect of innovation on firm success for European firms (D'Attoma and Pacci 2018) or of the role of innovative activity in ensuring economic sustainability for the case of dairy farms in Ireland (Läpple and Thorne 2019) as well as the impact of federal financial aid programs on firms in northern Italy (Bia and Mattei 2012)

5.3 Estimation of the Generalised Propensity Score

We first estimate the generalized propensity score. Unlike a binary treatment setting, the generalized propensity score relies on estimating the distribution of the amount of treat-

ment, given the observable covariates. As derived in Bia and Mattei (2008), the following paragraph explains the underlying theory.

Let N be a random sample from a large population. For every observational unit i , there is a vector of pre-treatment covariates, X_i . We also observe the amount of treatment received, D_i . The model is based on the potential outcome framework, known as the Rubin Causal Model (Holland 1986). Here, the potential outcome variable, Y , is defined as $\{Y_i(t)\}_{d \in \tau}$, where τ represents a continuous set of treatment levels. The outcome is thus modeled as a random variable that maps a treatment level to a potential outcome. Hirano and Imbens (2004) define the generalized propensity function, $r(d, x)$, to model the density of the realized treatment conditional on observed covariates, $f_{D|X}(d|x)$. To keep the notation manageable, the subscript i is dropped below.

$$r(d, x) = f_{D|X}(d|x) \quad (1)$$

The generalized propensity score, R , is defined as the value of the conditional density function for the realized treatment and observed pre-treatment covariates:

$$R = r(D, X) \quad (2)$$

One important property of this GPS is that, as shown by Hirano and Imbens (2004), within strata of a given value of $r(d, X)$, the likelihood that a certain treatment value $D=d$ occurs is independent of the covariates. Together with the appropriate unconfoundedness assumption, stating that the assignment of the treatment level is independent of the outcome, given the level of covariates, the utilization of the GPS can remove any bias resulting from an a-priori imbalance in the included covariates.

The original approach derived by Hirano and Imbens (2004) requires the treatment variable to follow a normal distribution. However, as this is not supported by our data, we employ an extension of the propensity score published by Guardabascio and Ventura (2014). Their methodology allows an unbiased calculation of the GPS for other distributions of the treatment variable. Specifically, it employs a log transformation of the treatment variable and allows the description of the treatment variable distribution with a gamma distribution.

5.4 Propensity-Score Based Covariate Adjustment

We use the computed generalized propensity score to identify the effects using a GPS-based covariate adjustment with an ordinary least squares (OLS) estimator to identify the impact of the revenues from new wind turbines (installed within the previous year) on each of the following outcome variables separately: personal income and its components (entrepreneurial income, wages, etc.), municipality budget and its components, and employment and sectoral employment.

Following Feyrer et al. (2017), we regress on the first difference of the outcome to estimate the effects on level changes. Further, we normalize the outcomes and revenues to per capita values. Thus, we estimate the following equation:

$$\Delta Y_{i,t} = \sum_{j=1,2,3} \beta_1 Revenues_{i,t-j} + \gamma R_{it} + \omega_t + \epsilon_{i,t} \quad (3)$$

where Y_{it} denotes the outcome variable (personal income, municipal budget, or employment) in municipality i in year t , $Revenues_{i,t}$ the revenues from power production from new wind turbines (“new revenues”) connected to the grid in municipality i in year t , R_{it} the value of the generalized propensity score R for municipality i in year t , ω_t the year fixed effect and $\epsilon_{i,t}$ the error term. Standard errors are clustered at the municipality level.

It is important to note that this approach, borrowed from impact evaluations in the medical literature (Austin 2008, 2011, 2018), empirically identifies the entire treatment effect, including impacts from all potential channels (for example the effects associated with the local sourcing of some parts of the turbines or with the increased revenues and income for local wind farm owners). Given the GPS is a flexibly specified function of relevant observables, directly including the GPS into a linear regression allows a more flexible way of controlling for those covariates. Most of our results are robust to the inclusion of the variables used for the computation of the GPS as ordinary controls in an OLS regression, without using the propensity score adjustment.²²

5.5 Covariate Balance

As with any identification approach, the quality of the propensity score estimation crucially depends on the richness of the data used to estimate it. In our case, we identify the following *observables* that may impact wind power deployment: wind potential, past unemployment rates as a proxy for economic conditions, and the stock of already installed wind turbines to capture the historic commitment to renewable energy deployment. We use them to estimate the generalized propensity score.

To ensure the endogeneity concerns are adequately addressed by the propensity score adjustment, it requires certain conditions and assumptions to be met. Firstly, the covariates must be balanced across treatment categories. To achieve the best possible covariate balance, we let the data guide our choice and tested different specifications. Finally, we find that employing lagged unemployment (first lag), lagged average wind density (second lag), and lagged installed wind turbines (third lag) provides the best balancing properties.

We follow Bia and Mattei (2008) and divide the continuous treatment into four intervals, based on percentiles of the observed treatments. The estimation algorithm checks for covariate balance within each treatment interval, conditioned on the propensity score. Details of the procedure are described in Bia and Mattei (2008). For each treatment interval, we find that testing for differences in mean across covariates results in a two-sided t -statistic that is smaller than 1.5 in absolute value in most cases. Thus, the hypothesis of no systematic differences in the covariates cannot be rejected and there is mostly no evidence against the covariate balancing property. The only exception is average wind density, where the covariate balance is not achieved for some treatment intervals. To further ensure that covariate imbalance does not drive our results, we follow Nguyen et al. (2017) and include all covariates, plus a measure for available agricultural surface, as an additional control in a robustness exercise. Our results remain robust.

²² We report those results in Appendix 5.

5.6 Unconfoundedness and Placebo Tests

In addition to the covariate balancing, we require an unconfoundedness assumption for our estimator to be unbiased. Specifically, the distribution of the treatment variable must be unconfounded, given the employed covariates, meaning municipalities with similar covariates should be equally likely to receive a given treatment level. In other words, no unobserved variables can affect both the treatment variable and the outcome.²³ Thus, insofar as there are variables or shocks that we do not observe, which influence the distribution of wind power deployment across municipalities and which influence our outcomes of interest, the change in the directly following periods, the risk of bias remains. However, as support policies for renewable energy were implemented at the national level, we suspect the regional variation in wind power deployment to be largely driven by favorable wind conditions and the availability of land. Further, we hope that unobserved shocks influencing wind power deployments, such as political climate or economic conditions, are sufficiently captured by the use of the unemployment rate and the stock of installed turbines as covariates for the GPS calculation. Political climate or economic conditions could include local politicians anticipating a decline in economic activity, and reacting by working towards an increased adoption of wind turbines as a means to stimulate the local economy.

Still, to further minimize the concern about potential confounders, we run placebo tests inspired by Chetty et al. (2009), regressing on artificially varied treatment timing. In our case, we rerun our main specification, but we regress the outcomes in revenues that occur in the future. The idea behind it is as follows: if unobservable factors influence wind power deployment and economic outcomes, they would likely have to be correlated over time to account for the time necessary for planning and construction. If this is the case, we would expect revenues in the future to be correlated with current unobservables and should find non-zero coefficients for future revenues. They would still be correlated with the unobservables, but cannot have any real effect. To conduct the test, we estimate the following equation:

$$\Delta Y_{i,t} = \beta \text{Revenues}_{i,t+3} + \gamma R_{it} + \omega_t + \epsilon_{i,t} \quad (4)$$

We report the results of this placebo test for the main outcomes in Table 2. We find non-significant coefficients. This gives confidence that the role of any unobservables in our regression is small. The tables with the Placebos for all outcomes are reported in Appendix 2 (Tables 13, 14, 15, 16, 17 and 18). They generally give the same results, except for some subcategories of employment.²⁴ Very interestingly, we find significant results for public spending in utilities and employment in manufacturing of chemicals, which can plausibly be explained to public spending and the pre-ordering of parts in preparation of wind farm investments.

²³ A detailed discussion can be found in Bia and Mattei (2008) and Bia and Mattei (2012).

