Local Costs and Benefits of Power Installations: Hedonic Evidence from Germany

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Abstract. Germany's energy system is in the midst of a massive transformation: The last three nuclear plants went off-line in 2023, coal power is slated for nixing by 2038 at the latest, while renewable electricity generation facilities are further expanding substantially. The reverberations of these changes are of key policy importance given the centrality of the electricity sector to the economy. Previous studies using hedonic price models to quantify how surrounding house values are impacted by changes in energy infrastructure often focus on the opening or closing of just a single type of facility. In this study, we consider the entire electricity production portfolio, adopting a spatial difference-in-differences approach to assess the impact of different types of facility openings and closures simultaneously under a unified modeling framework. To this end, we leverage an extensive geo-referenced data set of house sale advertisements from 2008 to 2019 containing almost 2.4 billion observations on asking prices and property characteristics. We find that the opening of both wind and coal power facilities is associated with significant discounts on surrounding house values, with the discount of coal power plant openings being of much larger magnitude. Somewhat surprisingly, we also find evidence that closures of coal power plants are associated with reduced house prices, a possible result of economic channels, such as reduced employment in the aftermath of a large plant closure. Our results highlight potentially important distributional implications that warrant consideration in ensuring a just energy transition.

JEL classification: Q21, D12, R31.

Keywords: Coal power; wind power; hedonic price model.

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1 Introduction

The transition to a low-carbon future requires the creation of new energy infrastructure and the decommissioning of old power plants. Such a fundamental transformation has important implications for the residential sector, as the placement of electricity generation facilities is associated with a multitude of externalities that could affect house values in surrounding areas. For example, there is a rich literature on the externalities of onshore wind power installations with regards to noise pollution and visual dis-amenities, as turbines cast shadows and create flickering (Ladenburg et al., 2020; Meyerhoff et al., 2010). Similar externalities arise from conventional power plants, notably the visual dis-amenities of smoke stacks and adverse health impacts related to local air pollution (Currie et al., 2015). In fact, one of the biggest challenges in siting new plants and infrastructure is resistance from citizen groups concerned about their environmental and aesthetic impacts (Simora et al., 2020), as well as the resulting reduced house prices in the immediate vicinity of the plants (Davis, 2011).

These negative effects might be expected to be countered by positive impacts on house prices when energy facilities are closed, but the evidence on this relationship is mixed. While Strasert et al. (2019) find increases in house prices from reduced pollution, Bauer et al. (2017) and Jolley et al. (2019) find negative effects, attributed at least in part to the loss of employment. Given such contrary effects, the net economic impacts of openings and closings is unclear and remains an empirical question.

The present study takes up this question in the context of Germany's residential sector, econometrically estimating the impact of both the installation and closure of electricity generation facilities on local housing prices. The study thereby builds on a wealth of research that uses hedonic price models to quantify the impact of electricity generation facilities on house values (Brinkley and Leach, 2019; Davis, 2011; Rivas Casado et al., 2017; Hoen et al., 2015; Dröes and Koster, 2016; Sunak and Madlener, 2016; Boes et al., 2015; Bauer et al., 2017; Maddison et al., 2022). The majority of studies focuses on either the opening or closing of just a single or two types of generation facilities (Heintzelman and Tuttle, 2012). A notable exception is the recent work by Eichholtz et al. (2023), who study the impact of openings and closings of renewable and non-renewable electricity generation facilities on house prices in the Netherlands.

We adopt a similar analytical approach to studying this issue in Germany, a country whose strong commitment to reaching carbon neutrality of its economy by 2045 lends itself as a particularly relevant case for such an empirical analysis. For starters, in comparison with many of its neighbors, Germany has traditionally had a highly diversified energy mix comprising nuclear, coal, gas, and renewable sources. Moreover, spurred by the Russian attack on Ukraine, the country is advancing full throttle on a massive transformation of its energy system toward renewables that began some two decades ago with the passage of the Renewable Energy Act. Germany's last three nuclear plants recently went off-line, and legislation is in place to completely wean itself of coal by 2038, at the latest.

We adopt a holistic perspective that considers the openings and closures of these different types of facilities under a unified modelling framework. To this end, we leverage an extensive geo-referenced data set of house sale advertisements from 2008 to 2019 containing almost 2.4 billion observations on asking prices and property characteristics. Our econometric model draws on a spatial difference-in-differences approach, thereby circumventing endogeneity problems that could arise from the nonrandom placement of power plants (Kok et al., 2014).

Among our key results, we find a coal power plant opening is associated with an average price discount of - 12.6% for properties in a 2-km surrounding area, nearly ten times the magnitude of the estimated effect of - 1.8% for the installation of wind turbines. On the other hand, and in line with other empirical studies finding negative effects on house prices after the closure of large-scale plants (Bauer et al., 2017; Eichholtz et al., 2023), we also find that the closure of coal power plants is associated with a discount of - 7.8% on surrounding house values, which is likely the result of economic channels such as employment (Burke et al., 2019; Jolley et al., 2019; Clark and Zhang, 2022). However, these negative effects appear to be limited in their spatial scope: Both the opening and closure effects of coal power plants are weaker as distance to the facility increases, while the impact of wind power installations remains persistent up to 4 kilometers. Otherwise, we find no statistically significant effects of openings or closures of solar, gas or nuclear facilities. The latter results is at odds with the negative effect of nuclear closures found by Bauer et al. (2017), though it is noted that their study tracked the time period directly following the Fukushima disaster in 2011, when a heated debate erupted in Germany surrounding continued reliance on nuclear power.

