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Energy transition strategies in Portugal: wind and solar externalities on municipalities housing prices

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Abstract

Purpose – This paper aims to investigate the impact of wind and solar farms on housing prices in Portugal to better understand their role in shaping social acceptance.

Design/methodology/approach – Fixed-effects models with Driscoll–Kraay standard errors are estimated using municipal-level panel data for 177 municipalities from 2011 to 2022. Renewable energy deployment is captured through three measures: presence, number of farms and installed capacity (MW) of wind and solar power.

Findings – Results indicate that wind farms generally do not affect housing prices. However, for each additional MW of installed wind capacity, the median housing price decreases, on average, by €1.11/m^2. By contrast, solar farms are linked to higher housing values, with municipalities hosting solar farms exhibiting average housing prices €28.51/m^2 above those without.

Practical implications – Findings highlight the importance of accounting for housing market externalities in renewable energy planning to foster social acceptance and improve policy design.

Originality/value – This study examines how wind and solar energy projects may affect housing markets in Portugal, a country simultaneously leading the energy transition and experiencing sharp increases in housing prices. It also contributes methodologically by using municipal-level aggregated data, providing a broader perspective than studies focused on micro-level or property-specific data.

Keywords Housing prices, Renewable energy, Wind farms, Solar farms, Externalities, Social acceptance

Paper type Research paper

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1. Introduction

1.1 Global context of energy transition

Environmental challenges, including global warming, biodiversity loss and water scarcity, have become increasingly relevant and discussed among policymakers, researchers and society. In this context, many countries have sought to commit to practices aimed at preserving the environment (United Nations, 2015a), while several Sustainable Development Goals (SDGs) focus on environmental issues (United Nations, 2015b). Specifically, reinforcing the need for efforts to combat climate change (SDG 13), to the conservation and sustainable use of oceans and marine resources (SDG 14), as well as protecting ecosystems, forests, biodiversity and combating land degradation (SDG 15), while ensuring access to affordable and sustainable energy (SDG 7).

The Paris Agreement establishes the objective of limiting the increase in global average temperature to below 2°C above pre-industrial levels (United Nations, 2015a). Meeting the targets of this agreement is vital for preserving biodiversity (Couce *et al.*, 2023) and reducing carbon emissions to combat climate change (Wu, 2016), as emissions of gases like carbon dioxide are among the leading contributors to environmental degradation (Nejat *et al.*, 2015).

Given this, it is essential to analyze the energy sector. Fossil fuel-based energy generation significantly increases carbon dioxide emissions (Khan *et al.*, 2016) and accounts for approximately 75% of greenhouse gas (GHG) emissions (Voumik *et al.*, 2023). Moreover, the energy demand has been increasing since 1970 not only within G7 (Voumik *et al.*, 2023) but also globally, due to various factors, including the growth of agricultural production and the modernization of agricultural systems, which require more technology and energy (FAO, 2024; Flammini *et al.*, 2022). Indeed, global agrifood system emissions, closely linked to energy use in crop and livestock production, land-use change and supply chain activities, increased by 10% between 2000 and 2022, reaching 16.2 Gt CO_2 eq (FAO, 2024). However, regional patterns differ: since 1970, emissions decreased in Europe, moderately increased in North America, and approximately doubled in Asia and Africa between 1990 and 2019 (Flammini *et al.*, 2022).

Considering these aspects, renewable energy sources (RES) emerge as part of the solution for building a better future, improving public health, reducing GHG emissions and enhancing energy security, while remaining sustainable for future generations (Blazejczak *et al.*, 2014; Dimanchev *et al.*, 2019; Karkour *et al.*, 2020; Khan *et al.*, 2024; Paramati *et al.*, 2018; Taşkın *et al.*, 2020).

However, the impacts of RES must be carefully considered and analyzed to provide a holistic perspective. Potential negative effects include harm to local fauna and flora (Polinori, 2019), noise (Dröes and Koster, 2021) and visual impact (Mariel *et al.*, 2015), which can reduce housing prices (Dorrell and Lee, 2020) and affect local social acceptance, crucial for project success (Segreto *et al.*, 2020). By considering the relationship between RES and property values, these projects can be designed and implemented in ways that minimize negative impacts on local communities.

1.2 Energy transition in Portugal

Since 2005, Portugal has expanded RES investment, with 80.5% of the 9,146 GWh generated in mainland territory in early 2025 sourced from renewables – 29.13% by wind energy and 7.28% by solar energy (APREN, 2025). In addition, Portugal has committed, through its National Energy and Climate Plan (European Commission: Directorate-General for Communication, 2024), to set ambitious, yet achievable (Robaina, Oliveira, *et al.*, 2025), national targets for 2030, particularly regarding the reduction of GHG emissions and the increased integration of RES.

Figure 1 presents the number of wind and solar farms per municipality in Portugal. The North and Center regions stand out as the main areas for wind energy production, whereas the distribution of solar farms is heavily concentrated in the South, particularly in the Alentejo and Algarve regions.

Given Portugal's high share of renewables in electricity generation and the dense territorial distribution of wind and solar power, the country provides an interesting case study to assess the costs and benefits of RES deployment. This study examines whether wind and/or solar farms influence housing prices across 177 Portuguese municipalities, using data from 2011 to 2022 and a fixed-effects panel model with Driscoll– Kraay standard errors.

The present work contributes to the literature in several ways. First, it focuses on the municipality level in one of the European Union's leading renewables producers. Second, unlike many previous studies, it examines whether investments in wind and solar farms affect housing prices at the municipal level. Third, it considers three dimensions of RES infrastructure in each municipality: presence, number and installed capacity (MW).

