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ORIGINAL PAPER

Socioeconomic impacts of wind farms in small and rural areas: a case study in North-eastern Spain

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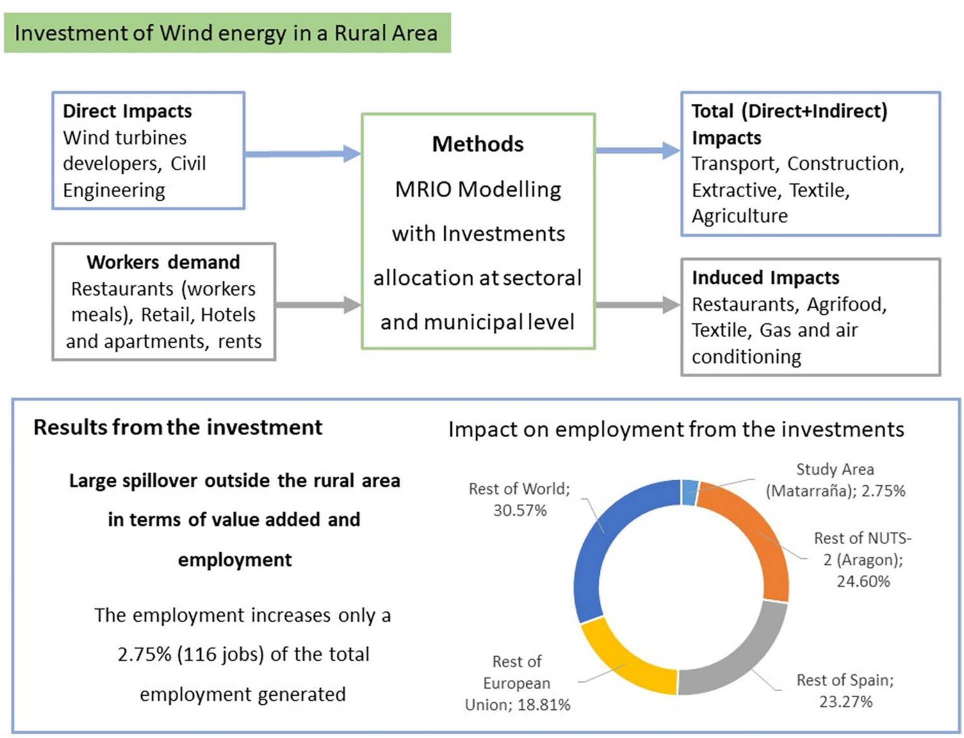
Abstract

It is now clear that the adoption of renewable energies is of high importance in addressing climate change. In this sense, this work aims to contribute to the discussion on the net socioeconomic effects of renewable energy deployment on the places, especially rural areas, in which the plants are installed. To this end, we particularise the analysis to the case of wind power in an Aragonese county: Matarraña, in North-eastern Spain. We use the input–output approach to account for the local direct, indirect, and potentially induced effects in terms of value added and employment. Unlike previous versions of this methodology, the multiregional input–output method, with a high level of spatial and sectoral disaggregation, allows us to identify the place and the economic sector in which those effects occur. This high granularity of both the data and the model we use constitutes one of the main contributions of the paper. At the same time, we take into account the temporal sequence of the effects, an aspect that is essential in this case. Our results provide information on the issue of local acceptance of renewable energy deployments. Specifically, they suggest that, in the absence of other compensations, wind power does not seem to generate meaningful economic value or employment in the area (Matarraña county) where the windmills are installed.

Graphical abstract



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Introduction

Green electrification of the economy is a necessity for the decarbonisation process, which in turn is necessary to slow down climate change. For this to be possible, we need a significant increase in the production of renewable energies. However, these energies bring along some undesired modifications to the territories (residential, landscape and ecological impact, noises, etc.) in the sites (which are usually rural areas) where the plants are installed. While it is clear that renewables are necessary, the question that arises is how this energy transition could also be positive for the socioeconomic future of the actual inhabitants of the territory where plants really are. In some areas of installation adverse effects of renewable energy plants, with environment, landscape, and local development impacts have been documented (just in the Iberian Peninsula, e.g. Prados 2010; Delicado et al. 2016; Serrano et al. 2020; Rodríguez et al. 2024) and so there can be and there is a debate on where the private and social costs and benefits of installing and using renewable energies—in this case, wind power—occur. This paper aims to contribute to the debate by estimating the magnitude of certain potential local benefits that the energy transition could bring to the residents of the affected territories, and to put them into the context of what those benefits are globally. Specifically, it focuses on quantifying the impact of this transition for wind energy in terms of two measurable variables: Employment and income.

In our view, three different aspects need to be addressed. First, the central problem is that the benefits fall on society as a whole, while the costs mainly affect the territories in which these wind plants are located. Indeed, from the point of view of the local population, their share in the positive effects for the planet (global-level emission's reduction) could clearly be compensated by the potential negative impacts suffered in the area where the windmills are installed. Second, economic impacts are quite different in the short run than in the long one. The construction phase is likely to involve more economic activity, whilst the later phase of operation and maintenance does not result in a significant increase compared to the previous situation. Third, the positive effects could take place in economic sectors and firms far away from the place that bears all the costs. Even though there are clear positive net effects for society as a whole, a fair calculation of compensations is needed.

To do this, the input–output approach has proven to be appropriate. From the very beginning of studies on the effects of these kinds of investments, input–output methodology (Leontief 1941) has been widely used. This methodology is able to quantify all the relations among sectors and agents, and it takes into account the direct, indirect, and potentially induced effects. The direct effect is the one caused in the first moment, the indirect effect is the one derived from the intersectoral relations, and finally, the induced effect is generally defined as the effect provoked by income changes (Miller and Blair 2021).

