Environmental Economics: Policy Report

The Environmental and Ecological Impacts of Windfarms in the UK

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1.Wind Energy and Great Britain

The latest Intergovernmental Panel on Climate Change (IPCC) report highlights the urgency needed to avoid a global climate catastrophe. Projected emissions from current climate policies are above those needed to meet climate goals in all countries (IPCC, 2023). However, the cost of wind energy has fallen 55% since 2010 globally, highlighting its viability in mitigating global warming (IPCC, 2023).

The UK's Committee on Climate Change (CCC) outlined how the UK can deliver a decarbonised power system. They modelled hourly energy demand until 2035, finding that the electrification of sectors like transport and buildings to meet net-zero targets contribute to a 50% higher electricity demand by 2035. To meet this energy demand in a sustainable, non-polluting way, wind power should be the backbone of the UK energy mix. If the government sticks to their promise of 40GW of offshore wind by 2030 (HM Government, 2020), wind power alone meets national energy demand for 1/3 of the hours modelled (CCC, 2023). Not only does the UK's climate display high wind energy potential, but offshore wind particularly produces more energy during the winter, when more energy is used for heating and lighting (CCC, 2023).

The intermittence of wind power suggests the importance of supporting wind production with low-carbon alternatives which can be 'switched on' when needed because of the possibility of wind droughts. The projected quantity of Wind Farms (WFs) means in the next 7 years, the UK needs to build 5-times the long-distance power transfer network built in the past 30 years (CCC, 2023). The huge infrastructure project necessitates an in-depth analysis of its effects. For example, Albanito et al. (2022) highlight that the loss of carbon sinks when building onshore windfarms can cause emissions comparable to fossil fuel technologies.

Section 2 explains how economists model the effects of increased wind production; Section 3 examines the biodiversity effects of Offshore Wind Farms (OWF), specifically for fish stocks; and Section 4 describes methods to evaluate the environmental impacts of WFs.

2.How Economists Model Climate Change

A range of mathematical models have been created to explain how the economy and environment interact, accounting for factors like energy production, the climate, and technology (to name a few). These are called Integrated Assessment Models (IAMs) and have been crucial in informing climate-related policy decisions. In the 1970s IAMs were typically used to project future emissions and understand the socio-economic implications, taking a high aggregation level to look at global effects. These IAMs usually calculate a single measure of 'climate damages' so are used to set emissions or temperature targets. A different type of IAM called Detailed Process (DP) IAMs consider policies to reduce emissions (like WF investment) and how effective they are in meeting climate targets (Weyant, 2017). DP IAMs model more systems so can, for example, also account for the socio-political response to an energy policy (Freeman and Pye, 2022).

Within IAMs, researchers emulate a carbon tax by setting a cost per unit of emissions for firms. With a cost to emitting, it makes sense to reduce emissions whilst the abatement cost is lower than the tax. With a higher carbon price, firms abate more because the cost of polluting is higher. IAMs can show the price of carbon which induces adequate abatement for reaching climate targets, as done in the Stiglitz et al. (2017) report. Even though carbon pricing is theoretically considered the most 'efficient' way to reduce emissions, because tax revenues can be used to reduce emissions further, there are practical drawbacks in its implementation and political acceptability (Stiglitz et al., 2017). They find 96% of global emissions were priced below their lowest estimate of an effective carbon price (Stiglitz et al., 2017. pp. 35).

When using an IAM to, instead, simulate a direct change in energy composition, the model no longer predicts the level of abatement. Allan et al. (2020) model the emissions and economic effects of adding 2GW of installed wind capacity each year from 2019-2029. They estimate the cost of installing the WFs with data from previous development, operation, and maintenance. Then, the energy sector component of the model estimates the emissions reduction from using WFs instead of the current energy production, accounting for the emissions from construction and maintenance. Overall, you have the cost of building the farms, the emissions reduction from changing the energy mix, and usually a model-specific outcome. In this case, they study local economy effects, finding the creation of over 310,000 full-time jobs.

However, IAMs are limited because their simplifications of reality do not take every possible effect into account. Gambhir et al. (2019) stress the importance of supplementing IAM findings with other analytical approaches to take a multi-disciplinary perspective. An economist's perspective can often be focused on the 'margin', considering the cheapest or most effective way to have a small decrease in emissions. This perspective might fall short of the deep decarbonisation needed to meet net-zero targets. In the UK, taxing carbon emissions has been effective, reducing the power sector's emissions by 55% in the first 5-years from implementation in 2013 (Gugler et al., 2021). However, these reductions largely came from burning gas instead of coal in power production, which is less carbon-emitting but does not characterise a net-zero power sector. Tvinnerim and Mehling (2018) stress the danger of carbon taxes because they fail to prevent long-term investments in carbon-emitting energy production, not causing change at the pace and scale required to meet climate targets. Moreover, IAMs struggle to capture ecological effects like reductions in biodiversity, so key outcomes can be missed, highlighting the value of a multidisciplinary perspective.

