The Economic Costs of NIMBYism: Evidence from Renewable Energy Projects

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Abstract

Large infrastructure projects have important social benefits, but can also prompt strong local opposition. I study the economic costs of NIMBY (Not In My Backyard) attitudes and local planning restrictions by looking at renewable energy projects. Using data on thousands of permitting applications, I show that wind and solar projects have heterogenous impacts that sometimes include significant external local costs. I then show that planning officials are particularly sensitive to these local costs, often at the expense of considering the wider benefits of these projects. This systematic bias increased costs by 10-25% and led to substantial underinvestment.

JEL Codes: Q42, R11, Q51, Q53, R31
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1 Introduction

Large infrastructure projects can create widespread economic benefits and are often critical to tackling major national or global problems. In most countries new buildings and infrastructure require some form of local permitting. Getting planning approval can often be challenging, especially where there are concentrated local impacts that prompt strong pushback from affected residents.

This kind of local opposition is sometimes pejoratively labeled NIMBY (Not In My Backyard) behavior. It is most commonly associated with projects that combine public goods with private bads and spans issues as diverse as highways to landfills (Frey, Oberholzer-Gee and Eichenberger, 1996; Feinerman, Finkelshtain and Kan, 2004). Available evidence on housing construction suggests that the economic costs of distortions created by local planning restrictions can be substantial (Glaeser and Gyourko, 2018; Hsieh and Moretti, 2019).

In this paper I estimate the economic costs of NIMBYism and local planning restrictions by examining the case of renewable energy projects. Renewable energy is of particular interest because governments in most countries have committed to policies that require a dramatic rollout of new energy infrastructure. Based on existing policies and announced pledges, global electricity production from wind and solar is expected to increase four-fold by 2030, and twelve-fold by 2050 (IEA, 2022). Currently wind and solar account for 10% of global electricity output, but this could rise to 30% by 2030 and 60% by 2050 (IEA, 2022). NIMBYism and permitting challenges have increasingly been raised as significant barriers to this rollout (Carley et al., 2020).

My analysis focuses on the United Kingdom, where I am able to draw on detailed planning data for all proposed projects, including those that were denied planning permission and did not go ahead. The data covers roughly four thousand large wind and solar projects proposed in the UK over the past three decades. I start by describing some of the key trends observed in the data. I find that wind projects have a tougher time getting approved than solar projects. I find evidence that local county decisonmakers are more hostile to these projects than national ones. I also provide evidence on some of the key drivers of local opposition, which appears to be heavily motivated by the visual and noise disamenitites that residents have historically associated with these projects, particularly wind power.

It is possible that observed planning outcomes, and the low approval rates for wind power, are simply the efficient result of the planning process accounting for local external costs. Alternatively, local permitting decisions may be placing outsize weight on local factors, while dismissing the wider social merits for expanding renewable energy. To test this I move to more explicitly evaluating the effectiveness of the planning process.

First I estimate the full range of costs and benefits for each project. Here I incorporate a wide range of information to estimate the electricity production for each project; the market value of that electricity production and the external value of any emissions or pollution abated. I also bring together numerous sources to estimate the costs of constructing and operating each project.

A critical further addition I make is to estimate the local external costs on nearby residents and businesses. To fill this gap I focus on the capitalization into local property values. A number of studies have used hedonic methods to quantify the visual and noise disamenities from wind farms, finding negative effects on property values at distances up to 4km (Parsons and Heintzelman, 2022). There are also important margins of heterogeneity, such as visibility or the size and number of turbines installed (Gibbons, 2015; Sunak and Madlener, 2016; Dröes and Koster, 2016; Jensen et al., 2018; Dröes and Koster, 2020). The evidence for solar projects is less extensive, but mostly points to smaller effects limited to distances within 1km (Dröes and Koster, 2020; Gaur and Lang, 2020). Using the capitalization effects from these prior studies, I calculate the change in nearby property values for each project. In doing so I account for both the proximity and line-of-sight visibility for each property.

Of course, changes to property values are unlikely to capture all the local impacts of interest (e.g. employment or wildlife). Nevertheless, there are good reasons to think these capture a substantial portion of the impacts of interest in this setting, particularly when thinking about sources of local opposition.

Taken together my estimates of project-level costs and benefits reveal significant heterogeneity. This is despite the relatively homogenous nature of the technologies used and the output produced. In general larger projects have lower capital costs due to economies-of-scale. For wind projects they also tend to be more productive due to installing larger turbines. Productivity is mainly a function of location - namely how windy or sunny a site is. There are important tradeoffs here though. For instance, some of the most productive locations may be in remote areas, which raises the operational costs of transmitting power back to population centers. But locating projects near to population centres can also result in larger local external costs. Bigger projects with larger turbines also increase the external costs to nearby residents.

Using my complete set of estimates for project-level costs and benefits, I proceed to examine whether the planning and permitting process actually does a good job of accounting for these different tradeoffs when deciding which projects get built and which ones do not. Using a fixed effects regression analysis I find evidence that local planning decisions are indeed particularly responsive to local factors - a 1% increase in local property value costs leads to a 1.5% reduction in the likelihood of approval. This is especially the case in wealthier areas. By comparison, variation in the other wider social costs and benefits (e.g. electricity production benefits or capital and operating costs) do not meaningfully affect the likelihood of approval. This finding appears consistent with the localised nature of the planning process, with decisions for most projects being made by local planning authorities.

Refusing a proposed project to avoid adverse local impacts may indeed benefit local residents. But what appears optimal for a given local area can in aggregate create harmful outcomes for society as a whole. To quantify the scale of the problem and the scope for Pareto-improving trades, I calculate the potential gains from approving and constructing an alternative set of projects drawn from all of those that were proposed. I look at the gains from approving all projects with a positive social net present value, and a more constrained analysis that reproduces the observed annual deployment of renewable energy at least cost.

I find that inefficiencies in planning and permitting decisions have contributed to a significant misallocation of investment. The wind and solar projects actually built as of 2021 have lifetime capital and operating costs of £145 billion. My analysis indicates that the same deployment of renewable energy could have been achieved with costs savings of 10%. In some more aggressive scenarios the savings are closer to 25%.

Furthermore, the existing rate of deployment has likely been much too slow. Approving all socially beneficial projects would entail almost doubling the amount of wind and solar power, pointing to significant underinvestment. The majority of socially beneficial projects that failed to be built were refused planning permission, indicating that much of the blame can be attributed to the planning and permitting process.

Policymakers have tried a range of policies that could address the misaligned incentives identified here. I examine the feasibility of developers making direct payments to nearby residents. I show that a simple transfer scheme can be designed that compensates the large majority of affected households, often at a manageable cost to developers. Understanding the effectiveness of these transfer payments, and possible changes that could improve the local permitting process, remains a key area for further research.

Clean energy investment is expected to reach $2 trillion per year by 2030, mostly to build new wind and solar power (IEA, 2022). The findings in this paper suggest that this expansion could be achieved at much lower cost and with less political opposition if changes are made to the planning and development process. The local opposition to renewable energy studied here also shares many similarities with challenges faced by other large infrastructure projects in areas like transportation, water and waste. There is every reason to think that similar planning inefficiencies may be present in those sectors too.

Prior literature and Contributions

This work contributes to several important literatures. First there is a range of research on the economic impacts of place-based policies. In some cases these policies can be aimed at encouraging desirable local development, often with mixed results (Greenstone and Moretti, 2003; Glaeser and Gottlieb, 2008; Sadun, 2015; Chen et al., 2019). In other cases the goal is to restrict local development viewed as disruptive. Much of this work has been limited to studying housing development, where local planning restrictions have been shown to cause chronic underinvestment in important locations, creating a substantial drag on the economy (Glaeser and Gyourko, 2018; Hsieh and Moretti, 2019; Anagol, Ferreira and Rexer, 2021).

The findings in this paper provide new evidence of significant costs in the context of large-scale infrastructure deployment. Research of this kind for infrastructure projects is particularly challenging due to small sample sizes and the idiosyncratic nature of large projects. This paper leverages the fact that renewable energy projects are numerous and fairly homoegenous, making consistent valuation more tractable. The planning database used here also contains both completed and failed projects which is key to providing new insights into the effectiveness of the permitting process.

Second there is a rich literature focused on the location of undesirable industrial facilities. Studies in this area have linked siting decisions to both the size of the local external costs imposed and to the political power of nearby residents (Mitchell and Carson, 1986; Hamilton, 1993; Currie et al., 2015). Linkages are often made to concerns about NIMBY-ism, and possible ways to mitigate this kind of local opposition (Frey, Oberholzer-Gee and Eichenberger, 1996; Feinerman, Finkelshtain and Kan, 2004). This paper explores many of the same issues in a new context, and is able to conduct a more detailed assessment of the feasibility of a common policy solution: transfer payments to affected residents.

Early studies on landfills and harzardous waste sites also formed the basis for the broader literature on environmental justice (Banzhaf, Ma and Timmins, 2019). The transition to renewable energy has often been held up as a panacea to many unequal distributions of environmental burdens. But wind and solar projects create their own winners and losers, and political processes will be key to determining whether they perpetuate past inequities (Carley and Konisky, 2020). My findings reinforce this point.

Lastly, there is the extensive literature on climate change and the deployment of renewable energy. Much of this has considered the optimal policy mix to solve emissions and pollution market failures, with the accelerated uptake of renewable energy a consistent focus (Callaway, Fowlie and McCormick, 2018; Fell, Kaffine and Novan, 2021; Holland, Mansur and Yates, 2022; Borenstein and Kellogg, 2022).

Beyond getting price incentives right, a key challenge is overcoming regulatory and political barriers (Carley et al., 2020). A wealth of survey-based studies have examined community acceptance for renewable energy projects, with several questioning the validity of the NIMBY characterisation (Wolsink, 2000; Bell, Gray and Haggett, 2005; Rand and Hoen, 2017; Hoen et al., 2019). But a growing body of revealed preference evidence does suggest that wind farms can prompt political and regulatory pushback at the local level. This can come through the emergence of new restrictive zoning regulations (Winikoff, 2019) or efforts to punish "green" politicians at the ballot box (Stokes, 2016; Germeshausen, Heim and Wagner, 2021).

This paper builds on prior revealed preference studies by studying the observed decisions made by local planning officials. The findings provide new evidence quantifying the scale of the inefficiencies being created, and the potential benefits from policy changes that can improve infrastructure permitting more broadly.

2 Data and Context

2.1 Renewable Energy Policy in the UK

The first commercial wind farms in the UK were constructed in the early 1990s. Capacity has since grown to 26GW as of 2021. These wind farms produce 33% of Great Britain's electricity, and this is expected to rise to 61-69% by 2030 (NGET, 2022). Projects are mostly located in the windier and more remote regions of the north and west of the country. Many projects have also been sited in coastal areas with roughly half of the total capacity now located offshore.

The emergence of solar power in the UK has been more recent, starting in the 2010s. By 2021 total solar capacity stood at 13GW. Solar power currently produces 5% of Great Britain's electricity, and this is expected to rise modestly to 5-10% by 2030 (NGET, 2022). Most of this capacity has been located in the flatter agricultural areas in the south of the country where solar potential is highest. Unlike wind power, small-scale residential and commercial solar installations are widespread making up roughly a third of total solar capacity.

Despite a relatively broad political consensus in the UK on the importance of tackling climate change, the expansion of renewable energy has still been uneven and contentious. Both wind and solar projects have historically been dependent on carbon taxes and production subsidies, both of which are set at the national level. In the 1990s and 2000s onshore wind was the most widespread technology, but from 2009 a range of more generous subsidies spurred the expansion of solar power and offshore wind.

In 2015 several reforms were introducted that led to a decline in new investment for both solar power and onshore wind, including freezing the UK carbon tax, cutting renewable subsidies and requiring greater consensus from local residents for projects to be approved. Some of these changes were driven in part by the vocal opposition of rural voters to onshore wind turbines, with then-prime minister David Cameron vowing to "rid" the countryside of these "unsightly" structures. Notably offshore wind was not subjected to the same withdrawl of policy support. In recent years some of these subsidy cutbacks have been reversed, although the issue remains politically contentious.

2.2 Planning and Permitting Process for Renewable Energy

In most countries the planning and permitting process is a key determinant of the deployment of any large-scale infrastructure, including renewable energy projects. Like many jurisdictions, the UK decides the overwhelming majority of planning applications at the

Figure 1: Renewable Energy Projects in the UK

Notes: These figures show the location of projects and the timing of when they were submitted for planning permission. Project sizes are determined by their capacity (in MW). Projects are classified by their development status. "Pending" are projects that have submitted a planning application but have yet to receive a final decision. "Approved" are projects that have been approved and are either awaiting construction, under construction, operational or have been subsequently decommissioned. "Refused" are projects that were refused planning permission or were otherwise withdrawn or halted. The administrative boundaries depicted are the local planning authorities responsible for processing planning applications.

local level through local planning authorities. Local authorities are the primary unit of local government in the UK and are broadly analogous to counties or municipalities in other countries. Project developers submit a planning application to the relevant local authority. The proposal is reviewed in line with national and local planning guidelines. A public consultation period is required where affected residents and stakeholders have the opportunity to provide comments. The local authority then decides to either approve or refuse the planning application.

In making their determinations, local planning officials must weigh a range of competing factors. In the UK they have a legal duty under the 2008 Planning Act to mitigate and adapt to climate change. However, the national guidelines are relatively open-ended, stating that "all communities have a responsibility to help increase the use and supply of green energy, but this does not mean that the need for renewable energy automatically overrides environmental protections and the planning concerns of local communities". Important local concerns often center on changes to the character of the surrounding landscape, particularly for culturally and environmentally important sites (e.g., castles, monuments, national parks etc). For wind projects a noise assessment must be conducted, and there are several safety standards to ensure the turbines do not interfere with flight paths or radar installations.

A common approach in many countries is to set out certain zoning criteria that restrict development (e.g., setbacks stating how far a project must be from nearby properties or quotas for the number of projects in a certain area). The planning process in the UK is generally less prescriptive, but officials do still have a lot of scope to deem certain siting decisions to be harmful. Planning authorities may also seek amendments to planning applications, or approve them with conditions aimed at mitigating certain concerns.

There are two main exceptions to local control of the planning process in the UK setting. The first arises when projects are sufficiently large that they are deemed to have substantial national importance (e.g., motorways, airports, rail networks, ports etc.). In the case of renewable energy, projects with a capacity greater than 50MW have historically been deemed to be of national significance. In these situations the decision is made by the national Planning Inspectorate, although local views are still consulted. The second exception arises when a developer appeals the decision of a local planning authority. Once an appeal is lodged the national Planning Inspectorate conducts a review and decides to either uphold or overturn the initial decision. In both cases the split between local and national control provides an opportunity to examine the decisionmaking of officials at different levels of government.

2.3 Renewable Energy Planning Database

The primary dataset used in this paper is a UK government database on the planning applications for renewable energy projects. The Renewable Energy Planning Database includes all projects with a capacity of 1MW or greater that have been proposed since 1990 (BEIS, 2021*a*). Small-scale residential or commercial systems (e.g. rooftop solar) are excluded. I limit my analysis to wind and solar projects as these are the two largest sources of renewable energy, and are expected to provide the vast majority of future capacity additions both in the UK and globally (NGET, 2022; IEA, 2022).

Figure 1 shows where these projects have been located and when they were submitted for planning approval. Table 1 provides a range of additional summary statistics on outcomes from the planning process as documented in the database.