As indicated by Garrett-Peltier (2017), these input–output models are usually used for impact analyses because of their transparency, the few assumptions they need, and because they are easily replicable and updatable when new data appear. In the issue at hand, it is necessary that the data and the model can deal with high sectoral and spatial granularity, and this is precisely the main advantage that we can achieve from multiregional input–output models. To sum up, our main goal is to build a replicable model capable of evaluating the effects of the new investments associated with new wind plants in a very specific place. Such a model is then exportable to other territories, provided a detailed dataset is also available.

As a case study, this paper examines the effects that would occur if the project for the installation of 214.5 MW of wind energy plants in Matarraña county, a rural area in North-eastern Spain, were to take place, see BOE (2022). Matarraña county, in the southeast of the Autonomous Community of Aragon, represents almost 2% of its territory (Fig. 1). It has marked topographical diversity along the north–south axis. In the north, there is more abundant agricultural land, and in the south, more mountainous forest land predominates. Between them lies the central area with softer orography and an equitable distribution of both types of land use. We use this regional subdivision, which also responds to sociodemographic and economic structure differences. Matarraña county has been subdivided into three smaller areas: Northeast, Centre, and Southwest.

The demographic evolution of the county so far this century is in line with the average of the Aragonese counties (almost no population growth), although we should highlight a hopeful trend that is still to be consolidated. Against this global framework, though, Matarraña Southwest shows the most concerning data in terms of the well-known demographic "emptying" and general ageing, whilst the subregion Matarraña Centre is a relatively positive case in this respect in the context of Aragon.

The region of Matarraña stands out for its agricultural and touristic orientation, especially long-term (or

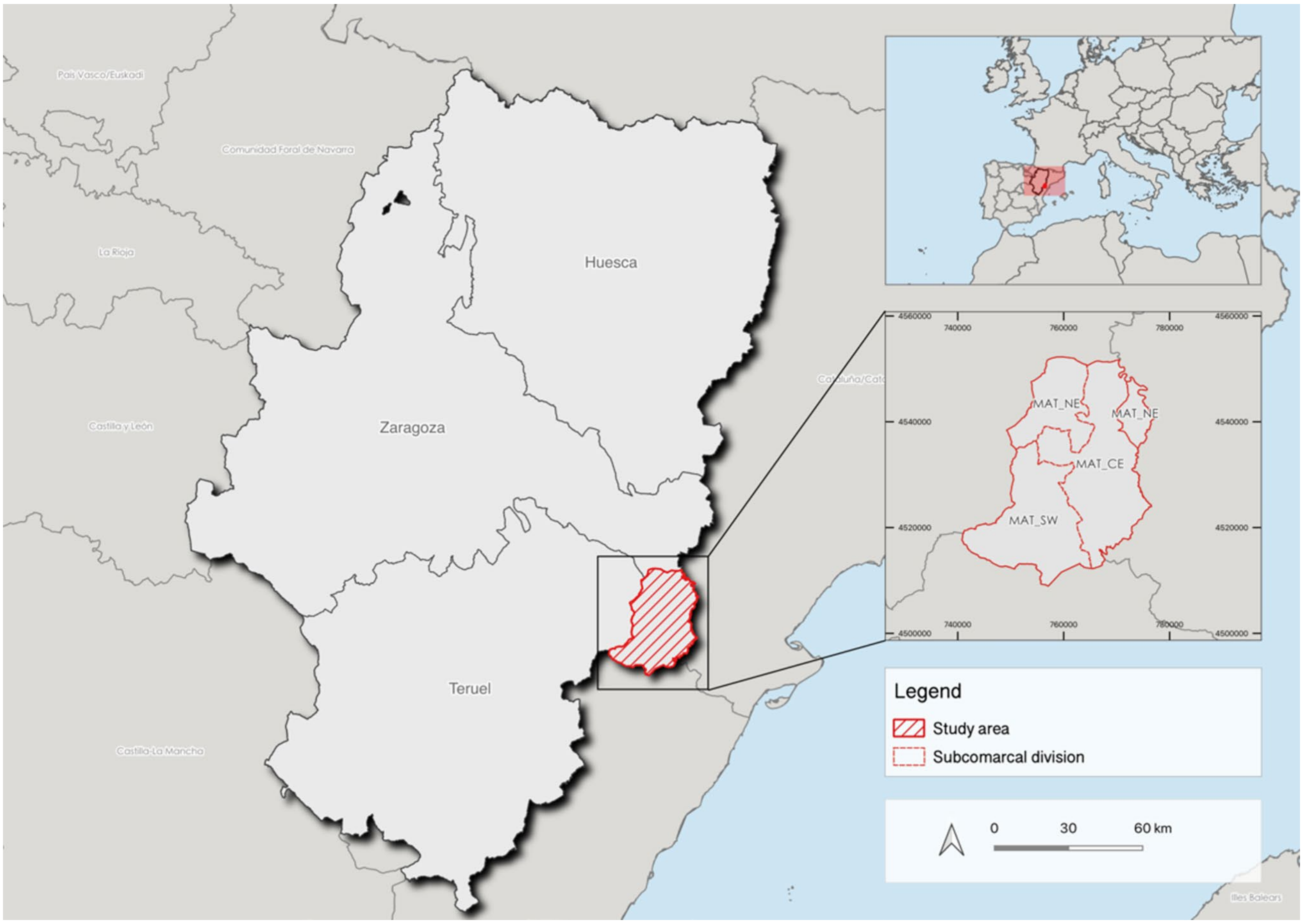

Fig. 1 Study area. *Source*: Own elaboration

residential) tourism. Using more granular data on municipal employment, we can qualify this global image in the sense that the Northwest and Southwest specialise more in the agro-livestock sector, and Matarraña Centre presents a tourism specialisation similar to the Aragonese regions that stand out most in that aspect. From this first broad view, it is worth mentioning the agrifood specialisation of Matarraña Centre and the relative weight of the tourism sector in Matarraña Southwest.

The recent historical evolution of employment does not show large overall variations, although the sectoral gross value-added data seem to indicate a certain growing trend towards the trade, hospitality, and construction sectors. With the historical data we have, there seems to be a certain trend towards the tourism sector, especially residential. The most hopeful aspect regarding employment is that its activity rate (estimated with respect to the total population) lies in the upper third of Aragon's counties.