Another key novelty of this study lies in its broad geographic and temporal scope. Unlike localized case studies (e.g. [Delicado *et al.*, 2016]) it covers 177 municipalities in Portugal over 12 years (2011–2022), capturing the evolution of energy policies and trends. This timeframe allows the identification of major policy shifts, such as feed-in tariff reforms, and the analysis of emerging energy patterns post-COVID-19, offering valuable insights into the dynamics of Portugal's energy transition.

The results indicate that solar farms positively affect housing prices at the municipal level, whereas the presence of wind farms is not statistically significant. However, higher installed wind capacity is associated with lower housing prices. These findings are essential for policymakers, promoters and other stakeholders involved in RES investment processes or the energy market, enabling the development of holistic plans that address this issue. The municipal-level results enable tailored compensation schemes for affected communities.

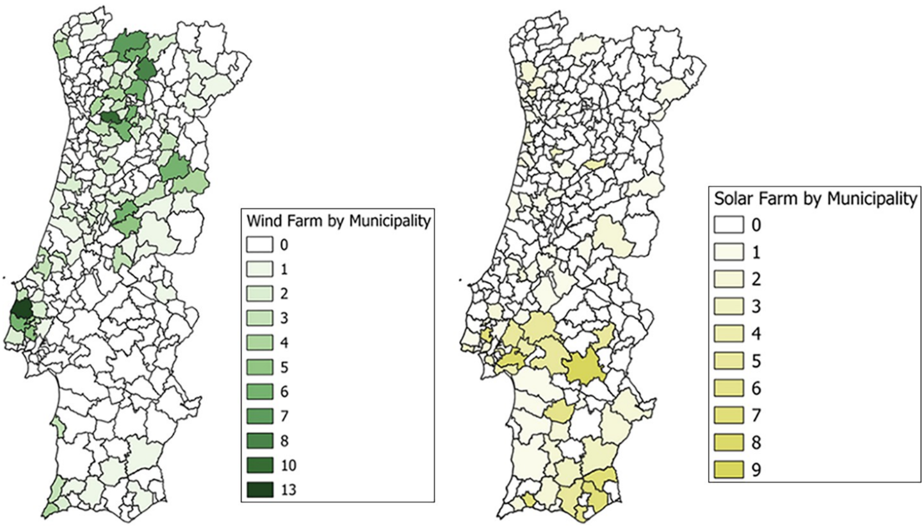

Figure 1. Territorial distribution of wind and solar farms in Portuguese municipalities
Source: Data collected from E2P – Endogenous Energies of Portugal (INEGI): https://e2p.inegi.up.pt/index.php?Lang=EN%20

This study contributes new evidence to the literature by documenting a pattern that diverges from most micro-level findings: at the municipal scale, solar farms in Portugal are associated with higher median housing values. While the international literature generally reports negative proximity effects on individual property prices, municipal-level analyses remain scarce and may capture different mechanisms, such as local economic development, investments in infrastructure or community-level improvements triggered by renewable energy deployment. By examining a long temporal horizon and multiple measures of renewable energy installations, this study provides a broader perspective on the relationship between renewable energy infrastructure and housing markets that complements, rather than contradicts, existing proximity-based studies.

This article is structured as follows: first, a literature review is presented, discussing the externalities associated with wind and solar farms, focusing on their impact on housing prices and their relevance for social acceptance. Next, the methodology is outlined, followed by the presentation and discussion of the results. Finally, the main conclusions are drawn, and suggestions for future research are provided.

2. Literature review

2.1 Externalities of renewable energy sources

Investments in RES involve multiple externalities (Kipperberg *et al.*, 2019), locally and on a broader geographic scale (Sundqvist, 2004). The advantages of RES are widely discussed, particularly regarding environmental benefits, such as reducing emissions of pollutants like CO_2, SO_2 and NOx by decreasing fossil fuel consumption (Karkour *et al.*, 2020). The external cost of RES is notably lower than that of other alternatives like oil or coal (Karkour *et al.*, 2020; Robaina, Madaleno., *et al.*, 2025), especially when the health-related impacts of different energy sources are monetized.

Nonetheless, negative externalities must also be considered, and the adverse effects are primarily experienced by residents living near RES facilities (Jensen *et al.*, 2014). The acceptance and collaboration of these communities are crucial for the success of RES projects (Lennon *et al.*, 2019; Scovell *et al.*, 2024). Regarding wind farms, externalities are typically grouped into three categories: impact on well-being, turbine-related impacts and avoided externalities (Krekel and Zerrahn, 2017; Ramalho *et al.*, 2025). The latter refers to environmental benefits (Dröes and Koster, 2016; Mattmann *et al.*, 2016), already mentioned for RES in general. Impacts on well-being include land use conflicts (Meyerhoff *et al.*, 2010; Polinori, 2019), effects on local recreation (Kipperberg *et al.*, 2019), disruptions to economic activities such as tourism and real estate (Skenteris *et al.*, 2019), and employment (Dugstad *et al.*, 2020; Skenteris *et al.*, 2019). Turbine-related impacts often affect local fauna and flora, potentially leading to biodiversity loss (Polinori, 2019). In addition, noise and shadow flicker (Dröes and Koster, 2021; Meyerhoff *et al.*, 2010) have been linked to human health issues, including sleep disturbances, stress and anxiety (Dröes and Koster, 2016; Skenteris *et al.*, 2019). However, the most extensively studied externality is the visual impact (Jensen *et al.*, 2018; Mariel *et al.*, 2015; Mirasgedis *et al.*, 2014).

