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WIND & SOLAR POWER: AN OVERVIEW OF NON-MARKET EXTERNALITIES AND METRICS

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KEYWORDS

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ABSTRACT

Wind and solar power projects are relevant alternatives to fossil fuels and constitute a focal point for achieving greenhouse gas (GHG) emissions reduction in national strategies (e.g. Portugal). Yet, despite the relevant contribution to electricity generation, renewable energy projects also entail externalities, i.e. impacts that inadvertently affect ecosystems and communities at different levels, and that are not accounted for by the agents that produce them. For instance, health benefits provided by avoided emissions of wind and solar power deployment as positive externalities, or biodiversity loss that affects flora and fauna as negative externalities.
Valuation of externalities may resort to a myriad of methods, among which contingent valuation, travel cost valuation, or market price-based methods. This paper intends to summarize the main externalities ascribed to wind and solar power projects and the methods of their economic valuation. To promote a better understanding between impacts and possible valuation alternatives a specific research string was adopted and applied to the research database; followed by an exclusion/inclusion criteria that allowed to establish a restricted sample of articles to assess. This overview may contribute to discerning different types of economic valuation for each socioeconomic and environmental category, contributing to the economic and energy engineering scope. Finally, policy implications for energy transition based on wind and solar power projects are provided.

INTRODUCTION

Numerous countries around the world are actively shifting their energy sources to renewable options to fight climate change and minimize environmental impact (Georgiou and Francisco J Areal 2015; Kim, Lee, and Yoo 2018; Koto and Yiridoe 2019; Moran and Sherrington 2007). Wind and solar energy, in particular, have experienced significant growth, and installations are projected to continue increasing (Lee, Nam, and Kim 2023). In 2023, the revised Renewable Energy Directive has established ambitious targets for European countries to decrease greenhouse gas (GHG) emissions, boost the share of renewable energy to a minimum of 42.5%, and improve energy efficiency by 2030 (Renewable Energy Directive 2023). Furthermore, global efforts are underway to promote the adoption of renewable energy, with projections suggesting that by 2050, 60% of the world's final energy consumption will be from renewable sources (International Renewable Energy Agency (IRENA) 2018). These transitions require substantial investments in renewable energy infrastructure and the implementation of policies to enhance public acceptance and support for renewable energy projects (Kim, Lee, and Koo 2020).

The global shift towards renewable energy sources such as wind and solar power plays a crucial role in electricity generation (Renewable Energy Directive 2023). This transition is motivated by the goal of mitigating the negative environmental impacts linked to traditional energy sources, underscoring the vital role of renewable energy in the future of energy production. However, externalities present substantial obstacles to the widespread acceptance of wind and solar power as renewable energy sources (Kim et al. 2020; Lee et al. 2023; Woo et al. 2019).

Externalities are the effects on individuals or communities that are not reflected in market prices. These externalities are considered "non-market value" because their effects are not bought and sold in conventional markets. In the realm of wind and solar energy, externalities encompass both positive and negative impacts associated with renewable energy generation (Mattmann, Logar, and Brouwer 2016). Positive externalities include lower GHG emissions, improved air quality, reduced dependence on fossil fuels, and job opportunities (Moran and Sherrington 2007). Conversely, negative externalities encompass visual intrusion, noise pollution, impact on flora and fauna, and conflicts with local land use (Moran and Sherrington 2007).

The externality concept is very wide-ranging and often differs according to the study area (e.g. economics vs engineering). Yet according to (Bielecki et al. 2020) 5 main pathways/topics to address externalities, namely: Social costs of GHG emissions, impacts of non-GHG pollution, landscape and noise impacts, impacts on ecosystems and biodiversity, and external costs associated with radionuclides. The present study considers the non-market nature of externality, subject to economic valuation, and as so is aligned with social costs of GHG emissions (net of market costs of GHG emissions); landscape and noise impacts; impacts on ecosystems and biodiversity (beyond those related to climate change), identified as the most common topics in the performed research databases.