Taken together, our results indicate that in pursuing the goal of a successful energy transition, the costs associated with coal power plant closures, as well as those with wind turbine installations, warrant consideration, not least when deciding on where to place new electricity generation infrastructure. These costs may turn out to be substantial, as demonstrated by a back-of-the-envelope calculation that indicates several billion euros in house value losses from the combined effects of wind turbine openings and coal plant closures. While we are skeptical about the efficacy of compensating homeowners to offset reduced property values, we argue that negative economic spillovers should be taken into account when designing policies to ensure distributive justice in the transition to carbon neutrality (Carley and Konisky, 2020).

In the following Section 2, we outline the policy backdrop of Germany's energy transition. In Section 3, we describe the data employed for our analysis, and in Section 4 the empirical strategy. Section 5 presents our empirical results, a suite of robustness checks is provided in Section 6. In Section 7 we present back-of-the-envelope calculations on the magnitude of local costs, and Section 8 closes with conclusions.

2 Germany's Energy Transition

In an attempt to reach carbon neutrality by 2045, Germany has introduced a suite of policies – collectively referred to as the *Energiewende* – to rapidly decarbonize its energy system. This energy transition rests on three key pillars that render Germany particularly relevant for this paper's research focus. First, Germany established instruments to heavily promote investments into renewable energy technologies, most notably a feed-in-tariff scheme, which was introduced in the year 2000 as part of the Renewable Energy Act (EEG). Wind and solar power installations have particularly benefited from this support scheme, having jointly increased over 9-fold from a base of 12 Gigawatt (GW) in 2000. Wind onshore capacities amounted to about 58 GW in 2022, and photovoltaics capacities to about 67 GW. Together, these capacities exceeded the total capacity of conventional power plants of about 81 GW.

Recently, in light of the energy crisis triggered by Russia's invasion of Ukraine, Germany's government amended the EEG to accelerate the deployment of renewables to reach a share of 80% of green electricity in total electricity consumption by the year 2030.Highly ambitious expansion plans were developed. By 2030, onshore wind capacities are to be increased to 115 GW. This implies nearly doubling current onshore wind capacities. Even more ambitious is the intended expansion of photovoltaics (PV). By 2030, PV capacities should amount to 215 GW, implying more than a tripling of current photovoltaic capacities. These figures illustrate that the number of openings of wind and solar power installations may substantially increase further in the upcoming years.

Second, Germany is one of the few countries in the world to phase out nuclear power plants. After the Fukushima incident of 2011, Germany decided to shut down eight of its nuclear reactors immediately, and slowly phase-out the remaining plants by 2022. This decision, rooted in a long history of anti-nuclear movements dating back to the 1970s, has often been criticized internationally. However, public opinion in Germany around the time of the decision strongly favored the shutdown of nuclear plants. More recently, once more spurred by the energy crisis, the government decided to extend the lifetime of its three remaining nuclear plants by slightly more than three months. Ultimately, these three plants were closed on April 15, 2023.

Third, in addition to the nuclear phase-out, Germany plans to shut down its coal-fired stations by the year 2038 at the latest. This stance, spelled-out in the Coal Exit Law, entails closing down 22.8 GW of hard coal and 21.1 GW of lignite capacities that operated at the end of 2019, the year before the law went into force. The law also recognizes the economic downturn that the shut-downs will have on surrounding communities and paves the way for economic support programs in coal regions. In addition to €5 billion that are designated for the early retirement of older workers set to lose their jobs from plant closures, up to €40 billion are stipulated to support the coal regions.

Overall, Germany's energy transition sets out clear policy objectives of a double phase-out of nuclear and coal power plants, as well as the expansion of renewables, most notably onshore wind power and solar parks. The recent energy crisis has, however, forced the government to take decisions for energy security that implied the re-opening of power plants: Due to current fears over energy security, five lignite-powered plants have been temporarily re-activated (Bryce, 2022). Understanding the local costs of these openings and closures of power plants on the values of surrounding houses is thus a crucial ingredient to assess the consequences of these decisions.

3 Data

Our empirical analysis draws on two longitudinal data sets, one covering home prices and the other energy facilities. These are merged using a geographic information system. The data on home prices is obtained from ImmobilienScout24, the leading German real estate online platform. The data contains the asking prices and characteristics of homes and apartments, including their geocoordinates, for the period spanning 2008 to 2019. In our analysis, we solely focus on house sales, as we expect amenities to be more relevant for these transactions than for rentals.

3.1 Home Prices

The use of asking prices for our empirical estimations raises the question of whether they are a good substitute for transaction prices. Dinkel and Kurzrock (2012) explore this question using data from rural areas of Germany. They compare the asking price advertised on ImmobilienScout24 with the actual transaction price, finding a differential of about 15%. More recently, Frondel et al. (2020) compare ImmobilienScout24 data with transaction prices from Berlin and find a difference of about 7%, one that remains stable over time. Taken together, the evidence suggests that asking prices, while not ideal, are a reasonable proxy for transaction prices in the German real estate market.

We drop observations of special properties such as villas, castles, farmhouses and bungalows, and houses built before 1800, as well as observations with extreme values in any of the explanatory variables and missing values. We retain observations with asking prices between €1,000 and €10 million, living areas between 25 and 500 m^2, base areas between 50 and 10,000 m^2, and with less than 11 rooms.

Table 1 reports the summary statistics for house characteristics after the data has been cleaned, leaving us with just under 2.4 million observations on house sales in the period 2008 to 2019. Most important for our analysis is the distance to the next electricity generation facility. On average, the nearest wind turbine or solar park to a house, ranging between 7 and 8 kilometers, is closer than the nearest conventional power plant. This is due to the fact that there are many more wind turbines and solar parks in Germany than coal, natural gas and nuclear power plants.