²⁴ We have also run the tests proposed by Cai et al. (2016), implemented in Li et al. (2023) and Ji et al. (2023).

Table 2 Placebo tests—varied timing

Outcome variable: Change in income by type, normalised per capita.
Explanatory variables: placebo treatment: revenues three years in the future, GPS

	Total income	Total budget	Total employment
Placebo	0.223 (0.583)	0.193 (0.244)	−0.0530 (0.356)
GPS	−316.0 (0.161)	−378.1*** (0.000)	−38.05* (0.092)
Year FE	Yes	Yes	Yes
Observations	680	680	680

p-values in parentheses, **p* < 0.1, ***p* < 0.05, ****p* < 0.01

6 Results

In the following subsection, we present two blocks of results. First, we follow Austin (2011) and report the results of regression, using the GPS as covariate adjustments for the whole sample. Next, we split the sample by capacity size of the new installations and conduct heterogeneity analyses. Finally, we employ the methods described by Hirano and Imbens (2004) as well as Bia and Mattei (2008) and report dose-response functions, which plot the treatment effect as a function of the treatment level. We report and discuss those in Appendix 4.

6.1 Covariate Adjustment

The results of the estimation with GPS-covariate adjustment are reported in Tables 3, 4, 5, 6, 7 and 8.^{25,26}

We expect the new revenues to impact the local economy via several channels. First, the new revenues directly induce an increase in the income of local entrepreneurs, e.g. farmers,

Table 3 Effect of wind power deployment on the personal income—GPS covariate adjustment

Outcome variable: Change in income by type, normalized per capita.

Explanatory variables: generalised propensity score, new revenues from wind power deployment

	Total	Entre.	Wages	Pensions	Educ.	Benefits
L.Revenue per capita	0.840* (0.091)	0.597** (0.031)	0.0549 (0.873)	0.119 (0.207)	−0.0137* (0.073)	0.0347 (0.703)
L(2).Revenue per capita	0.575 (0.504)	0.613* (0.060)	0.0453 (0.901)	0.0912 (0.576)	−0.00260 (0.801)	0.168* (0.084)
L(3).Revenue per capita	−0.298 (0.625)	−0.104 (0.809)	−0.220 (0.626)	0.222 (0.192)	0.0126 (0.414)	−0.309** (0.020)
GPS	−360.2 (0.852)	−519.7 (0.520)	2476.1* (0.055)	−904.8** (0.048)	101.0** (0.037)	−577.6 (0.137)
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	641	641	641	641	641	641

p-values in parentheses, **p* < 0.1, ***p* < 0.05, ****p* < 0.01

²⁵ Note that, according to Hirano and Imbens (2004), there is no qualitative interpretation of the coefficient associated with the GPS.

²⁶ Notice that whether the coefficient on the GPS variables is significant only indicates whether the used observables would have introduced any bias when not controlling for them.

Table 4 Effect of wind power deployment on the municipal Budget—GPS covariate adjustment

Outcome variable: Change in municipal budget by type, normalized per capita.

Explanatory variables: Generalised Propensity Score, New revenues from wind power deployment

	Total	Admin	Educ.	Health	Housing	Utilities	Infra
L.Revenue per capita	0.377*** (0.000)	0.0560*** (0.000)	0.00271 (0.945)	0.258*** (0.000)	-0.0156 (0.685)	-0.0693 (0.266)	0.135* (0.092)
L(2).Revenue per capita	0.337 (0.180)	0.0219 (0.617)	0.0607 (0.169)	0.218 (0.224)	0.00210 (0.955)	0.0265 (0.247)	-0.0266 (0.374)
L(3).Revenue per capita	0.151 (0.253)	0.0521 (0.328)	-0.0294 (0.663)	0.122 (0.376)	-0.0425 (0.181)	-0.106 (0.187)	0.139 (0.207)
GPS	-1590.5** (0.017)	184.7 (0.135)	72.27 (0.667)	-1835.8*** (0.002)	-141.1 (0.296)	87.64 (0.424)	80.67 (0.292)
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	641	641	641	641	641	641	641

p-values in parentheses, **p* < 0.1, ***p* < 0.05, ****p* < 0.01**Table 5** Effect of wind power deployment on employment—GPS covariate adjustment

Outcome variable: Change in employment by sector, normalized per 10.000 capita.

Explanatory variables: Generalised Propensity Score, New revenues from wind power deployment

	Total	Social Institutions	Mfr. of basic metals	Construction	Agriculture	Education	Retail and Repair
L.Revenue per capita	0.0210 (0.551)	0.0421 (0.142)	0.0404 (0.276)	0.0151 (0.634)	0.0121 (0.732)	-0.00307 (0.886)	-0.0114 (0.545)
L(2).Revenue per capita	-0.0271 (0.481)	0.0169 (0.662)	0.0645* (0.093)	0.0930*** (0.004)	-0.0568 (0.197)	0.0217 (0.491)	0.000254 (0.994)
L(3).Revenue per capita	0.0412 (0.310)	0.0274 (0.531)	0.0470 (0.414)	-0.0492 (0.168)	-0.0249 (0.455)	0.00336 (0.939)	-0.0140 (0.706)
GPS	-39.59 (0.802)	-139.1 (0.314)	(0.282) -229.1	-168.5 (0.105)	330.1** (0.010)	-11.60 (0.891)	-80.76 (0.486)
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	641	641	641	641	641	641	641

p-values in parentheses, **p* < 0.1, ***p* < 0.05, ****p* < 0.01

who own the turbines. This positive budget effect may affect sectors of the economy where these entrepreneurs procure some of their goods. The generated revenues might translate into increased local spending and small local enterprises may retain a significant share of the resulting profits. The local municipal budget might also be impacted by the payments made by wind power project developers ahead of the construction and by local taxes.²⁷ Finally, spill-over effects may result in changes in local sectoral employment.

We start by discussing the impact of the new revenues from renewable energy on the various components of the personal income in the municipality (see Table 3). Given our specification in per capita values, with the outcome in first differences, the coefficients are to be interpreted as the absolute monetary change per capita as a response to one extra euro per capita of additional revenues from wind power deployment. A positive coefficient for

²⁷ In Denmark, municipalities are rather large organizations. According to Blom-Hansen (2002) and Blom-Hansen (1998), they are responsible for a large share of public consumption (37% in 1990 and 45% in 2002) and can finance expenditure by independent local income taxation.

Table 6 Effect of wind power deployment on employment—GPS covariate adjustment

Outcome variable: Change in employment by sector, normalized per 10.000 capita.

Explanatory variables: Generalised Propensity Score, New revenues from wind power deployment

	Business Activities	Public Administration	Whole-sale (No vehicles)	Health activities	Transport	Asso-ciations and Culture	Mfr. of food
L.Revenue per capita	0.000359	−0.0240 (0.985)	0.00153 (0.936)	−0.00699 (0.744)	0.0230 (0.626)	−0.0477 (0.130)	0.0184 (0.422)
L(2).Revenue per capita	−0.0281 (0.360)	0.0310 (0.228)	−0.00650 (0.834)	0.00935 (0.616)	0.0319 (0.439)	0.0823 (0.129)	−0.0200 (0.419)
L(3).Revenue per capita	0.0128 (0.673)	0.0184 (0.518)	−0.0116 (0.719)	−0.00625 (0.843)	−0.0536 (0.505)	0.101 (0.178)	0.0650* (0.099)
GPS	71.26 (0.478)	−129.7 (0.275)	−45.31 (0.654)	22.29 (0.753)	163.3* (0.066)	−157.4 (0.110)	−0.471 (0.997)
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	641	641	641	641	641	641	641

p-values in parentheses, **p* < 0.1, ***p* < 0.05, ****p* < 0.01**Table 7** Effect of wind power deployment on employment—GPS covariate adjustment

Outcome variable: Change in employment by sector, normalized per 10.000 capita.