The social costs of GHG emissions are related to human health, material harm, crop degradation, loss of biodiversity, and climate change. The valuation of emissions, such as CO_2, SO_2, and NO_x, plays a crucial role in determining the external costs of production (Bielecki et al. 2020). Wind power shows benefits in reducing CO_2 emissions compared to coal and natural gas power sources (Munksgaard and Larsen 1998). These external costs highlight the importance of considering the broader societal impacts of GHG emissions in energy production and the need for sustainable and renewable energy sources to mitigate these effects (Sovacool and Monyei 2021; Trapp and Rodrigues 2016).

The impact of wind energy developments on landscapes and noise levels is important to consider as it can affect public perception and acceptance (Mirasgedis et al. 2014; Yoo and Kwak 2009). Wind turbines can visually impact landscapes, especially in scenic upland areas, leading to opposition due to environmental alteration; additionally, noise generated during the construction and operation of wind farms can be a concern, although advancements in turbine design have mitigated this issue to some extent (Moran and Sherrington 2007). Several external costs have been identified, including the negative effects of wind farms on ecosystems and biodiversity. Wind farms can harm seabird populations, either through collisions with the turbines or by acting as a barrier to their migration (Winiarski et al. 2014). Given their increasing relevance for different stakeholders, there is a need to take them into account in the decision-making process for the development of renewable energy projects. Among the most common methods to monetize non-market externalities (costs or benefits) are the economic valuation methods, such as stated or revealed preference (including contingent valuation and choice experiments or hedonic prices) (Sovacool, Kim, and Yang 2021). Contingent valuation (CV) is used to value non-market goods and services by directly asking people to specify their willingness to pay (WTP) to gain access/obtain a given good or service or their willingness to accept (WTA) a compensation to relinquish or give up a given good or service, based on a hypothetical market (Polinori 2019). Meanwhile, choice experiments (CE) are based on the 'ability to capture WTP', before different attributes or scenarios of a given good or service, such as the location of an offshore wind park (e.g.(Ladenburg and Dubgaard 2007). Revealed preference (RP) methods, on the other hand, are often based on existing consumer behavior at the market level and look to analyze the externalities (non-market) associated with the proximity of renewable energy facilities on the nearby property (e.g. housing or land prices) ((Gaur and Lang 2023).

Given the relevance of considering non-market goods and services for individuals in the context of wind and solar power investments, the present work looks to address the following research questions:

- What are the main non-market externalities for wind and solar power projects?;
- What are the main economic valuation methods used to account for non-market externalities?.

The following is the structure of the paper: Introduction: This section provides examples of wind and solar power. Methods: Describes the specific research methodology and the steps taken to establish inclusion/exclusion criteria. Results and Discussion: Focuses on non-market externalities and metrics of wind and solar power. Conclusions: Summarize the main findings of the study and conclude.

METHODS

The present overview of identified externalities and economic assessment methods for wind and solar power projects is a task of the second phase (Phase 2) of the *Economic and Externalities Valuation of Renewable Energies in Portugal' (R3EA Project)* R3EA Project (R3EA PROJECT 2021). This task is aligned with the project's aim to promote the socioeconomic and environmental impact of new investments in solar and wind power for the Centro Region of Portugal. The current task a), was developed according to Phase 2 methodology of R3EA Project (Max López-Maciel et al. 2023). It includes the following steps:

a) Preliminary literature review to gather information on wind and solar power externalities and metrics: ("contingent valuation" OR "travel cost valuation" OR "market price-based methods" AND wind AND power OR solar AND power; combined with externalit*) in Scopus database that encompasses topics of interest, namely within social sciences and energy engineering fields; only articles in English, considering wind and/or solar power were contemplated, mentioning externalities and that focused economic valuation methods. The snowball sampling technique, (Rao et al. 2017) was also used as a complement to the proposed research string (the initial sample (n=35) that was reduced to the final sample (n=19));
b) Economic assessment of identified externalities;
c) 'Design and implementation of surveys to quantify the costs or benefits of externalities, resorting to willingness-to-pay (WTP) and willingness-to-accept (WTA) concepts' (Max López-Maciel et al. 2023).