The projects in the planning database comprise the overwhelming majority of wind and solar capacity in the UK. There is a roughly even split across the two technology types, although wind projects are larger and so account for most of the total capacity. Despite this, it is noticeable from Table 1 just how much tougher the planning process is for wind projects. Recieving a planning decision takes three to four times longer for wind projects. The approval rate is much lower as well, with 41% of wind projects being approved compared to 73% for solar projects.

Interestingly, Table 1 provides suggestive evidence that national planning decision-makers are more positively predisposed to renewable energy projects. This is reflected in

Table 1: Summary Statistics on Project Planning Outcomes

	Solar	Wind
Number of Projects	2025	1885
Total Capacity (MW)	20756	73133
Average Capacity (MW)	10.2	38.8
Length of Planning Process to Initial Decision (days)	156	546
Length of Planning Process to Final Decision (days)	192	644
Initial Decision Approval Rate	0.73	0.41
Share of Projects subject to National Authority Decision	0.01	0.14
National Authority Initial Decision Approval Rate	0.75	0.67
Local Authority Initial Decision Approval Rate	0.73	0.37
Share of Projects Appealed	0.11	0.23
Appeal Success Rate	0.46	0.48
Final Decision Approval Rate	0.78	0.51

Notes: This table contains summary statistics for all wind and solar energy projects in the UK with a capacity of 1MW or greater that were submitted for planning approval since 1990. This excludes projects that are under review at the time of writing. Projects can be subject to approval by either a local or national planning authority. The planning authority makes an initial decision to either approve or refuse the project. Projects may then be appealed in which case the final decision may differ from the initial decision.

the higher approval probability for projects decided at the national level than by local authorities. This is also further demonstrated by the impact of the appeals process. There is a roughly even split between projects that were upheld on appeal and projects that were overturned on appeal. Accounting for appeals means the final planning approval rates increase to 51% for wind projects and 78% for solar projects.

To highlight some of the factors that correlate with projects successfully receiving planning permission, Table 2 shows the results of regressing a binary indicator for whether a project was approved on a range of project characteristics.

As expected, there is a marked drop in wind project approvals post-2015, but not for solar. This corresponds to changes made to the planning process that gave local residents more power to block onshore wind projects. In general, approvals appear less likely for larger projects, projects sited in conservative areas, and projects where nearby property values are high. Conversely, offshore wind projects and those decided at the national level are more likely to be approved. Many of these relationships remain significant even when looking at within-county variation. These findings are consistent with the broad

Table 2: Planning Process Regressions for Project Characteristics

	Wind			Solar		
Model:	(1)	(2)	(3)	(4)	(5)	(6)
Variables						
Post-2015	-0.123**			0.056		
	(0.047)			(0.046)		
log(Capacity (MW))	-0.036**	-0.041**	-0.036**	-0.020	-0.024	-0.035**
	(0.015)	(0.015)	(0.014)	(0.021)	(0.020)	(0.016)
Distance to National Park (km)	0.001***	0.001***	0.002**	0.000	0.000	0.001
	(0.000)	(0.000)	(0.001)	(0.000)	(0.000)	(0.001)
National	0.151***	0.156***	0.145***	-0.018	-0.119**	-0.004
	(0.021)	(0.018)	(0.017)	(0.060)	(0.050)	(0.086)
Conservative	-0.109***	-0.090**	-0.060	-0.032	-0.024	-0.085
	(0.038)	(0.036)	(0.067)	(0.024)	(0.025)	(0.054)
Avg. Property Value (thou. £)	-0.001*	-0.001**	-0.000	-0.000**	-0.000**	-0.001**
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
On/Offshore	0.305***	0.294***	0.338**			
	(0.101)	(0.103)	(0.127)			
Fixed-effects						
Year		Yes	Yes		Yes	Yes
Local Authority			Yes			Yes
Fit statistics						
Observations	1,825	1,825	1,825	1,928	1,928	1,928
R^2	0.05389	0.09718	0.23415	0.01269	0.04161	0.25676
Within R^2		0.03589	0.01868		0.01083	0.01161
Technology	Wind	Wind	Wind	Solar	Solar	Solar

Clustered (Year & Local Authority) standard-errors in parentheses
*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

Notes: This table shows the impact on approval probability of various project characteristics. "Post-2015" is a dummy for whether a project was due to come online after 2015. "Capacity" refers to the capacity of a project in MW. "National" coefficients capture whether a project's planning application was decided at the national level. "Conservative" captures whether a local authority is politically conservative. "Avg. Property Value" captures the average residential property value within 4km of a wind project and within 2km of a solar project. "On/Offshore" is a dummy for whether a project is located Offshore and is only relevant for wind projects.

findings of Roddis et al. (2018).

To provide further information on some of the key reasons why projects are refused I collected the decision letters for 120 wind and solar projects. By far the most cited reason for refusal is the visual impact of a project, which was mentioned in 60% of solar refusals and 75% of wind refusals. By comparison, noise concerns do not feature particularly heavily, This is unsurprising for solar projects. For wind projects though, the noise from rotating turbine blades is a common complaint so it is interesting that noise is mentioned in only 25% of wind refusals. It may simply be that, while important, noise impacts are still small relative to visual disamenities. Another explanation is that there are already clear objective regulations for noise limits, and so developers are likely to ensure these are met for all proposed projects. Visual impacts, on the other hand, are harder to explicitly include in planning procedures and so provide far greater latitude for subjective interpretation by planning officials.

The planning outcome data described here makes clear that a big challenge for the deployment of renewable energy is getting permitting approval. A key determinant of success is likely to be the extent of opposition from local residents and firms. In many ways this makes renewable energy projects similar to most other large-scale infrastructure projects, and so the findings here may be instructive for other sectors.

However, the particular importance of national and global factors (e.g., climate change) makes wind and solar projects an especially challenging case when planning processes are so dominated by local decisionmakers. Unlike more traditional local infrastructure like transport or housing, most of the benefits of wind and solar projects are spread diffusely throughout wider society while certain key costs remain concentrated locally. Quantifying the economic impacts arising from this misalignment between local and wider social incentives is the primary aim of this paper.

3 Empirical Strategy

To examine the potential economic impact of NIMBYism and local planning restrictions I conduct four pieces of analysis. Further detail on each can be found in the appendix.

First, I quantify the key costs and benefits of each project. The goal is to understand how large the local impacts are relative to the other wider non-local impacts that motivate the deployment of renewable energy in the first place.

Second, I conduct a regression analysis to understand how responsive planning officials are to economic impacts that are local or non-local. This builds on the exploratory regressions on project characteristics in the previous section.

Third, I estimate the costs of inefficient planning decisions in the form of misallocated investment. I do this by looking at the gains from reallocating across the range of proposed projects to see if beneficial ones are systematically denied planning permission.

Lastly, I conclude by examining the feasibility of a key policy solution - making transfer payments to affected local residents.

3.1 Estimating project-level costs and benefits

3.1.1 Benefits of Installation and Electricity Production

Estimating electricity production

Electricity production for wind and solar projects is almost entirely determined by three factors: the available wind or solar resource, the capacity of the project and the characteristics of the turbines or panels installed. A key statistic for summarizing the output from any renewable energy project is the capacity factor: the average amount of power the project produces normalized by the maximum power output capacity. In the UK this is generally around 35% for wind projects and 10% for solar projects.

To estimate the capacity factors for solar projects I use the photovoltaic power potential estimates from the World Bank Solar Atlas. This provides estimated solar power productions profiles on a 1km grid for a representative solar installation. I use the coordinates of each project to extract the nearest solar production profile from this grid. Solar panels are generally fairly homogenous so it seems reasonable to think actual output is similar to the representative values produced by the World Bank.

For wind projects the capacity factor is much more heavily dictated by the kind of turbine installed. To account for this I use data from Renewables Ninja (Pfenninger and Staffell, 2016; Staffell and Pfenninger, 2016). Here a user can select a set of location coordinates, a wind turbine model and a hub height, and then Renewables Ninja will calculate a wind power production profile that accounts for the characteristics of the turbine and the wind conditions in the specified location. For each wind project I first assign a likely turbine model from the list of possible turbine models in the Renewables Ninja database.[1] I use the location coordinates of each project to extract an hourly power production profile from Renewables Ninja, which I then collapse to a single average capacity factor value.

Market value of electricity

To value the electricity produced by each project I rely on data from the UK government's guidance on cost benefit analysis and the valuation of climate change policies (BEIS, 2021*b*). I measure the market value of the electricity produced by each project using the wholesale price of electricity. Pre-2020 the electricity prices are based on observed traded wholesale market prices. Post-2020 the electricity prices are based on projections out to 2050 that were made based on the UK government's modeling of the future electricity grid.[2]

Wind and solar projects do also receive production subsidies in addition to any wholesale market revenues. I do not include subsidy revenues in my estimates of the market

[1] To do this I start with the data on turbine manufacturers and models in The Wind Power Turbine Database. I match these to the turbine models available in the Renewables Ninja database. For each project in the planning database I calculate both the turbine capacity (in MW) and the turbine power density (in MW per m^2 of blade swept area). For each project I then find the closest turbine model on these two metrics that is also in the Renewables Ninja database. Where possible I prioritize selecting turbine models that have been more commonly installed in the UK.

[2] This modeling includes forecasting fuel prices, demand and investment in new capacity, and then running a dispatch model to solve for clearing market prices.

value of the electricity produced because from the perspective of a social planner they are simply transfers.

External value of emissions and local pollution abated

The electricity produced by renewable projects has added non-market benefits when it displaces other forms of environmentally harmful power production. In particular, where increased production of renewable electricity displaces coal or gas-fired power plants it will reduce both carbon emissions and local pollutant emissions.

To calculate the amount of emissions abated I start with historical data on annual total electricity generation and annual power plant emissions by source. I calculate annual average marginal emissions factors for CO_2, SO_2, $PM_{2.5}$, PM_{10} and NO_X assuming any operating fossil fuel power plants are the marginal source of generation. I then project these marginal emissions factors forward to 2050 assuming they decline in line with the forecast long-run marginal carbon emission intensity of the total generation mix. These forecasts are again taken from the UK government's modeling of the future electricity grid. Marginal abated carbon emissions are then valued using the UK values for the social cost of carbon and local pollution damages (BEIS, 2021*b*).[3]

Capacity value

The capacity value reflects the value a project provides in being available to match demand, particularly during peak demand periods when supply is tight. As such it is calculated per MW capacity installed. For this I rely on data from National Grid's Capacity Market Auction, as well as analysis by Harrison et al. (2015). The result is a capacity value for each project in £/MW/year. In practice the capacity value estimates are very small and do not meaningfully affect the results.

Learning-by-doing

As well as their static benefits, constructing a new wind or solar project has important dynamic effects through learning-by-doing. This is often one of the key reasons cited for

[3] In the 2019 guidance the central values are £68/ton for CO_2, £7,612/ton for SO_2, £128,415/ton for $PM_{2.5}$, £82,442/ton for PM_{10}, and £7,521/ton for NO_X.

subsidizing renewable energy in the early years of its development, beyond any direct emissions reduction benefits. The rapid declines in the costs of both wind and solar do point to significant scope for learning-by-doing effects.

Unfortunately quantifying these benefits is incredibly challenging. Here I rely on a method set out by Newbery (2018), which produces learning-by-doing benefits in 2015 of £600,000/MW for solar and £250,000/MW for onshore wind. These values decline steadily over time as each technology matures, and so can be substantially higher for some of the earliest projects. Ultimately these estimated learning-by-doing benefits are highly uncertain, but fortunately in most instances do not meaningfully drive my results. More details on their calculation is found in the appendix.

3.1.2 Costs of Construction and Operation

Capital costs

It is particularly challenging to get detailed project-level data on costs as this is usually treated as commercially confidential. Therefore to estimate capital costs I rely primarily on data from the International Renewable Energy Agency (IRENA), which provides country-level annual average installed capital costs for onshore wind and solar projects (IRENA, 2022). For offshore wind IRENA only publishes global average values, although given the UK makes up such a large portion of offshore wind projects these values are likely to be a decent approximation of costs for the UK. Moreover, due to the size of offshore wind projects I am able to supplement this part of the analysis with direct project specific estimates taken from various industry sources.

I then make an additional adjustment to account for variation in capital costs due to economies-of-scale. To capture this I use additional US data from Lawrence Berkeley National Laboratory (LBNL) on relative capital costs by project size (Wiser et al., 2022; Bolinger et al., 2022). For example, they show that the per MW capital costs for a 50MW solar project are 10% lower than those for a 5MW solar project. The difference is even more pronounced for wind projects where the equivalent cost reduction is 35%. I therefore use the LBNL data to scale the costs of large projects relative to small ones.

I convert my final estimates to consistent £/MW capital costs and multiply by the capacity of each project to get project-level values for total installed capital costs.[4]

Operating costs

To calculate project specific estimates of ongoing O&M costs I also rely primarily on data from IRENA. Here no UK specific data is available and so for onshore wind I use US values while for solar I use the values for projects in developed countries (IRENA, 2022). For offshore wind I assume the O&M costs are twice those of onshore wind to capture the increased costs of servicing turbines out at sea. I compare to UK government estimates to ensure this approach is reasonable.

An important additional contributor to O&M costs are grid connection and transmission charges. These costs can vary substantially depending on the location that a wind or solar project is connected to the grid. To capture this I modify the average O&M costs based on transmission system charging data from National Grid. This ensures that projects connecting to the grid in remote regions have appropriately higher costs than projects located close to demand centers.[5] This includes accounting for the additional grid infrastructure costs associated with the offshore wind.[6]

I multiply my £/MW/year estimates by the capacity and lifetime of each project to get project-level values for O&M costs.[7]

3.1.3 Costs to local residents

Finally, renewable energy projects create a number of local economic impacts. Of primary interest here are the various visual and noise disameneties associated with these projects. Credibly estimating these impacts is challenging. Here I draw on empirical evidence

[4]Where the available data does not span the full sample period from 1990 to 2025 I extrapolate using the observed rates of growth/decline over the nearest ten-year period.

[5]For example, the locational portion of National Grid's transmission charge can vary from more than £20,000/MW/year in Scotland to less than -£10,000/MW/year near London.

[6]These add an average of roughly £45,000/MW/year to the costs for offshore wind projects.

[7]Where the available data does not span the full sample period from 1990 to 2025 I extrapolate using the observed rates of growth/decline over the nearest ten-year period.

of how wind and solar projects affect nearby residential property values. I apply these hedonic effects to the value of properties located nearby to calculate the local impacts.

I focus on capitalization into residential property values as this likely captures a significant portion of the local impacts of interest.[8] These effects on nearby residents also seem important in the UK context given the extent to which visual and noise concerns are raised during the planning process. Other potential local costs and benefits (e.g. impacts on employment, taxes or wildlife) are discussed at the end of Section 3.1.

Capitalisation effects

A number of studies have used hedonic methods to study the local impacts of wind projects. Estimates from Jensen et al. (2018) imply that the median wind project in Denmark led to a roughly 2% decrease in residential property values within 3km. They also find these effects are large for the first few turbines, but attenuate after that. Similarly, Dröes and Koster (2020) find that turbines in the Netherlands led to a 2.5% reduction for properties less than 2km away, rising to 5% for larger turbines. Gibbons (2015) finds more pronounced effects for directly visible properties, in the UK, with those located within 2km experiencing reductions of 5-6%. Parsons and Heintzelman (2022) conduct a comprehensive review of these studies and several others. They find negative effects of 5%, 4%, 2.6% and 1.2% at distances of within 1km, 2km, 3km and 4km respectively.