Explanatory variables: Generalised Propensity Score, New revenues from wind power deployment

	Sale and repair of vehicles	Mfr. of wood products	Hospitality	Finance and Insurance	Mfr. of chemicals	Mfr. of furniture	Communi-cation
L.Revenue per capita	−0.0420*** (0.005)	−0.00444 (0.859)	0.0344 (0.328)	0.00174 (0.857)	−0.0482** (0.022)	0.0178 (0.289)	0.00450 (0.654)
L(2).Revenue per capita	−0.0110 (0.438)	0.0466** (0.041)	−0.0595 (0.191)	−0.0000642 (0.994)	−0.00493 (0.720)	0.0128 (0.556)	−0.0213*** (0.003)
L(3).Revenue per capita	0.0187 (0.287)	0.0254 (0.316)	−0.159* (0.096)	0.00963 (0.511)	0.0486** (0.038)	−0.0418 (0.238)	0.0000996 (0.995)
GPS	−74.90 (0.193)	−162.5 (0.120)	38.12 (0.676)	17.89 (0.719)	90.49 (0.165)	162.7 (0.152)	−35.43 (0.467)
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	641	641	641	641	641	641	641

p-values in parentheses, **p* < 0.1, ***p* < 0.05, ****p* < 0.01

one of the lags indicates a one-off jump in income growth in that period, which returns to the baseline if the following coefficients are zero.

We expect the new revenues to directly impact personal income in two ways. First, in the study period, around two-thirds of Danish wind power was owned by individual citizens, for example, farmers (Gorroño-Albizu et al. 2019). In such a case, most of the net income generated by the power produced by the new turbines is reported as entrepreneurial income,²⁸

²⁸ Individuals who own their turbines and are not members of a partnership may consume part of the electricity they produce. This consumed electricity is not reported in the wind turbine register and cannot be considered in our analysis. In the example of the Skinnerup installation mentioned in Sect. 3, around 7% of the power produced is consumed by the farmer while the rest is sold to the grid.

Table 8 Effect of wind power deployment on employment—GPS covariate adjustment

Outcome variable: Change in employment by sector, normalized per 10.000 capita.

Explanatory variables: generalised propensity score, new revenues from wind power deployment

	Letting and Real Estate	Mfr. of mineral products	Mfr. of textiles	Utilities	Not stated	Fishing	Mining
L.Revenue per capita	−0.00383 (0.708)	0.0303** (0.044)	0.0183* (0.092)	−0.00470 (0.770)	0.00513 (0.616)	−0.0123** (0.033)	−0.00746* (0.065)
L(2).Revenue per capita	−0.0116 (0.463)	−0.0107 (0.435)	0.00597 (0.740)	−0.0102 (0.400)	−0.000836 (0.957)	0.000550 (0.926)	−0.00603 (0.323)
L(3).Revenue per capita	0.0122 (0.337)	−0.0191 (0.411)	−0.0208 (0.187)	0.0339** (0.013)	0.00297 (0.850)	0.0147** (0.032)	0.00846 (0.197)
GPS	−30.30 (0.538)	2.711 (0.975)	−87.49 (0.424)	34.58 (0.244)	48.75 (0.168)	28.33 (0.331)	52.41 (0.170)
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	641	641	641	641	641	641	641

p-values in parentheses, **p* < 0.1, ***p* < 0.05, ****p* < 0.01

a category of the personal income data (as explained in Sect. 4).²⁹ Second, according to Statistics Denmark, the private income from land rental is also reported in entrepreneurial income. There is hence a potential additional direct income effect if wind turbines are built on rented land.

Considering the total income effect, we observe a positive effect of the new revenues on total income, though the coefficient is only significant at the 10% level. However, looking in further detail at the impact on the reported categories, we see impacts for entrepreneurial income and income from social benefits. In the case of entrepreneurial income, we find that one additional euro of new revenues is associated with an increase in entrepreneurial income growth of 60 cents after one year.³⁰ This covers the income gain due to power produced by new wind turbines owned by individual entrepreneurs as well as the potential income gain for owners of land rented for wind power production. Additionally, we find a reduction in income from social benefits received in the municipality after three years. One additional euro of new revenues reduces the income received from public benefits by around 31 cents. This suggests that revenues from wind power deployment reduce the reliance of the population on social benefits.

In the second year after the connection of the new turbines to the grid, we cannot detect any additional increase in entrepreneurial revenue or any other income category with high significance. The new turbines involve new revenues in the first year of connection. These revenues continue in subsequent years but do not necessarily grow further. This suggests there is no impact of the first-year revenue increase on the income in the following year, in addition to the increase already achieved after the first year. Any additional impact observed on the other outcome variables in the second year or later would have to arise from a spillover on other sectors over time. Our results do not allow us to detect any such spillovers and

²⁹ Costs in connection with operating a personally owned business are eligible to be deducted in determining the taxable income.

³⁰ We observe the income declared to the tax authorities, meaning costs have been deducted.

suggest the impacts we observe are directly related to additional income received by wind turbine owners.

To analyze the impact of renewable energy deployment on the municipal budget, we have examined the budget spent by municipalities for current expenditures in the six main categories of municipal public spending, namely administration, education and culture, health care activities, traffic and infrastructure, housing and community amenities, public utilities. The results are reported in Table 4. We find that the total budget spent by municipalities for current expenditures increases in the first year following the connection of new turbines to the grid: an additional euro in revenue triggers 38 cents more in per capita spending. In more detail, this increase arises from increases in spending for administration (6 cents) and health care (26 cents more per capita). We explain this swift increase in some categories of the municipal budget in the year right after the new turbine connection by donations or payments made by wind project developers ahead of the construction of new turbines. Such agreements with municipalities contributed to facilitating local acceptance. As explained by Olsen (2022) (see Sect. 3), this was later formalized under the Green Scheme and the Green Fund. Municipalities may use this additional income to contribute to health care activities (the largest municipal budget category), maybe counteracting potential concerns about wind turbine syndrome³¹ or simply addressing budgetary needs that could not be addressed without these new revenues. The budget increase for administration might balance the additional workload of administrative procedures following the construction of new turbines.

Regarding the impact on employment, we expect direct and indirect effects of the installation of new turbines on local employment. The results are reported in Tables 5 and 8 (in the order of the sector description presented in Table 1). The outcome variable used here is normalized by 10,000 capita. In aggregate, we find that total employment in a municipality is not significantly impacted by new wind revenues: the coefficient 0.0210 is positive but not significant (see Table 5). When we examine employment sector by sector, we observe very limited impacts: significant coefficients are always smaller than 0.1 in absolute values. To better explain the order of magnitude that this represents, this means that absolute new wind revenues of 50,000 euros per capita in an average municipality with 10,000 workers induce a change of less than half a full-time position in employment in a given sector in this municipality.³² This is extremely small. In addition, job creation in some sectors is compensated by job losses in others. The largest employment increase we can detect is in the construction sector, where our results suggest that an additional revenue of 50,000 euros per capita results in approximately 0.45 full-time positions. We find smaller increases in the manufacturing of minerals and chemicals, but decreases in employment in communication, fishing and repair of motor vehicles cancel out the positive employment effects in aggregate. Various channels may explain these results. One possible explanation is that the individuals who see their entrepreneurial income increase use it to improve their private or professional installations by constructing new buildings. Or these same individuals may take advantage of their new income increase to reduce their activities in other sectors. In all cases, the

³¹ Whilst there does not seem to be evidence for long-term health impacts of wind turbines (European Commission, Joint Research Centre 2016), recent studies have found that the perceived threat of the former is a significant barrier to local acceptance of wind power projects (Devine-Wright and Batel 2017; Diogenes et al. 2020; Segreto et al. 2020). Notably, Leer Jorgensen et al. (2020) found this to be the case in a study conducted in the context of Denmark.

³² In our sample, average total employment is 10,758 and average new revenues are 49,699 €.

results at the sector level are very small. The absence of a strong impact on employment is consistent with the rest of the literature.