RESULTS AND DISCUSSION

Table 1 describes the main externalities mentioned, according to the economic evaluation methods used to assess them in the final sample.

Table 1: Identified externalities by economic valuation method

Economic Valuation Methods		Stated Preferences		Revealed Preferences		Other
	Externalities	CV	CE	Hedonic Prices	Travel cost	Market-based Prices
Environmental	Climate change/Air pollution	✓	✓			✓
	Visual/landscape Impact	✓	✓			
	Deforestation/Biodiversity		✓	✓	✓	
	Noise		✓			
	Shadow flicker effect	✓	✓			
Socioeconomic	Housing prices	✓		✓		
	Land use	✓				
	Revenues		✓			
	Regulatory issues	✓	✓			
	Other	✓	✓			✓
Total		10	4	2	1	2

According to Table 1, regarding the impact areas, two main categories were identified: environmental and socioeconomic areas, with a total of 6 categories and 5 categories for each, respectively. Preliminary results show their distribution according to the three main economic valuation methods: contingent valuation (CV) and choice experiment (CE) related to stated preference and hedonic prices and travel cost related to revealed preferences, as well as other methods, such as the market-based price model. The most common method used for economic valuation of externalities is the stated preferences, and among them CV (n= 10) and CE (n=4), vs revealed preference methods (hedonic prices and travel cost). These results are expected and in keeping with prior studies (e.g.(Polinori 2019; Zerrahn 2017)). Among stated preferences, CV (WTP) (n=7) studies are more frequent than CV (WTA) (n=1), although some studies have used a combined approach (WTP/WTA) (n=2), as a welfare measure. Meanwhile, travel cost is the least used revealed price method, in contrast to hedonic prices (n=2). It should also be noted that among externality types environmental ones tend to be more focused, with visual or landscape impact at the forefront, being mentioned in 10 out of 19, followed by climate change concerns (n=3). Most studies focus on one specific externality with few exceptions, such as Ladenburg and Dubgaard (2007) that focus simultaneously on market (e.g. construction,

operational and maintenance costs) and non-market impacts (e.g. climate change, deforestation, ‘avoided costs from displaced generation’ and ‘non-use disamenity’). It should also be noted that studies that mention climate change, often refer to the reduction of greenhouse gas emissions, namely CO_2, and as such this is viewed as a positive externality, meanwhile visual and noise impacts tend to be viewed more negatively.
A large majority of studies focus on wind power in contrast to solar power (n= 13 vs n=2), regardless of the economic valuation method used, either stated or revealed preferences. These results are expected as onshore wind power is a well-established renewable energy alternative, in comparison to offshore wind and solar power, despite recent increases in the latter alternatives. In fact, among wind power studies n= 7 already feature offshore wind alternatives, denoting the relevance of this alternative shortly, but also the need to better understand and account for environmental and social externalities these developments entail.

Georgiou and Francisco J. Areal (2015) recognize this increase and resort to CV dichotomous choice methods, estimating WTP for offshore wind farms in low-populated areas in Greece. These authors claim that, taking into consideration climate change concerns and socioeconomic context, it is possible to conciliate offshore wind farms with local acceptance, by reducing externalities such as visual and noise impact and contributing to reduce GHG emissions. Therefore, according to Georgiou and Francisco J. Areal (2015), individuals' attitudes towards the ‘environment, climate change, and renewable energy’ are crucial to establishing their WTP for offshore wind farms.
Also, resorting to CE, to study the preferences regarding the changes in welfare in marine life (ecology) and visual impact (amenity) from offshore wind farms located in the Irish Sea. The ecological improvement promoted by the wind farm infrastructure as an artificial reef was emphasized/preferred by people surveyed in contrast to the visual impact generated, requiring a more distant location from the coastline (Börger, Hooper, and Austen 2015). Although both externalities (positive and negative) should be further considered for future marine integrated planning of offshore wind farms, authors alert that externalities that go beyond the visual impact, such as the marine life benefits are often overlooked.