Disposable income and production (measured through gross value added) have experienced an evolution similar to the average of Aragon and Spain, with a certain growing trend since 2016. The disposable income data logically show a smaller oscillation because they contain monetary transfers from the State, but it is important to note that, judging by the comparative figures, a good part of the capital income from economic activities does not stay in the region. Although this is not a specific aspect of this region, it is an issue that influences the possibilities of future economic development.

Previous research has examined the socioeconomic repercussions associated with the establishment of wind farms (Cazcarro et al. 2024); however, their analysis has been constrained to assessing regional and/or national effects. In this study, a multiregional input–output approach is developed to evaluate the implications within the rural municipalities where the wind farms are deployed. To do this, two primary data sources support this analysis: Aggregated regional data for the economic and demographic variables and census and economic data disaggregated by sectors. The municipal level of disaggregation has been possible thanks to the Aragonese Institute of Statistics (IAEST, 2022) data. This includes employee affiliation data by sectors at the municipal level, enabling detailed geographic analysis.

This work reveals three key categories of impacts: (1) The direct and indirect effects of the investment, (2) the induced effects linked to the arrival of workers, and (3) the long-term impacts. The investment in the wind power project is expected to generate 5 million euros of value added (VA) and 116 annual full-time equivalent employments (AFTEE) in Matarraña county during the construction phase (6 months). Additionally, during the construction phase, the induced effect, which includes spending on local goods and services by workers, provides 880 thousand euros of VA and 26 additional AFTEE, which represents a modest but significant economic boost, particularly to the hospitality and retail sectors. Despite these short-term impacts, long-term local benefits remain limited; the projected annual economic impact includes 0.3 to 1.5 million euros from windmill leasing and 0.43 million euros from taxes, leading to a total annual tax income of 0.7 to 2 million euros once the wind farms are fully operational.

The structure of the paper is organised as follows: Section "Literature review" reviews the relevant literature; Section "Materials and methods" details the data sources and methodology; Section "Results" presents the main results; Section "Policy implications and discussion" delves into policy implications and discussion; and Section "Concluding remarks" concludes with final remarks.

Literature review

The implementation of wind farms in rural areas has generated abundant literature in recent years. As Zografos and Saladié (2012) point out, it is difficult to compare the cost of landscape destruction with the benefits that can be obtained from these projects. In particular, there is recent and very interesting literature on the local valuation of these investments, either through revealed preferences (Germeshausen et al. 2023) or stated preferences (Sundt and Rehdanz 2015). In both meta-analyses, the dilemma of local costs and widespread benefits shows up in public direct responses or in indirect choices and valuations. Various works have tried to estimate the net local balance of this type of investment. Fabra et al. (2023, 2024) exhaustively collected data from all wind turbine plants built in Spain and found that, in retrospect, between 2006 and 2020, wind turbines did not contribute significant employment to the local communities where they were deployed. The same conclusion was reached very recently by Shoeib et al. (2022) when they massively analysed all the wind deployments carried out so far this century, mostly in rural counties of the USA. In Germany, however, there were hardly any areas with low population density and poorly diversified economies. In this case, wind turbines had no choice but to compete with industrial and urbanised land uses. But still, May and Nilsen (2015) analysed the wind expansion between 2000 and 2010 in Germany, reaching similar conclusions to those of the two aforementioned papers. On the contrary, biomass-based projects are able to contribute to income and employment in rural communities in China (Du and Takeuchi 2019). They also say that wind energy-based projects have the potential to increase income and employment in the primary industry in rural areas.

The potential negative effects mentioned in the introduction (such as visual impact or noise) have been studied in the literature (Nadaï and Labussière 2009; Cowell 2010), and the concern about the location of wind farms has existed for a long time (Ek and Persson 2014). "Landscape externalities" (in their terms) have also been analysed (Meyerhoff et al. 2010). A negative visual impact is considered a negative externality. Some literature uses housing sales prices to reveal local preferences for views. In this sense, Gibbons (2015) found that wind farm visibility reduces local house prices, indicating a high visual cost, in that case for England and Wales. Krekel and Zerrahn (2017) also found temporal negative externalities regarding landscape, in this case in Germany. Similarly, Mei et al. (2023) studied the impact of the installation of wind farms on land value, finding significant impacts on land transaction prices in China. However, for the specific case of offshore wind power and its impact on local fisheries, Shimada et al. (2022) found that offshore wind farms installed in Japan are unlikely to disrupt local fisheries. Aksoy et al. (2023) evaluated the impacts of wind turbines on vegetation and soil cover in some cases in Turkey.

The impacts of local governments' wind policies have been analysed by Xu et al. (2023) for the case of China, and they found that supply-side policies are more effective than environmental-side policies for the development of wind power. Adami et al. (2022) conclude that the development of the wind energy industry is highly linked with other policies, such as those governing technology, environment, and infrastructure. In a context close to that of this study, Duarte et al. (2022) found great heterogeneity between agents and territories, both in the evaluation of impacts and in their hopes, with the type of management model playing a critical role in social acceptance.

Regarding the methodology used, as stated in the introduction, the input–output approach is a versatile tool that has been widely used to assess various environmental and economic impacts. For instance, Duarte et al. (2002) applied the hypothetical extraction method to identify key water-related sectors, and Almazán-Gómez et al. (2024a) also use the hypothetical extraction method to analyse the socioeconomic trade-offs of decarbonisation in European regions. Cazcarro et al. (2013) calculated the water footprint of the tourism sector in Spain. In Ferng (2009), the input–output methodology is used to analyse a scenario of ecological footprints. Carbon emissions have also been analysed using input–output models (Akpan et al. 2015; Banerjee 2021; Ueda 2022). Additionally, energy sector has also been analysed with the input–output methodology, such as in Pan and Köhler (2007), Liang et al. (2010), and Sarkar et al. (2023). Other studies have also analysed the energy sector using computable general equilibrium models based on input–output techniques (Eisenbarth 2017; Blackburn and Moreno-Cruz 2021). Regarding employment effects, Garrett-Peltier (2017) assessed global employment impacts of renewable energies compared to those of fossil fuels. Tomás et al. (2023) answer a similar question for the Spanish economy. Lastly, Laplaza-Abadía and Simón-Fernández (2019) focus their study on the Aragon region.