Regarding solar farms, they require extensive land use, which can lead to increased CO_2 emissions due to deforestation (Turney and Fthenakis, 2011). However, this environmental impact is still significantly lower than fossil fuel consumption (Turney and Fthenakis, 2011). Improper management of solar farms can also disrupt local vegetation, cause habitat loss and negatively impact biodiversity (Randle-Boggis *et al.*, 2020; Xu *et al.*, 2024).

The visual impact of solar farms is also among the most studied externalities. Their implementation affects landscapes in natural, agricultural or urban areas (Chiabrando *et al.*, 2009; Zheng *et al.*, 2023). The scale and design of solar installations, as well as their surrounding context, play a significant role in determining their visual impact, highlighting the need for strategic site selection to minimize disruption and promote landscape integration (Sánchez-Pantoja *et al.*, 2018).

In addition, changes to the surrounding landscape caused by wind and solar farms may influence housing values. While factors such as infrastructure and public services have a greater effect on property pricing (Zerrahn, 2017), the presence of natural scenery tends to enhance housing values (Ek and Matti, 2015; Zerrahn, 2017). Because wind and solar farms alter the visual environment, their development may similarly impact property prices.

2.2 Impact of renewable energy sources on housing prices

Proximity to energy infrastructures is generally associated with declining housing prices (Brinkley and Leach, 2019), with greater reductions near larger facilities (Davis, 2011). This pattern is observed in thermal power plants (Tsai, 2022), though similar effects extend to RES. Houses within 1 km of solar farms, for instance, experience price declines exceeding 1.5% (Gaur and Lang, 2023; Maddison *et al.*, 2023). Large solar farms tend to reduce nearby property values, mainly due to the loss of open space amenities rather than glare effects (Georgic *et al.*, 2024). Despite this, it seems that the impact of solar farms on housing prices may disappear when homes are more than 1 km away from a solar farm (Elmallah *et al.*, 2023).

Unlike solar farms, empirical findings on wind farms' housing price impacts show greater variation across studies. Some studies report negative effects, with reductions of up to 3% attributed to visual impacts and 3–7% to noise (Dorrell and Lee, 2020; Heintzelman and Tuttle, 2012; Jensen *et al.*, 2014; Krueger *et al.*, 2011). However, other studies find region-specific differences, indicating that wind farm effects on housing prices vary across locations (Skenteris *et al.*, 2019).

Furthermore, distance plays an important role (Schütt, 2024), as properties located more than 2 km away seem to be unaffected, while properties within 1.6 km of a wind turbine may experience a significant decline (Brunner *et al.*, 2024). Even within this distance, the impact diminishes over time, becoming statistically insignificant after nine years (Brunner *et al.*, 2024). The gradual disappearance of this negative externality has been documented for onshore wind turbines affecting homes within 1 km (Guo *et al.*, 2024). However, in some locations, the effect persists (Dong *et al.*, 2023).

Despite evidence of negative impacts, several studies find no statistically significant relationship between wind farms and nearby housing prices (Castleberry and Greene, 2018; Dong and Lang, 2022; Hoen and Atkinson-Palombo, 2016; McCarthy and Balli, 2014). In some cases, property values may even appreciate, particularly for agricultural land directly affected by or included in wind farm development plans (Myrna *et al.*, 2019). Regarding solar farms, proximity to power transmission lines can result in value increases after installation, reflecting perceptions that the area is more suitable for future solar developments (Abashidze and Taylor, 2023).

Considering these findings, the prevailing trend indicates a generally negative impact of both wind and solar farms on the values of nearby houses. Nonetheless, this effect tends to weaken with increasing distance from the infrastructure and over time.

Despite the extensive body of literature documenting the externalities of renewable energy facilities – particularly their visual, acoustic and ecological effects – the empirical evidence remains fragmented and presents several important limitations. First, most studies rely on highly localized or property-level data, often focusing on specific wind or solar projects. While these micro-level analyses capture proximity effects, they overlook broader municipal dynamics, such as regional development trajectories, labor market conditions or local public investment, all of which may influence how communities perceive and respond to RES deployment. Second, the literature remains geographically unbalanced: evidence from peripheral European countries, including Portugal, is scarce, even though these countries have experienced rapid RES expansion alongside substantial changes in their housing markets. Third, research tends to analyze wind and solar farms separately, seldom comparing their differentiated externalities within the same modeling framework or using multiple measures of RES deployment (presence, number of farms and installed capacity). Fourth, existing studies rarely address the temporal dimension of RES externalities – particularly the potential normalization or dissipation of impacts over time, which is crucial in countries such as Portugal where many wind farms are more than a decade old while solar farms are still expanding. Finally, few studies explicitly link RES externalities to social acceptance, leaving unclear whether, and under what conditions, housing market impacts translate into broader community support or opposition.

By addressing these gaps, the present study provides a more comprehensive, municipality-scale assessment of how wind and solar infrastructures influence housing values in a national setting characterized by mature wind capacity, rapid solar expansion and strong policy commitments to renewable energy. By examining different dimensions of RES deployment and comparing two technologies within a single empirical framework, the study contributes to a more integrated understanding of how renewable energy infrastructure interacts with local socioeconomic conditions – an area where the existing literature remains underdeveloped.

2.3 The role of local community acceptance for the success of renewable energy sources projects

Social acceptance plays a predominant role in the outcomes of RES projects, significantly influencing their success and viability (Lima *et al.*, 2025; Segreto *et al.*, 2020). Therefore, it has been increasingly highlighted by policymakers and academics (Ellis *et al.*, 2023).