To conclude, coming back to the earlier motivation of this study, we find that wind power deployment does induce an increase in entrepreneurial income at the local level, accompanied by a decrease in received social benefits. We observe an increase in the total expenditures of municipalities after new turbines are installed. Regarding employment, wind power deployment seems to induce only very minor job creations in some sectors, compensated by similarly small job losses in others. In aggregate, we do not find any significant impact of new wind revenues on employment in the municipality. This is rather consistent with the finding from Costa and Veiga (2021) in the case of Portugal. Focusing on unemployment, they find a very limited impact in the operation phase of the turbines. The limited impact on employment can be explained by the fact that the sourcing of turbine parts and the construction activities are likely conducted by specialized firms moving across municipalities for individual projects. Concerning the debate on green growth or the double dividend, our study suggests that entrepreneurs investing in wind power projects benefit from local wind power deployment and that the dependence on social benefits is reduced for some people. However, in aggregate, local employment alone cannot be an argument for encouraging these projects, as job creation or losses are very limited and compensate one another among sectors.

6.2 Treatment-Effect Heterogeneity

It is reasonable to assume that the scale of wind power deployment matters, as utility-scale wind parks likely have other ownership structures and require more substantial construction efforts. Thus, to investigate whether there is treatment effect heterogeneity, we run our estimations, once excluding the observations below the 25th percentile of yearly capacity additions, and once excluding the observations above the 75th percentile of yearly capacity additions. We report the results in Appendix 3.

For employment, we continue to find no notable results in either specification, except for an increase in construction employment in both cases. However, a notable difference arises for the income and budget categories. We find the one-off change in income growth is mostly driven by smaller installations, whilst the associations with budget increases arise from larger installations.

For income, we find a larger effect on entrepreneurial income when excluding the largest 25% of yearly capacity additions. Local entrepreneurial income increases by 93 cents for every euro of new wind revenues if the revenue is generated by installations with capacities below the 75th percentile. This is very much in line with the anecdotal observations that smaller installations are more likely owned by local farmers and residents. However, we no longer find any effect on the public budget and income from social benefits.

Those effects reappear when we exclude the lowest 25% of yearly capacity additions. Interestingly, the effect on local entrepreneurship is no longer detectable. This indicates that the larger-scale installations are not owned by local farmers, but contribute strongly to the municipal budget through the green fund framework discussed above. Notably, we then also find a significant increase in municipal spending on infrastructure by 19 cents. This is in line with ex-ante expectations that larger wind parks require more substantial investment into surrounding infrastructure as opposed to small, locally owned installations.

7 Conclusions and Policy Implications

We analyze the local economic impacts of wind power deployment in the case of Denmark. We take advantage of the long Danish wind power experience to examine the effect of the revenues from new wind turbines on personal income, the municipal budget, and employment at the municipal level, potentially taking into account spill-over effects on the various economic sectors. Using the detailed data available, we build a panel and exploit the regional and time variations. We focus on the period 1993–2002 when the extension of wind power was the largest. To address potential endogeneity concerns, we employ a quasi-experimental set-up and use the generalized propensity score introduced by Hirano and Imbens (2004), which allows for causal inference with observational data.

We find positive associations of new wind power deployment on the personal per capita income on the municipality level in the year after the grid connection. This effect is mostly on entrepreneurial income and social benefits. The increase in entrepreneurial income is explained by the fact that a significant share of wind turbines are owned by individuals, for example, farmers. This is supported by estimations only considering smaller installations, where the effect on entrepreneurial income is larger. We observe an increase in the current expenditures of municipalities after new turbines are connected to the grid, particularly for health care and administration. This can be explained by donations and payments made by wind project developers to municipalities ahead of the construction. These impacts are driven by larger installations. We find that the addition of new wind turbines does not significantly increase employment in the municipality. Some sectors experience very small job creation but these are compensated by comparable losses in others. This is consistent with the findings from studies employing data from Portugal (Costa and Veiga 2021) and Spain (Fabra et al. 2024). We note, in particular, that our results are in line with Fabra et al. (2024) who find limited employment impacts of wind power deployment but can detect increases in income and public spending.

In terms of policy implications, our findings suggest that the political communication to support wind power deployment needs to be adjusted. Whilst our estimates imply that there are positive impacts of wind power deployment on the local economy, in particular on personal income and public spending, these are rather focused on specific groups and categories of public services. There is no significant impact on local aggregate employment. This alone cannot be a sufficient argument to address the not-in-my-backyard syndrome.

A limitation we could see in this study is the fact that we use data from before 2000. However, our analysis of how the size of the installations impacts the results allows us to draw implications that are still relevant today. The effects on local entrepreneurial income are largely driven by smaller installations, whilst the effects on public budget and social security arise from the deployment of larger ones. As turbines are becoming larger and more expensive (in particular with higher upfront investment costs), the role of local communities in these large-scale investments tends to diminish, which means that the positive local impact via entrepreneurial income is going to be strongly reduced. Given the current trend towards utility-scale projects, we suggest that offering residents to buy shares of the turbines (for example at cost price) would ensure they still directly benefit from the projects. Even if the NIMBY syndrome mainly arises out of non-market impacts (Jensen et al. 2014, 2018), such an involvement of the residents might help mitigate it.

Ideas for further research include exploring comparable sectoral changes across countries and examining the longer-term effects of large-scale installations. Indeed, examining if there are cross-country patterns might help policymakers anticipate and mitigate potential negative consequences in certain sectors if there are some. This could inform decisions in future wind power projects. The increase in the size of installations might also imply longer-term effects which would be worth analyzing.

Appendices

Appendix 1: Further Descriptives

See Tables 9, 10, 11 and 12.

Table 9 Onshore wind support policies in Denmark in the time period of the study

Date of commission	Support scheme
From 1984 to 2001	Electricity price paid to producers: 85% of the local retail price, excluding taxes
From 1991 to 2001	Fixed premium of 3.6 eurocents/kWh in addition to the previous scheme
Existing turbines bought before the end of 1999	Feed-in tariff of 8 eurocents/kWh for a number of full load hours, then feed-in tariff of 5.8 eurocents/kWh until the turbine is 10 years old, then premium of 1.3 eurocents/kWh or less until the turbine is 20 years old
From 2000 to 2002	Feed-in tariff of 5.8 eurocents/kWh for 22,000 full load hours, then premium of 1.3 eurocents/kWh or less until the turbine is 20 years old with a limit of 4.8 eurocents/kWh on the sum of market price and premium, and an additional premium of 0.3 eurocents/kWh for balancing costs

Source Jaureguy-Naudin (2010)

Table 10 Summary Statistics of key variables, by group of municipalities for the year 1993

Group	Observations	Population	Income, total (millions)	Entrepr. Income (millions)	Budget, total (millions)	Employment (in persons)	Agr. Surface (in hectar)	Avg. Wind Density (in W/m ²)	Stock of installed Turbines (in numbers)
1	31	14800.94 (11849.74)	269.18 (218.7201)	18.91 (16.86055)	43.68 (40.13262)	7818.16 (5990.789)	4910.08 (4551.78)	356.76 (48.64)	5.1 (7.28)
2	219	16276.71 (25859.13)	264.61 (430.3454)	22.87 (25.26555)	43.68 (85.4612)	8205.27 (12687.46)	11770.47 (6635.97)	394.82 (73.87)	13.74 (19.38)

Group 1: municipalities without any wind turbine installations in the time period of the study

Group 2: municipalities with wind turbine installations in the time period of the study

Standard deviation in parentheses

Table 11 Summary Statistics of the first difference of key variables per capita, by group of municipalities for the years 1993–94

Group	Observations	Population	Income, total (millions)	Entrepr. Income (millions)	Budget, total (millions)	Employment (in persons)
1	31	1.910813 (.1871147)	.0358137 (.0034084)	.0027862 (.0009169)	.0059252 (.0011061)	.9876874 (.0122036)
2	219	1.98447 (.1319038)	.0338739 (.0018571)	.0036793 (.0010226)	.006002 (.0007108)	.9893458 (.0007108)

Group 1: municipalities without any wind turbine installations in the time period of the study

Group 2: municipalities with wind turbine installations in the time period of the study

Standard deviation in parentheses

Table 12 Statistics of the difference in means of key variables between the two groups of municipalities for the year 1993

Variable	Mean	Mean	Difference	<i>T</i> -statistic	<i>P</i> -Value
	No New Revenue	New Revenue	In Mean		
Population	14800.9	16276.7	1475.8	−0.3	0.8
Income, total	269.2	264.6	−4.6	0.1	1.0
Entrepreneurial Income	18.9	22.9	4.0	−0.8	0.4
Budget, total	43.7	47.6	3.9	−0.3	0.8
Employment, total	7818.2	8205.3	387.1	−0.2	0.9
Agr. Surface	4910.1	11770.5	6860.4	−5.6	0.0
Avg. Wind Density	356.8	394.8	38.1	−2.8	0.0
Stock of installed Turbines	5.1	13.7	8.6	−2.5	0.0

Group 1: municipalities without any wind turbine installations in the time period of the study

Group 2: municipalities with wind turbine installations in the time period of the study

Appendix 2: Placebos

See Tables 13, 14, 15, 16, 17 and 18.