The multiregional input–output (MRIO) approach is based on Isard's (1951) interregional input–output (IRIO) model, which extends Leontief's original approach by incorporating interregional linkages for two or more regions. Because the IRIO model requires detailed data on interregional transactions and assumes constant interregional trade relations, MRIO models have been developed to produce consistent estimates of both intra- and interregional transactions (Chenery 1953; Moses 1955; Leontief and Strout 1963; Polenske 1970, 1980; Hewings and Jensen 1987; Miller and Blair 2021). According to Tukker and Dietzenbacher (2013), the MRIO model is a specific type of IRIO model, as it only requires knowledge of the production flow from sector i to sector j in region r, irrespective of the region from which that production originates. It is worth mentioning that the MRIO model has been employed to assess international trade, economic integration, the impact of emissions, and the effects of disasters and war on regions (Dietzenbacher et al. 1993; Dietzenbacher et al. 2019; Llano 2009; Temurshoev 2010; Boundi Chraki 2017; Wang et al. 2021; Su et al. 2021; Ferreira et al. 2023; Almazán-Gómez et al. 2023; Almazán-Gómez et al. 2024b). In this study, the MRIO analysis is employed to estimate the direct, indirect, and induced effects of wind farm installation.

Materials and methods

The methodology employed in this study is designed for replication using regional input–output tables, allowing for its application in diverse contexts. The first subsection provides a description of the input–output table used and the process of adapting it to the region under analysis. This is followed by an explanation of the input–output model applied, which is then utilised to obtain the results presented in the subsequent section.

The input–output table

The starting point is a multiregional input–output table (MRIOT) for the Ebro river basin (Almazán-Gómez et al. 2019, 2021), in North-eastern Spain. Note that our study area is a small rural area, so we must rearrange the MRIOT to be able to offer results at this scale and capture the sectoral and geographical interdependencies of our study area. This is not a problem, as the MRIOT can be geographically disaggregated to the municipal level (Almazán-Gómez et al. 2021).

The initial MRIOT consists of five main regions of the Ebro river basin (Almazán-Gómez et al. 2019) and 69 sectors by region, plus 3 supra-regions that represent Rest of Spain, Rest of European Union, and Rest of the world.

For the disaggregation into a higher spatial level, we have constructed an auxiliary matrix that contains the sectoral weightings of each industry included in the MRIOT for the study area. Then, the strategy developed by Almazán-Gómez et al. (2021) is applied: Let's denote these weights as vector $\mathbf{s^r}$. Then, the matrices $\mathbf{Z^{rs}}$, which represent the intersectoral trade between zones '**r**' and '**s**', were obtained as shown in Eq. (1). These sub-matrices make up the matrix of intermediate inputs **Z** of the new MRIOT. In Eq. 3, **Z** is the matrix of intermediate inputs in the Ebro basin, $\hat{\mathbf{s}}^{\mathbf{r}}$ is the diagonal vector of weightings for region '**r**', and $\hat{\mathbf{s}}^{\mathbf{s}}$ is the diagonal vector of weightings for region '**s**'. A similar method applying the relevant percentages is used to allocate the needed vectors (output, value added, taxes, employment, etc.) and to obtain the final demand matrix.

$$\hat{\mathbf{s}}^{\mathbf{r}}\mathbf{Z}\hat{\mathbf{s}}^{\mathbf{s}} = \mathbf{Z}^{\mathbf{rs}}; \quad \hat{\mathbf{s}}^{\mathbf{r}}\mathbf{Y} = \mathbf{Y}^{\mathbf{r}} \tag{1}$$

The application of this equation (or distribution method) to the rows and columns of the MRIOT for the ERB assumes that each sector of each zone sells and buys according to its own weighting and to the equivalent ratios for the region as a whole. With this, we have a MRIOT with 69 industries. Note that the energy sector up to now is only one sector, classified in division 35, NACE Rev. 2 (Eurostat 2008a), "Electricity, gas, steam, and air-conditioning supply," covering electricity and gas, as well as the different steps of the production process and different production technologies. More details on the geographical disaggregation can be found in the Online Appendix.

For disaggregating the electricity sector, we follow the work of Langarita et al. (2021), where an input–output table was constructed from the supply and use tables, and a disaggregation of the energy and electricity sectors was previously addressed. Making use of SABI, 2017, and other regional and national sources, such as the supply and use tables (SUTs) for Spain (NSI 2019, see also Eurostat, 2008b). More details on the electricity sector disaggregation can be found in the Online Appendix.

The investment vector

As regards the disaggregation of the final demand, and particularly the investment vector, we should highlight that, first, we ensured that Matarraña is split within the whole of Aragon based on information from the shares of Matarraña's final demand and economic activity within the region. Furthermore, we conducted interviews (a Delphi-type method) with a dozen practitioners and technicians who have installed or are installing such wind generators in the area, enquiring about the absolute numbers and shares in the regions versus other territories regarding investments, expenditure, and direct hiring (in construction, lodging, local services, etc.). A key insight checked for investment is that for the estimated investment, around 200 workers from the Matarraña region itself and nearby regions would be contracted over 6 months in the construction sector to prepare the area, while a similar number of workers would come from other areas (including some more specialised technicians). Investments follow the sectoral structure derived from the specific and detailed information from the Ministry of Industry, Trade and Tourism of the Government of Spain (AEE-MINCOTUR 2019) linked to the Aragonese sectoral classification by Cazcarro et al. (2024). The share of investments received by the Matarraña region versus other regions is based on the work of Almazán-Gómez et al. (2019), being a key assumption the share of construction expenditure (local or external hiring, etc.). Based on our interviews, the domestic share would range between 30 and 70%, typically being 50%. We evaluate those ranges in different scenarios to obtain more robustness. All in all, the geographical distribution of the investment vector is depicted in Table 1.