Table 1: Summary Statistics for the Estimation Sample

Variable	# Obs.	Mean	St. Dev.	Max	Min
House price (EUR)	2,399,949	283,744	229,823	10,000,000	1000
Number of rooms	2,399,949	5.5	1.7	10	1
Living area (m^2)	2,399,949	157.3	55.8	500	25
Lot size (m^2)	2,399,949	696.6	550.8	5000	50
Detached	2,399,949	0.59	–	1	0
Unfinished	2,399,949	0.12	–	1	0
Multi-family home	2,399,949	0.09	–	1	0
Age of the house	2,399,949	35.3	35.3	199	0
Distance in meters from:					
a wind turbine	2,399,949	8007	5366	54,648	33.6
a coal power plant	2,399,949	31,406	23,071	151,242	78.3
a nuclear power plant	2,399,949	96,865	65,146	368,615	553
a solar park	2,399,949	6908	4435	33,882	14.1
a gas power plant	2,399,949	20,814	15,220	104,831	78.3

3.2 Facility Data

Geo-referenced data on wind turbines and solar parks is taken from the Federal Network Agency and regional authorities reporting to it (BNetzA, 2021). Dropping all solar parks with a capacity below 1 Megawatt (MW), we only take account of large-scale PV installations, thereby assuming that smaller installations, in particular rooftop solar, do not affect the prices of surrounding houses. Data on conventional power plants is taken from the power plant list of the federal network agency (BNetzA, 2022), and complemented with data from the German Environmental Agency (UBA, 2013). The data on conventional plants was geo-referenced with the help of Open power systems data (OPS, 2020), which provides precise geographical information. The spatial distribution of the conventional plants is presented in Appendix A, as well as the distribution of the wind turbines and the solar parks.

Table 2 reports the number of facilities of each type at the start of the observation period in 2008 and at the end in 2019. Within this period, a large number of wind turbines and solar parks were installed, but only a handful of turbines and a single solar park were closed. Conversely, no new nuclear power plant was opened over the period, while nine plants were taken off-line. The number of coal power plants decreased from 95 to 88, a result of ten openings and 17 closures.[1] Gas power plants increased in number from 174 to 207, with 48 openings and 15 closures. These changes in the composition of the facility portfolio motivate our approach of studying both openings and closures under a unified framework.

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[1] Note that we group lignite and hard coal power plants together because we do not expect home buyers to value houses near a hard-coal-powered plant differently than those near a lignite-powered plant.

Table 2: Number of Energy Generation Facilities, Openings, and Closures in the Estimation Sample.

Type of Facility	2008	2019	Openings	Closures	Net change
Wind turbines	14,230	27,097	12,949	82	12,857
Solar parks	389	3585	3197	1	3196
Nuclear power plants	16	7	0	9	-9
Coal power plants	95	88	10	17	-7
Gas power plants	174	207	48	15	33

Note: By the terms openings and closures, we are referring to the commissioning and decommissioning of facilities, respectively.

4 Empirical Identification Strategy

Energy infrastructure is not distributed randomly across the landscape. Rather, its siting is correlated with any number of factors that may also bear on home prices, one being the value of land in surrounding areas (Kok et al., 2014). To mitigate the likely endogeneity bias that emerges from our inability to control for all of these factors, we adopt a spatial difference-in-difference approach (DiD) (Eichholtz et al., 2023; Dröes and Koster, 2016; Muehlenbachs et al., 2015; Heckert and Mennis, 2012; Lang et al., 2014). Estimated as a hedonic price model via OLS, the specification simultaneously considers both the openings and closures of energy facilities:

$$\begin{aligned} \ln P_{cijt} &= \beta_0 + \beta_{\mathbf{x}}^T \mathbf{x}_i + \sum_{k=1}^{4} \beta_{OPk}\, OP_{ki} + \sum_{k=1}^{3} \beta_{CLk}\, CL_{ki} \\ &+ \sum_{k=1}^{4} \beta_{POPk}\, OP_{ki} \cdot PostOP_{kit} + \sum_{k=1}^{3} \beta_{PCLk}\, CL_{ki} \cdot PostCL_{kit} \\ &+ \lambda_j + \gamma_t + \epsilon_{cijt} \quad , \end{aligned} \tag{1}$$

where $\ln P_{cijt}$ stands for the natural logarithm of the asking price P of property i in postal area $j \in \{1, ..., 7565\}$ in year $t \in \{1, ..., 11\}$.

OP_k, $k \in \{1, .., 4\}$ and CL_k, $k \in \{1, .., 3\}$ designate a series of dummy variables that equal unity if property i is within a 2-km distance of the opening (OP) or closing (CL) of an electricity generation facility of type k, irrespective of when the opening or closing transpires – see Figure 1. The 2-km radius follows the buffer size typically employed in the literature to capture the main visual impacts of onshore wind turbines (Dröes and Koster, 2016, 2021), as well as conventional facilities (Davis, 2011). In our robustness checks presented in Section 6, we explore whether the results change substantially when we expand the buffer area to three and four kilometers.

Among the five types of facilities considered in this study, nuclear is excluded from the list of openings as no plants opened during the observation period. Solar is excluded from the list of closings as only a single solar park closed. We also exclude wind because although 85 turbines closed, these were all clustered in a remote area with very few houses in proximity.

$PostOP_k$ is a series of dummy variables indicating the time period after facility k is operational. The interaction term $OP_{ki} \cdot PostOP_{kit}$ thus indicates that property i is within 2 kilometers of an opening electricity generation facility of type k in year t after the facility has been installed. Correspondingly, $PostCL_k$ is a series of dummy variables indicating the time period after facility k was closed. $CL_{kit} \cdot PostCL_{kit}$ thus indicates that property i is within 2 kilometers of a closing facility of type k in year t after it has been closed.