Table 13 Placebo of wind power deployment on the personal income—varied timing

Outcome variable: Change in income by type, normalised per capita.

Explanatory variables: Placebo Treatment: Revenues Three Years in the Future, GPS

	Total	Entre.	Wages	Pensions	Educ.	Benefits
Placebo	0.223 (0.583)	0.0331 (0.829)	0.0251 (0.890)	0.0629 (0.569)	0.00623 (0.436)	0.136 (0.248)
GPS	−316.0 (0.161)	−55.71 (0.609)	153.2 (0.302)	−220.5*** (0.000)	−1.345 (0.819)	59.11 (0.144)
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	680	680	680	680	680	680

p-values in parentheses, * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 14 Placebo of wind power deployment on the municipal budget—varied timing

Outcome variable: Change in budget by type, normalised per capita.

Explanatory variables: Placebo Treatment: Revenues Three Years in the Future, GPS

	Total	Admin	Educ.	Health	Housing	Utilities	Infra
Placebo	0.193 (0.244)	-0.0164 (0.713)	0.0155 (0.322)	0.111 (0.275)	-0.0189 (0.332)	0.0991*** (0.008)	-0.00891 (0.472)
GPS	-378.1*** (0.000)	-30.47* (0.059)	-9.689 (0.636)	-345.2*** (0.000)	3.113 (0.776)	37.50** (0.035)	-21.72 (0.250)
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	680	680	680	680	680	680	680

p-values in parentheses, * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$ **Table 15** Placebo of wind power deployment on employment—varied timing

Outcome variable: Change in employment by type, normalized per capita.

Explanatory variables: Placebo Treatment: Revenues Three Years in the Future, GPS

	Total	Social Institutions	Mfr. of basic metals	Construction	Agriculture	Education	Retail and Repair
Placebo	-0.0530 (0.356)	-0.0461* (0.095)	-0.0607 (0.266)	0.0159 (0.478)	-0.0341 (0.227)	-0.0118 (0.660)	0.0247* (0.079)
GPS	-38.05* (0.092)	-51.88** (0.020)	56.68** (0.031)	-0.240 (0.982)	-17.13 (0.275)	-4.687 (0.648)	-22.20* (0.097)
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	680	680	680	680	680	680	680

p-values in parentheses, * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$ **Table 16** Placebo of wind power deployment on employment—varied timing

Outcome variable: Change in employment by type, normalised per capita.

Explanatory variables: Placebo Treatment: Revenues Three Years in the Future, GPS

	Business Activities	Public Administration	Whole- sale (No vehicles)	Health activities	Transport	Asso- ciations and Culture	Mfr. of food
Placebo	-0.0297 (0.245)	0.0288 (0.273)	-0.0180 (0.521)	0.0161 (0.275)	0.0125 (0.524)	0.0339 (0.192)	0.000223 (0.992)
GPS	-30.94** (0.018)	12.52 (0.303)	-14.58 (0.213)	-1.865 (0.813)	29.66** (0.039)	-34.71** (0.023)	2.295 (0.884)
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	680	680	680	680	680	680	680

p-values in parentheses, * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 17 Placebo of wind power deployment on employment—varied timing

Outcome variable: Change in employment by type, normalised per capita.

Explanatory variables: Placebo Treatment: Revenues Three Years in the Future, GPS

	Sale and repair of vehicles	Mfr. of wood products	Hospitality	Finance and Insurance	Mfr. of chemicals	Mfr. of furniture	Communication
Placebo	0.00599 (0.407)	0.000433 (0.991)	0.0108 (0.514)	0.0107* (0.086)	0.0233*** (0.010)	0.00688 (0.764)	−0.00906 (0.216)
GPS	3.727 (0.529)	16.64 (0.202)	−0.612 (0.962)	−4.175 (0.406)	0.308 (0.970)	−25.65** (0.031)	−5.182 (0.199)
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	680	680	680	680	680	680	680

p-values in parentheses, * *p* < 0.1, ** *p* < 0.05, *** *p* < 0.01**Table 18** Placebo of wind power deployment on employment—varied timing

Outcome variable: Change in employment by type, normalised per capita.

Explanatory variables: Placebo Treatment: Revenues Three Years in the Future, GPS

	Letting and Real Estate	Mfr. of mineral products	Mfr. of textiles	Utilities	Not stated	Fishing	Mining
Placebo	0.0106 (0.495)	0.00164 (0.848)	0.0137 (0.392)	−0.00777** (0.046)	−0.0476** (0.049)	0.0101 (0.143)	−0.00291 (0.594)
GPS	−3.654 (0.532)	7.550 (0.471)	−3.446 (0.773)	−6.765* (0.060)	−11.23*** (0.003)	8.945** (0.017)	4.140 (0.202)
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	680	680	680	680	680	680	680

p-values in parentheses, * *p* < 0.1, ** *p* < 0.05, *** *p* < 0.01

Appendix 3: Treatment Effect Heterogeneity

Results Excluding the Top 25% of Yearly Capacity Additions

See Tables 19, 20 and 21.

Table 19 Effect of wind power deployment on the personal income—excluding the top 25%

Outcome variable: Change in income by type, normalised per capita.

Explanatory variables: Generalised Propensity Score, New revenues from wind power deployment

	Total	Entre.	Wages	Pensions	Educ.	Benefits
L.Revenue per capita	1.262 (0.140)	0.927** (0.024)	0.106 (0.770)	0.0774 (0.622)	−0.0124 (0.215)	−0.0416 (0.743)
L(2).Revenue per capita	−0.995 (0.404)	0.269 (0.557)	−0.473 (0.360)	0.204 (0.247)	−0.0153 (0.338)	0.353** (0.031)
L(3).Revenue per capita	0.0302 (0.964)	0.353 (0.441)	−0.417 (0.222)	0.104 (0.457)	0.00633 (0.731)	−0.171 (0.231)
GPS	−1492.4 (0.502)	−407.9 (0.707)	1615.2 (0.303)	−1465.7*** (0.004)	75.44 (0.176)	−333.2 (0.533)
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	458	458	458	458	458	458

p-values in parentheses, * *p* < 0.1, ** *p* < 0.05, *** *p* < 0.01

Table 20 Effect of wind power deployment on the municipal budget—excluding the top 25%

Outcome variable: Change in municipal budget by type, normalised per capita.

Explanatory variables: Generalised Propensity Score, New revenues from wind power deployment

	Total	Admin	Educ.	Health	Housing	Utilities	Infra
L.Revenue per capita	0.164 (0.452)	0.0445 (0.110)	0.0135 (0.802)	0.168 (0.179)	−0.0320 (0.648)	0.00923 (0.662)	−0.0304 (0.115)
L(2).Revenue per capita	0.511 (0.178)	0.0640 (0.196)	0.137 (0.149)	0.302 (0.273)	0.00555 (0.924)	−0.0314 (0.455)	0.0531 (0.122)
L(3).Revenue per capita	0.237 (0.235)	0.0155 (0.702)	0.0633 (0.490)	0.158 (0.466)	−0.0455 (0.271)	0.0550* (0.074)	−0.0296 (0.103)
GPS	−869.6 (0.275)	186.9 (0.231)	200.1 (0.401)	−1237.8* (0.086)	−85.08 (0.598)	172.5 (0.151)	−3.128 (0.968)
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	458	458	458	458	458	458	458

p-values in parentheses, * *p* < 0.1, ** *p* < 0.05, *** *p* < 0.01**Table 21** Effect of wind power deployment on employment—excluding the top 25%

Outcome variable: Change in employment by sector, normalised per 10.000 capita.