The evidence for solar projects is less extensive. Dröes and Koster (2020) do suggest there is weak evidence of a 3% reduction in property values within 1km of a solar project, although their sample is very limited. Gaur and Lang (2020) is probably the most credible paper available and finds a 1.7% reduction in property values within 1 mile of a solar project in the US.

Table 3 shows the assumptions I use for the capitalisation into residential property values. Further detail on how these effects are implemented can be found in the appendix.

Project and property locations

[8]There is no research on effects on commercial property values. Haan and Simmler (2018) do find positive capitalization of wind energy subsidies into agricultural land values, although the way these values are affected by the actual siting of a project is unclear.

Table 3: Assumptions on Residential Property Capitalization Effects

			Effect		
Technology	Distance	Visible	Low	Base	High
Wind	0-1km	No	0%	-2%	-3.3%
Wind	0-1km	Yes	0%	-4%	-6.6%
Wind	1-2km	No	0%	-0.8%	-1.7%
Wind	1-2km	Yes	0%	-1.7%	-3.3%
Wind	2-3km	No	0%	-0.4%	-0.8%
Wind	2-3km	Yes	0%	-0.8%	-1.7%
Wind	3-4km	No	0%	-0.2%	-0.4%
Wind	3-4km	Yes	0%	-0.4%	-0.8%
Solar	0-1km	No	0%	-0.5%	-1%
Solar	0-1km	Yes	0%	-1%	-2%
Solar	1-2km	No	0%	0%	-0.1%
Solar	1-2km	Yes	0%	-0.1%	-0.2%

Notes: This table contains the assumed values for the capitalization of a wind or solar project into the value of a nearby residential property. Values shown are the equivalent % change in property values for a 10MW project.

Key to conducting this analysis is determining which of these capitalization effects applies to which properties. For property locations I use data from the Office for National Statistics (ONS) on the centroid of each postcode. These are a very granular geographic measure in the UK context, with each postcode representing around 15 properties.

For project locations I use the centroid of each project. This information is provided directly in the Renewable Energy Planning Database (BEIS, 2021*a*). Where possible I check these locations against more detailed spatial information available from Open Street Map (OpenStreetMap, 2022). For many larger projects OSM provides information on the overall footprint of a project (e.g. the area covered by solar panels or the location of individual wind turbines). For the projects where this information is not available I approximate the footprint based on the capacity of the project and the size of the turbines installed.[9] I calculate the distance from each nearby postcode to the edge of the footprint taken up by a given project. I also calculate the direct line-of-sight visibility from each project to the same set of nearby postcodes (see appendix for details).

Property values by postcode

The capitalisation effects in Table 3 are multipled by the total value of any properties

[9]Solar projects are assumed to require 6 acres per MW of capacity. Wind projects are assumed to require an area for each turbine that is the square of seven times the rotor diameter.

in the relevant postcodes. Unfortunately no dataset exists that provides a consistent panel for the value of all properties at the postcode level over my sample period. As such I estimate the total value of all properties in the UK by starting with more aggregated data and then downscaling these to the postcode level.

To get the number of properties in each postcode I start with data on annual total counts of properties at the local authority level from the Valuation Office Agency (VOA) for England & Wales and from the National Registers of Scotland (NRS) for Scotland. To downscale the property counts to each post code I proportionally allocate the total number of properties in each local authority based on census data of the number of households in each postcode.

To get the average price of properties in each postcode I start with data on annual average prices published by the UK Office for National Statistics (ONS) at the local authority level for all local authorities in England, Wales and Scotland. These are originally constructed using property transaction data, adjusted to reflect the overall composition of the property stock.

To downscale the average property prices to each postcode I download raw property transaction data from Her Majesty's Land Registry (HMLR). This covers virtually all sales of residential properties for England & Wales since 1995. Each transaction includes the price, date and postcode of the property being sold. I then merge a range of other variables that are likely to be correlated with prices while also being consistently available at the post code level. This includes measures of whether a post code is rural or urban, index scores of social deprivation and census data on the socioeconomic status of residents. I then using machine learning to fit a predictive model with the transaction price as my outcome variable and these various postcode-level characteristics as my covariates. The fitted model achieves an out-of-sample R-squared of 0.57. Once this model is fitted, I make predictions of the average property price for every postcode.

Finally I downscale the local authority annual average prices using my predicted postcode-level prices to get a set of annual average residential property prices at the postcode-level that also remain consistent with the original local authority values. These are multiplied by the relevant capitalisation effects to get the impact of each project on local property values. Further details can be found in the appendix.

3.1.4 Other factors and limitations

There are some limitations to the various costs and benefits estimated here. The focus on reductions to local property values does risk obscuring some of the local benefits these projects can provide. For instance, a portion of a project's operating costs are land lease payments to the landowner of the site (Wiser, Bolinger and Lantz, 2019; Wiser, Bolinger and Seel, 2020).[10]. Project operating costs also include property and business taxes, some of which may be levied by local government. There are instances of projects yielding direct payments to local communities as well, either through schemes set up by the developer or through local ownership. Importantly though many of these local revenue streams are captured by my estimates of operating costs and can therefore be thought of as transfers. I will return to the role of local taxation, compensation and ownership as possible policy solutions in the final portion of the paper.

With regard to other more indirect local effects, persistent impacts on local employment appear to be limited (Costa and Veiga, 2019). This is consistent with wind and solar projects requiring minimal direct employment for ongoing maintainence and much of the upstream supply chain being located away from the project site. There is some evidence from the US of broader economic benefits at the county-level, primarily driven by boosts to local tax revenues (Brown et al., 2012; De Silva, McComb and Schiller, 2016; Brunner and Schwegman, 2022). In the UK these effects are likely to be muted as the relevant taxes have historically gone directly to the central government budget, rather than remaining in the local area. Lastly, impacts on wildlife are another factor often cited by opponents of wind projects in particular, although evidence on the economic nature of these effects is lacking and so can't be incorporated here.

[10]Lease contracts are commercially confidential and depend on the site, but limited evidence in the US finds leases priced of $2000-5000/MW/yr for wind and $1000-8000/MW/yr for solar.

Each of the costs and benefits I do estimate are still subject to significant uncertainty. To deal with this I examine additional low and high sensitivities for some of the most uncertain categories. A final source of uncertainty is the discount rate used when converting everything to present value levelized quantities. Here I examine a baseline real discount rate of 3.5% in line with UK Treasury guidance, but also check sensitivities using 1.5% and 7%.

I conduct all of my analysis in terms of annual averages. In reality there is significant temporal variation in the output from wind and solar resources and the value of renewable energy production (Borenstein and Bushnell, 2018; Callaway, Fowlie and McCormick, 2018). Fully simulating these dynamics at an hourly level is beyond the scope of this paper. To a first order though, annual averages should be sufficient for the purpose envisaged here, especially given the focus on the value of projects over their entire lifetime.

To keep the analysis tractable I treat each project as if it is "on-the-margin" and being considered in isolation. The alternative would be to consider many projects in aggregate or treat larger projects as non-marginal. Doing so would require making complex alternative assumptions about equilibrium electricity prices or project costs, which is beyond the scope of this study. Treating each project as a marginal project also has the added benefit of mirroring the governmental guidance that planning officials should be following when individually valuing these projects.

An important final limitation to the valuation undertaken here is that the data and approaches used are necessarily based on our current understanding, which may be quite different from the state of knowledge available to decisionmakers at the time they were considering a project. Moreover, the use of a mixture of observed and forecasted data is also slightly incongruous. In reality, any decisionmaker appraising a project would be relying on forecasts made at the time. Fully tackling these issues is beyond the scope of this paper. As such I continue to use values based on current knowledge and methods, but this should be kept in mind when considering the results.

3.2 Determinants of planning approvals

Armed with a comprehensive assessment of the costs and benefits of each project, I next move to evaluating how effectively policymakers balance these different impacts. To do this I employ a fixed effects regression model that links variation in project costs and benefits with the likelihood of a project being approved.

$$approve_{iat} = \beta_1 C_i^{prop} + \beta_2 C_i^{other} + \beta_3 B_i^{elec} + \theta_t + \lambda_a + \epsilon_{iat} \qquad (1)$$

The observations here are the roughly four thousand wind and solar projects in my sample. The dependent variable is a binary approval decision indicator, *approve*, for each project, i, in local authority, a, in year, t and it is regressed on the local property costs, C^{prop}, the other capital and operating costs, C^{other}, and the benefits of the electricity production, B^{elec}. The resulting coefficients capture the percentage change in approval probability for a change in eithercosts or benefits.[11]

To control for general national trends in the likelihood of projects being approved I include year-of-sample fixed effects, θ. To capture static differences in planning approvals across jurisdictions I also include local authority fixed effects, λ. Coefficients in the main specification are therefore identified using within-authority variation from the range of projects that each local authority is in charge of reviewing.

In this context we might expect an idealized global social planner to find that an equivalent change in costs or benefits should have the same impact on approval likelihood, irrespective of where it occurs (i.e. $-\beta_1 = -\beta_2 = \beta_3 > 0$). A national planner is likely to get pretty close to this, although most of the carbon emission reduction benefits do accrue to other countries. However, for a local planner we might reasonably expect them to only pay attention to the local net benefits as these are the ones that directly affect constituents in their jurisdiction (i.e. $-\beta_1 > -\beta_2 = \beta_3 = 0$).[12]

[11] I examine specifications where the costs and benefits enter linearly or in logs. My main specifications are estimated using a linear probability model. Estimation using a logit model gives qualitatively similar results. Results for alternative specifications can be found in the appendix.

[12] Altruistic motivations are an obvious exception to this though.

Lastly, I extend the analysis to look at differential effects to see whether planning decisions differ based on: 1) whether a project is in a wealthy area; 2) whether the local authority was politically conservative; and 3) whether the decision was made nationally or locally. Areas were classified as wealthy based on data from the UK's Index of Multiple Deprivation.[13] For the political makeup of a local authority, I use data on local elections to identify areas that have a majority of Conservative party councillors.[14] National control can be directly observed in the planning data.

3.3 Quantifying misallocated investment

If the planning and permitting process places outsize emphasis on avoiding certain costs (e.g. adverse impacts on local property values) then socially beneficial projects will be consistently refused, leading to under-investment. Even if aggregate deployment of renewable energy is unaffected, a systematic bias towards approving more expensive projects could still emerge. This could take the form of building solar power instead of wind; building more remote wind projects or even moving projects offshore.

To try and quantify the potential for insufficient or misallocated investment, I use my estimates of project specific costs and benefits to find an alternative "best" set of proposed projects. I do this in two main ways.

First, I find the set of proposed projects that can produce the observed annual deployment of renewable energy at least cost. I start by grouping projects by their actual or expected start year and then rank them in order of their social net present value. I sum up the least cost set of projects necessary to reproduce the actual observed increase in renewable energy production for each year. I then compare the cumulative total costs and benefits between this least cost set of projects and the actual ones that were built.

[13]The IMD provides a composite index that assigns neighborhoods a score based on their level of deprivation on a range of measures, where high scores indicate high levels of deprivation. The average deprivation score was calculated for postcodes in a 10km radius of each project, with scores below the national median being classed as wealthy.

[14]The local elections data is from Election Centre. In the UK, councillors for each local authority are elected at least every four years and the vast majority of councillors are affiliated with one of the main UK political parties.

Second, I also seperately examine the potential gains from approving and constructing all positive net present value projects. This latter approach is particularly valuable for understanding possible under-investment.

3.4 Compensation for local residents

A range of policy solutions could help resolve the misalignment between local and wider social incentives, from permitting process reforms to increased local ownership. One natural solution may be to introduce some form of direct transfers to affected local residents. This practice does already happen for some projects, with voluntary payments being made by wind and solar developers to local communities in the form of grants to fund public services or discounts on electricity bills.

To understand how feasible it is to target payments to affected households I use my estimates of household specific impacts on property values to examine a range of simple transfer schemes. At the most basic these involve making lump sum payments to all affected households within a certain distance. Increasing complexity involves allowing payments to vary based on the capacity of the project, how close a resident is to the project, and the average county-level property values.

The goal here is to understand it is feasible to offset the bulk of the local external costs to nearby residents using a few simple project and property characteristics, and how cost effective transfers might be for developers. Full details on how the payment amounts are derived can be found in the appendix.

4 Results

4.1 Project costs and benefits

Figure 2 summarizes the estimated costs and benefits for all the wind and solar projects studied here. The top panel shows how annual averages of these costs and benefits have changed over time. The large declines in project capital costs are clearly visible and reflect the substantial technological progress that has taken place over this period. The declining environmental benefits over time are also striking and reflect the fact that the marginal electricity production being displaced by a project built in 1990 was much dirtier than for a project built in 2020. The bottom panel shows the full ranking of projects in order of their total net present value. This makes clear the significant heterogeneity across projects, particularly with regard to the local property value impacts.

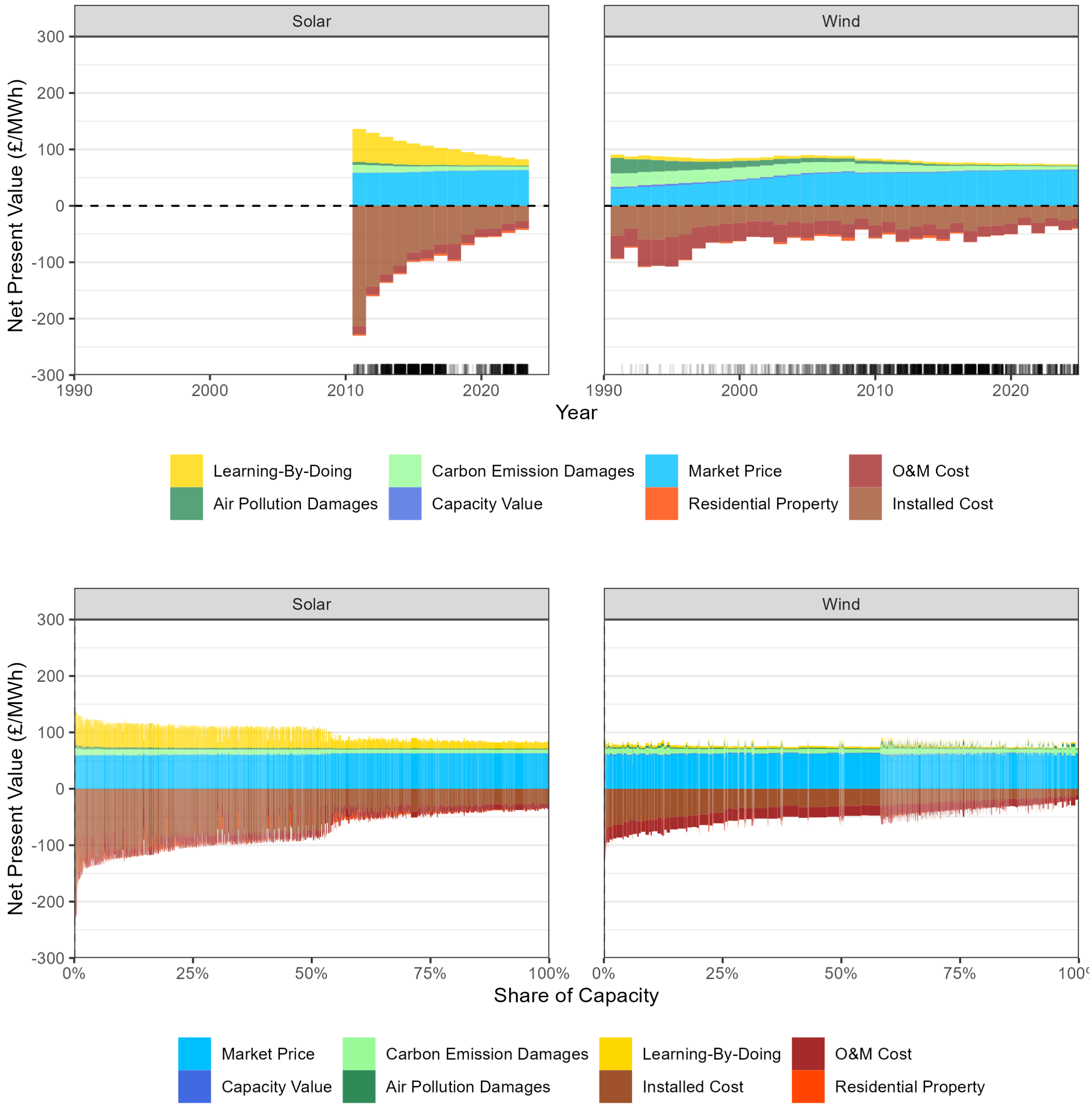
4.2 Determinants of planning approvals

Table 4 presents the results of the planning approvals analysis. The purpose is to understand how responsive planning officials are to different costs and benefits when deciding whether to approve a project.