The remaining control variables include a vector of housing characteristics, x, capturing the number of rooms in the house, the size of the living area, lot size, and indicator variables for whether the house was constructed prior to 1945, is detached, unfinished, or a multi-family home. While ϵ_{cijt} designates the stochastic error term, the term λ_j represents fixed effects that control for time-invariant factors across zip codes, of which there are 8170 in Germany having an average size of 44 square kilometers. γ_t are year-fixed effects that control for intertemporal changes in housing markets across Germany as a whole. We additionally estimate a specification that replaces this term with county-year fixed effects, η_{ct}, allowing us to control for time-varying trends across counties.[2]

The coefficients of interest are β_{POPk} and β_{PCLk}, which capture the average difference in the change in prices between houses near an opened or closed facility of type k after the facility has been installed or closed, respectively, and comparable houses that are never near any facility. Identification rests on several assumptions. A key assumption is parallel trends: Conditional on the controls, we assume that the prices

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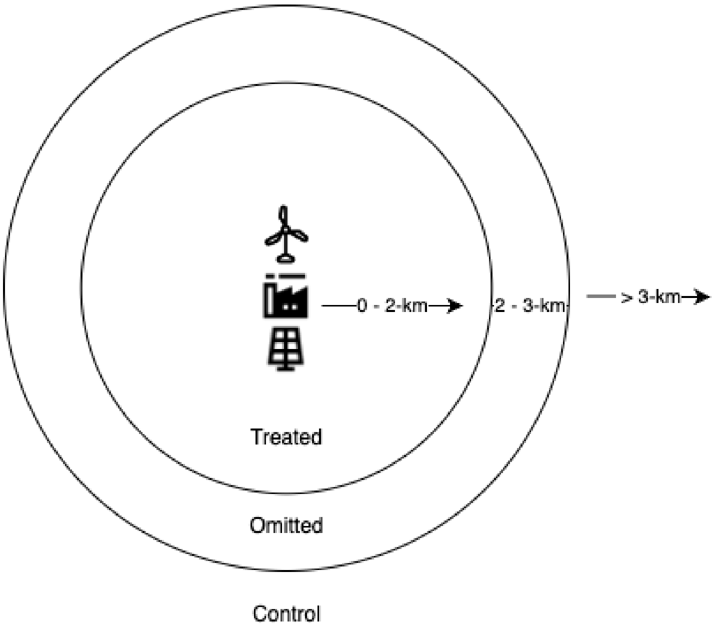
[2] Germany has 401 counties with an average size of 830 square kilometers.

of houses located close to and far away from a facility would have followed the same trend in the absence of the facility's opening or closure. We will probe this assumption using a series of robustness checks on a facility-by-facility basis.

We also assume the absence of anticipation, meaning that the treatment has no causal effect prior to its implementation. This would be violated if, in anticipation of a facility being built, the market already priced in the impact on the house value prior to the facility's opening. Under this circumstance, changes in the outcome for the treated group between the pre- and post periods would reflect not just the causal effect in the post period but also the anticipatory effect in pre-period (Abbring and Van den Berg, 2003; Malani and Reif, 2015). We attempt to rule out anticipation effects with additional robustness tests that alter the estimation sample based on the timing of openings and closures.

Figure 1: Treatment and Control Groups.



Notes: Treatment group: Houses located 0 - 2 km from a facility. Control group: Houses located at least 3 km from a facility. Houses located 2 - 3 km from any facility are omitted.

Finally, identification requires a stable unit treatment value assumption (SUTVA), implying that the treatment solely exerts a direct effect on the unit being treated, thereby excluding general equilibrium effects and treatment externalities. It is plausible, for example, that (dis)amenities affecting property prices in one area spillover and affect prices in neighboring areas, potentially violating SUTVA and biasing the estimate of the treatment effect. As illustrated in Figure 1, we address this possibility by dropping properties that are 2 to 3 kilometers away from a facility, with the aim to clearly demarcate control observations that are not subject to spillovers. We also omit properties from the analysis that are near to facilities that always operate throughout the sampling period, as these observations do not help to identify the effect on house prices due to lacking variation in the operating status.

5 Empirical Results

Table 3 presents two specifications of Model (1), distinguished by the inclusion of year fixed effects or county-year fixed effects. Corroborating evidence from other studies (Dröes and Koster, 2016; Gibbons, 2015), wind turbines have a negative and statistically significant association with house prices. The magnitude of the effect varies substantially across the specifications. The estimate obtained from the year-fixed-effects specification suggests that the introduction of a wind turbine is associated with a decrease of 6.7 % in house prices, which is roughly four times the magnitude of the estimate of -1.8% reported in the panel on the right-hand side of Table 3.[3] This discrepancy may owe to the fact that, as Davis (2011) notes, the siting of power plants is a highly political process. Recognizing that Germany's regulatory framework bestows substantial autonomy to county authorities in designating priority areas for wind power (Frondel et al., 2019), the inclusion of the county-year fixed effects may serve to account for shifting regional sentiments, whose neglect could otherwise pose a source of bias.

Coal power plant openings likewise have a negative and statistically significant association with house prices. Based on the estimate stemming from our preferred specification, houses in proximity of a coal power plant opening see a reduction in value amounting to roughly 12.6%, some eight times larger than the corresponding estimate found for wind and almost double the impact that Davis (2011) finds for coal power plant openings in the US. Conversely, we find no evidence that either openings of solar parks or gas power plants have a statistically significant association with house prices. For both photovoltaics and gas power plants, the null effect appears unsurprising given that these facilities lack many of the negative externalities associated

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[3] Slightly more precise, the correct effect is estimated as follows: -6.5% (=exp(β) -1), a difference of 0,2 percentage points.

with coal power plants, including air pollution, as well as traffic and noise pollution from fuel deliveries. In contrast, gas power plants have lower emissions of nitrogen oxides, sulfur dioxide, ash, and other residues. Moreover, whereas hard coal typically arrives by train, truck, or barge at all hours of the day, generating noise and traffic, and, in addition, coal processing produces fly ash, gas is delivered relatively inconspicuously by pipeline. Last, due to fundamental differences in the exhausts load, the smoke stacks of coal power plants are typically much taller than those of gas power plants, which usually are hardly higher than the building of the plant.