Explanatory variables: Generalised Propensity Score, New revenues from wind power deployment

	Total	Social Institutions	Mfr. of basic metals	Construction	Agriculture	Education	Retail and Repair
L.Revenue per capita	−0.0179 (0.917)	0.0913* (0.056)	0.0657 (0.246)	0.00525 (0.918)	−0.0493 (0.294)	−0.0204 (0.467)	−0.00393 (0.923)
L(2).Revenue per capita	0.295 (0.132)	−0.0128 (0.828)	0.0431 (0.492)	0.103** (0.026)	−0.0111 (0.839)	0.0805** (0.041)	0.0551 (0.361)
L(3).Revenue per capita	0.0463 (0.755)	0.0259 (0.640)	−0.00350 (0.949)	−0.0399 (0.349)	−0.0566 (0.184)	−0.0252 (0.561)	0.0393 (0.333)
GPS	−829.1 (0.183)	−170.1 (0.336)	59.15 (0.787)	−82.42 (0.474)	224.7 (0.153)	−103.5 (0.326)	−7.270 (0.961)
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	458	458	458	458	458	458	458

p-values in parentheses, * *p* < 0.1, ** *p* < 0.05, *** *p* < 0.01

Results Excluding the Bottom 25% of Yearly Capacity Additions

See Tables 22, 23 and 24.

Table 22 Effect of wind power deployment on the personal income—excluding the bottom 25%

Outcome variable: Change in income by type, normalised per capita.

Explanatory variables: Generalised Propensity Score, New revenues from wind power deployment

	Total	Entre.	Wages	Pensions	Educ.	Benefits
L.Revenue per capita	0.791* (0.096)	0.403 (0.111)	0.184 (0.666)	0.119 (0.275)	0.00242 (0.776)	0.0510 (0.618)
L(2).Revenue per capita	0.995 (0.223)	0.646* (0.064)	0.0791 (0.856)	0.0234 (0.895)	−0.000384 (0.972)	0.111 (0.326)
L(3).Revenue per capita	−0.392 (0.627)	−0.148 (0.759)	−0.155 (0.798)	0.263 (0.270)	−0.00487 (0.807)	−0.364** (0.014)
GPS	−814.5 (0.749)	−1781.9 (0.122)	3332.6* (0.066)	−1173.4** (0.028)	237.0*** (0.001)	−1021.7* (0.078)
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	505	505	505	505	505	505

p-values in parentheses, * *p* < 0.1, ** *p* < 0.05, *** *p* < 0.01**Table 23** Effect of wind power deployment on the municipal budget—excluding the bottom 25%

Outcome variable: Municipal budget by type, normalised per capita.

Explanatory variables: Generalised Propensity Score, New revenues from wind power deployment

	Total	Admin	Educ.	Health	Housing	Utilities	Infra
L.Revenue per capita	0.458*** (0.000)	0.0458** (0.014)	0.00836 (0.872)	0.277*** (0.008)	−0.00822 (0.746)	−0.0637 (0.291)	0.189*** (0.003)
L(2).Revenue per capita	0.344 (0.209)	0.0199 (0.673)	0.0380 (0.446)	0.258 (0.230)	−0.000883 (0.981)	0.0485* (0.054)	−0.0452 (0.100)
L(3).Revenue per capita	0.0366 (0.847)	0.0823 (0.292)	−0.0663 (0.555)	0.0471 (0.799)	−0.0346 (0.486)	−0.212** (0.017)	0.215* (0.062)
GPS	−2030.1** (0.013)	196.3 (0.283)	70.70 (0.767)	−2290.7*** (0.001)	−232.7 (0.214)	75.79 (0.699)	229.7** (0.033)
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	505	505	505	505	505	505	505

p-values in parentheses, * *p* < 0.1, ** *p* < 0.05, *** *p* < 0.01**Table 24** Effect of wind power deployment on employment—excluding the bottom 25%

Outcome variable: Change in employment by sector, normalised per 10.000 capita.

Explanatory variables: Generalised Propensity Score, New revenues from wind power deployment

	Total	Social Institutions	Mfr. of basic metals	Construction	Agriculture	Education	Retail and Repair
L.Revenue per capita	0.183 (0.332)	0.0308 (0.335)	0.0526 (0.170)	0.0251 (0.363)	0.0536* (0.078)	0.0206 (0.483)	−0.0207 (0.457)
L(2).Revenue per capita	0.162 (0.226)	0.0350 (0.414)	0.0716 (0.118)	0.0870** (0.032)	−0.0760* (0.097)	0.0153 (0.632)	−0.0156 (0.639)
L(3).Revenue per capita	−0.108 (0.696)	0.00725 (0.903)	0.0603 (0.443)	−0.0482 (0.202)	−0.0548 (0.365)	−0.0186 (0.808)	−0.0517 (0.306)
GPS	−281.9 (0.673)	−318.1* (0.097)	−323.3 (0.316)	−197.0 (0.144)	441.1*** (0.008)	102.6 (0.362)	−163.0 (0.340)
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	505	505	505	505	505	505	505

p-values in parentheses, * *p* < 0.1, ** *p* < 0.05, *** *p* < 0.01

Appendix 4: Dose-Response functions

In addition to the covariate adjustment, we estimate dose-response functions, as described in Bia and Mattei (2008), Hirano and Imbens (2004), and employed in Bia and Mattei (2012). Conceptually, it estimates the conditional expectation of the outcome, as a function of the treatment and the propensity score Bia and Mattei (2008). The treatment effect function is derived as the derivative of the estimated conditional expectation of the outcome with respect to the treatment variable, calculated at each level of the treatment. For more details, we refer the reader to the excellent discussions of the methods provided in the original articles.

The method has been employed in other recent studies in environmental economics to exploit variations in treatment intensity (Sitko et al. 2021; Barath and Fertő 2024). The dose-response function on the left-hand side of the graphs depicts the expected outcome, in our case the level change in income, budget, and employment, as a function of the treatment level. On the right-hand side, the treatment effect function is depicted, which is derived as the first derivative of the dose-response function. We follow (Barath and Fertő 2024) to have the richest possible specification. Thus, we include polynomials of the third degree and interaction terms of treatment and propensity in the estimation of the conditional expectation function, allowing a cubic relationship between outcome and treatment.

We show the plots for the outcomes with meaningful results from the previous sections. Thus, we limit the number of graphs and keep the article readable. Given that the effects are estimated individually per treatment interval, we lack the statistical power to precisely estimate the effects separated by treatment level. Thus, whilst complementing the analysis of treatment effect heterogeneity, the results should be interpreted with caution. Thus, we report the results with a bootstrapped confidence interval at the 10% level. Treatment effect functions on the 5% level are not significantly different from zero for any treatment level, caused by very wide confidence bands.

In line with the regression results, we are not able to detect a significant treatment effect on total personal income with statistical significance. It seems the effect on personal income is declining with increasing treatment levels. This is in line with the anecdotal observation that smaller turbines are often owned locally by farmers, whereas larger wind parks generating high revenues are most often owned by larger businesses, who do not necessarily report their income in the municipality. We find a similar pattern for entrepreneurial income. Still, the point estimates support the results from the regression analysis in the previous section, especially the observations that the effect on entrepreneurial income decreases with higher revenues from utility-scale installations. We specifically can only detect a significant treatment effect for very low revenue levels. For the reliance on social benefits, our data does not allow us to estimate the treatment effect for each level with sufficient precision to draw notable conclusions.

For the other outcomes, we also do not find significant results and patterns in the dose-response functions, in line with the regression results. We plot the functions for the main outcomes, total municipal budget, and total employment below (Figs. 7, 8, 9, 10 and 11). For the results on individual budgets, again we lack statistical power to identify effects for individual treatment levels.