Several factors influence social acceptance, notably, the externalities mentioned in the previous subsection, such as visual impact (Hoen *et al.*, 2019; Rand and Hoen, 2017; Ruddat, 2022), noise (Müller *et al.*, 2023; Rand and Hoen, 2017), impact on biodiversity and effects on economic sectors such as the labor market (Ponce Oliva *et al.*, 2024) and tourism (Hübner *et al.*, 2023; le Maitre *et al.*, 2024). It is therefore reasonable to hypothesize that the effect of RES projects on housing prices may also influence local community acceptance (Hübner *et al.*, 2023), or at least raise concerns among some locals, increasing sensitivity to other issues such as noise annoyance (Müller *et al.*, 2023).

The level of acceptance of RES projects is dynamic, changing over time (Wolsink, 2007). Social acceptance generally increases as the implementation process progresses (le Maitre *et al.*, 2024), although it may initially decline during early stages, resulting in a U-shaped trajectory (Wolsink, 2007). Acceptance also tends to be lower for residents living closer to the facilities (le Maitre *et al.*, 2024). Notably, general or national-level acceptance is typically higher than local acceptance (Baur *et al.*, 2022; Ruddat, 2022).

Several measures can mitigate potential community opposition and enhance social acceptance of RES projects. Key strategies include promoting public participation (Segreto *et al.*, 2020), stimulating co-investments (Sirr *et al.*, 2023) and ensuring distributional justice (Ponce Oliva *et al.*, 2024). The reliability of the information source is also critical, encompassing who communicates, how and when information is provided (Karakislak and Schneider, 2023). Post-implementation measures, such as constructing recreational areas near parks (Maleki-Dizaji *et al.*, 2020) or providing monetary compensation for losses and inconveniences (Leer Jørgensen *et al.*, 2020), may also help. However, preventive efforts and prior consultation with residents are generally more effective than compensatory measures (Maleki-Dizaji *et al.*, 2020; Terwel *et al.*, 2014). In this context, the present study contributes to the literature by analyzing the effects of wind and solar farms on municipal housing prices, providing insights that can help policymakers and developers anticipate potential challenges and minimize the need for less effective post-implementation compensation measures.

Taken together, the existing evidence shows that conclusions about renewable energy externalities depend heavily on methodological choices, spatial scales and the maturity of national energy systems. However, no studies to date have examined how wind and solar installations jointly affect housing values across Portuguese municipalities, nor have they explored whether municipal-level patterns diverge from micro-level property effects documented in other contexts. This absence represents a significant gap in the literature, particularly for countries with high renewable penetration and heterogeneous regional development such as Portugal. The present study addresses this gap by providing a systematic, national-scale assessment using multiple measures of renewable energy deployment.

3. Methodology

This study adopts a positivist, quantitative and deductive approach with an objectivist epistemology, aiming to empirically identify generalizable causal relationships between renewable energy infrastructure (wind and solar farms) and housing prices across Portuguese municipalities. This framework aligns with the study's objective of examining systematic effects while controlling both observed and unobserved municipal characteristics.

The analysis considers annual data from 177 Portuguese municipalities between 2011 and 2022. From an initial sample of 308 municipalities, only 177 with sufficient housing price data were retained.

To estimate the econometric model, this study uses a fixed effects model with Driscoll–Kraay robust standard errors (Driscoll and Kraay, 1998). This approach was selected due to the panel data structure, which often exhibits serial autocorrelation, heteroskedasticity and cross-sectional dependence – issues that can lead to incorrect statistical inferences if not properly addressed. The Driscoll–Kraay method corrects for three common problems in panel data:

(1) heteroskedasticity, where error variances differ across municipalities;
(2) serial autocorrelation, where errors within the same municipality over time are correlated; and
(3) cross-sectional dependence, where shocks affecting one municipality may influence others.

After verifying the assumptions, such as the variance inflation factor (VIF), the model used is the one presented in equation (1):

$$Value_{it} = \beta_0 + \beta_1 NH_{it} + \beta_2 Pop_{it} + \beta_3 PPO_{it} + \beta_4 SHE_{it} + \beta_5 ME_{it} + \beta_6 WindYN_{it} + \beta_7 SolarYN_{it} + \alpha_i + \varepsilon_{it} \quad (1)$$

where *i* refers to the municipality and ? to the year. All variables were collected from official sources and measured consistently across municipalities, ensuring comparability. Municipality fixed effects are included to control for time-invariant differences such as some housing market characteristics, while time-varying factors such as population, new housing, student enrollment and average earnings are included as control variables.

Table 1 summarizes all variables, including their definitions, units of measurement and data sources.

Regarding control variables, their selection was guided by prior empirical findings. For instance, the construction of new homes affects housing supply and, consequently, can influence property prices (Muellbauer and Murphy, 2008). The literature presents somewhat conflicting findings on this matter. While some authors provide evidence that the availability of new housing reduces prices by increasing supply (Li, 2022), others argue that the consequent population growth, along with the associated economic development and dynamism, tends to drive house prices upward (González-Pampillón, 2022). Regarding population size, it is closely linked to housing market dynamics, as higher population levels are generally associated with increased property values (Choi and Jung, 2017; Czinkan and Horváth, 2019).