For wind projects, there is fairly consistent evidence of a statistically significant effect for local property values. The coefficient indicates that a 1% increase in losses to nearby residential property values reduces the likelihood of project approval by 1.5%. The same magnitude of responsiveness is not apparent for the other non-local costs and benefits, which do not show any statistically significant effects. These findings hold up when using a range of alternative specifications, such as considering linear changes in costs and benefits (rather than logs) and when estimating using logit instead of OLS. See the appendix for these results. The fact that we only observe sensitivity to local property costs fits with the hypothesis set out earlier; namely that local decisionmakers are incentivized to focus on costs to local actors while ignoring other impacts that are largely externalized to non-local actors.

The findings for solar projects are less precise than for wind projects. Overall they do not reveal statistically significant effects from variations in property value costs, or from the other costs and benefits. This is not necessarily surprising given that the evidence for negative property value effects from solar projects is weaker. Solar projects also tend to be less controversial as evidenced by their higher approval rates overall.

Figure 2: Estimated Project Costs and Benefits



Notes: This figure shows the estimated project-level costs and benefits for all the projects submitted for planning approval since 1990. The left panel is for solar projects and the right panel is for wind projects. All value categories have been converted to consistent levelized net present value terms in £/MWh. These values use a 3.5% real discount rate in line with UK Treasury guidance. Assuming a higher 7% real discount rate produces estimates more in line with industry figures on private developer levelized costs. The top figure shows how average costs and benefits over time. In each year the median was calculated for each value category across all projects that were or would have been commissioned in that year. The black dashes at the bottom of the plot indicate the number of projects in a given year to convey when the bulk of projects were being proposed and commissioned. The bottom figure shows the full ranking of projects in order of their total net present value. The width of each bar is determined by the capacity of each project.

Lastly, Table 4 also examines whether these effects are heterogeneous. I find that the negative effect of property value costs on approvals is concentrated at projects sited in wealthy areas. This suggests that wealthy areas are more inclined and better able to resist new wind power deployment. I do not find statistically significant differences based on how conservate a local authority is, or if the decision is being made at the national level.

Table 4: Planning Process Regressions for Project Costs and Benefits

	Wind				Solar			
Model:	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Variables								
log(Cost Property)	-0.015**	-0.004	-0.014**	-0.012*	-0.000	-0.000	0.004	-0.000
	(0.006)	(0.007)	(0.007)	(0.006)	(0.005)	(0.006)	(0.006)	(0.005)
log(Cost Other)	0.037	0.062	0.008	0.013	-0.351	-0.297	-0.386	-0.382
	(0.120)	(0.113)	(0.118)	(0.114)	(0.373)	(0.391)	(0.387)	(0.392)
log(Benefits)	-0.031	-0.059	-0.003	-0.028	0.314	0.259	0.352	0.345
	(0.109)	(0.101)	(0.108)	(0.104)	(0.375)	(0.394)	(0.389)	(0.393)
log(Cost Property) × Wealthy		-0.028**				0.001		
		(0.011)				(0.007)		
log(Cost Other) × Wealthy		0.043				-0.033		
		(0.075)				(0.063)		
log(Benefits) × Wealthy		-0.028				0.034		
		(0.076)				(0.066)		
log(Cost Property) × Conservative			-0.008				-0.008	
			(0.012)				(0.005)	
log(Cost Other) × Conservative			0.274				-0.017	
			(0.206)				(0.106)	
log(Benefits) × Conservative			-0.261				0.016	
			(0.202)				(0.106)	
log(Cost Property) × National				-0.021				-0.039
				(0.020)				(0.049)
log(Cost Other) × National				-0.268				1.006
				(0.168)				(0.758)
log(Benefits) × National				0.276				-0.950
				(0.170)				(0.729)
Fixed-effects								
On/Offshore	Yes	Yes	Yes	Yes				
Year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Local Authority	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Fit statistics								
Observations	1,806	1,806	1,800	1,806	1,870	1,870	1,870	1,870
R^2	0.23362	0.24239	0.23225	0.23689	0.25558	0.25632	0.25724	0.25654
Within R^2	0.00911	0.02045	0.01066	0.01333	0.00442	0.00542	0.00665	0.00572
Technology	Wind	Wind	Wind	Wind	Solar	Solar	Solar	Solar

Clustered (Year & Local Authority) standard-errors in parentheses
*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

Notes: This table shows the impact on approval probability for changes to various project costs and benefits. Columns reflect the range of fixed effects included and differential effects studied. The "National" coefficients are where a variable has been interacted with a dummy for whether a project's planning application was decided at the national level. The "Conservative" coefficients are where a variable has been interacted with a dummy for whether a local authority is politically conservative.

4.3 Misallocated investment

Table 5 shows that the potential gains from more efficiently reallocating investment amongst the set of proposed projects. A range of possible scenarios are examined to understand the likely drivers of misallocation.

Table 5: Misallocated Investment Results

Scenario		Scenario Output Constraints				Project Characteristics			Project Costs and Benefits			
		Year	Wind/ Solar	Off/ On-shore	Local Authority	Output (TWh)	Capacity (GW)	Projects	Cost Property (£bn)	Cost Other (£bn)	Benefits (£bn)	Social NPV (£bn)
0	Actual	Yes	Yes	Yes	Yes	2323	41	1883	-2.2	-144.9	186.9	39.7
1	Best	Yes	Yes	Yes	Yes	2323	40	1756	-2.0	-143.1	186.7	41.6
2	Best	Yes	Yes	Yes	-	2323	38	1356	-0.6	-135.4	186.2	50.1
3	Best	Yes	Yes	-	-	2323	43	1967	-1.9	-112.2	185.2	71.1
4	Best	Yes	-	-	-	2323	42	1611	-2.0	-107.2	183.3	74.1
5	Best	-	-	-	-	4244	76	2983	-4.0	-219.9	335.9	112.0

Notes: This table shows the aggregate costs and benefits of the actual observed set of wind and solar projects, as well as the same information for a range scenarios identifying the least cost set of proposed projects. All values are the cumulative lifetime totals for all wind and solar projects. The "Actual" row refers to the observed set of projects that were actually built. The "Best" rows then refer to different scenarios for the optimal set of projects subject to a series of constraints on the extent to which deployment can be reallocated. "Scenario 1" allows reallocation subject to the total output remaining unchanged by year, technology, on/offshore and local authority. "Scenario 2" allows reallocation subject to the total output remaining unchanged by year, technology and on/offshore. "Scenario 3" allows reallocation subject to the total output remaining unchanged by year and technology. "Scenario 4" allows reallocation subject to the total output remaining unchanged by year. "Scenario 5" allows complete reallocation and so may lead to a different total output than was actually observed.

To begin with we can see the observed actual set of projects comprise just over 40GW of wind and solar capacity, and have a discounted lifetime electricity output of 2,323 TWh. The costs of constructing and operating these projects is £145 billion, and yields benefits of £187 billion. Local property value costs are relatively small at £2.2 billion. The result is a social net present value of almost £40 billion.

Now we can consider the potential gains available in various counterfactual scenarios. If the planning process is producing efficient outcomes we would expect relatively small differences between the observed set of projects and some hypothetical alternative set taken from the range of proposed projects. If the planning process is producing inefficient outcomes we would expect there are many socially beneficial projects that did not go ahead after failing to recieve permitting approval.

To start let us consider the scope for reallocation across projects to be highly constrained. If reallocation is only possible subject to the total output remaining unchanged by year, technology, on/offshore and local authority, we see that social net present value can be increased slightly to £42 billion (Scenario 1).

Moving to allowing reallocation across local authorities causes social net present value to rise more significantly to £50 billion (Scenario 2). This is mostly achieved by shifting to fewer, larger projects and by prioritising projects in the sunniest and windiest regions of the country. While this lowers total local property value costs, the bulk of the savings come from lower capital and operating costs.

Moving to allowing reallocation between onshore and offshore wind projects leads to a large increase in social net present value to £71 billion (Scenario 3). This reflects the high costs of the early offshore wind projects built in the UK, and the significant number of inexpensive onshore wind projects that failed to get planning approval.

Moving to allowing reallocation between technology types leads to social net present value rising to £74 billion (Scenario 4). This mostly reflects substitution from solar to wind projects. The UK is particularly well-suited for wind power, and the costs for onshore wind were significantly below those of solar power in the early 2010s.

Finally, I examine the result of allowing full reallocation. This is equivalent to considering the impact of approving and constructing all positive net present value projects. Here we see total lifetime output from wind and solar almost doubles from observed levels, and social net present value increases to £112 billion (Scenario 5). This is evidence of substantial under-investment in wind and solar power overall, with many socially beneficial projects failing to go ahead. Notably total local property value costs also increase significantly in this case, suggesting there are many projects worth pursuing even where they create adverse external costs to nearby residents.

The large misallocation costs found here can also be clearly attributed to failings in the local planning and permitting process. When a socially beneficial project fails to be built, this could be for two main reasons: 1) the project was refused planning permission, or 2) the project was approved for planning permission but did not go ahead for other reasons (e.g. a failure to secure sufficient financing). In all scenarios the significant majority of socially beneficial projects that failed to be built were refused planning permission.

The analysis set out here is also necessarily based on the set of proposed projects that even made it to the planning submission stage. In principle the costs may be larger when considering the full range of hypothetical projects that could have been proposed.

An important caveat to note with this misallocation analysis is that many of the findings are subject to uncertainties in the underlying estimates of costs and benefits.[15] However, even when looking at a range of sensitivities (e.g. with regard to local property value costs, discount rates and environmental benefits) the same broad findings emerge (further details are available in the appendix).

Overall, I find compelling evidence that the fragmented and localised nature of the planning process does risk significant spatial misallocation of infrastructure investment. In terms of under-investment, this may have resulted in roughly half as much wind and solar power being built than may have been desirable. Even when constraining the analysis to reproduce the observed annual deployment of total wind and solar output, cost savings of 10% are entirely plausible, with some scenarios as high as 25%. These sums are substantial when considering the £145 billion in lifetime capital and operating costs incurred to date.

4.4 Transfer payments to local residents

One possible policy solution that could help remedy some of the inefficiencies in the planning process is to make transfer payments to local residents in order to better align local and wider social incentives.

Figure 3 shows the external costs to local property values for all nearby residents affected by the wind and solar projects in the sample. For most residents the impacts

[15] Despite the lengths this paper has gone to in estimating the impacts of these projects, it is impossible to fully account for the the idiosyncracies of each project and local area. For any given project, planning officials will have a better understanding of their specific circumstances, and so some humility about the ability of this kind of analysis to second guess individual decisions is probably in order. Still, the overall insights about systematic biases in the broader process remain.

are relatively minor, although there is a long tail of larger impacts for wind projects, primarily for those near particularly expensive properties.

Figure 3 illustrates how relatively simple schemes for targeting compensation to local residents can offset much of the impacts on affected households. These range from simple flat payments based on distance, to payments that account for project size and are made proportional to the average local authority property value. Most individual payments to households end up being on the order of a few hundred pounds.

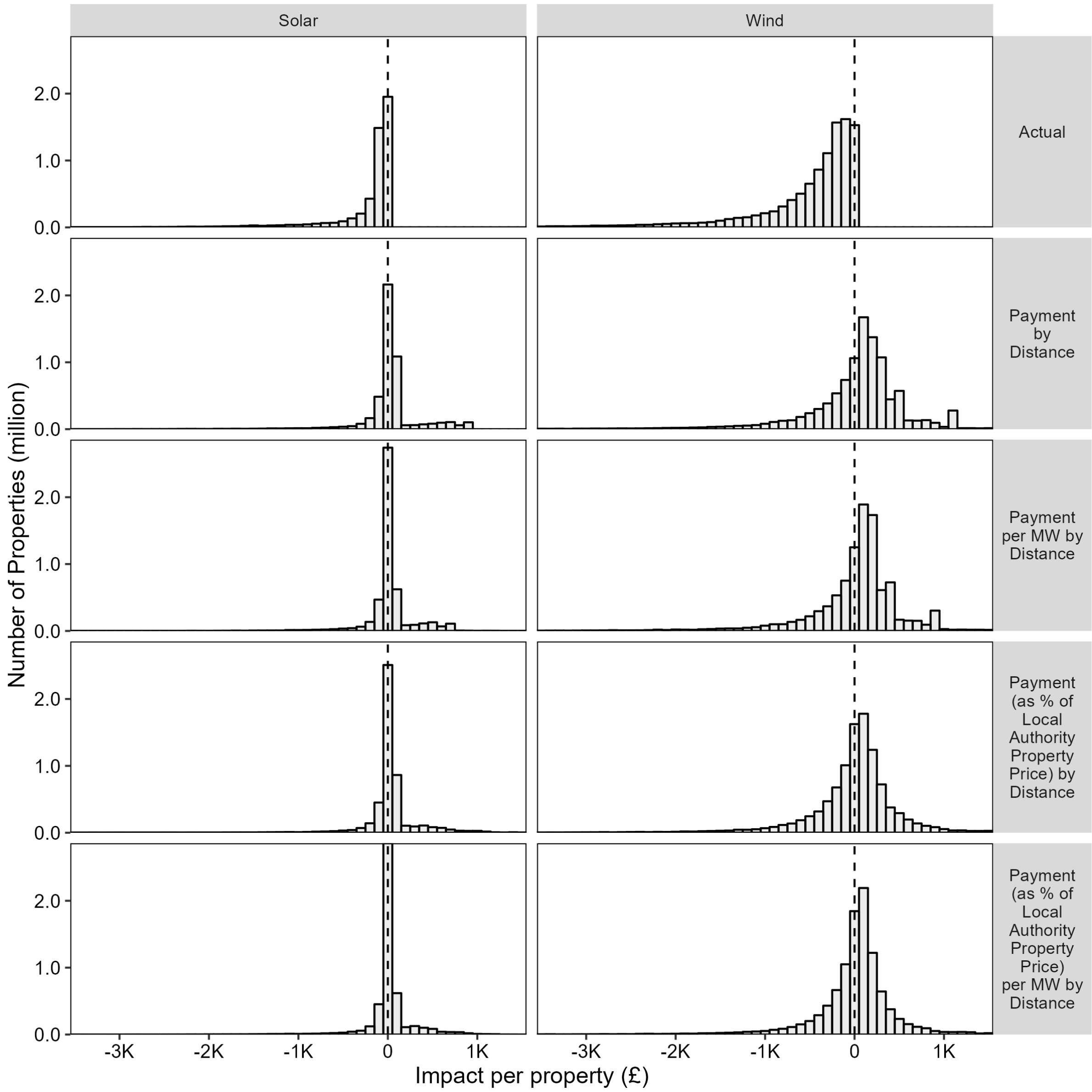
In principle it is possible to more exactly match the payments made to the precise local external costs calculated here. However, fully compensating those with the largest negative impacts would require conditioning payments on individual property values and this does not seem desirable from an administrative, political or equity standpoint.