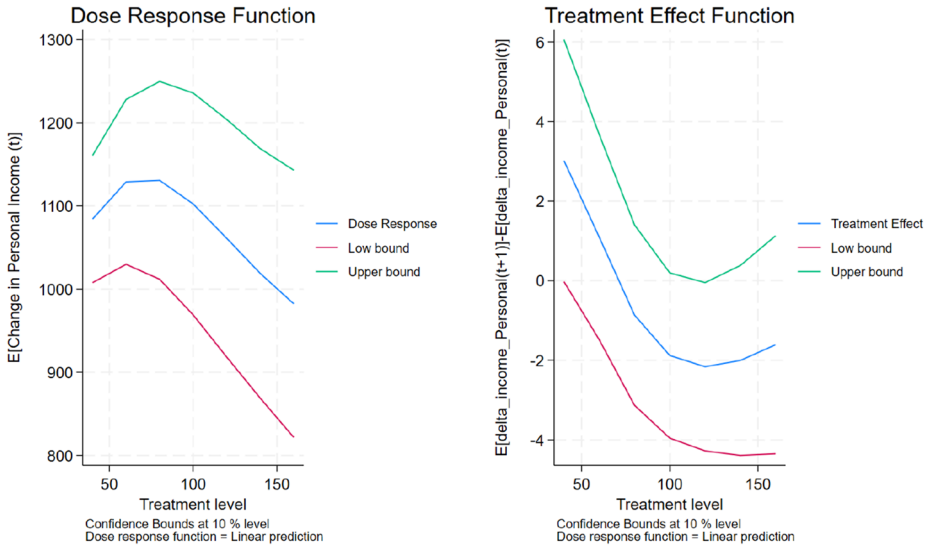


Fig. 7 Dose-response and treatment effect—total income

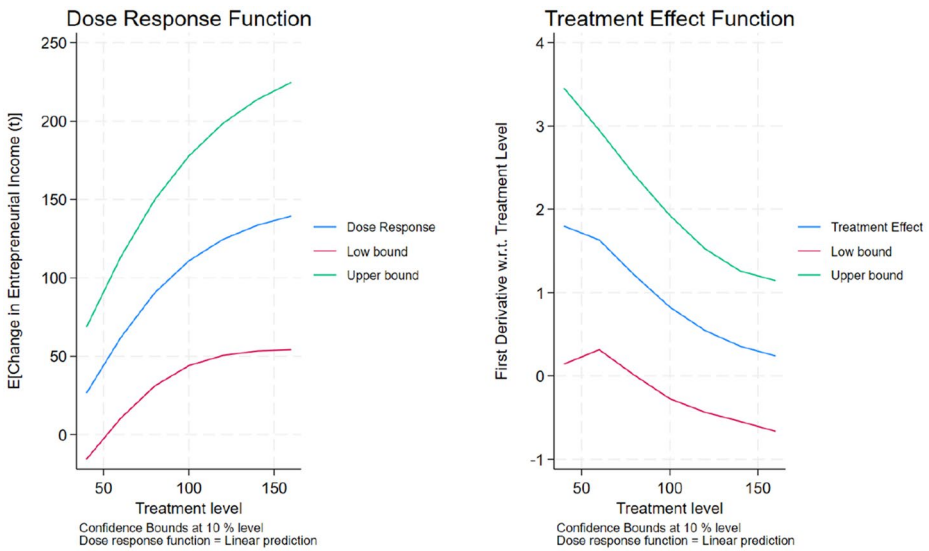


Fig. 8 Dose-response and treatment effect—entrepreneurial income

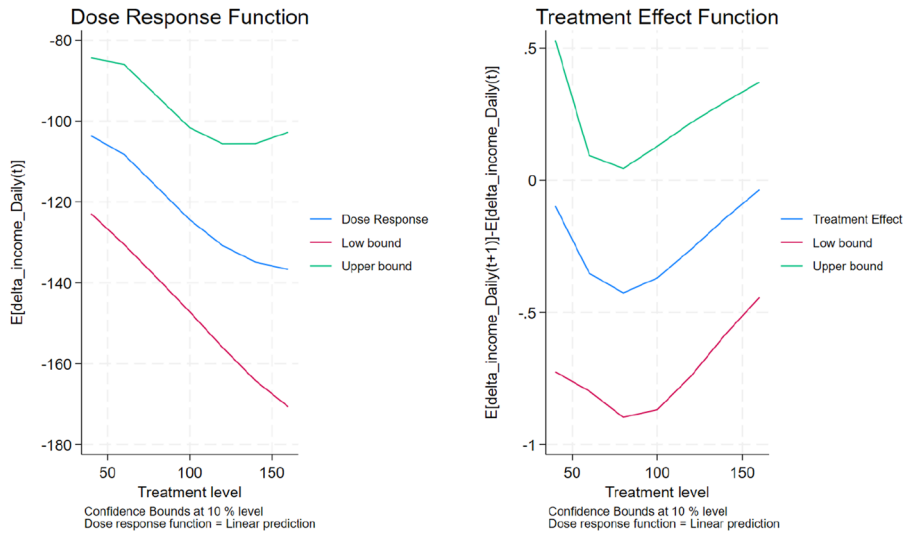


Fig. 9 Dose-response and treatment effect—daily benefits

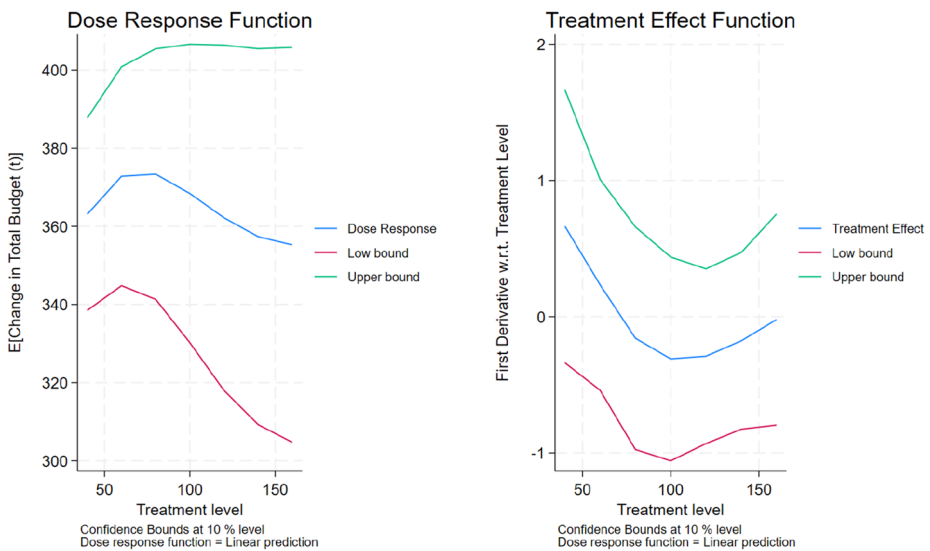


Fig. 10 Dose-response and treatment effect—total municipal budget

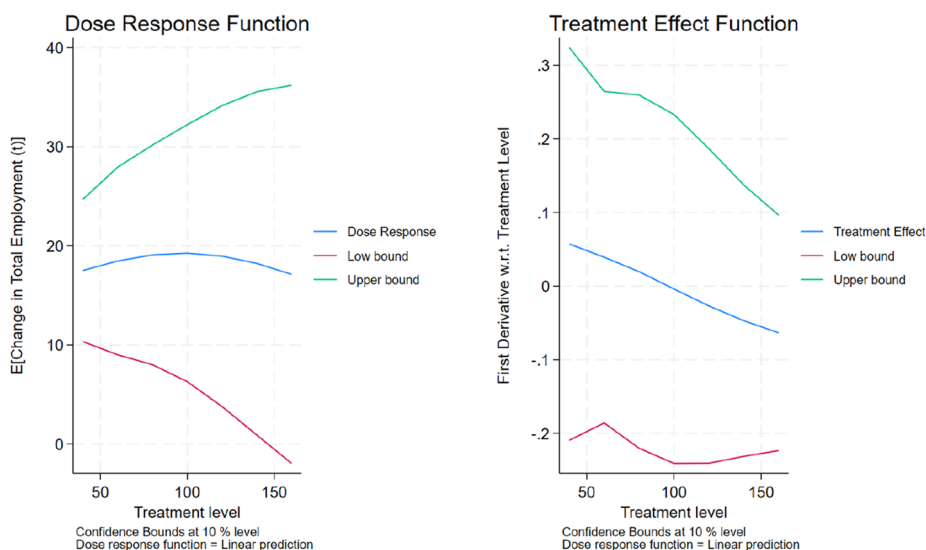


Fig. 11 Dose-response and treatment effect—total employment

Appendix 5: Direct Inclusion of Controls

See Tables 25, 26, 27, 28, 29 and 30.