Therefore, although a commonly mentioned externality visual impact (e.g. (Börger et al. 2015)), is far from being a consensual one, since a recent study, resorting to CV, conveys that the willingness to pay to avoid, because of proximity to wind turbines, could instead be people ‘willing to forego’ under a given compensation (Gudding et al. 2018). These results are aligned with the theory (*“proximity versus reverse proximity”*) that states that proximity to wind farms is not as relevant as ‘environmental or socioeconomic or local community features, such as place attachment and past experiences’ (p. 217) with other renewable energy projects, to improve the willingness to accept enlargement of wind power projects; considered nowadays an alternative to increase onshore wind projects by (Polinori 2019). Yet, from the sampled studies few consider revenue and profit sharing to promote willingness to accept solar and wind power projects in Korea, for the inconvenience of renewable energy facilities (e.g. (Kim et al. 2020)). In this context, while investigating the willingness to pay for wind energy and its determinants in Canada, Koto and Yiridoe (2019) were among the few studies that considered several externalities, besides landscape impact, on biodiversity, noise, land use, impact on housing prices, as well as issues related to the manner local community was consulted during wind power deployment. This stream of research that looks into local community engagement in renewable energy projects is recent but considered relevant in the context of externalities and future wind and solar power developments.

Regarding the impact on housing and property prices, these externalities’ though mentioned in CV studies, their assessment is performed by the revealed preferences with the hedonic price technique. Among the few studies encountered considering this impact is the one by Gaur and Lang (2023), which looks to assess the impact of utility-scale solar arrays on housing prices in the USA. According to these authors, this constitutes one of the local externalities of solar power on rural communities, along with deforestation; households near solar power plants tend to suffer a price decrease between 1.5–3.6%.
The last method considered in Table 1, focuses on studies that resort to market-based prices, and where the context is based in electricity markets such as the Iberian Market, MIBEL (MIBEL 2008) and is subject to market competitors and regulatory policies (e.g. taxation, or subsidies) that condition renewable energy development (Wang, Moreno-Casas, and Huerta de Soto 2021). An example is the application of feed-in-tariffs (FIT), to promote the dissemination of renewable energy projects, such as solar plants; recently China stopped this incentive which might jeopardize

carbon emission targets; Wang, Moreno-Casas, and Huerta de Soto (2021) study the combined effect of carbon trading scheme and FIT in electricity sector through dynamic computable general equilibrium (CGE) model. The author concludes that to reduce emissions and to promote economic development FIT should terminate only in 2025 and ETS afterward (2030 and 2035) (Wang et al. 2021). Incentives for the expansion of renewable energies, such as FIT, have also been introduced in Europe, namely for wind power generation in Germany, where some are for it and others against it, for preventing 'welfare-optimal energy supply', as described by Drechsler, Meyerhoff, and Ohl (2012). Although difficult to establish, because too low or too high FIT might lead to lowering social welfare, it was found that FIT promotes social welfare in West Saxony, Germany. Therefore, although focusing on a few externalities, it was found that economic valuation methods were used to assess a diversified range of topics, from the social costs of wind energy to visual disamenities or local acceptance of wind and solar based on environmental and socioeconomic externalities.

CONCLUSIONS

Environmental impacts, namely visual or landscape, and climate change impacts, seem to prevail as main externalities focused in economic valuation studies. Yet, it is recognized that social acceptance is increasingly relevant for the development of wind and solar power projects. Additionally, studies focusing on wind farms largely overcome studies focusing on solar power, with special emphasis on offshore wind farms. These last studies have emphasized that other ecosystem externalities are largely dismissed and remain unaccounted for. Therefore, there is a need to consider a larger scope for externality assessment, overall, and in this particular study, where the set of keywords might pose a limitation to the acknowledgment and quantification of other existing energy-related externalities, such as impacts on human health. Further research should extend toward the energy system field, to encompass a wider range of externalities, that need to be internalized.

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