In this context, the number of higher education students was also considered due to its influence primarily on the rental market, which, in turn, may impact housing prices. A growing student population creates higher demand for housing, which can drive up both rental and housing prices (Mocanu and Tremacoldi-Rossi, 2023). The post office variable

Table 1. Variables

Variables	Definition	Source
Value	Median value of bank appraisal (€/m²) by municipality	INE – statistics Portugal
NH	Completed dwellings (No.) in new constructions for family housing by municipality	INE – statistics Portugal
Pop	Resident population (No.) by municipality	INE – statistics Portugal
PPO	Inhabitants per post office (No.) by municipality	INE – statistics Portugal
SHE	Students enrolled in higher education (No.) by municipality	INE – statistics Portugal
ME	Average monthly earnings (€) over the year, by municipality	INE – statistics Portugal
WindYN (1 = Yes)	Dummy variable that takes the value of 1 if there is at least one wind farm in the municipality, and 0 otherwise	Project E2P – Endogenous Energies of Portugal, from the Portuguese Renewable Energy Association (APREN) and the Institute of Science and Innovation in Mechanical and Industrial Engineering (INEGI)
SolarYN (1 = Yes)	Dummy variable that takes the value of 1 if there is at least one solar farm in the municipality, and 0 otherwise	Project E2P – Endogenous Energies of Portugal, from APREN and INEGI
Wind	Number of wind farms by municipality	Project E2P – Endogenous Energies of Portugal, from APREN and INEGI
Solar	Number of solar farms by municipality	Project E2P – Endogenous Energies of Portugal, from APREN and INEGI
WindIC	Installed wind energy capacity (MW) by municipality	Project E2P – Endogenous Energies of Portugal, from APREN and INEGI
SolarIC	Installed solar energy capacity (MW) by municipality	Project E2P – Endogenous Energies of Portugal, from APREN and INEGI

Note(s): Website of the E2P project – https://e2p.inegi.up.pt/index.php?Lang=EN was incorporated to capture the role of local services and infrastructure in shaping housing values (Garretsen and Marlet, 2017; Shin *et al.*, 2024). Areas with fewer services per resident are expected to exhibit lower house prices, implying that a higher number of inhabitants per post office correlates with reduced property values (Garretsen and Marlet, 2017). While other variables, such as the presence of hospitals, were considered, only the post office variable demonstrated significant explanatory power. In addition, average monthly income was included on the basis that higher disposable income generally leads to increased housing prices (van der Drift *et al.*, 2023).

4. Results and discussion

4.1 Descriptive statistics

Table 2 presents the descriptive statistics regarding all the variables considered in this study.

The average median housing price across municipalities is €844.08/m^2, with a standard deviation of €309.27. The mean lies closer to the minimum value (€455) than to the maximum (€3,495), reflecting the persistent gap between rural municipalities and major coastal cities, where housing markets have experienced substantial price growth.

There is also considerable variation in new housing construction: municipalities report an average of 75 newly completed housing units per year, with a standard deviation of 101. Population levels differ markedly, ranging from 6,416 to more than 500,000 inhabitants, resulting in a high standard deviation of 67,349. This reflects the coexistence of highly urbanized areas, such as Lisbon and Porto, and much smaller municipalities in the interior. On average, each post office serves 8,367 inhabitants.

The number of students enrolled in higher education institutions varies considerably, with a mean of 2,156 and a standard deviation of 10,454. This high dispersion is expected, as more than half of the municipalities do not have higher education institutions, whereas larger cities accommodate several thousand students. For instance, in Lisbon, the number of students enrolled in higher education institutions reached 128,394.

Regarding income, the average monthly earnings across municipalities are €1,008.14, with a standard deviation of €188.38. The minimum value (€688.80) reflects earlier years in the 2011–2022 period, when minimum wage levels were substantially lower.

Observing RES infrastructure, approximately one-third of the municipality-year observations include a wind farm, with an average installed capacity of 15.89 MW per municipality. In

Table 2. Descriptive statistics

Variable	Mean	SD	Minimum	Maximum
Value	844.08	309.27	455	3,495
NH	75	101	0	1,221
Pop	54,120	67,349	6,416	561,578
PPO	8,367	9,947	1,109	172,116
SHE	2,156	10,454	0	128,394
ME	1,008.14	188.38	688.8	2,331.2
WindYN	0.33	0.47	0	1
SolarYN	0.18	0.38	0	1
Wind	0.81	1.71	0	13
Solar	0.41	1.16	0	9
WindIC	15.89	41.21	0	263.5
SolarIC	1.46	6.09	0	75.13

Source(s): Authors' own work

contrast, only about 18% of the observations include a solar farm, with a significantly lower average installed capacity of 1.46 MW per municipality. This disparity reflects the earlier development and more rapid expansion of wind energy compared to solar energy in Portugal (Observatório da Energia, DGEG, and ADENE, 2024).

4.2 Impact of wind and solar farms on housing prices

Table 3 presents the results from equation (1). The equation is statistically significant, with a within *R*-squared of 73.39%.

All control variables are statistically significant. For NH, the results indicate that for each additional newly constructed housing unit, the median housing price increases, on average, by €0.18/m^2. This may be explained by the fact that new houses incorporate more advanced technology and modern features that older homes may lack, leading to higher values (Koengkan and Fuinhas, 2022). In this regard, it is important to note that, as construction costs increase, housing prices tend to rise accordingly (Guan and Cheung, 2023).

Regarding Pop, the findings show that for each additional resident in a given municipality, the median housing price rises, on average, by €0.05/m^2. This result is likely linked to increased housing demand, which drives prices upward. For PPO, the coefficient indicates that if there are fewer post offices, the median housing price decreases.

Concerning the SHE, the coefficient is also statistically significant. For each additional student enrolled in a local higher education institution, the median housing price increases, on average, by approximately €0.04/m^2.

Regarding ME, housing prices tend to be higher in municipalities with higher income levels. Specifically, a €1 increase in average income is associated with an average increase of €1.36/m^2 in median housing prices.