The impact of workers arrival to the study area (induced effect)

The knowledge about the sector from previous studies and interviews provides further insights into an assumption with the average estimated values, which is that part of the jobs generated in other regions that requires workers to work on-site. Specifically, 200 workers need to move to the study area to work for 6 months. Each of them spends €25 per day in the hospitality industry. Additional expenditures of €5 per day per worker are assumed for retail businesses and other sectors; this amount is distributed using household final demand as a pattern. In addition, we assume that workers pay local inhabitants a total of €240,000 for accommodation rents (shared apartments). This amount corresponds to the following insight, converted into an assumption: An apartment is rented (€500 per month) for every 2.5 people on average. These amounts totalled over 6 months are €1,320,000 ((500 * 200 * 6/2.5) + ((25 + 5) * 200 * 30 * 6) = 240,000 + 1,080,000 = 1,320,000). These figures represent an additional demand shock, and the results in terms of output, value added, and employment are shown in Section "Effect due to the arrival of workers during the construction period".

Table 1 Distribution of the investment vector (thousands of euros and %). *Source*: Own work

Reg. code	Reg. name	Investment (thousand euros)					Spatial share of the investment (%)				
		S30%	S40%	S50%	S60%	S70%	S30%	S40%	S50%	S60%	S70%
MAT	Matarraña	5898	7308	8718	10,128	11,538	2.76	3.41	4.06	4.72	5.38
BAR	Bajo Aragon	2306	2291	2276	2260	2244	1.08	1.07	1.06	1.05	1.05
BAC	Bajo Cinca	745	740	735	730	725	0.36	0.35	0.34	0.34	0.34
HUE	Huesca	3940	3914	3888	3861	3834	1.83	1.82	1.81	1.80	1.79
RZA	Zaragoza	53,069	52,710	52,351	51,993	51,634	24.73	24.57	24.41	24.24	24.07
RTE	Rest of Teruel	2237	2222	2207	2192	2177	1.05	1.04	1.03	1.02	1.01
ARA	Aragon	68,198	69,186	70,174	71,163	72,152	31.78	32.25	32.72	33.18	33.64
CAT	Catalonia	15,223	15,120	15,017	14,914	14,811	7.10	7.05	7.00	6.95	6.91
NAV	Navarre	6903	6857	6811	6764	6717	3.22	3.20	3.18	3.15	3.13
PVA	Basque Country	3565	3541	3517	3493	3469	1.66	1.65	1.64	1.63	1.62
RIO	La Rioja	1270	1262	1254	1245	1237	0.60	0.59	0.58	0.58	0.58
RSP	Rest of Spain	75,143	74,636	74,129	73,621	73,113	35.04	34.80	34.56	34.32	34.09
ESP	Spain	170,304	170,603	170,902	171,200	171,499	79.41	79.54	79.67	79.81	79.95
ROEU	Rest of EU	35,797	35,556	35,315	35,073	34,831	16.70	16.58	16.46	16.35	16.24
ROW	Rest of World	8398	8341	8284	8227	8170	3.92	3.89	3.86	3.84	3.81
TOT	TOTAL	214,500	214,500	214,500	214,500	214,500	100.00	100.00	100.00	100.00	100.00

The input–output model

Let's $\mathbf{Z}$ depicts a block matrix with $\mathbf{Z}^{rs}$ matrices that capture the inter-industry relations between regions r and s. Therefore, each submatrix $\mathbf{Z}^{rs}$ is an n-by-n matrix where n is the number of sectors accounted for. The matrices on-diagonal $\mathbf{Z}^{rr}$) capture the domestic intermediate flows (intraregional intermediate flows). By contrast, all off-diagonal matrices ($\mathbf{Z}^{rs}\forall$ r $\neq$ s) contain the inter-industry interregional flows where Z_{ij}^{rs} is the value of the production generated by sector i in region r that is being used as an intermediate input by sector j in region s (interregional inter-industry flow). Let's also denote $\mathbf{x}$ as the vector that depicts the gross output of each industry (which includes fixed capital consumption). Then, dividing each element of the intermediate input's matrix (Z_{ij}^{rs}) by the gross output of the sector j of the region s (x_j^s), we obtain the matrix of technical coefficients, in matrix form: $\mathbf{A} = \mathbf{Z}\hat{\mathbf{x}}^{-1}$. Each element of this matrix (A_{ij}^{rs}) informs about the requirements that the industry j of region s has from the industry i from region r to produce an output of 1 monetary unit (one million euros in our case). Let's call the matrix of value added generated as $\mathbf{M}$, where each component M_{cj}^{s} depicts the component c of value added (gross operating surplus, compensation of employees, other net taxes of production, etc.) associated with industry j from region s. For the sake of simplicity, let's assume there are no other components on the supply side and aggregate the matrix $\mathbf{M}$ to obtain a vector called $\mathbf{m}\left(m_j^s = \sum_c M_{cj}^s\right)$. Then, dividing each element of the $\mathbf{m}$ vector by the gross output, we obtain, for each sector of each region, the share of value added over the total output, let's call this vector as $\mathbf{v} = \left\{\frac{m_j^s}{x_j^s}\right\}$. Note that this vector ($\mathbf{v}$) is a vector of value-added requirement per unit of output. This can also be done with the employment, where vector $\boldsymbol{l}$ depicts the level of employment needed per unit of output $\boldsymbol{l} = \left\{\frac{e_i^r}{x_i^r}\right\}$. Finally, the final demand matrix, usually called $\mathbf{Y}$, is also a matrix of blocks of matrices $\mathbf{Y}^{rs}$ where each component Y_{id}^{rs} represents the final demand that agent d (households, government, non-profit institutions serving households (NPISHs), etc.) of region s makes from industry i of region r. Let's also aggregate all columns in the final demand matrix to obtain a column vector ($\sum_{sd} Y_{id}^{rs} = y_i^r \rightarrow \mathbf{y}$), then, the main equations are the following:

$$\mathbf{x} = \mathbf{A}\mathbf{x} + \mathbf{y} \rightarrow \mathbf{x}(\mathbf{I} - \mathbf{A}) = \mathbf{y} \tag{2}$$

$$\mathbf{x} = (\mathbf{I} - \mathbf{A})^{-1}\mathbf{y} \tag{3}$$

$$\Delta\mathbf{x} = (\mathbf{I} - \mathbf{A})^{-1}\Delta\mathbf{y} \tag{4}$$

$$\Delta\mathbf{m} = \hat{\mathbf{v}}(\mathbf{I} - \mathbf{A})^{-1}\Delta\mathbf{y} \tag{5}$$

$$\Delta\mathbf{e} = \hat{\boldsymbol{l}}(\mathbf{I} - \mathbf{A})^{-1}\Delta\mathbf{y} \tag{6}$$

Equation (3) depicts the output level associated with a final demand. Equation (4) shows the changes in the output when the final demand changes, while Eqs. (5) and (6) depict the changes in the value added and employment, respectively. In Eqs. (5) and (6), the hat (^) depicts a diagonalised vector. Note also that $(\mathbf{I} - \mathbf{A})^{-1}$ is the well-known Leontief inverse, where each component indicates the increase in the output of industry j (of region s) to supply one unit of final demand of industry i (of region r). In the same way that $(\mathbf{I} - \mathbf{A})^{-1}$ is a matrix of output multipliers, $\hat{\mathbf{v}}(\mathbf{I} - \mathbf{A})^{-1}$ is a matrix of value-added multipliers that depict the (gross) value added generated in industry j (of region s) per unit of final demand of industry i (of region r); and $\hat{\boldsymbol{l}}(\mathbf{I} - \mathbf{A})^{-1}$ is the matrix of employment multipliers which identify the number of employees (annual full-time equivalent) of industry j (of region s) needed per unit of final demand of industry i (of region r).

Using the investment vector described in the previous subsection as a shock ($\Delta\mathbf{y}$), the Eq. (4) results in a column vector of changes in the gross output $\left(\Delta\mathbf{x} = \left\{x_i^r\right\}\right)$ that informs changes in the gross output of each industry of each region, as a consequence of this shock. In the same way, Eqs. (5) and (6) denote also column vectors that inform about changes in value added and employment also at the sector-region level. These equations are used to calculate the effects of the investment (Section "Direct and indirect effects of the investments (goods and services)") and also to calculate the induced effect[1] (associated with the arrival of workers (Section "Effect due to the arrival of workers during the construction period")). The assumptions regarding this induced effect are explained in Section "The impact of workers arrival to the study area (induced effect)".

Results

This section shows the impacts on output, value added, and employment associated with the construction of a wind farm of 214.5 MW in the study area. The plan DGA (2021) implies the installation of 214.5 MW, and the investment needed for this is 214.5 million euros (DGA

[1] More about the induced effect can be found in Emonts-Holley et al. (2021) and Kratena (2021). These works illustrate the ways of calculating multipliers, and the necessary cautions needed when interpreting them.

2021; Cazcarro et al. 2024). The results are shown in three separate subsections. The first subsection shows the impacts associated with the investment, while the second subsection is dedicated to the induced effect. Despite the income generated from the installation of the wind farm, this facility will generate permanent income in the region, such as taxes and rental income; this is discussed in the third subsection.

Direct and indirect effects of the investments (goods and services)

Results shown in this section have been calculated using Eqs. (4–6), and the vector of changes in final demand ($\Delta\mathbf{y}$) used is the investment shock, which has been calculated assuming a total of 214.5 million euros ($\sum_i \Delta y_i = 214.5$) and distributed as indicated in Section "The investment vector". Table 2 shows the impact of the investment due to the construction of the wind farms. As it can be seen, the investment of 214.5 million euros to develop the wind power industry in the study area generates about 207 million euros and supports more than 4 thousand annual jobs globally. We could alternatively also indicate that the employment multipliers, as an aggregate, reveal that for every million euros of investment, around 0.7 jobs are supported in the study area, 4.8 in the rest of Aragon, 4.6 in the rest of Spain, 3.7 in the rest of the EU, and 6 in the rest of the world.

To ensure a correct interpretation of the results, it is important to note that the methodology used is a comparative statics approach based on multipliers derived from an input–output model. A demand shock is assumed—representing the investment required to construct the wind farm plant—and the model provides the changes in production, value added, and employment required to supply that demand across different regions. As a result, the figures are not time-dependent but are associated solely with this specific demand shock. The effect on employment is measured through annual full-time equivalent employments (AFTEE), quantifying the total workforce necessary to meet the new demand. This does not necessarily indicate the creation of new jobs but rather reflects the labour input needed to support the existing employment levels required by the investment.

The regions included in the input–output approach vary significantly in terms of economic scale and productive capacity, so direct comparisons between them should be made cautiously. However, it is noteworthy that, even though the wind farm plant is planned to be installed in a very specific area, Matarraña county, the region captures only a small fraction of the total value added and employment generated. Specifically, the study area accounts for approximately 2.5% of the total value added and about 2.75% of the total employment generated by the investment. This limited local impact can be attributed to the productive structure of the region, which is predominantly rural and lacks the industrial capacity to supply the extensive resources and inputs required for such direct investment. As a result, most of the necessary goods and services are sourced from other regions or countries, and the local economy does not capture significant spillover effects from the investment.

The investment results in a limited impact within the study area: Around 5.2 million euros of value added and supporting approximately 116 AFTEE. These figures represent about 4.33% of the total annual value added generated in Matarraña county, and 3.57% of the employment level. In contrast, the largest portion of value added is generated outside the local region, with significant shares accruing to the rest of Aragon (approximately 74 million euros), the rest of Spain (approximately 56 million euros), and notably, a substantial portion generated abroad. The rest of the European Union and the rest of the world contribute approximately 45 million euros and 27 million euros in value added, respectively. This pattern is also reflected in the employment figures, where a significant number of AFTEE are supported outside the local region, including 793 AFTEE in the rest of the EU and 1289 AFTEE in the rest of the world.