Table 3: Spatial Difference-in-Differences Estimation Results on the Effects of Openings and Closings of Electricity Generation Facilities on Asking Prices of Houses.

	Year Fixed Effects		County-Year Fixed Effects	
Openings:				
Wind Turbine < 2 km	-0.067***	(0.011)	-0.018*	(0.008)
Solar Park < 2 km	0.013	(0.010)	0.009	(0.006)
Coal Power Plant < 2 km	-0.126*	(0.052)	-0.135**	(0.049)
Gas Power Plant < 2 km	0.027	(0.033)	0.003	(0.018)
Closings:				
Coal Power Plant < 2 km	-0.175***	(0.035)	-0.081**	(0.031)
Gas Power Plant < 2 km	0.085	(0.055)	-0.033	(0.036)
Nuclear Power Plant < 2 km	0.000	(0.094)	-0.052	(0.103)
adjusted R^2	0.712		0.727	
# Observations	2,399,949		2,399,949	

Notes: *** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$. Standard errors, reported in parentheses, are clustered at the county level. # Houses near Wind Turbine Openings: 69,090, # Houses near Solar Park Openings: 160,189. # Houses near Coal Power Plant Openings: 474. # Houses near Gas Power Plant Openings: 5199, # Houses near Coal Power Plant Closings: 1292, # Houses near Gas Power Plant Closings: 393, # Houses near Nuclear Power Plant Closings: 375 .

According to our results, there is no evidence that the negative effects of wind and coal power plant openings are mirrored by positive effects when these energy facilities are closed. Instead, the evidence points in the opposite direction: the results from our preferred specification indicate that the closure of a coal power plant is associated with a 7.8% decrease in house prices. Likewise, there seem to be negative effects of gas and nuclear plant closures, though the respective estimates are statistically imprecise. Nevertheless, the negative result for nuclear plants is, at least qualitatively, in line with Bauer et al. (2017), who find a 4.8% fall in house prices following nuclear plant closures in response to the Fukushima accident in 2011. The weaker effect of nuclear closures found here may owe partially to the fact that our analysis extends until 2019, during which time the charged atmosphere surrounding debates about nuclear power may have dissipated. Some support for this explanation is presented in the appendix, where we broadly replicate the result of Bauer et al. (2017) by aligning our estimation sample with the temporal frame of their analysis.

The negative impacts of both openings and closing of coal power plants presented in Table 3 are not immediately reconcilable: If the introduction of disamenities from a plant opening decreases house prices, then, all else equal, we would expect that their removal following a plant closing would increase prices. Two factors may account for the absence of such a pattern, one being an asymmetry in the effect of disamenities. Specifically, the market forces compelling home sellers to reduce prices with the arrival of a disamenity may be stronger than the forces pushing prices up with the disamenity's exit. This would be the case if the compensation required by a prospective home buyer to tolerate noise and air pollution from a coal plant is higher than the premium the home buyer would pay for the removal of these nuisances, akin to the well-established inequality between willingness-to-pay and willingness-to-accept (Frondel et al., 2021).

Beyond this, a second, and probably more important, factor accounting for the negative effect of plant closings are the long-term positive economic effects on the local community that the plants generate, which increase property prices. The importance of such favorable economic effects on the local welfare is prominently highlighted by the government's support of the coal regions of €40 billion, stipulated in Germany's Coal Exit Law to prevent the economic downturn of these regions, where in some cases, the coal sector is among the most important occupiers, such as in the lignite-mining districts in the economically weak parts of Eastern Germany (Dehio and Schmidt, 2019).

Accordingly, an important channel through which these long-term positive effects are likely to propagate is employment (Bauer et al., 2017): At the end of 2018, a total of about 32,800 employees were directly employed in the coal sector, including both lignite- and hard-coal-based power plants and coal production. In particular, with around 15,600 jobs, the employment volume of lignite mining, where the mining sites are always located next to lignite plants, exceeded that of coal power plants.[4] These direct employment impacts contribute to the local economy in numerous ways, such as indirect employment, and hence multiplier effects, and through spillovers. For example, while reporting about 19,800 employees for the lignite-mining and lignite-based electricity production sector in 2016, Dehio and Schmidt (2019, p. 5) estimate this sector's total employment, including indirect employment, to reach 55,600. In a similar vein, Montrone et al. (2022) discuss the impact of mining jobs related to coal extraction as a potential economic channel by which plants contribute to the local welfare. Moreover, infrastructure spillovers are also discussed, as hard coal power plants require the construction of railways, roads, or ports for coal transport, which typically supports other sectors such as hotels and restaurants (Donaldson, 2018).[5] If, over time, these positive spillovers and multiplier effects are capitalized in higher house values, then the closure of the facility could conceivably have an immediate negative impact on the surrounding housing market.

6 Robustness Checks

We check the robustness of the results in several ways. First, an important assumption in interpreting our results is the presence of parallel trends during the pre-treatment period. While this assumption cannot be formally tested, it can be corroborated by testing directly for differential trends between treatment and control regions. We implement this using an event-study specification that includes dummies for leads at two, three, and four and more years prior to treatment. The year prior to the opening/closure is excluded from the analysis.

Figures 2, 3 and 4 illustrate the results, Standard errors in every case are clustered at the county level. Pre-treatment leads in each case are statistically insignificant, providing support for the parallel trends assumption. Note that the coal opening and

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[4] Lignite plants are always located next to mining sites due to the low energy density of lignite, which would imply prohibitively large transportation cost if power plants were to be far away from mining sites.