Overall, these findings are consistent with broader theoretical mechanisms in housing and environmental economics and with key strands of prior empirical research. The positive associations between population, income and housing values align with classical models of housing demand, in which demographic pressure and higher purchasing power raise equilibrium prices (Glaeser *et al.*, 2005b, 2005a; Gyourko *et al.*, 2013).

Regarding RES, while wind farms do not appear to have a statistically significant effect on housing prices, solar farms do. The coefficient associated with the presence of wind farms is positive, but it is not statistically significant. In contrast, the coefficient for solar farms is statistically significant. This suggests that municipalities with solar farms have a median price per square meter that is, on average, €28.52 higher than those without.

Table 3. Results of equation (1): fixed effects model with Driscoll–Kraay standard errors

Variables	Coefficients	*t*-statistics	*p*-values
NH	0.18437	3.57	0.004
Pop	0.05093	14.98	0.000
PPO	−0.00432	−3.10	0.010
SHE	0.03893	5.25	0.000
ME	1.35750	15.88	0.000
WindYN (1 = Yes)	20.27773	1.33	0.212
SolarYN (1 = Yes)	28.5217	3.37	0.006
Within *R*-Squared	0.7339	–	–

Source(s): Authors' own work

This result differs from the findings commonly reported in the literature, as most authors provide evidence of a negative impact of solar farms on housing prices (e.g. [Gaur and Lang, 2023; Maddison *et al.*, 2023]). However, several factors may explain this outcome. One possible explanation is that, in this case, solar farms may positively influence median housing prices because they are being installed in economically less dynamic municipalities. In this case, investment in solar energy may be perceived as an economic driver, increasing employment opportunities (Milani *et al.*, 2020; Proença and Fortes, 2020) and contributing to housing value appreciation. On the other hand, investment in solar farms may provide local governments with additional funds to improve regional infrastructure (Marolin *et al.*, 2020), which could be particularly relevant given that these projects are often located in less developed municipalities.

These findings do not imply that solar farms universally increase property values; instead, they highlight that the scale of analysis matters. Micro-level studies typically examine properties located within 1–2 km of solar installations, where visual and land-use externalities are strongest. In contrast, our municipal-scale results likely capture broader economic effects, such as increased local investment, tax revenue, or employment linked to recent solar tenders and installations in less dynamic regions. Thus, our findings complement existing research by revealing municipality-wide dynamics that cannot be detected through property-level data sets.

Comparing the results for wind and solar farms, several factors may explain the differing impacts of these two types of RES infrastructure. A central aspect is the timing of their deployment: wind farms tend to be considerably older, with many projects installed in the early 2000s, whereas investment in solar energy has expanded more recently, particularly after 2015. As a result, the externalities associated with wind farms may have already dissipated. This interpretation aligns with the literature, which shows that the effects of RES projects on housing prices tend to diminish after several years of operation (Brunner *et al.*, 2024; Guo *et al.*, 2024). This may explain why wind farms show no significant effect in this study, whereas solar farms are positively associated with housing prices.

These results also contribute to broader conceptual debates on social acceptance and externalities of renewable energy infrastructure. The contrasting patterns observed between wind and solar farms illustrate that local perceptions and societal impacts are shaped not only by technology-specific externalities but also by territorial development dynamics. From an energy justice perspective, the negative association between wind installed capacity and housing prices suggests a potential distributional imbalance, where communities hosting older or repowered wind farms may carry a disproportionate share of visual and noise burdens without receiving equivalent economic benefits. In contrast, the positive associations found for solar farms may reflect early-stage dynamics in which municipalities perceive solar investment as a source of local development, increased fiscal capacity, or employment opportunities. These findings imply that societal responses to renewable energy infrastructure cannot be fully understood through externalities alone, but must be interpreted within broader regional development and institutional contexts, aligning with current theoretical work at the intersection of energy transitions and spatial justice.

5. Additional analysis

5.1 Impact of wind and solar farms on housing prices: the role of the number of parks

To complement the previous analysis, additional tests were conducted using alternative measures for wind and solar farms. In equation (2), instead of the binary variables used in equation (1) – where municipalities were assigned a value of 1 if they had at least one wind

(WindYN) or solar (SolarYN) farm – this specification incorporates the actual number of wind and solar farms per municipality:

$$Value_{it} = \beta_0 + \beta_1 NH_{it} + \beta_2 Pop_{it} + \beta_3 PPO_{it} + \beta_4 SHE_{it} + \beta_5 ME_{it} + \beta_6 Wind_{it} + \beta_7 Solar_{it} + \alpha_i + \varepsilon_{it} \quad (2)$$

Table 4 presents the results from equation (2).

The control variables are consistent with those in equation (1). All remain statistically significant, including the number of new housing units, population, average monthly earnings, number of higher education students and inhabitants per post office. Median housing prices are higher in municipalities with more new homes, larger populations, higher incomes, greater student enrollment and more inhabitants per post office.

Regarding wind and solar farms, the results indicate that only the variable associated with solar farms is statistically significant. The number of wind farms has a negative coefficient – unlike the result from equation (1) – but remains statistically insignificant.

Conversely, the number of solar farms in a municipality significantly impacts housing values. Specifically, each additional solar farm in a municipality is associated with an average increase of €21.60/m^2 in median housing prices.

5.2 Impact of wind and solar farms on housing prices: the role of installed capacity

In equation (3), the model incorporates the installed capacity of wind (*WindIC*) and solar (*SolarIC*) energy in each municipality as an alternative measure:

$$Value_{it} = \beta_0 + \beta_1 NH_{it} + \beta_2 Pop_{it} + \beta_3 PPO_{it} + \beta_4 SHE_{it} + \beta_5 ME_{it} + \beta_6 WindIC_{it} + \beta_7 SolarIC_{it} + \alpha_i + \varepsilon_{it} \quad (3)$$

In Table 5, the results from equation (3) are presented.