These results highlight the highly globalised nature of the supply chain for the products and services required to undertake this investment. The construction of the wind farm relies heavily on inputs sourced from outside the local economy, indicating a dependence on international markets,

Table 2 Socioeconomic effects of investment by region. *Source*: Own work

	Output (thousands of euros)	Value added (thousands of euros)	Employment (AFTEE)
Study area (Matarraña)	7264	5173	116
Rest of NUTS-2 (Aragon)	189,120	73,982	1037
Rest of Spain	162,739	55,643	981
Rest of European Union	117,319	45,109	793
Rest of World	73,098	27,429	1289
TOTAL	549,540	207,336	4216

especially within Europe and globally. This dependency reduces the potential local economic benefits and suggests that the investment does not significantly stimulate the local economy in terms of value added or employment.

Going deeper in the analysis, Table 3 shows the study area results at the sector level. The sector that would benefit the most by far is the construction sector, followed by, at a large distance, several industrial sectors (e.g. textile industry, clothing manufacturing, and leather and footwear industry; and extractive industries), by transport, by agriculture, livestock, hunting, and related services, and by the wood and cork industry, which already falls below 10 thousand euros of value added. The sectoral impacts in the rest of Spain and globally (study area + rest of Spain + rest of Europe + rest of the world) can be seen in the Online Appendix.

Effect due to the arrival of workers during the construction period

Let us move to the evaluation of the effects from the direct hiring of local workers and from the effects of workers coming from other areas, who reside in the area of installation during the construction phase.

Taking into account the information provided in Section "The investment vector", the total demand shock is €1,320,000, and the effects of this shock, region by region, are shown in Table 4, where changes in output, value added, and employment are depicted.

As it can be seen, this effect has a much larger impact on the study area. The value added generated here is slightly more than €800,000 and supports 26 AFTEE. In the rest of the NUTS-2 region of Aragon, 2 AFTEE are supported and 3 in the rest of Spain. These figures represent approximately 0.74% of value added and 0.8% of employment in Matarraña county, in relation to its baseline economic indicators. The figures used in the assumptions are relatively rough estimates, but they are the best we have been able to obtain through interviews and insights from technicians and workers involved in such investments. However, note that since the model used is linear, even if these figures vary slightly in absolute terms, the results would have the same expected distribution among regions and sectors. Note also that, although in absolute terms the main impacts of this induced effect on value added and employment fall outside the study area, those effects do not have a significant impact in relative terms.

Going deeper into the results, Table 5 shows the most relevant impacts in the study area at the sectoral level. As expected, the hospitality sector is emerging as the main beneficiary, with more than €700,000 in terms of value added and 18 AFTEE. Additionally, other sectors show notable

Table 4 Arrival/visit of workers effect. *Source*: Own work

	Output (thousands of euros)	Value added (thousands of euros)	Employment (AFTEE)
Study area (Matarraña)	1131	884	26
Rest of NUTS-2 (Aragon)	479	172	2
Rest of Spain	451	159	3
Rest of European Union	105	42	1
Rest of world	107	45	4
TOTAL	2273	1302	36

Table 3 Effects of investment in the study area at the sector level. *Source*: Own work

Sector	ΔVA	ΔAFTEE
Construction	5078	114.24
Textile industry, clothing manufacturing, and leather and footwear industry	17	0.12
Extractive industry	16	0.04
Transport	15	0.43
Agriculture, livestock, hunting, and related services	10	0.38
Wood and cork industry	9	0.04
Forestry and logging and Fisheries and aquaculture	8	0.04
Food industries, beverage manufacturing, and tobacco industry	4	0.08
Vehicle and fuel trade; repair shops	3	0.08
Machinery, electronic, and optical equipment	3	0.05
Metal, furniture, footwear, etc.	2	0.04
Editing, sound, programming & financial services and other personal services	2	0.07
Manufacture of pharmaceuticals and other non-metallic mineral products	1	0.02
Insurance and pension plans	1	0.02
Gas and air conditioning	1	0.00

Value added in thousand euros and employment in AFTEE

Table 5 Effects at the sector level—construction time—workers effect. *Source*: Own work

Sector	Value added (thousands of euros)	Employment (AFTEE)
Hospitality	712.98	18.45
Retail trade	156.70	7.43
Food industries, beverage manufacturing, and tobacco industry	4.18	0.08
Forestry and logging and Fisheries and aquaculture	1.71	0.01
Textile industry, clothing manufacturing, and leather and footwear industry	1.56	0.01
Gas and air conditioning	0.92	0.00
Vehicle and fuel trade; repair shops	0.91	0.02
Electricity production of conventional thermal—origin GAS	0.88	0.00
Insurance and pension plans	0.56	0.01
Education, health, and sanitation	0.53	0.02

gains in value added: Retail trade, food and beverage industries, forestry, and the textile industry. It should be noted that, although all sectors benefit from indirect effects (spillover effects), these effects tend to extend beyond the limits of the study area.

Long-term effects

While the previous results capture the socioeconomic impacts during the six-month construction phase, the maintenance of the wind farms represents a sustained economic impact over their operational lifespan. In this subsection, we present a preliminary assessment of these ongoing impacts during the maintenance period. This assessment considers several factors: Taxes (specifically special taxes), rental income, and the employment required for wind farm maintenance.

The projected annual figures for rental income and tax revenues are derived from two primary sources. First, the leasing of windmills is expected to generate between €0.3 million and €1.5 million per year (at current values) in rental income. Second, municipal authorities are projected to collect approximately €0.43 million per year in business taxes related to wind farm operations. Consequently, the cumulative annual financial impact is estimated to range between €0.7 million and €2 million, once all the wind farms are fully operational.