[5] Both of these channels, direct employment as well as spill-over effects, are expected to be less relevant for gas-fired power plants, due to, first, the generally lower employment across the entire value chain (Czako, 2020) and, second, the fact that the fuel supply of gas-fired plants is managed by pipelines that do not serve alternative economic purposes – in contrast to the railway, shipping, and street infrastructure required for hard coal power plants.

wind opening post-treatment indicators are insignificant in these models, though of similar magnitude to those reported in the previous section.

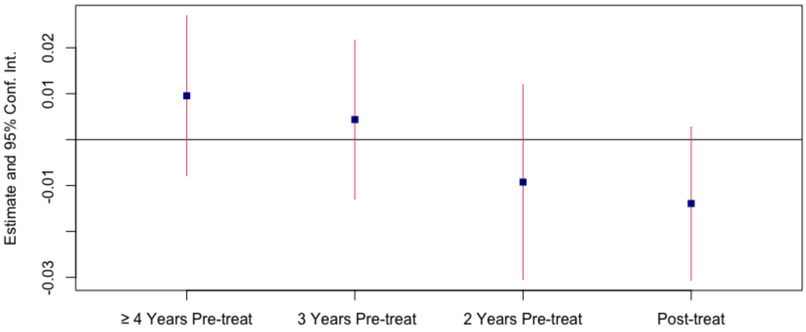

Figure 2: Pre-treatment Effect on Asking Price: Wind Turbine Opening

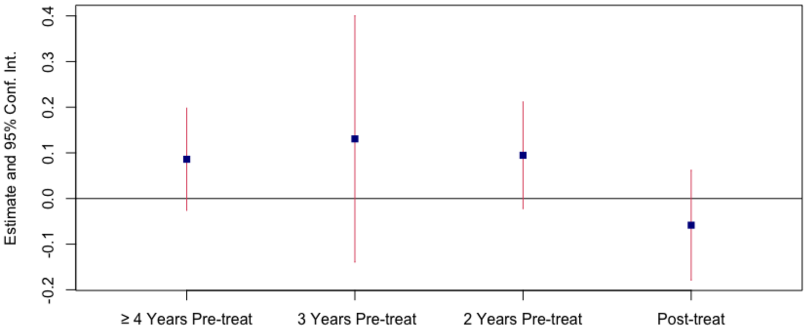

Figure 3: Pre-treatment Effect on Asking Price: Coal Power Plant Opening

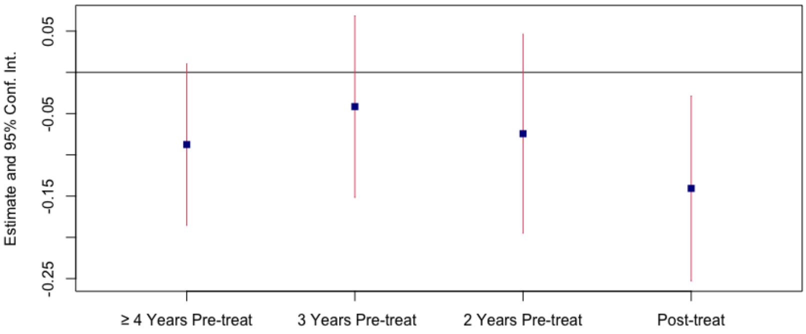

Figure 4: Pre-treatment Effect on Asking Price: Coal Power Plant Closure.

A second concern is the absence of anticipation effects: Even before a power plant is commissioned, news of its opening may be internalized into house prices. In a similar vein, the announcement on the imminent closure of a plant may also have serious impacts on the demand for housing prior to the actual decommissioning. To rule out anticipation effects, we re-estimate Model (1) after dropping houses near facilities during the year of opening/closure, as well as in the two preceding years. Our reduced estimation sample is in this case comprised of houses near facilities at least three years before the opening/closure of the facility, and at least one year after. The results are presented on the right-hand side of Table 4, alongside the results from our preferred specification on the left side. Ruling out anticipation effects renders all of our significant estimates of higher magnitude. This is especially the case for coal power plant openings, where the estimated coefficient nearly doubles in magnitude.

Finally, we re-specify the treatment groups by using larger buffer areas around plants, considering either properties located up to a radius of 3 kilometers away from an opening/closing facility as treated or up to 4 kilometers. The results of this exercise, reported in Table 5, indicate that the impact of coal power plants is weaker when the buffer extends beyond two kilometers, both when a plant is newly installed or decommissioned. Given the causes for negative external effects of coal power plants discussed in the previous section, it appears plausible that negative effects weaken with larger buffers, most notably because the intensity of noise originating from traffic due to hard coal deliveries diminishes with the distance, as well as other disamenities, such as traffic jams. In contrast, the coefficient estimates for wind turbines remain of similar magnitude even with larger buffers. This is in line with the results obtained from the literature, which finds significant effects of wind turbines across large distances (Frondel et al., 2019; Gibbons, 2015).

Table 4: Spatial Difference-in-Differences Estimation Results on the Effects of Openings and Closings of Electricity Generation Facilities on Asking Prices of Houses when Ruling-out Anticipation Effects.