From the developer perspective, the capacity-weighted average cost of these transfer schemes for the socially beneficial projects is £4,000/MW/year for wind and £1,400/MW/yr for solar. This masks significant variation with the bottom 5% of projects making virtually zero payments and the top 5% of projects making payments in excess of £18,000/MW/year for wind and £6,000/MW/yr for solar.

These overall costs are actually quite similar in size to the payments observed by voluntary community benefits funds that many developers have already established. In Scotland, onshore wind projects with voluntary community benefits funds have made payments of around £2,000-4,000/MW/year (Local Energy Scotland, 2022). The latest government guidance calls for developers to adopt funds with a value of £5,000/MW/year (Scottish Government, 2019). The similarity between estimated transfers and actual voluntary payments could suggest that the status quo of Coasian bargaining is actually functioning fairly well.

However, some caution is probably in order. Available data is based on a selected sample of developers that self-report information on their community engagement for successful projects. Whether all local communities near proposed projects are receiving these kinds of opportunities remains unclear. It is possible there are many communities at risk of missing out, or poorly placed to negotiate a desirable settlement. Moreover, most existing community benefits funds appear to provide grants to local community organisations. Very few make direct payments to nearby residents (e.g. via a discount on their electricity bills). Examining the effectiveness of these community payment schemes is an important area for further study.

Figure 3: Local Compensation Schemes



Notes: This figure shows the net external costs incurred by local residents due to the wind and solar projects in the sample. The top panel shows a histogram of the observed uncompensated distribution of impacts on local residents. The four remaining panels then show the net impact on local residents after accounting for several different compensation schemes of varying levels of complexity.

5 Conclusion

In this paper I estimate the economic costs of NIMBYism and local planning restrictions by examining the case of renewable energy projects. First I estimate the full range of costs and benefits for each project and find significant heterogeneity. This is particularly the case for the local external costs of these projects, as captured by impacts on local property values. I then show how planning decisions are particularly responsive to local factors, especially in wealthier areas. This is consistent with the localised nature the planning and permitting process, but raises the risk that the wider social benefits of renewable energy are systematically overlooked. In fact I find that inefficiencies in planning and permitting decisions have contributed to a significant misallocation of investment. The same rate of deployment could likely have been achieved with cost savings of 10-25%. There is also a compelling case that biases in the permitting process have led to underinvestment, when a much more expansive rollout of wind and solar power would have been socially desirable.

There are a range of policy solutions that could remedy this misalignment between local and wider social incentives. The approach of providing direct compensation to affected local residents was explored. Providing these kinds of community benefits is voluntary in the UK so they can vary significantly in prevalence, size and structure. In many instances the current process of Coasian bargaining does appear to be resulting in payments of a similar scale to the local costs estimated here. However, where negotiation frictions are a concern, mandating a level of local compensation could be desirable. My analysis indicates that payments could be also better targeted if they accounted for important margins of heterogeneity, such as proximity or visibility.

Concerns have been raised in the past about the effectiveness of direct payments to combat NIMBYism (Frey, Oberholzer-Gee and Eichenberger, 1996). Another way to keep more of the benefits of renewable energy in local communities is greater local ownership. This has been growing in the UK, but a key challenge is scalability. Community owned capacity represents about 1% of total renewable electricity generation in the UK

(Braunholtz-Speight et al., 2018). It seems unlikely that local communities can deploy the kind of financial and technical resources that larger private companies can to roll out renewable energy at the scale and pace required.

Ultimately though the siting of any new infrastructure project is at some level a political decision. Reforming the extent of local control over planning and permitting decisions is therefore an important issue that is raised by the findings in this paper. Of course, shifting more control over siting decisions to regional or national policymakers could backfire if it results in affected residents believing their concerns are not being heeded. But recent evidence that boosts to local tax revenues can increase the attractiveness of new wind and solar projects is encouraging (Germeshausen, Heim and Wagner, 2021; Brunner and Schwegman, 2022). It may be that pairing decisionmaking reforms with favorable tax changes could help offset the objections of local residents and officials.

Managing the tension between local and national decisionmaking is a significant challenge, and one that is not unique to renewable energy. For many other forms of infrastructure there is a tension between meeting the needs of local residents and considering the merits of a project for society as a whole. Finding policies to resolve those tensions will require further research and experimentation. The findings in this paper on the shortfalls of the current planning and permitting process suggest this work is sorely needed.

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Online Supplementary Appendix

Contents

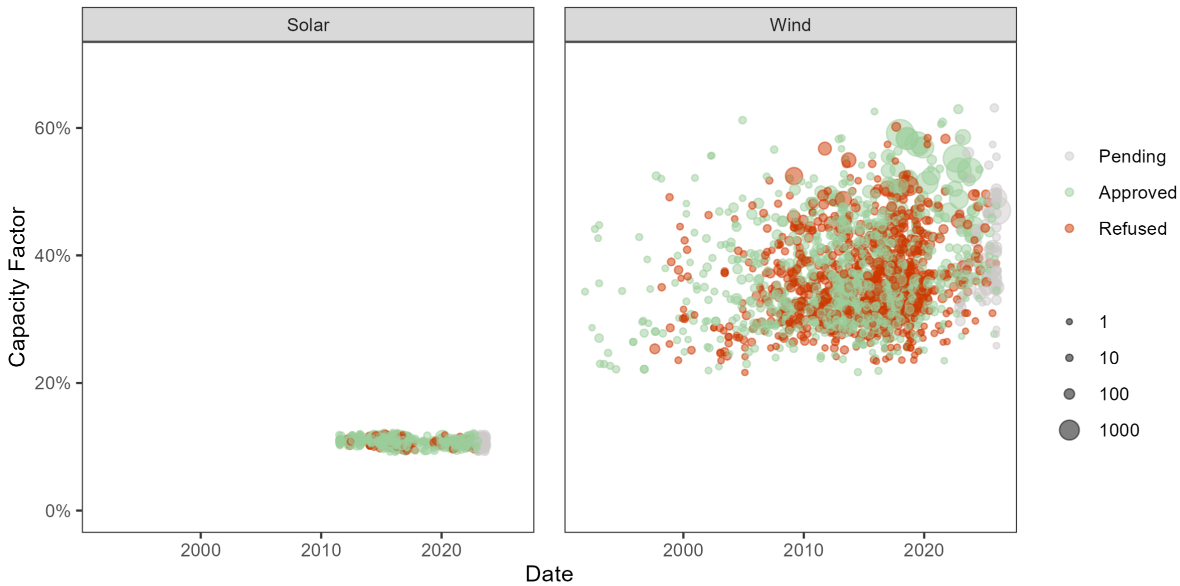
A Project Costs and Benefits (Detail)

Further detail on the estimation of project costs and benefits is provided here.

A.1 Electricity production

Further detail and figures on the estimation of local property values by postcode is provided here. The resulting capacity factors are shown in Figure 4.

Figure 4: Estimated Project Capacity Factors

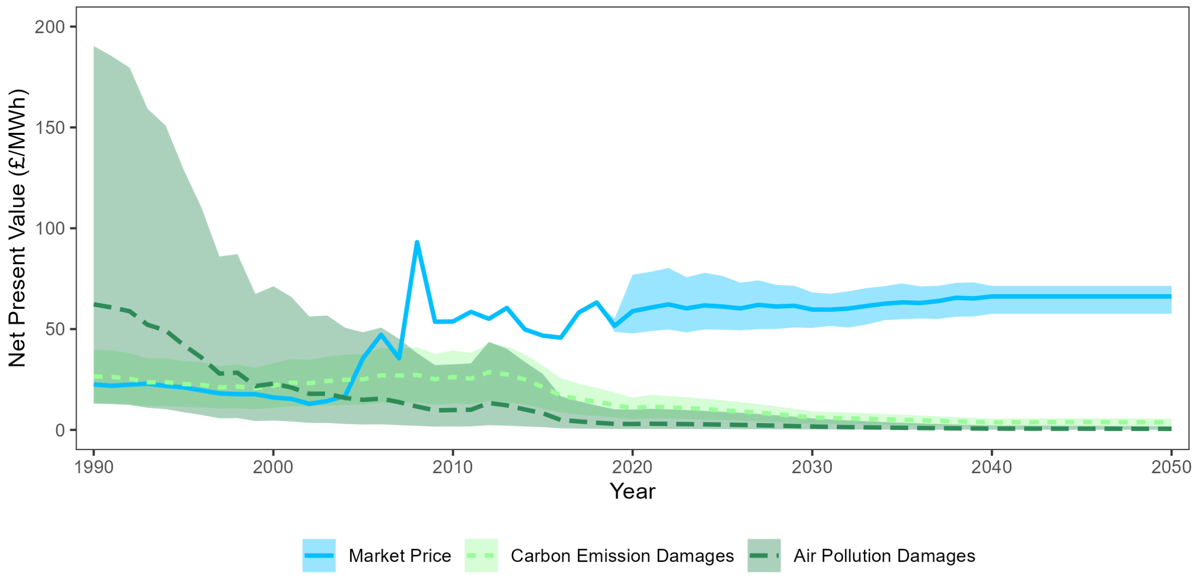


Notes: This figure shows the estimated project capacity factors over time. Each point refers to a project. Point sizes are determined by the capacity (in MW) of a project. Projects are classified by their development status. "Pending" are projects that have submitted a planning application but have yet to receive a final decision. "Approved" are projects that have been approved and are either awaiting construction, under construction, operational or have been subsequently decommissioned. "Refused" are projects that were refused planning permission or were otherwise withdrawn or halted.

A.2 Market and Environmental Value of Electricity

Further detail and figures on the private and external value of electricity production is provided here. The resulting marginal values per MWh of electricity produced are shown in Figure 5 alongside the wholesale price of electricity.

Figure 5: Marginal Market and Non-Market Values of Renewable Electricity Production



Notes: This figure shows the changing marginal value of renewable electricity production over time. "Market Price" refers to the private value of the electricity produced as captured by wholesale electricity prices. "Carbon Emission Damages" refers to the external value of the CO2 emissions abated by displacing generation from other sources. "Air Pollution Damages" refers to the external value of the local pollution emissions abated by displacing generation from other sources. The lines are based on the UK government's central scenario values and the shaded areas are bounded by the low and high scenario values.

A.3 Capacity Value

Further detail and figures on the estimation of capacity value is provided here. For intermittent power sources like wind or solar the capacity value is generally thought of in relative terms by starting with the capacity value of a conventional dispatchable generator (e.g. a natural gas-fired power plant) and then calculating "the proportion of installed renewable capacity that is able to 'displace' conventional generation or support extra demand while maintaining system reliability levels" (Harrison et al., 2015). Statistical modelling for the UK indicates that at present a wind project can expect around 10-20% of its capacity to provide this kind of reliable "firm" supply, while for solar the equivalent number is as low as 1%. These percentages are sometimes referred to as "equivalent firm capacity" de-rating factors. The values for the UK reflect the fact that peak demand periods in the UK occur on winter evenings, and so while there is a decent probability the wind will be blowing at this point, the sun will almost certainly have set.

My starting point for calculating capacity value is National Grid's guidance on the de-rating factors they use for the UK capacity market auctions. For the auctions in 2020 they settled on de-rating factors of roughly 8.5% for onshore wind, 13% for offshore wind, and 1.5% for solar. These values can and will change over time - they will fall as the generation share of wind or solar increases, and rise as demand shifts towards periods when the wind is usually blowing or the sun is shining. This is particularly important to capture for wind power because this is expected to provide such a large portion of the UK's electricity supply by 2050.

To capture the change in de-rating factors for wind projects over time I therefore rely on estimates by (Harrison et al., 2015).[16] Their analysis examines how de-rating factors for onshore and offshore wind vary as the total wind power capacity in the UK increases. I converted this to points in time using information on the past and forecast growth of wind capacity from National Grid. Based on this, onshore wind de-rating factors were around 20% in 1990, but have fallen to 9% today, and will likely reach 7% by 2050.

[16]Namely those shown in Figure 11 in their paper.

Offshore wind de-rating factors were likely as high as 35% in 1990, but have fallen to 15% today, and will likely be as low as 9% by 2050. I assume solar de-rating factors remain at 1.5% across the entire period.

To get the capacity value of each wind or solar project I multiply the relevant "equivalent firm capacity" de-rating factor by the capacity of each project and then value the remaining "firm" capacity based on the UK government's capacity market guidance. The result is a capacity value for each project in £/MW/year. In practice the capacity value estimates are very small. Furthermore, because they only vary annually for each technology type they do not end up meaningfully driving any subsequent results which are conducted using variation that is within-technology and within-year.

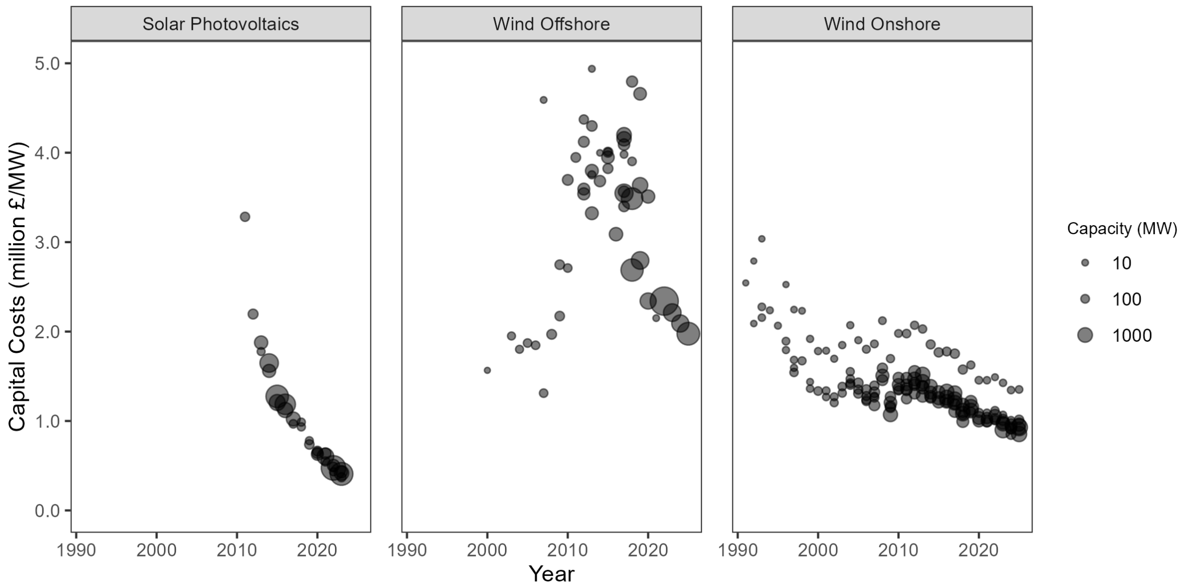
A.4 Capital and Operating Costs

Further detail and figures on the estimation of capital and operating costs is provided here. The resulting estimates for capital costs and operating costs are shown in Figure 6.