The significance and direction of the control variables remain consistent with the findings from equations (1) and (2). Median housing prices increase with a higher number of new housing units, larger population, more students in higher education, higher average income and fewer inhabitants per post office.

Regarding wind and solar farms, some differences emerge when compared to the previous results. While the presence or number of wind farms in a municipality does not affect housing prices, installed wind capacity has a significant effect: each additional MW of

Table 4. Results of equation (2): fixed effects model with Driscoll–Kraay standard errors

Variables	Coefficients	*t*-statistics	*p*-values
NH	0.20768	4.25	0.001
Pop	0.04963	13.92	0.000
PPO	−0.00429	−3.21	0.008
SHE	0.03841	5.31	0.000
ME	1.34024	17.76	0.000
Wind	−18.39235	−1.60	0.137
Solar	21.60159	3.73	0.003
Within *R*-Squared	0.7378	–	–

Source(s): Authors' own work

Table 5. Results of equation (3): fixed effects model with Driscoll–Kraay standard errors

Variables	Coefficients	*t*-statistics	*p*-values
NH	0.18686	3.87	0.003
Pop	0.05144	15.11	0.000
PPO	−0.004398	−3.12	0.010
SHE	0.03786	5.31	0.000
ME	1.37611	17.16	0.000
WindIC	−1.11392	−2.56	0.026
SolarIC	1.57489	4.07	0.002
Within *R*-Squared	0.7339	–	–

Source(s): Authors' own work

installed wind capacity is associated with an average decrease of €1.11/m^2 meter in median housing prices.

This result is particularly relevant given that recent wind energy investment in Portugal has focused primarily on repowering existing wind farms rather than constructing new ones. Despite the economic, energy and environmental benefits of repowering (Abadie and Goicoechea, 2021; Haces-Fernandez, 2021), there appears to be something in the process that is not being properly managed in Portugal. One possible explanation for this phenomenon is that increasing installed capacity often entails the addition of more wind turbines, which can intensify externalities such as noise, shadow flicker, and landscape intrusion, potentially depressing property values (Jensen *et al.*, 2018; Mariel *et al.*, 2015).

In contrast, the installed solar energy capacity in a municipality positively affects housing values. Specifically, for each additional MW of installed solar capacity, the median housing price increases by an average of €1.57/m^2.

Considering the results in Tables 2, 3 and 4, several key findings warrant attention, as they diverge from the patterns most commonly reported in the literature. On the one hand, the presence and number of wind farms do not significantly affect the median housing price. This contrasts with several previous studies, which report a statistically significant, predominantly negative impact of wind farms on property values – an effect that typically diminishes with distance from the wind farm and over time (Brunner *et al.*, 2024; Dong *et al.*, 2023; Schütt, 2024). In this regard, unlike studies focusing on individual housing prices, this research considers median housing prices in an aggregated manner, which may explain the discrepancies in the results. Nevertheless, larger installed wind capacity is associated with lower median housing prices, in line with the well-documented effects of turbine size and quantity on landscape and housing values (Jensen *et al.*, 2018; Mariel *et al.*, 2015). Because higher installed capacity usually involves larger or more numerous turbines, this may partly explain the observed negative effect on housing values.

However, the impact of wind farms on property values can vary depending on location, community attitudes and local economic conditions. Some studies even report positive effects. For example, in Scotland, an analysis of over 500,000 property sales from 1990 to 2014 found no consistent evidence of negative impacts from wind turbines on house price growth. In some areas, properties located 2–3 km from visible turbines experienced significant price increases (Heblich *et al.*, 2016). In parts of the US, wind turbines raised local incomes by around 5% and house values by 2.6%, attributed to economic benefits such as employment, taxes and land payments (Brunner and Schwegman, 2022). Similarly, in counties along the west coast of Ireland, houses located 1–2 km from wind turbines were

16.2% more valuable than those 5–15 km away (Gillespie and McHale, 2023). In sum, these positive effects are often attributed to:

- economic benefits, as wind farms can boost local economic activity by providing employment and other economic benefits to communities;
- community funds provided by energy companies that improve local infrastructure and housing demand; and
- recreational amenities, such as walking, cycling or horse-riding trails, which attract visitors and may enhance property values.

On the other hand, the presence of a solar farm in a municipality is associated with higher median housing prices, with prices increasing as the number of solar farms grows. Overall, greater installed solar capacity corresponds to higher median housing values. These results suggest that investment in solar farms positively affects housing prices, contrary to much of the existing literature, which generally reports a negative impact, particularly for properties located near solar installations (Elmallah *et al.*, 2023; Georgic *et al.*, 2024; Maddison *et al.*, 2023). Nevertheless, properties near utility-scale solar farms may see value increases of 0.5% to 2.0% (Hao and Michaud, 2024), with smaller projects under 20 MW showing even stronger positive effects, sometimes raising land values by up to 2%. These effects are generally attributed to local economic benefits, including higher tax revenues supporting amenities such as schools and infrastructure, and job creation during construction and ongoing operations (Marolin *et al.*, 2020; Milani *et al.*, 2020; Proença and Fortes, 2020). In this sense, the positive effects observed in this study may be explained by the fact that solar farms are developed in less economically developed municipalities. Investment in solar energy can act as a driver of local development, enabling improvements in infrastructure and funding that enhance regional conditions. From a municipal perspective, solar energy investment appears to be a rational choice, offering benefits beyond environmental gains, including higher housing values. Although literature suggests that properties adjacent to solar farms may experience depreciation, the aggregated housing market at the municipal level tends to appreciate.