	Results of Table 3		Ruling-out anticipation	
Openings:				
Wind Turbine <2 km	−0.018*	(0.008)	−0.023*	(0.010)
Solar Park <2 km	0.009	(0.006)	0.012	(0.007)
Coal Power Plant <2 km	−0.135**	(0.049)	−0.235***	(0.069)
Gas Power Plant <2 km	0.003	(0.018)	0.019	(0.021)
Closings:				
Coal Power Plant <2 km	−0.081**	(0.031)	−0.099***	(0.027)
Gas Power Plant <2 km	−0.033	(0.036)	−0.055	(0.057)
Nuclear Power Plant <2 km	−0.052	(0.103)	0.025	(0.133)
Fixed Effects	postal code + county-year			
adjusted R^2	0.727		0.728	
# Observations	2,399,949		2,279,865	
Openings:				
# Houses near Wind Turbine	69,090		55,165	
# Houses near Solar Park	160,189		133,056	
# Houses near Coal Power Plant	474		203	
# Houses near Gas Power Plant	5199		4117	
Closings:				
# Houses near Coal Power Plant	1292		876	
# Houses near Gas Power Plant	393		235	
# Houses near Nuclear Power Plant	375		334	

Note: *** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$. Standard errors, reported in parentheses, are clustered at the county level.

Table 5: Spatial Difference-in-Differences Estimations Results on the Effects of Openings and Closings of Electricity Generation Facilities on Asking Prices of Houses under various Distance Definitions.

	2-km radius		3-km radius		4-km radius	
Openings:						
Wind Turbine	−0.018*	(0.008)	−0.018**	(0.006)	−0.016**	(0.006)
Solar Park	0.009	(0.006)	0.007	(0.005)	0.006	(0.004)
Coal Power Plant	−0.135**	(0.049)	−0.019	(0.083)	−0.044	(0.041)
Gas Power Plant	0.003	(0.018)	0.018	(0.016)	0.025	(0.020)
Closings:						
Coal Power Plant	−0.081**	(0.031)	−0.043	(0.045)	−0.017	(0.021)
Gas Power Plant	−0.033	(0.036)	−0.016	(0.032)	−0.020	(0.021)
Nuclear Power Plant	−0.052	(0.103)	−0.045	(0.075)	−0.044	(0.064)
Fixed Effects	postal code + county-year					
adjusted R^2	0.727		0.729		0.730	
# Observations	2,399,949		2,072,471		1,806,583	
Openings:						
# Houses near Wind Turbine	69,090		133,583		182,164	
# House near Solar Park	160,189		257,942		342,297	
# Houses near Coal Power Plant	474		771		1181	
# Houses near Gas Power Plant	5199		9280		10,803	
Closings:						
# Houses near Coal Power Plant	1292		2059		2855	
# Houses near Gas Power Plant	393		807		870	
# Houses near Nuclear Power Plant	375		846		1440	

Notes: *** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$. Standard errors, reported in parentheses, are clustered at the county-level.

7 Back-of-the-Envelope Cost Estimates

Expecting the largest price effects from wind turbine installations and coal power plants closures, as our estimation results presented in Table 3 suggest, in this section, we gauge the magnitude of the costs of these two energy infrastructure changes on local housing markets in the upcoming years until 2030. Simultaneously, these events are two of the key pillars of the German energy transition. Given the rapidly changing landscape due to substantial alterations in the electricity supply infrastructure, our forward-looking calculations can provide guidance on the costs of Germany's energy transition that are frequently ignored by policy-makers.

To this end, in addition to the data on asking prices from Immobilienscout24, we draw on data from RWI-GEO-GRID on the number and spatial distribution of houses (Breidenbach and Eilers, 2018), and focus on the infrastructure events associated with the policy goals of (i) installing 115 GW of onshore wind capacity until 2030 and (ii) closing down the 45 remaining large-scale coal plants until 2038. Confining ourselves to one- and two-family houses, as these types of houses represent the bulk of the houses in the data, our back-of-the-envelope calculation provides a crude estimate of the costs, as it is based on several simplifications, one being the omission of the rental market. We also ignore the heterogeneity in the magnitude of effects across the landscape.

We begin by calculating the number of houses within 2 kilometers of coal plants set to close, which amounts to 80,465 – see Table 6. Second, for the case of wind, we calculate the number of houses affected by future wind turbine installations within 2 kilometers at 81, which is estimated on the basis of 2019 data on number of houses in proximity to existing turbines, and multiply this by the minimum number of turbines that still need to be built to meet capacity targets, 12,600.[6] Finally, to calculate the overall cost of these policy decisions, we multiply the number of affected properties in each case by the average price of houses in affected areas, and then by our coefficient estimates.

The results of these calculations, presented in Table 6, yield total costs of €8.3 billion from these two policy decisions set to take place in the near future. Finally, it is

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[6] Computed by dividing the gap between current onshore wind capacity and the 115 GW target (52 GW) by the maximum capacity that modern wind turbines can provide (5 MW).

worth noting that while the substitution of coal for wind power abates carbon emissions in the German power sector, we omit the social cost of carbon from this calculation owing to the waterbed effect: Due to the prevalence of the EU Emissions Trading Scheme (EU ETS), reduced emissions in the German electricity sector will be offset by emissions increases in other sectors that are part of the EU ETS, rendering net effects of zero.

Table 6: Back-of-the-envelope Estimates of the Costs related to Future Coal Power Plant Closures and Wind Turbine Openings

	Point Estimate	# Affected Houses	Average Price in €	Per-property Cost in €	Total Cost in Billion €
Coal Power Plant Closure	-0.081	80,465	463,064	$-37{,}508$	-3.0
Wind Turbine Installations	-0.018	1,020,600	290,369	-5227	-5.3

8 Summary and Conclusions

In this article, we have provided a comprehensive hedonic price analysis of the impact of both the opening and closure of electricity generation facilities on local house prices in Germany. Identification has been based on a spatial difference-in-differences approach that included county-year fixed effects to control for the influence of temporal changes in regional socioeconomic conditions. The empirical results indicate that, compared to houses that are three or more kilometers away from a facility, both wind turbine installations and coal power plant openings are associated with reductions in the values of surrounding houses, with the impact of coal power plants being of much larger magnitude than that of wind turbines.