Regarding employment and value added after installation, we can estimate the regular impact based on employment and value added per megawatt (MW) of installed capacity. It is anticipated that approximately 10 workers per year will be employed directly in the wind energy sector for maintenance activities. Additionally, a similar number of workers are expected to be employed in auxiliary sectors such as construction, repairs, and other services associated with ongoing maintenance. This results in a total of around 20 AFTEE positions sustained annually during the maintenance phase.

It is important to note that these jobs may not necessarily be filled by residents of the study area due to the specialised skills required for wind farm maintenance and associated services. This could limit the direct employment benefits to Matarraña county unless efforts are made to train and employ local workers.

Policy implications and discussion

We consider this work an important piece in addressing the complex challenges of the energy transition and regional development in European countries, involving not only questions of employment and value-added generation, but also other potential damages and benefits (see e.g. Munday et al. 2011), which often create local opposition to wind energy projects. For that, there are articles that consider key acceptance factors for those wind projects from social science and interdisciplinary research (Hübner et al. 2023), the extent to which financial benefits may be one way to counteract a lack of community support (Knauf 2022), citizens' willingness to invest in wind projects (Sirr et al. 2023) and the role of local political figures and social norms in local responses (Karakislak and Schneider 2023). Issues of population fixation/attraction and landscape preservation are also usually under debate. Accordingly, MITECO (2023) approved a law in which it commits to making the conservation of natural heritage compatible with the deployment of renewable energies.

As the transition to renewable energy continues to develop, the integration of wind farms into rural landscapes presents both opportunities and challenges. Next, we delve into the policy implications arising from such investments, particularly in the context of rural areas where the direct and indirect benefits for local communities are not always evident. Understanding the dynamics of wind farm investments in rural areas reveals a spectrum of implications, particularly when local communities do not obtain substantial direct or indirect benefits. A fundamental element in this discourse is the participation of local capital in these projects, which could increase the capabilities of local actors to mitigate the potential adverse effects. Moreover, they could benefit from the operational profits of the parks.

Compensation systems should be designed to ensure residents receive adequate compensation for any losses incurred. These compensations, developing initiatives beyond merely financial ones, negotiated between developers and local representatives, ensure that a portion of the benefits—such as infrastructure development, educational opportunities, or other community-centric projects—directly enhance the local quality of life. In parallel, the significance of fostering local employment and skill development cannot be underestimated. Policies that prioritise job creation for local residents in the construction and maintenance phases of wind farms not only provide immediate economic benefits but also contribute to building a skilled workforce.

Going further from the direct implications obtained here, we are sensitive to the voices that call for claiming that the implementation of these projects also demands a participatory approach. Engaging local communities in the planning and decision-making processes ensures that their voices are heard and their concerns are addressed. This participatory planning cultivates a sense of shared responsibility and mutual benefit, which is fundamental for the long-term success of renewable energy initiatives. In such view, given that private and social benefits and costs can be very unevenly distributed (spatially and across individuals), a portion of the revenues obtained from these projects should be allocated for direct reinvestment in local communities, supporting public services and infrastructure development. Environmental care is integrally involved in this narrative, as efforts should be made to mitigate environmental damage, for instance in terms of local biodiversity, landscape preservation, and land use, in the development of renewable energy. Finally, the establishment of transparent monitoring systems is essential, incorporating feedback mechanisms that allow for continuous adaptation and responsiveness to community needs.

Concluding remarks

The imperative of green electrification in combating climate change has brought renewable energy sources to the forefront. Wind power plants, a significant player in the transition, hold the promise of reducing global emissions. While these installations are pivotal in the ecological transition, they come with local impacts encompassing residential, ecological, and landscape concerns. Our study focused on understanding how this ecological transition could benefit the socioeconomic well-being of residents in the areas hosting these plants, emphasising employment and income as key indicators.

Our results suggest that, with current value chains, wind energy projects would mainly offer short-term economic benefits during the construction phase, contributing modestly (up to 5%) to local employment and value added, primarily in sectors like hospitality and retail. However, this short-term boost does not necessarily translate into sustained economic growth in these areas. Most of the positive socioeconomic effects extend beyond local boundaries, emphasising the need for well-designed compensation systems to enhance local benefits and counteract potential negative impacts. In the long term, the primary income for the affected territories seems to be mostly coming from land rents and taxes. Limitations to this work are avenues for future research and have mostly to do with the exploration of the dynamics associated with such investments, which this type of MRIO models are not fully suited to capture, especially for the long-run with changes in technical or employment coefficients. They also have to do with the full valuation of local and global benefits and costs in the economic, social, and environmental dimensions, both in the short and in the long term.

This study highlights the importance of conducting exhaustive assessments on the socioeconomic impacts of renewable energy projects, particularly in rural communities. While renewable energy undoubtedly offers broader societal benefits, the challenge of providing equitable compensation to the regions affected by these projects persists as an unresolved issue. The evidence, as the estimates obtained here regarding the direct and indirect jobs associated with the investments, is growing in suggesting that if the argument is solely focused on job creation, it is not always strong for rural areas. In this regard, the positive net effects of wind farm investments in rural areas could be significantly enhanced through different strategies. As it has been suggested in some literature and social movements (and as mandated and implemented in some countries), these projects could harmonise the reduction of carbon emissions with community well-being, for example by ensuring local involvement, equitable compensation, environmental care, and transparent governance and so on.

So, to conclude, the findings of this research reveal the intricate balance between environmental imperatives and the varied socioeconomic realities at both local and global scales. This complexity requires a carefully calibrated approach in implementing renewable energy solutions, ensuring that both environmental goals and community necessities are adequately addressed.

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Author's contribution JB, GR, and IC initiated the research question design. GR and MA made an initial analysis of the data. JB and RL developed the literature review. MA, IC, and RL designed the methodology and data curation. All authors contributed to the analysis of the results and their implications, as well as in the writing, editing, and revising the article.

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Data availability No datasets were generated or analysed during the current study.

Declarations

Competing interests The authors declare no competing interests.

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