3.Effect on Fish Stocks

One ecological impact missed by IAMs is the effect of offshore WFs on fish stocks. Pile driving during OWF construction (Galparsoro et al., 2022) and the consequent smothering of fish with uplifted sediment (Mangi, 2013) damages fish stock levels and distribution. However, the artificial reefs created by OWFs provide shelter for demersal fish, usually increasing biodiversity and biomass post-construction (Mangi, 2013). The increase in prey stocks has a knock-on effect since predator species have more abundant food – benefitting biodiversity in a previously homogenous seabed (Galparsoro et al., 2022).

These effects are conflicting, with an initial decline in fish stocks from construction, but greater potential for reproduction thereafter. Box 1 estimates the long-term effect on fish stocks from construction, increased carrying capacity of the fishery, and more difficult fishing conditions. Even if fish stocks decline 40% during construction, fish are more abundant post-construction, with a similar amount of fish caught. This theoretical finding is supported by Shimada et al. (2022), who found no decrease in fishery production post-WF-installation.

We should note that these findings are case-specific, our results only consider one reproductive function of fish stocks. There could also, for example, be an aggregation of fish around the OWF, affecting distant fisheries due to changing migratory patterns which our model does not account for (Galparsoro et al., 2022).

If there were a Marine Protected Area (MPA) introduced alongside the OWF development, then the effects on fish stocks depends on how the ban is implemented. The pure MPA effects allow for higher fish stocks, and the spill-over effects on surrounding fisheries mitigate the access loss effects on the fishing industry (Halouani et al., 2020). McDermott et al. (2019) analyse the announcement of an MPA near Kiribati 1-year before the policy began. This increased fishing leading up to the ban with 1.5-years-worth of fishing efforts taking place. Clearly, above the sustainable fishing level. Depending on the fish species, this type of overfishing could reduce the population below recoverable levels and lead to local extinction.

Box 1

To model the effect of OWFs on fish stocks and catches in the surrounding fishery, we use a Gordon-Shaefer model. This is a bioeconomic model to predict the maximum sustainable yield of a fishery. (Perman et al., 2003). The stock of fish S_t, changes according to:

$$S_{t+1} = S_t + gS_t^{\alpha}\left(1 - \frac{S_t}{S_{max}}\right), \quad 0 < \alpha < 1 \tag{1}$$

Where g is the unrestricted growth rate of the stock, S_{max} is the maximum carrying capacity of the fishery, and α represents depensation of the stock.

The efforts of fishers, E_t, is dynamic, depending on the profits in the previous period:

$$E_{t+1} = E_t + d(p(aE_tS_t) - wE_t) \tag{2}$$

Here, $aE_tS_t = H_t$, where H_t is the fish caught in period t, w is the cost of effort, p is the price of fish, a is the efficiency of effort, and d is a constant. Introducing OWFs changes 3 model parameters: $S_{\max}$ increases because of the artificial reef effect; a decreases because the non-homogenous seabed lowers catches using the same effort; and the S_0 is 40% lower because the negative effects of OWF construction.

Figure 1 shows the modelled effects of OWF presence. Even though fisher effort is lower (1B), we see the sustainable production level is similar (1C), and fish stocks are higher (1A). This implies a higher catch per unit of effort, as evidenced for almost all species around an OWF near Kent (Mangi, 2013). Although, this is for one parameterisation of the model. Since effects are case-specific, the magnitude of each change should be estimated using data.