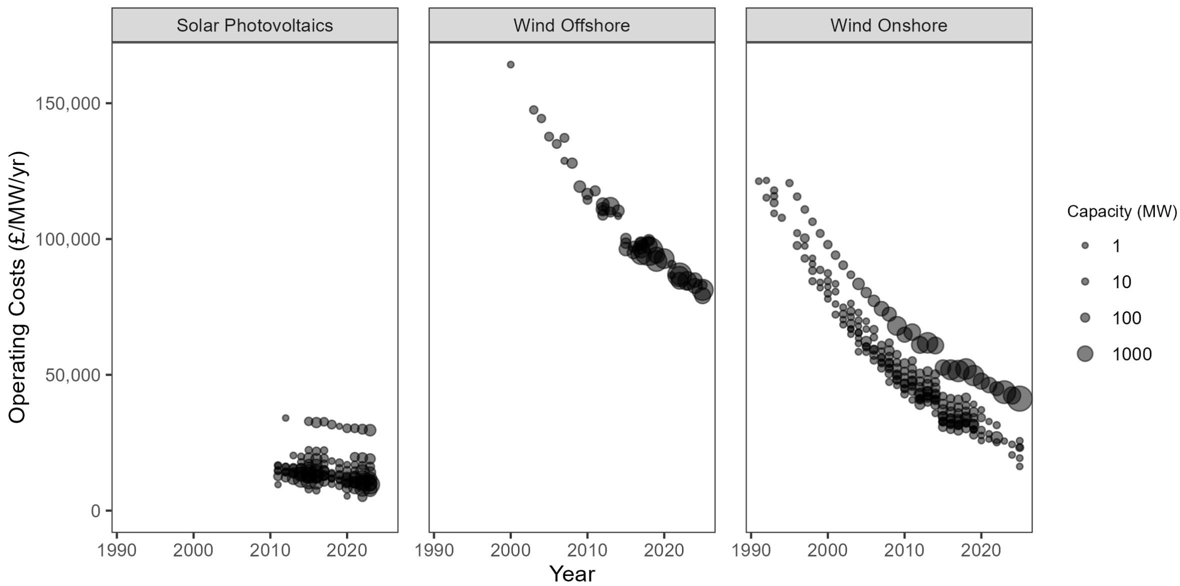
A.5 Learning-by-doing

Further detail and figures on the estimation of learning-by-doing benefits is provided here. To try and capture some of the uncertainty in this particular impact I create "low", "medium" and "high" sensitivities. To do this I use the range of scenario assumptions set out by Newbery (2018) in Table 1. In particular, the "low", "medium" and "high" sensitivities for solar projects were taken from columns F, C and B respectively, and for wind projects from K, J, and I respectively. In all cases the optimal subsidy is scaled based on the average global installed capital cost for wind and solar projects in 2015, using data from IRENA. The resulting values can be seen in Figure 7.

Figure 6: Estimated Project Capital and Operating Costs by Year



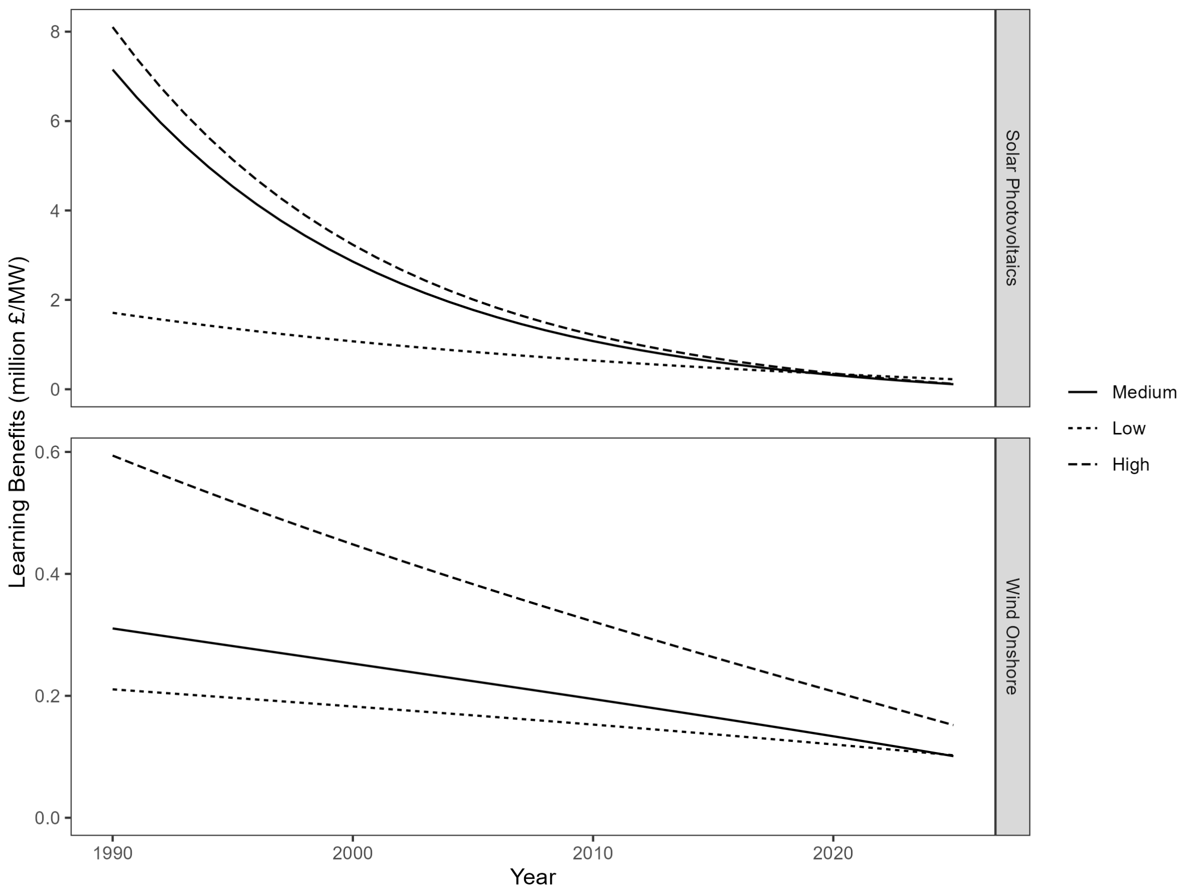
(a) Capital costs



(b) Operating costs

Notes: This figure shows the estimated costs over time. Each point represents the total amount of proposed capacity of a given technology type at a given cost level. Capital costs are at the top and operating costs are at the bottom. Panels refer to three different technology types: solar, onshore wind and offshore wind.

Figure 7: Learning-by-doing Benefits from a New Wind or Solar Project by Year



Notes: This figure shows the changing learning-by-doing gains from installing a new wind or solar project in a given year over the sample period. These values were estimated based on the methodology developed by Newbery (2018). “Low”, “medium” and “high” sensitivities are shown by the different dashed lines.

A.6 Costs to Local Residents

A.6.1 Capitalisation effects

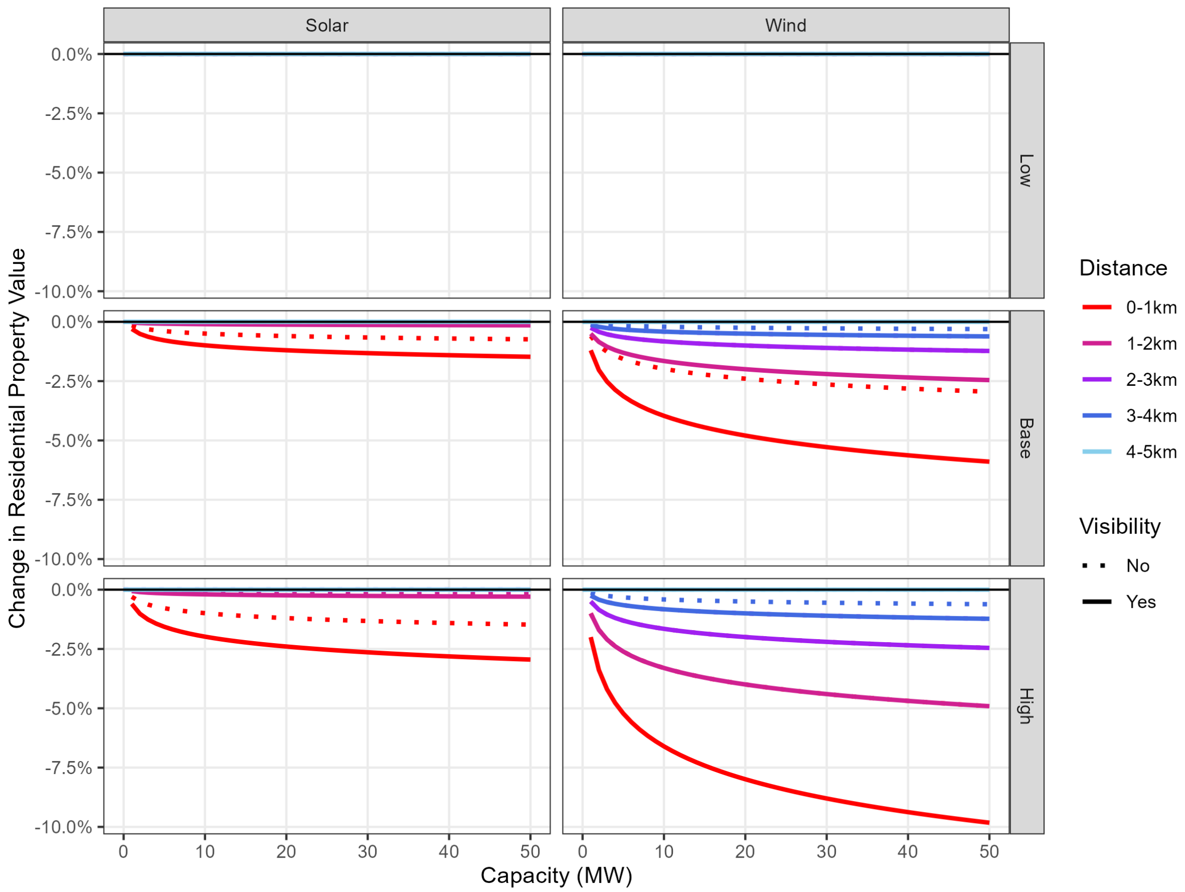
Table 3 set out the capitalisation effects used in this paper for the median-sized project (approximately 10MW). In practice we expect larger projects with more wind turbines or solar panels will have larger impacts on nearby property values. Existing hedonic studies back this up (Parsons and Heintzelman, 2022). However, it appears the increase is not linear. Instead the first MW of capacity is quite costly, while subsequent additions have a declining marginal effect. This can be captured using some form of log specification (Jensen et al., 2018).

I therefore pick a set of capitalisation effects, β, that produces a reasonable range of property value impacts that can approximate the hedonic estimates found in the literature, as discussed in the main text (Gibbons, 2015; Jensen et al., 2018; Dröes and Koster, 2020; Gaur and Lang, 2020; Parsons and Heintzelman, 2022). These coefficients assume a log specification. This conveniently produces a smooth increase that lends itself to the kind of extrapolation exercise envisaged here. Fortunately the smallest project in my sample is 1MW which avoids issues of taking logs producing negative values. I also make a slight adjustment to ensure the smallest projects have sensible effects. The resulting approach is set out below.

$$\Delta P = \beta \times (1 + log(capacity)) \tag{2}$$

For properties within 4km of a wind project with direct visibility I assume β values of -0.012, -0.005, -0.0025 and -0.00125 at distances within 1km, 2km, 3km and 4km respectively. For properties within 2km of a solar projects with direct visibility I assume β values of -0.003 and -0.0003 at distances within 1km and 2km respectively. In all cases these values are halved for properties without direct visibility. The “High” sensitivity case doubles these values. The “Low” sensitivity sets all of these to zero, assuming no significant impacts on nearby property values. See Figure 8 for an illustration of how these assumptions translate into property value changes.

Figure 8: Illustration of Assumed Capitalisation Effects by Project Capacity



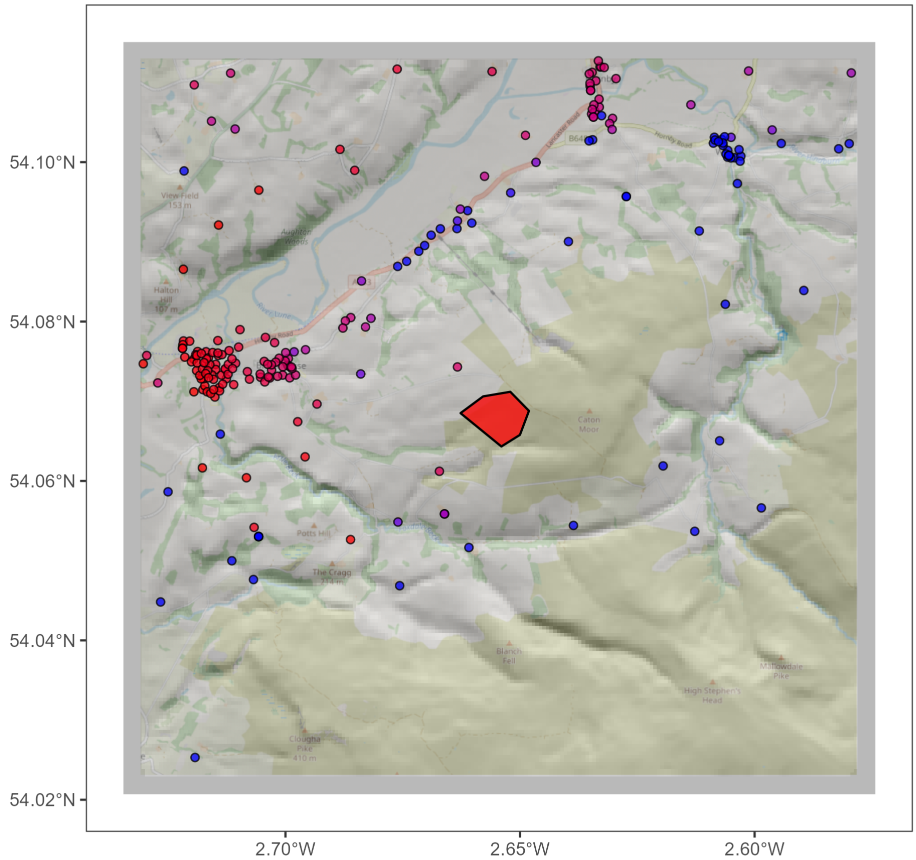
Notes: This figure plots the assumed property value impacts as a function of increasing project capacity. Colors represent different effects by distance of the property from the project. Solid lines refer to properties with direct visibility while dotted lines refer to properties without direct visibility. Impacts are shown sep

A.6.2 Project and property locations

To isolate the visual impacts of wind and solar projects I conduct a geospatial analysis to determine whether properties are likely to have direct line-of-sight to a project. An illustration of this analysis can be seen in Figure 9. This figure shows a map of the area surrounding the Caton Moor Wind Farm, denoted by the red polygon in the center. The red/blue points denote the postcodes where properties are located. Postcodes in blue have no direct line-of-sight to the project. Postcodes in red have full direct line-of-sight to the project. Postcodes with colors in between have some partial line-of-sight (e.g.

the tip of the turbine blades might be visible, while much of the base of the turbine is obscured).