In line with the findings of the literature on the closure of nuclear power plants (Bauer et al., 2017), we find that coal power plant closures are likewise associated with depressed prices on surrounding houses. Related studies, such as Jolley et al. (2019), Clark and Zhang (2022), and Burke et al. (2019) point to the role of reduced employment and network effects from infrastructure in explaining these reductions. In addition, we find evidence that the impact of wind turbines on house prices tends to be more spatially disperse, whereas the effect of both coal power plant opening and closures weaken as the buffer enlarges beyond two kilometers.

In a back-of-the-envelope calculation, we have provided guidance as to the magnitude of these local costs in the context of Germany's *Energiewende*, in which decarbonization, not least by the closure of all coal power plants until 2038, and increased reliance on renewables electricity generation technologies, are crucial components. The question arises as to what, if any, policy measures are warranted in response to associated losses in home prices. Do homeowners, for example, have a right to individual compensation? Without identifying what externalities would thereby be corrected, the economic basis for such compensation seems dubious. In general, government policies can have both positive and negative effects on property values. Just as homeowners are not expected to compensate taxpayers when publicly financed projects increase home values, it is not evident why compensation should flow in the opposite direction when socially beneficial projects, such as energy provision, lead to falling house prices.

Nevertheless, there may well be an economic case for regional investments in areas hit by economic disruptions due to the energy transition. Therefore, in the Coal Exit Law, the German government paved the way for economic support programs of up to €40 billion for coal regions set to face closures. This support can be used for the creation of new jobs, for example pairing with renewable investments in previous coal regions that could make use of the existing infrastructure and could help converting coal into solar-tech regions to stabilize the local workforce. The hope is that this mitigates the negative economic impacts and associated externalities from coal power plant closures, such as crime and mental health problems.

Although the importance of decarbonizing the energy system and shifting to renewable sources of energy cannot be overstated, most notably because of climate reasons, our study highlights that local costs are associated with Germany's *Energiewende* that should be taken into consideration when designing policies that ensure distributional energy justice principles.

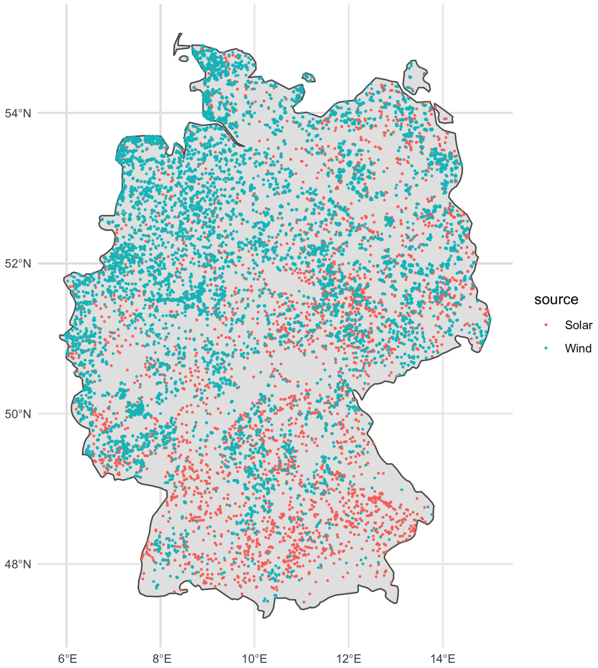
Appendix

A Location of Electricity Generation Facilities in Germany

Figure A1 presents the distribution of conventional power plants, including nuclear power, natural gas, hard coal and lignite, while Figure A2 presents the distribution of wind turbines and solar parks.

Figure A1: Location of Conventional Power Plants in Germany (2008 - 2019).

Figure A2: Wind and Solar Parks (with a Photovoltaic Capacity > 1 Megawatt) in Germany (2008 - 2019).



B Replication of the Results of Bauer et al. (2017)

Using data originating from Immobilienscout24, as we do in our analysis as well, but for a much larger time period spanning from 2008 to 2019, the aim of Bauer et al. (2017) is to study the impact of Germany's nuclear phase-out in the aftermath of the Fukushima nuclear disaster in 2011 on house prices in Germany. In their hedonic difference-in-differences approach, Bauer et al. (2017) consider houses in the vicinity of nuclear power plants as treated, defined as being less than 5 kilometers from a nuclear plant, while houses further away serve as the control group. Based on data for the time period spanning from 2007 to 2013, their main finding is that the closure of nuclear power plants led to a reduction of -4.8% in asking prices for houses in the surrounding area, relative to the control of houses farther away than 5 kilometers, an estimate that is statistically significant at the 1% level. As the authors argue, this finding suggests that economic channels largely explain the reduction in house values near nuclear power plant closures in the aftermath of Fukushima.

We adopt the regression and sample composition set-up of Bauer et al. (2017) in our replication of their findings: With observations restricted to the period 2008-2013, with the exception of the year 2007, we align the time frame to that employed in their paper (2007-2013), and consider houses up to 5 kilometers from nuclear plants as part of the treatment group. We thereby capture the impact of nuclear power plant (NPP) closures in the aftermath of Fukushima, closely mirroring the approach taken in Bauer et al. (2017). As presented in Table A.1, we estimate a statistically significant impact of -7.6% of a nuclear power plant closure on the asking price of houses near previously operating plants, thereby closely aligning with the estimate of -4.8% of Bauer et al. (2017).

Table A.1: Replication of the Results of Bauer et al. (2017) on the Effects of Nuclear Power Plant Closures on House Prices

NPP Closure < 5km	-0.076*** (0.023)
# Observations	$2{,}109{,}480$
Fixed Effects	post code + year
adjusted R^2	0.733

Notes: *** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$. Standard errors, reported in parentheses, are clustered at the county-level.

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