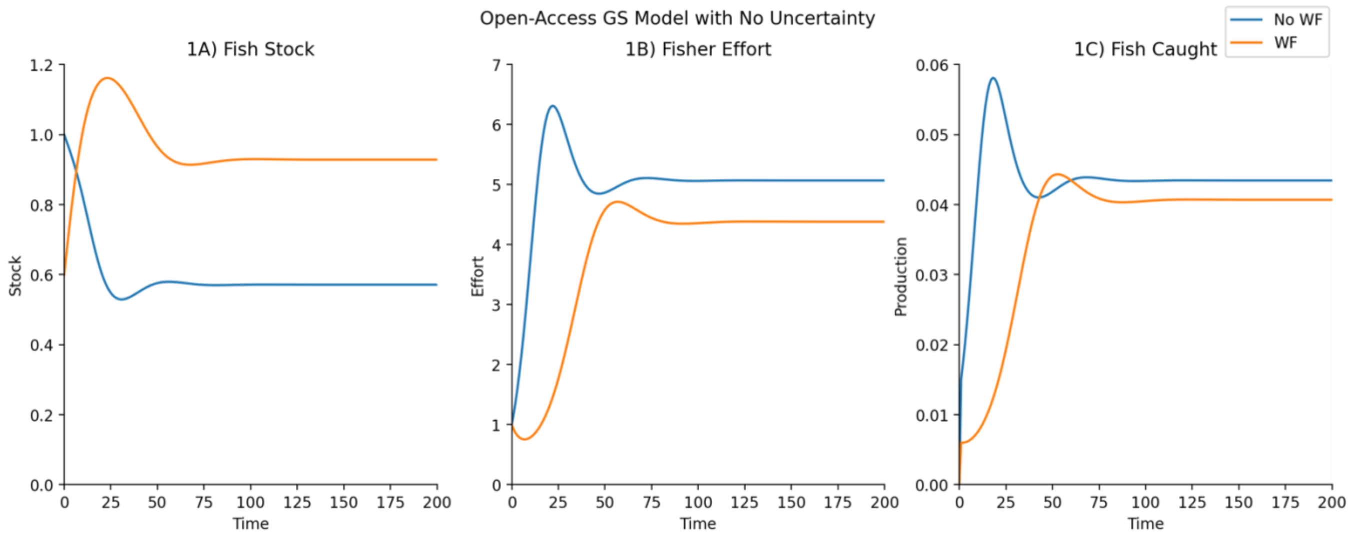

Figure 1: Panels A, B, and C. Gordon-Shaefer modelling outcomes for wind farm development. Model adapted from Workshop 4, 2023. (Link to Colab file used for modelling in references section)

4. Evaluating the Environmental Effects of Wind Farms.

To evaluate whether the environmental effects of WFs outweigh their costs, we need to assign a monetary value to all impacts. Building costs are simple to incorporate, but the effect on fish stocks, or noise pollution, can be much harder to value. The environmental costs are not paid for by any stakeholder, so need to be estimated to understand the full cost/benefit of the project.

Local Impacts:

First, we consider the impact on those living close to the WFs. Even though opinion polls show high levels of support for wind power in principle (Helm and McKie, 2022), there is usually opposition to their development in practise (Gibbons, 2015). This NIMBY-ism stems from WFs being visual eyesores and generating noise pollution. There are two methods to estimate these costs to locals: (i) Locals could be asked to state how much they would hypothetically pay for WFs to be located different distances from their residence or the coast (Ladenberg et al., 2020). (ii) For operating WFs, one can compare the price of identical houses close to and further away from the WFs to reveal how much people are willing to pay to be further from WFs (Skenteris et al., 2019).

In theory, both methods should obtain the same result, but in practice they find different valuations. Urama and Hodge (2006) found that 67% of survey respondents said they would pay a non-zero amount for the proposed project pre-implementation, but 98% of the respondents went on to actually pay towards the project. The disparity mainly stemmed from the respondents not grasping he full benefits in the hypothetical case. However, providing information on the full benefits may increase their stated payments, overestimating the project's true value through (i).

Box 2 discusses the technical drawbacks of (i) and (ii). Accurate estimates require careful survey design in (i), and comparable groups of houses close to/far from WFs in (ii). Since (ii) uses house price data, it can be less applicable to OWFs far from the coast or population centres because few houses are visually/audibly affected. Here, concluding that OWFs have no negative effect is inaccurate since they can still impact views for hikers for example. In this case (i) would be a more appropriate method to value the local disruption – clearly the choice of approach is case-specific.

The case-specific approach gives greater appeal to method (i) for a proposed WF dissimilar to existing WFs. Box 2 further explains the advantage of (i). Once individual values have been decided (through either method), the size of the affected population should be identified to aggregate the overall local impact.