Figure 9: Illustration of Postcode to Project Visibility



Notes: This figure shows the visibility of a wind project from different postcodes within a 5km radius. The red polygon in the centre is the Caton Moor Wind Farm in north west England. The red and blue points are postcodes. Blue points do not have direct line-of-sight. Red points do have direct line-of-sight. The background image is taken from Open Street Map and includes some shading to convey elevation.

This visibility metric was calculated using the GB SRTM Digital Elevation Model. Project coordinates were taken from the Renewable Energy Planning Database and Open Street Map as described in the main text. In the limited number of cases where the coordinate was missing, or appeared erroneous the project was dropped. All spatial data was converted to the Ordanance Survey National Grid reference system.

In addition to specifying coordinates in the east-west and north-south directions, determining line-of-sight also requires specifying an elevation for each point. The default is to simply use the ground-level elevation from the digital elevation model. No person standing by their property is realistically looking out at ground level, and so I assumed that the coordinate for each post code should be set at head height, around 1.6m off the ground.

For the wind and solar projects what matters is the visibility of the structures being installed (i.e., wind turbines or solar panels). For solar projects this is relatively trivial because panels are very homogenous and usually installed in very similar ways. As such I assume that the top of the solar panels are located at 3m off the ground.

For wind projects the height of the turbines is far more heterogenous, particularly as turbines have increased substantially in size over time. The planning dataset also does not include information on wind turbine tip heights. Fortunately it is possible to calculate the average capacity of the turbines installed by dividing the total capacity by the number of turbines. Turbine capacity has a fairly stable relationship to turbine size. I use data on thousands of different turbine models in The Wind Power Turbine Database to fit a simple regression model that traces out the effectively quadratic relationship between turbine capacity and turbine height. I then apply this to the information on turbine capacity in the project database. The resulting turbine tip heights range from around 50m to in excess of 200m. This is the height off the ground that I use for the project locations.

Finally, I conduct a direct line-of-sight analysis using the digital elevation model and each project-postcode pair within a 10km radius. For this I use the intervisibility algorithm developed by Cuckovic (2016) in QGIS. As well as calculating a binary indicator of whether there is direct line-of-sight between two points, it is also possible to use the "depth-below-horizon" algorithm to calculate what portion of the target structure is visible. So, if the top 40m of a 100m wind turbine is visible then I calculate a visibility metric of 0.4. Ultimately I convert this to a binary indicator which takes the value one if any of the project is visible. The results do not appear particularly sensitive to the use of alternative cutoffs.

A.6.3 Property values by postcode

Calculating the local external costs requires understanding the value of any properties located near the various projects in the sample. To estimate the average price of properties in each postcode I start with data on annual average prices at the local authority level and downscale to each postcode. To do this I fit a predictive model and then use the outputs to estimate postcode level averages that are consistent with the known local authority averages.

First I download property transaction data for England and Wales going back to 1995. This includes the price, P, of property, i, in year, t and postcode, p, of the property being sold for around 25 million property transactions. I can also match each postcode to each local authority, a.

I then divide all postcode-level transaction prices, P_{ipt}, by the local authority average in the year the transaction took place, P_{at}. This "postcode price ratio", R_{ip}, effectively removes annual time series variation from the data and produces a measure of how much higher or lower a transaction price is for a given postcode relative to the local authority average. This is the outcome variable used in the predictive model.

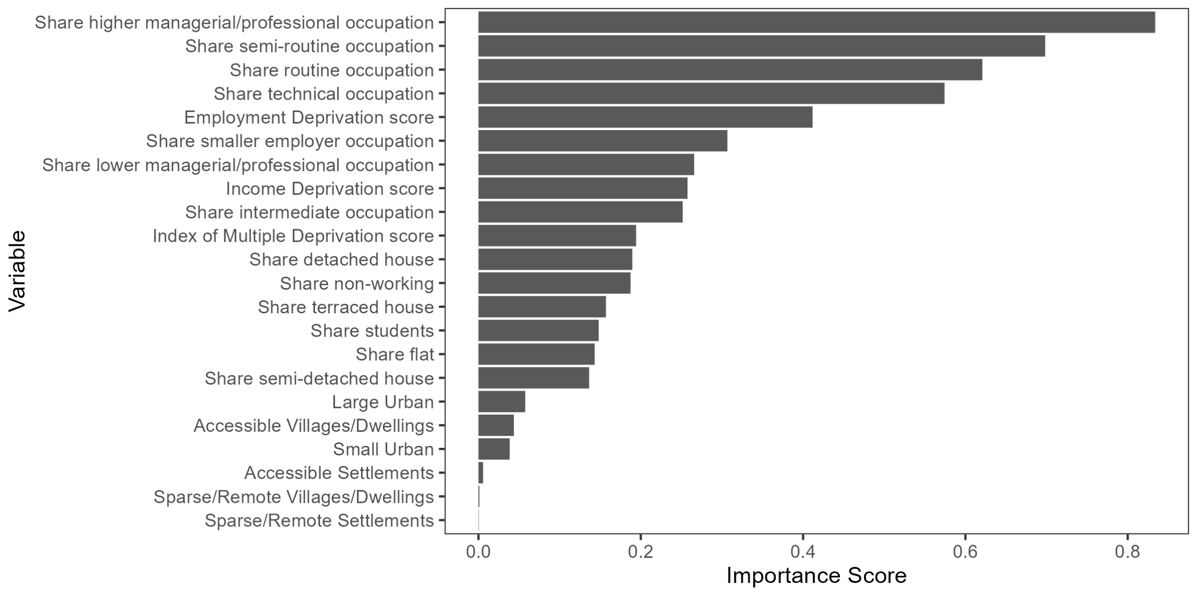
Next I download and merge a range of other variables, X_p, that are likely to be correlated with prices while also being consistently available at the post code level. This includes measures of whether a post code is rural or urban, index scores of social deprivation and census data on the socioeconomic status of residents. Many of these measures are only available for a single year and so this means the relationships I fit will provide a static picture of how much more or less expensive properties are in a given postcode relative to the local authority average. This means my predictions will not be able to capture spatial variation within-local-authority that changes over time. However, this approach is still likely to capture the bulk of the spatial variation of interest by distinguishing between typically rich and poor areas.

I then fit a machine learning model of my "postcode price ratio" outcome variable, R_{ip}, on the range of postcode-level covariates, X_p. For this I use the random forest algorithm.[17]

$$\frac{P_{ipt}}{P_{at}} = R_{ip} = f(X_p) \tag{3}$$

The model achieves an out-of-sample R-squared of 0.57. The relative importance of different covariates to the overall predictive power of the model can be seen in Figure 10. The most important covariates are those associated with the prevelance of different types of occupation and aggregated scores of deprivation. The least important covariates are those capturing differences between urban and rural areas.

Figure 10: Postcode Price Ratio Predictive Model Importance Scores



Notes: This figure shows the importance scores for the covariates included in the model used to predict the postcode price ratio.

Lastly, I use the model to make predictions of the "postcode price ratio" for every postcode in my sample, including those in Scotland which were not in the original transaction dataset. I then calculate the predicted postcode-level price in a given year by rescaling the local authority average price using the predicted "postcode price ratio".

$$P_{pt} = P_{at} \times \frac{\hat{R}_p}{\hat{R}_a} \tag{4}$$

[17]Fit using the "ranger" package with $num.trees = 200$ and $mtry = 4$.

The result is a consistent panel of average property prices for every postcode in each year of the sample.

B Determinants of Planning Approvals (Detail)

Table 6 provides a range of robustness checks to the main results presented in Table 4. These specifications all include a consistent set of fixed effects. Instead they illustrate the stability of the observed effects when changing from a log to a linear model, and when estimating using logit instead of an OLS. The findings are broadly consistent with those discussed in the main text.

C Misallocated Investment (Detail)

My primary approach to analyzing misallocated investment entails finding the set of projects that can produce the observed annual deployment of renewable energy at least cost. To further illustrate the main findings from Table 5, Figure 11 plots the actual or best set of projects across the range of scenarios studied.

Tables 7, 8 and 9 reproduce the findings from Table 5 for a range of sensitivities. The aim is to convey the extent to which the overall findings are affected by varying key assumptions. The sensitivies are as follows:

- "Base" is the base case seen earlier in Table 5. Here the central estimates for local property value costs and social market and environmental benefits are used, with a discount rate of 3.5%
- "Low/High Local Property Costs" is the same as the base case except alternative capitalisation effects are assumed for the property value costs. These alternative assumptions are shown in Table 3.
- "Low/High Social Benefits" is the same as the base case except the benefits of wind

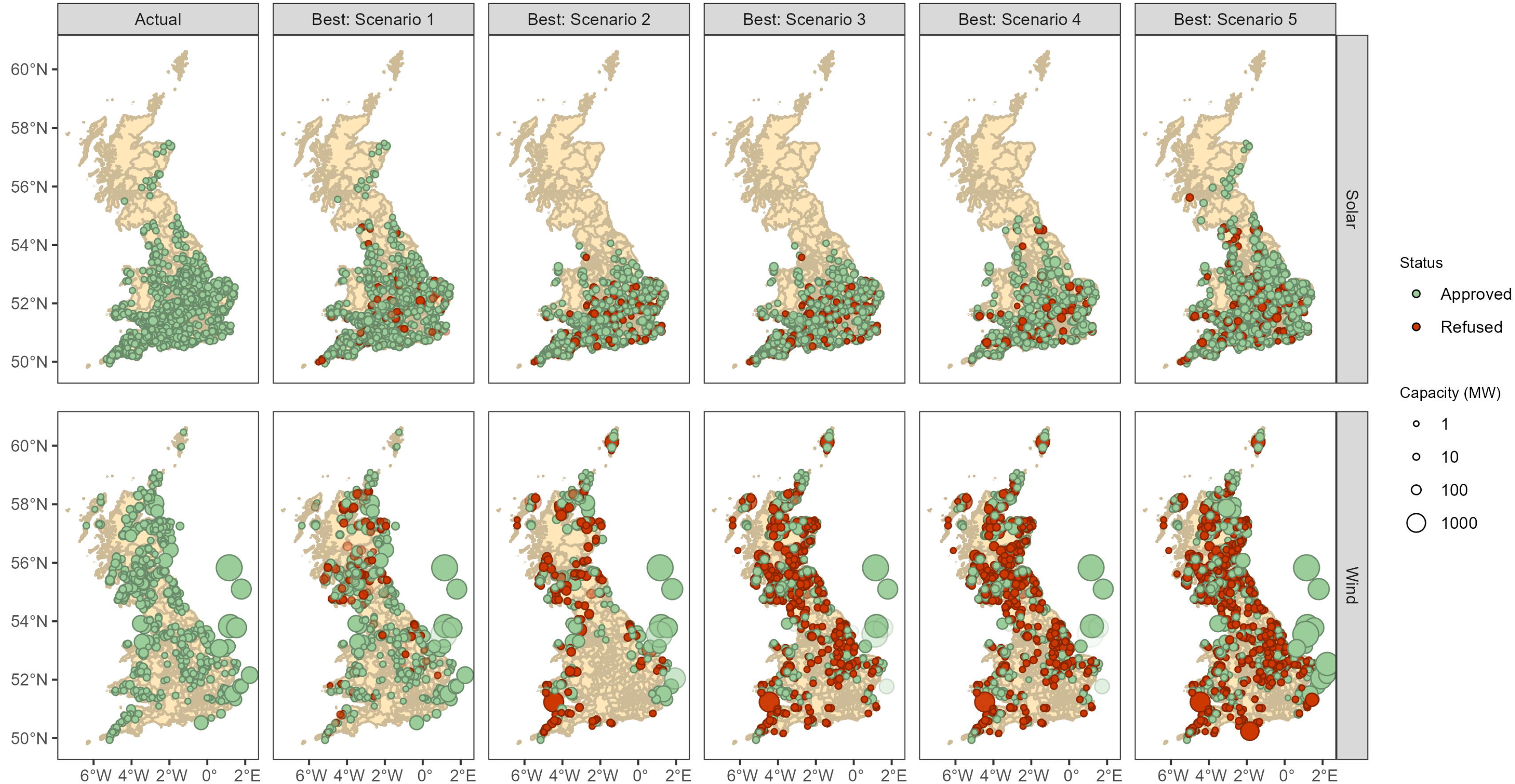
Table 6: Planning Process Regressions for Project Costs and Benefits (Alternative Specifications)

	Wind				Solar			
Model:	(1) OLS	(2) Logit	(3) OLS	(4) Logit	(5) OLS	(6) Logit	(7) OLS	(8) Logit
Variables								
log(Cost Property)	-0.015**	-0.078**			-0.000	-0.002		
	(0.006)	(0.033)			(0.005)	(0.044)		
log(Cost Other)	0.037	0.194			-0.351	-0.934		
	(0.120)	(0.589)			(0.373)	(3.449)		
log(Benefits)	-0.031	-0.162			0.314	0.678		
	(0.109)	(0.546)			(0.375)	(3.446)		
Cost Property (£m)			-0.005**	-0.026**			-0.004	-0.024
			(0.002)	(0.013)			(0.004)	(0.034)
Cost Other (£m)			0.000	-0.000			-0.004*	-0.020
			(0.000)	(0.000)			(0.002)	(0.013)
Benefits (£m)			0.000	0.000			0.002	0.007
			(0.000)	(0.000)			(0.001)	(0.009)
Fixed-effects								
On/Offshore	Yes	Yes	Yes	Yes				
Year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Local Authority	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Fit statistics								
Observations	1,806	1,587	1,942	1,718	1,870	1,481	2,042	1,641
Squared Correlation	0.23362	0.13623	0.23473	0.14186	0.25558	0.16569	0.24257	0.15406
Pseudo R^2	0.18355	0.10686	0.18431	0.11354	0.26789	0.14469	0.25261	0.13568
BIC	3,877.2	2,965.1	4,131.6	3,191.3	3,489.7	2,606.4	3,774.5	2,869.7
Technology	Wind	Wind	Wind	Wind	Solar	Solar	Solar	Solar

Clustered (Year & Local Authority) standard-errors in parentheses
*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

Notes: This table shows the impact on approval probability from changes to local vs non-local project impacts. These specifications all include a consistent set of fixed effects. Instead they illustrate the stability of the observed effects when changing from a log to a linear model, and when estimating using logit instead of an OLS. For logit specifications each coefficient has been scaled to reflect the odds ratio of approval. For specifications using linear versions of the cost and benefit covariates they reflect the effect of a £1 million change.

Figure 11: Misallocated Investment Results Detail



Notes: This figure shows the actual observed set of wind and solar projects, and then how these change across range scenarios identifying the least cost set of proposed projects. "Actual" refers to the observed set of projects that were actually built. The "Best" panels then refer to different scenarios for the optimal set of projects subject to a series of constraints on the extent to which deployment can be reallocated. "Scenario 1" allows reallocation subject to the total output remaining unchanged by year, technology, on/offshore and local authority. "Scenario 2" allows reallocation subject to the total output remaining unchanged by year, technology and on/offshore. "Scenario 3" allows reallocation subject to the total output remaining unchanged by year and technology. "Scenario 4" allows reallocation subject to the total output remaining unchanged by year. "Scenario 5" allows complete reallocation and so may lead to a different total output than was actually observed.

and solar projects are assumed to be from the lower or higher range estimated. These alternative values can be seen in Figure 5 and Figure 7.