Table 25 Effect of wind power deployment on the personal income—direct inclusion of controls

Outcome variable: change in income by type, normalized per capita

Explanatory variables: new revenues from wind power deployment, lagged wind density, lagged stock of installed turbines, lagged unemployment rate

	Total	Entre.	Wages	Pensions	Educ.	Benefits
L.Revenue	0.823*	0.590**	0.0579	0.0815	-0.0174**	0.0780
	(0.099)	(0.031)	(0.862)	(0.394)	(0.028)	(0.426)
L(2).Revenue	0.575	0.613*	0.0737	0.0448	-0.00659	0.211**
	(0.495)	(0.062)	(0.836)	(0.772)	(0.533)	(0.042)
L(3).Revenue	-0.178	-0.0730	-0.125	0.228	0.00509	-0.276**
	(0.771)	(0.867)	(0.776)	(0.167)	(0.744)	(0.037)
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	641	641	641	641	641	641

p-values in parentheses, **p* < 0.1, ***p* < 0.05, ****p* < 0.01

Table 26 Effect of wind power deployment on the municipal budget—direct inclusion of controls

Outcome variable: change in municipal budget by type, normalized per capita

Explanatory variables: new revenues from wind power deployment, lagged wind density, lagged stock of installed turbines, lagged unemployment rate

	Total	Admin	Educ.	Health	Housing	Utilities	Infra
L.Revenue per capita	0.361*** (0.000)	0.0438*** (0.006)	0.00301 (0.937)	0.256*** (0.000)	−0.0101 (0.779)	−0.0682 (0.267)	0.132* (0.096)
L(2).Revenue per capita	0.306 (0.218)	0.0149 (0.741)	0.0601 (0.170)	0.217 (0.252)	0.00462 (0.900)	0.0278 (0.230)	−0.0294 (0.346)
L(3).Revenue per capita	0.121 (0.346)	0.0576 (0.273)	−0.0227 (0.732)	0.0976 (0.463)	−0.0435 (0.193)	−0.107 (0.183)	0.137 (0.219)
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	641	641	641	641	641	641	641

p-values in parentheses, **p* < 0.1, ***p* < 0.05, ****p* < 0.01**Table 27** Effect of wind power deployment on employment—direct inclusion of controls

Outcome variable: change in employment by sector, normalized per 10.000 capita

Explanatory variables: new revenues from wind power deployment, lagged wind density, lagged stock of installed turbines, lagged unemployment rate

	Total	Social Institutions	Mfr. of basic metals	Construction	Agriculture	Education	Retail and Repair
L.Revenue per capita	0.00685 (0.848)	0.0339 (0.232)	0.0493 (0.175)	0.0159 (0.613)	0.00242 (0.943)	−0.00616 (0.771)	−0.0128 (0.500)
L(2).Revenue per capita	−0.0395 (0.309)	0.00988 (0.791)	0.0694* (0.072)	0.0928*** (0.003)	−0.0624 (0.147)	0.0191 (0.549)	−0.000976 (0.978)
L(3).Revenue per capita	0.0305 (0.462)	0.0269 (0.550)	0.0355 (0.560)	−0.0481 (0.187)	−0.0188 (0.573)	0.00128 (0.977)	−0.0129 (0.724)
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	641	641	641	641	641	641	641

p-values in parentheses, **p* < 0.1, ***p* < 0.05, ****p* < 0.01**Table 28** Effect of wind power deployment on employment—direct inclusion of controls

Outcome variable: change in employment by sector, normalized per 10.000 capita

Explanatory variables: new revenues from wind power deployment, lagged wind density, lagged stock of installed turbines, lagged unemployment rate

	Business Activities	Public Administration	Whole-sale (No vehicles)	Health activities	Transport	Associations and Culture	Mfr. of food
L.Revenue per capita	−0.00149 (0.937)	−0.0168 (0.413)	0.00746 (0.686)	−0.00687 (0.748)	0.0253 (0.594)	−0.0474 (0.132)	0.0219 (0.360)
L(2).Revenue per capita	−0.0282 (0.336)	0.0360 (0.153)	0.000353 (0.991)	0.00937 (0.616)	0.0353 (0.397)	0.0812 (0.124)	−0.0184 (0.441)
L(3).Revenue per capita	0.0220 (0.450)	0.0226 (0.446)	0.00265 (0.937)	−0.00758 (0.810)	−0.0508 (0.534)	0.104 (0.157)	0.0665* (0.082)
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	641	641	641	641	641	641	641

p-values in parentheses, **p* < 0.1, ***p* < 0.05, ****p* < 0.01

Table 29 Effect of wind power deployment on employment—direct inclusion of controls

Outcome variable: employment by sector, normalized per 10.000 capita

Explanatory variables: new revenues from wind power deployment, lagged wind density, lagged stock of installed turbines, lagged unemployment rate

	Sale and repair of vehicles	Mfr. of wood products	Hospitality	Finance and Insurance	Mfr. of chemicals	Mfr. of furniture	Communication
L.Revenue per capita	−0.0405*** (0.007)	−0.00178 (0.941)	0.0289 (0.400)	0.00121 (0.899)	−0.0499** (0.018)	0.00659 (0.681)	0.00544 (0.578)
L(2). Revenue per capita	−0.0104 (0.460)	0.0479** (0.031)	−0.0634 (0.166)	−0.000353 (0.966)	−0.00572 (0.680)	0.00452 (0.833)	−0.0212*** (0.007)
L(3). Revenue per capita	0.0190 (0.292)	0.0216 (0.403)	−0.162* (0.091)	0.0106 (0.477)	0.0465** (0.040)	−0.0471 (0.160)	−0.00000814 (1.000)
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	641	641	641	641	641	641	641

p-values in parentheses, **p* < 0.1, ***p* < 0.05, ****p* < 0.01**Table 30** Effect of wind power deployment on employment—direct inclusion of controls

Outcome variable: change in employment by sector, normalized per 10.000 capita

Explanatory variables: new revenues from wind power deployment, lagged wind density, lagged stock of installed turbines, lagged unemployment rate

	Letting and Real Estate	Mfr. of mineral products	Mfr. of textiles	Utilities	Not stated	Fishing	Mining
L.Revenue per capita	−0.00249 (0.808)	0.0306** (0.039)	0.0151 (0.154)	−0.00618 (0.702)	0.00309 (0.763)	−0.0117** (0.029)	−0.00876* (0.062)
L(2).Revenue per capita	−0.0112 (0.466)	−0.0103 (0.482)	−0.000564 (0.976)	−0.0108 (0.365)	−0.00198 (0.899)	0.000393 (0.950)	−0.00650 (0.331)
L(3).Revenue per capita	0.0121 (0.341)	−0.0205 (0.387)	−0.0228 (0.125)	0.0356** (0.011)	0.00395 (0.793)	0.0116* (0.076)	0.0109 (0.144)
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	641	641	641	641	641	641	641

p-values in parentheses, **p* < 0.1, ***p* < 0.05, ****p* < 0.01**Supplementary Information** The online version contains supplementary material available at DOI <https://doi.org/10.1007/s10640-025-00982-2>.

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Declarations

Competing Interests The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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