Wider Impacts:

There are also wider environmental impacts. Firstly, we can consider the ecological effect on fish stocks from section 3. The cultural benefits from greater biodiversity can be captured through method (i) (Mangi, 2013). We could also take a productivity perspective, measuring the effect of OWFs on total catches in the surrounding fishery. Shimada et al. (2022) estimate a fishery's production in the absence of OWFs. Using data from similar fisheries with no WFs, they create a 'synthetic' fishery whose production is as close to pre-WF production as possible. Then, after the OWF developments, they compare the synthetic fishery's production with the actual fishery production to see the OWF's effect, finding none. Section 3 highlighted the spatial effects of OWFs on fish stocks. Since this method focuses on the effect for one fishery, it could miss the spill-over effects from fish-aggregation and disrupted migratory patterns. Hence, this analysis under-estimates the total effect on the fishing industry because of its narrow scope. Shimada et al. control for this by assuming adjacent fisheries are affected by the OWFs, but this does not account for more distant effects. A full evaluation requires an in-depth analysis of the OWF's effect on fish distribution.

Emissions

The effect on total emissions, the principal reason for changing energy composition, should also be valued. A range of benefits are captured, including improvements in air quality and less extreme weather (IPCC, 2023). The magnitude depends on the scale of the WFs since smaller-scale farms minimally affect total emissions. Estimating the reduction in emissions can be modelled as in Allan et al. (2020), but we should assign a price to these emission reductions. Large-scale IAMs can estimate the damage from 1 ton of carbon, known as the Social Cost of Carbon (SCC), but the accuracy of these estimates has been questioned. Some IAMs fail to capture important costs of climate change like biodiversity loss, reduced productivity of workers, and large migratory movements, causing the models to underestimate the costs of emitting (Stigliz et al, 2017). Weitzman (2009) highlights the threat of low-probability, catastrophic effects of climate change which can make the cost of emitting near-infinite. The current estimates of SCC vary widely in the literature (IPCC, 2022). Tol (2018) suggests that the best estimates are from a few tens to a few hundreds of US$ per ton of carbon. Nonetheless, this vital benefit from WFs necessitates choosing an SCC.

For onshore WFs, the construction site also affects emissions. Building over terrestrial carbon stocks increases carbon emissions from the loss of those sinks (Albanito et al., 2022). The effect can be large, even comparable to the life cycle of fossil fuel technologies when displacing dystrophic basin peat habitats (Albanito et al., 2022). Hence, the emissions are higher for onshore WFs than OWFs.

Box 2:

Stated Preference (SP) methods, (i), have three main advantages over Revealed Preference (RP) methods, (ii). Firstly, they allow for estimation of Willingness To Pay (WTP) for goods which do not yet exist, in this context, meaning they can estimate costs for proposed WFs (Hanley et al., 2019).

Secondly, the surveys allow for exogenous variation of alternatives, so researchers can identify causal effects from different hypothetical cases like changing the distance from the coast (Angrist and Pischke, 2010). A causal estimate using RP requires a careful identification strategy because it is prone to bias, for example, if buyers are poorly-informed of the environmental attributes, their purchasing decisions do not reflect choices over these attributes. In SP methods, these informational issues can be alleviated through providing images of the proposed developments as in Figure 2. RP also requires controlling for all house characteristics. Gibbons (2015) uses post-code fixed effects, but this requires a panel of house sales, which may not be possible when houses are sold infrequently.

Thirdly, RP methods cannot capture intrinsic non-use values which have no behavioural trail (Adamowicz et al. 1994). Like the hiker example, RP only estimates the WTP of people who directly purchase/use the amenity, necessarily estimating WTP for a sub-set of the population – underestimating the aggregate WTP.

Though, SP valuations have bigger budget requirements for conducting surveys. Online surveys are low-cost options, but the type of individuals attracted to them are not typically representative (Cason and Wu, 2019). The hypothetical nature of the survey means their stated WTP could be a biased measure of their true WTP. Hanley and Czajkowski (2019) propose three conditions to make SP surveys incentive compatible, so respondent's best strategy is to state their true WTP. The individual should see the survey as consequential; the proposed payment vehicle should impose costs on all affected individuals if the project is undertaken; and the respondent should not see their decisions as influencing the future of the project.

Alternative A

Distance: 8 km, No. Turbines: 144, Number of wind farms: 5 and Cost: 40 euro/year

Alternative B

Distance: 18 km, No. Turbines: 49, Number of wind farms: 15 and Cost: 80 euro/year

I Choose A ☐ B ☐

Figure 2: A survey question from Ladenburg, 2020.

Conclusion:

WFs are a crucial component of Great Britain's net-zero future. To effectively evaluate their environmental impacts, it is important to consider a range of factors including effects far from the site. Valuing these impacts can be complex, necessitating a multi-criteria analysis using knowledge from a range of disciplines. The evidence thus far suggests that WFs have a net positive impact, but the effects are site-specific so each proposed WF should have an environmental evaluation.

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