- "Low/High Discount Rate" is the same as the base case except the discount rate is assumed to be a lower value of 1.5% or a higher value of 7%. Both are alternative values provided in UK government guidance (BEIS, 2021*b*). The lower value is likely the more informative from a social perspective as it is closer to central values used in recent work on the social cost of carbon (Rennert et al., 2022). The higher value is likely informative to the extent it better aligns with private rates of return.

D Local Compensation (Detail)

To study the feasibility of different local compensation schemes I look at a four transfer schemes. These were illustrated in Figure 3 and range from simple flat payments based on distance, to payments that account for project size and are made proportional to the average local authority property value.

The size of the payments made to different affected households is estimated using the data on the property value impacts from each project, i, at each post code location, p. I fit a regression model with the aim of best approximating the heterogeneity in local property value impacts using a parsimonious set of explanatory variables that could plausibly be used to target payments. The estimation is weighted based on the number of properties at each postcode. The sample is restricted to project-location pairs with non-zero impacts on nearby properties, which effectively means any properties within 4km of a project in my sample. Results of these regressions can be found in Table 10 below.

Table 7: Misallocated Investment Sensitivity Analysis (Local Property Costs)

Scenario		Scenario Output Constraints				Project Characteristics			Project Costs and Benefits			
		Year	Wind/ Solar	Off/ On-shore	Local Au-thority	Output (TWh)	Capacity (GW)	Projects	Cost Property (£bn)	Cost Other (£bn)	Benefits (£bn)	Social NPV (£bn)
0	Actual	Yes	Yes	Yes	Yes	2323	41	1883	-2.2	-144.9	186.9	39.7
1	Best	Yes	Yes	Yes	Yes	2323	40	1756	-2.0	-143.1	186.7	41.6
2	Best	Yes	Yes	Yes	-	2323	38	1356	-0.6	-135.4	186.2	50.1
3	Best	Yes	Yes	-	-	2323	43	1967	-1.9	-112.2	185.2	71.1
4	Best	Yes	-	-	-	2323	42	1611	-2.0	-107.2	183.3	74.1
5	Best	-	-	-	-	4244	76	2983	-4.0	-219.9	335.9	112.0

(a) Base

Scenario		Scenario Output Constraints				Project Characteristics			Project Costs and Benefits			
		Year	Wind/ Solar	Off/ On-shore	Local Au-thority	Output (TWh)	Capacity (GW)	Projects	Cost Property (£bn)	Cost Other (£bn)	Benefits (£bn)	Social NPV (£bn)
0	Actual	Yes	Yes	Yes	Yes	2323	41	1883	0	-144.9	186.9	42.0
1	Best	Yes	Yes	Yes	Yes	2323	40	1754	0	-143.0	186.7	43.6
2	Best	Yes	Yes	Yes	-	2323	38	1426	0	-135.2	186.1	51.0
3	Best	Yes	Yes	-	-	2323	43	2070	0	-111.6	185.1	73.5
4	Best	Yes	-	-	-	2323	42	1722	0	-106.4	183.1	76.7
5	Best	-	-	-	-	4291	77	3249	0	-223.0	340.0	117.1

(b) Low Local Property Cost

Scenario		Scenario Output Constraints				Project Characteristics			Project Costs and Benefits			
		Year	Wind/ Solar	Off/ On-shore	Local Au-thority	Output (TWh)	Capacity (GW)	Projects	Cost Property (£bn)	Cost Other (£bn)	Benefits (£bn)	Social NPV (£bn)
0	Actual	Yes	Yes	Yes	Yes	2323	41	1883	-4.4	-144.9	186.9	37.6
1	Best	Yes	Yes	Yes	Yes	2323	40	1761	-3.8	-143.1	186.7	39.7
2	Best	Yes	Yes	Yes	-	2323	38	1343	-0.8	-135.7	186.2	49.7
3	Best	Yes	Yes	-	-	2323	42	1905	-2.5	-113.1	185.2	69.7
4	Best	Yes	-	-	-	2323	42	1565	-2.8	-108.0	183.3	72.6
5	Best	-	-	-	-	4190	74	2763	-5.7	-216.8	331.3	108.8

(c) High Local Property Costs

Notes: These tables show the aggregate costs and benefits of the actual observed set of wind and solar projects, as well as the same information for a range scenarios identifying the least cost set of proposed projects. Each table refers to a different sensitivity. All values are the cumulative lifetime totals for all wind and solar projects. The "Actual" row refers to the observed set of projects that were actually built. The "Best" rows then refer to different scenarios for the optimal set of projects subject to a series of constraints on the extent to which deployment can be reallocated. "Scenario 1" allows reallocation subject to the total output remaining unchanged by year, technology, on/offshore and local authority. "Scenario 2" allows reallocation subject to the total output remaining unchanged by year, technology and on/offshore. "Scenario 3" allows reallocation subject to the total output remaining unchanged by year and technology. "Scenario 4" allows reallocation subject to the total output remaining unchanged by year. "Scenario 5" allows complete reallocation and so may lead to a different total output than was actually observed.

Table 8: Misallocated Investment Sensitivity Analysis (Social Benefits)

Scenario		Scenario Output Constraints				Project Characteristics			Project Costs and Benefits			
		Year	Wind/ Solar	Off/ On-shore	Local Authority	Output (TWh)	Capacity (GW)	Projects	Cost Property (£bn)	Cost Other (£bn)	Benefits (£bn)	Social NPV (£bn)
0	Actual	Yes	Yes	Yes	Yes	2323	41	1883	-2.2	-144.9	186.9	39.7
1	Best	Yes	Yes	Yes	Yes	2323	40	1756	-2.0	-143.1	186.7	41.6
2	Best	Yes	Yes	Yes	-	2323	38	1356	-0.6	-135.4	186.2	50.1
3	Best	Yes	Yes	-	-	2323	43	1967	-1.9	-112.2	185.2	71.1
4	Best	Yes	-	-	-	2323	42	1611	-2.0	-107.2	183.3	74.1
5	Best	-	-	-	-	4244	76	2983	-4.0	-219.9	335.9	112.0

(a) Base

Scenario		Scenario Output Constraints				Project Characteristics			Project Costs and Benefits			
		Year	Wind/ Solar	Off/ On-shore	Local Authority	Output (TWh)	Capacity (GW)	Projects	Cost Property (£bn)	Cost Other (£bn)	Benefits (£bn)	Social NPV (£bn)
0	Actual	Yes	Yes	Yes	Yes	2323	41	1883	-2.2	-144.9	147.9	0.8
1	Best	Yes	Yes	Yes	Yes	2323	40	1755	-2.0	-143.1	147.8	2.7
2	Best	Yes	Yes	Yes	-	2323	38	1360	-0.6	-135.4	147.3	11.3
3	Best	Yes	Yes	-	-	2323	43	1973	-1.9	-112.2	146.5	32.4
4	Best	Yes	-	-	-	2323	42	1604	-2.0	-107.1	145.4	36.2
5	Best	-	-	-	-	3188	55	1704	-2.8	-143.3	198.1	52.1

(b) Low Social Benefits

Scenario		Scenario Output Constraints				Project Characteristics			Project Costs and Benefits			
		Year	Wind/ Solar	Off/ On-shore	Local Authority	Output (TWh)	Capacity (GW)	Projects	Cost Property (£bn)	Cost Other (£bn)	Benefits (£bn)	Social NPV (£bn)
0	Actual	Yes	Yes	Yes	Yes	2323	41	1883	-2.2	-144.9	242.3	95.2
1	Best	Yes	Yes	Yes	Yes	2323	40	1755	-2.0	-143.1	242.1	97.0
2	Best	Yes	Yes	Yes	-	2323	38	1348	-0.6	-135.5	241.4	105.3
3	Best	Yes	Yes	-	-	2323	43	1962	-1.9	-112.2	239.8	125.7
4	Best	Yes	-	-	-	2323	42	1612	-1.9	-107.3	237.7	128.5
5	Best	-	-	-	-	4830	88	3742	-5.0	-271.6	497.0	220.4

(c) High Social Benefits

Notes: These tables show the aggregate costs and benefits of the actual observed set of wind and solar projects, as well as the same information for a range scenarios identifying the least cost set of proposed projects. Each table refers to a different sensitivity. All values are the cumulative lifetime totals for all wind and solar projects. The "Actual" row refers to the observed set of projects that were actually built. The "Best" rows then refer to different scenarios for the optimal set of projects subject to a series of constraints on the extent to which deployment can be reallocated. "Scenario 1" allows reallocation subject to the total output remaining unchanged by year, technology, on/offshore and local authority. "Scenario 2" allows reallocation subject to the total output remaining unchanged by year, technology and on/offshore. "Scenario 3" allows reallocation subject to the total output remaining unchanged by year and technology. "Scenario 4" allows reallocation subject to the total output remaining unchanged by year. "Scenario 5" allows complete reallocation and so may lead to a different total output than was actually observed.

Table 9: Misallocated Investment Sensitivity Analysis (Discount Rate)

Scenario		Scenario Output Constraints				Project Characteristics			Project Costs and Benefits			
		Year	Wind/ Solar	Off/ On-shore	Local Authority	Output (TWh)	Capacity (GW)	Projects	Cost Property (£bn)	Cost Other (£bn)	Benefits (£bn)	Social NPV (£bn)
0	Actual	Yes	Yes	Yes	Yes	2323	41	1883	-2.2	-144.9	186.9	39.7
1	Best	Yes	Yes	Yes	Yes	2323	40	1756	-2.0	-143.1	186.7	41.6
2	Best	Yes	Yes	Yes	-	2323	38	1356	-0.6	-135.4	186.2	50.1
3	Best	Yes	Yes	-	-	2323	43	1967	-1.9	-112.2	185.2	71.1
4	Best	Yes	-	-	-	2323	42	1611	-2.0	-107.2	183.3	74.1
5	Best	-	-	-	-	4244	76	2983	-4.0	-219.9	335.9	112.0

(a) Base

Scenario		Scenario Output Constraints				Project Characteristics			Project Costs and Benefits			
		Year	Wind/ Solar	Off/ On-shore	Local Authority	Output (TWh)	Capacity (GW)	Projects	Cost Property (£bn)	Cost Other (£bn)	Benefits (£bn)	Social NPV (£bn)
0	Actual	Yes	Yes	Yes	Yes	2917	41	1883	-2.2	-156.9	229.6	70.5
1	Best	Yes	Yes	Yes	Yes	2917	40	1755	-2.0	-154.9	229.5	72.6
2	Best	Yes	Yes	Yes	-	2917	38	1382	-0.6	-146.7	228.9	81.6
3	Best	Yes	Yes	-	-	2917	43	1996	-1.9	-122.2	227.9	103.8
4	Best	Yes	-	-	-	2917	42	1627	-2.0	-117.1	226.0	106.8
5	Best	-	-	-	-	5953	86	3537	-4.8	-285.6	464.4	174.1

(b) Low Discount Rate

Scenario		Scenario Output Constraints				Project Characteristics			Project Costs and Benefits			
		Year	Wind/ Solar	Off/ On-shore	Local Authority	Output (TWh)	Capacity (GW)	Projects	Cost Property (£bn)	Cost Other (£bn)	Benefits (£bn)	Social NPV (£bn)
0	Actual	Yes	Yes	Yes	Yes	1632	41	1883	-2.2	-131.0	136.8	3.6
1	Best	Yes	Yes	Yes	Yes	1632	40	1751	-2.0	-129.4	136.6	5.3
2	Best	Yes	Yes	Yes	-	1632	38	1322	-0.5	-122.3	136.1	13.3
3	Best	Yes	Yes	-	-	1632	42	1913	-1.7	-100.7	135.2	32.7
4	Best	Yes	-	-	-	1632	42	1575	-1.8	-95.7	133.2	35.7
5	Best	-	-	-	-	2264	56	1795	-2.8	-129.4	183.1	51.0

(c) High Discount Rate

Notes: These tables show the aggregate costs and benefits of the actual observed set of wind and solar projects, as well as the same information for a range scenarios identifying the least cost set of proposed projects. Each table refers to a different sensitivity. All values are the cumulative lifetime totals for all wind and solar projects. The "Actual" row refers to the observed set of projects that were actually built. The "Best" rows then refer to different scenarios for the optimal set of projects subject to a series of constraints on the extent to which deployment can be reallocated. "Scenario 1" allows reallocation subject to the total output remaining unchanged by year, technology, on/offshore and local authority. "Scenario 2" allows reallocation subject to the total output remaining unchanged by year, technology and on/offshore. "Scenario 3" allows reallocation subject to the total output remaining unchanged by year and technology. "Scenario 4" allows reallocation subject to the total output remaining unchanged by year. "Scenario 5" allows complete reallocation and so may lead to a different total output than was actually observed.

Table 10: Local Compensation Scheme Regression Results

	Wind				Solar			
Model:	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Variables								
£(0-1km)	3,174.97***	2,901.23***			943.04***	671.54***		
	(279.55)	(307.63)			(40.50)	(61.46)		
£(1-2km)	1,070.35***	881.78***			78.31***	54.58***		
	(108.37)	(134.75)			(2.62)	(5.31)		
£(2-3km)	501.82***	408.85***						
	(35.12)	(44.78)						
£(3-4km)	251.55***	207.52***						
	(14.05)	(17.10)						
£per MW (0-1km)		13.59**				18.20***		
		(5.57)				(4.59)		
£per MW (1-2km)		19.88***				1.00***		
		(4.31)				(0.50)		
£per MW (2-3km)		9.48***						
		(2.13)						
£per MW (3-4km)		4.13***						
		(0.87)						
% of Avg LA Prop. Value (0-1km)			1.71***	1.50***			0.46***	0.37***
			(0.15)	(0.11)			(0.02)	(0.03)
% of Avg LA Prop. Value (1-2km)			0.61***	0.48***			0.04***	0.03***
			(0.04)	(0.02)			(0.00)	(0.00)
% of Avg LA Prop. Value (2-3km)			0.31***	0.24***				
			(0.01)	(0.01)				
% of Avg LA Prop. Value (3-4km)			0.15***	0.12***				
			(0.01)	(0.01)				
% of Avg LA Prop. Value per MW (0-1km)				0.02***				0.00**
				(0.00)				(0.00)
% of Avg LA Prop. Value per MW (1-2km)				0.02***				0.00***
				(0.00)				(0.00)
% of Avg LA Prop. Value per MW (2-3km)				0.01***				
				(0.00)				
% of Avg LA Prop. Value per MW (3-4km)				0.00***				
				(0.00)				
Fit statistics								
Observations	529,102	529,102	529,102	529,102	251,723	251,723	251,723	251,723
R^2	0.35708	0.41149	0.49560	0.60467	0.36123	0.51998	0.52384	0.62229
Adjusted R^2	0.35707	0.41148	0.49560	0.60466	0.36123	0.51997	0.52383	0.62229

Clustered (Project) standard-errors in parentheses
*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

Notes: This table shows the regression results for four different transfer schemes. Wind and solar projects are treated seperately. The dependent variable for these regressions is the impact per property. The unit of observation is a project-postcode pair. The regression is weighted according to the number of properties at each postcode.