As previously mentioned, the differences in results between wind and solar farms may be attributed to the timing of investments, given that wind farms are generally older than solar farms in Portugal. As such, the effects of wind farms may have already been normalized over time, leading to their insignificance in the analysis (Brunner *et al.*, 2024).

These findings have important implications for policy and practice. The positive impact of solar farms on housing prices, likely due to local infrastructure improvements and economic benefits (Marolin *et al.*, 2020; Milani *et al.*, 2020), should be highlighted to municipal decision-makers, as it provides a tangible incentive for supporting RES projects. In terms of social acceptance, policymakers and developers can use this evidence to encourage communities to embrace solar energy, emphasizing that these projects can enhance property values in addition to delivering environmental benefits. The negative association between increased installed wind capacity and housing prices is a cause for concern, as much of Portugal's recent wind energy investment has focused on repowering existing farms, effectively increasing their installed capacity. Moreover, many of these wind farms are over 20 years old and contain obsolete equipment, which may also negatively influence community perceptions toward wind infrastructure (Caporale *et al.*, 2020). These results strongly reinforce the need for repowering strategies to be sustainable, balancing energy, economic and social outcomes to ensure a just and broadly accepted energy transition (Kitzing *et al.*, 2020).

6. Conclusions, policy implications and future research suggestions

This study contributes to the discussion on RES and their externalities by examining the impact of wind and solar farms on housing values. The success of RES projects depends on social acceptance by local communities. Given that changes in housing prices can significantly influence public perception, assessing these impacts is crucial to ensure that wind and solar investments achieve their intended benefits.

The analysis covers 177 Portuguese municipalities from 2011 to 2022 using a fixed-effects panel data model with Driscoll–Kraay standard errors. The results directly address the study's research objectives by providing clear empirical evidence on whether renewable energy infrastructures – measured through presence, number of farms and installed capacity – shape municipal-level housing prices in Portugal. Specifically, the findings show that while wind farms generally do not affect housing prices (except through installed capacity), solar farms consistently exhibit positive price effects across all specifications. This contrast synthesizes how the impacts differ by technology and measurement, fulfilling the objective of identifying nuanced, infrastructure-specific externalities.

The results also clarify the mechanisms through which these effects may operate. For solar farms, the positive price premium suggests that investment may be perceived as a signal of local economic dynamism or improved infrastructure, especially in less developed municipalities. For wind farms, the negative effect of installed capacity highlights that repowering strategies may intensify visual or noise-related externalities, thereby influencing housing markets even if the mere presence or number of farms does not.

The empirical findings carry important implications for housing market regulation and renewable energy planning. The negative price effects associated with higher wind installed capacity indicate that repowering strategies may require updated siting guidelines, mandatory community benefit schemes or compensation mechanisms explicitly linked to property value impacts. Such measures are increasingly adopted across Europe to address distributional fairness in renewable deployment. Conversely, the positive municipal-level price effects associated with solar farms suggest that solar project planning could be leveraged as part of broader territorial cohesion strategies, especially in economically lagging regions. However, these benefits must be managed cautiously: the disparity between municipal-level gains and potential micro-level depreciation near installations underscores the need for differentiated regulation that protects nearby homeowners while enabling local governments to capture fiscal benefits. Aligning renewable energy incentives with housing market safeguards would strengthen the coherence between energy and urban policy domains.

Overall, the findings provide actionable insights for policy and practice. They suggest that:

- solar energy expansion can be aligned with municipal development strategies due to its apparent positive local economic spillovers;
- wind farm repowering requires more careful territorial planning, improved community engagement and possibly new regulatory frameworks to mitigate emerging externalities; and
- housing market effects should be explicitly integrated into social acceptance assessments and environmental impact evaluations.

In doing so, policymakers can design RES deployment strategies that maximize local benefits and minimize distributional conflicts.

Beyond their economic implications, the results highlight important societal and equity dimensions. The divergent effects of wind and solar infrastructures suggest that different technologies may shape community perceptions, local identities, and quality of life in distinct ways. From a social acceptance perspective, declining housing prices linked to wind repowering may erode public support, while rising prices in municipalities with solar farms may enhance perceptions of local development and opportunity. These findings underscore the need for policy approaches grounded in energy justice principles – ensuring that local communities share in the economic gains of renewable energy while minimizing localized burdens. Recognizing the heterogeneity in community experiences is essential for designing inclusive energy transition strategies that maintain social legitimacy and prevent territorial inequalities.

Some limitations of this study should be acknowledged. Given that this study relies on aggregated municipal-level data, it was not possible to determine the precise distances at which residential properties are affected by wind and solar farms. In some cases, energy infrastructure may be located within one municipality but physically closer to residences in neighboring municipalities, meaning that residents of the hosting municipality may not always be the most directly affected. While the fixed-effects panel model with Driscoll–Kraay robust standard errors mitigates heteroskedasticity, serial correlation and cross-sectional dependence, potential spatial spillovers and endogeneity cannot be fully ruled out. Specifically, the siting of RES projects may be influenced by municipal characteristics that also affect housing prices, potentially introducing site selection bias. Moreover, the externalities of renewable energy infrastructure may extend beyond the municipality in which it is installed, affecting adjacent municipalities. Future research could address these limitations by using more granular, property-level data, spatial econometric models or instrumental variable approaches to more rigorously capture inter-municipal externalities and mitigate endogeneity concerns.

Finally, future research could consider alternative measures of housing prices, including rental values, to capture broader market dynamics.

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