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Understanding wind Energy Economic externalities impacts: A systematic literature review

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ABSTRACT

Electricity generation from wind energy is one of the main drivers of decarbonization in energy systems. However, installing wind farm facilities may have beneficial and harmful impacts on the habitat of living beings. This study reviews the literature based on economic analysis to identify the main externalities related to the installation of wind farms and the economic methodologies used to assess these externalities, filling an existent literature gap. A systematic literature review followed the Preferred Reporting Items on Systematic Reviews and Meta-analysis standards. A total of 33 studies were identified, most of them carried out in Europe. The studies cover 24 years, between 1998 and 2022. The externalities associated with wind electricity generation are classified into three categories: the impact on well-being, the impact of wind turbines, and the impacts of avoided externalities. Most studies (24 out of 33) determine economic values by stated preference methods through choice experiments, discrete choice experiments, and contingent valuation. Revealed preference methods were identified in 5 studies using hedonic pricing and travel cost techniques. The challenges and limitations of this analysis in terms of externalities identification and their assessment are also discussed, concluding that additional updated review studies are needed since the latest ones were published in 2016 and 2017. Moreover, it gives insights to policymakers and academics on a more complete approach they can use to evaluate the impacts of decarbonization, which, apart from the technological view, also considers and estimates the socio-economic and environmental perspectives.

1. Introduction

Energy is a crucial resource that propels business and technology growth, arising from the economic competition between corporations and governments. Certainly, the demand for energy will escalate as society progresses [1]. While energy demand should be met mainly by energy from renewable sources for sustainability purposes [2], renewable energy facilities, as for conventional energies, also have an impact [3] that may result in adverse effects, which can be local or of larger geographical reach [4]. When deciding where to produce energy, it is important to consider the effects not accounted for by market mechanisms, known as externalities [1]. These effects are essential for making socially optimal decisions about energy production site locations [5].

An externality, also known as an external cost or benefit, is a non-priced, unintentional, and unrewarded event that results from one party's activity and directly impacts the welfare of another [4]. Under this perspective, the environmental advantages of wind power are substantial from a socioeconomic standpoint, given that wind plants avoid the CO_2, SO_2, and NO_x emissions caused by conventional fossil-fuelled generation plants [6]. Nonetheless, wind turbines may aesthetically alter the environment and create noise pollution, casting shadows and causing flashing [7]. Furthermore, the negative effects of wind turbines are mostly felt by local inhabitants close to the generation facilities [8]. As a result, evaluating these effects using methods such as contingent valuation, hedonic pricing, travel cost, or other approaches is needed to find strategies to monetize the external effects of wind energy. In this sense, reviewing the literature on wind energy and externalities is important, as it gives a detailed account of the costs and benefits associated with using wind energy. The previous two reviews were

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Abbreviations

CE	Choice Experiment
CO_2	Carbon Dioxide
CV	Contingent Valuation
DCE	Discrete Choice Experiment
GW	Gigawatt
ID	Study Identification
NIMBY	Not in My Backyard
NOx	nitrogen oxides
PRISMA	Preferred Reporting Items on Systematic Reviews and Meta-Analysis
R3EA	Project Renewable Energy: Economic and Externalities Assessment Project
SO_2	Sulfur Dioxide
WTA	Willingness to Accept
WTP	Willingness to Pay

conducted about 5 years ago and do not justify the specific methods used to select the articles [9,10].

The motivation behind this research derives from the importance of providing a guide for the economic assessment of the externalities of wind generation. Moreover, wind power technology is one of the most developed renewable electricity generation, with still a huge growing potential and well-known environmental benefits regarding emissions [11]. Identifying the externalities and the assessment methodologies will allow us to analyze how they were quantified or evaluated, categorizing them into positive or negative externalities and classifying them based on their nature (e.g., environmental, social, and health).

Therefore, this study aims to conduct a systematic literature review of economic analysis studies to identify the main externalities and economic methodologies used to assess them. A strong body of literature on social, environmental, and economic impacts exists. Thus, it is imperative to recognize that this literature review covers only a portion of the literature to adopt a purely economic approach to the externality concept, misrepresenting broader external impacts in terms of economic and environmental aspects of wind energy. Despite its limitations, the study attempts to contribute significantly to the current body of knowledge by offering an up-to-date literature review analysis of these externalities and valuation approaches and by providing practical recommendations to researchers and policymakers for developing wind energy projects that are both sustainable and beneficial to the community, considering their environmental, social, and economic impact. Furthermore, it will be the basis for developing our methodology for assessing the externalities derived from the installation, in the Portugal Central Region, of additional wind power, as one of the objectives of project R3EA (Renewable Energy: Economic and Externalities Assessment) [12]. Moreover, the contribution of this study lies in using this knowledge to drive advancements in distinguishing externalities among renewable electricity generation technologies, namely wind power.

The study is organized as follows. Section 2 provides the methodology for the selection of studies. Section 3 presents the results of the literature analysis, selected works, and publication trends. Section 4 discusses the types of wind energy externalities, methods for valuing wind energy externalities, practical implications, research directions, and unexplored areas. Section 5 concludes.

2. Material and methods

In this review, the Preferred Reporting Items on Systematic Reviews and Meta-analysis (PRISMA) standards [13] were used to search and select studies. The PRISMA technique gives scholars hints for understanding and evaluating research presentations [13]. Though the relevance of the impacts of electricity generation is largely recognized in the literature, there is still a scarcity of studies regarding assessing externalities applied to the renewable energy case. In this context, the study promotes a systematized review, based on the sequence steps illustrated in Table 1, that aims to promote a systematized review of studies to answer the gap regarding the use of the externality concept and to answer the following research questions: What are the main externalities related to the installation of wind farms? and - What are the main economic methodologies used to assess these externalities?

We have followed several search criteria for the selection of the relevant literature, which we summarize in the following steps.

- **Eligibility criteria:** the work selected should be written in English language (language), peer-reviewed (studies and works), and approach the externalities of renewable energies related to wind energy. These study types were included as criteria to ensure a comprehensive synthesis of all terms and themes related to the review. Hence, this study was confined to examining the externalities of wind energy that are specifically associated with wind turbines, encompassing the spatial impacts resulting from the implementation of wind energy. These studies were included as criteria to ensure a comprehensive synthesis of all economic analysis terms and themes related to the review. Therefore, this study was limited to examining the externalities of wind energy specifically associated with wind turbines, covering the spatial impacts resulting from the implementation of wind energy, except the entire project process cycle. Furthermore, although macroeconomic and geopolitical effects are often relevant in discussions, it is extremely difficult to quantify them accurately or to determine how they affect various types of impact. Thus, this literature review also did not consider geopolitical and macroeconomic effects.
- **Ineligibility criteria:** The studies that do not explicitly mention the type of externalities that estimate the demand for wind energy, that examine the strategic decision of the future mix of electricity generation, and that deal with the technical aspects of the evaluation were considered ineligible. The preference for scientific articles arises from their peer-review process, which ensures the quality and credibility of the data, making them reliable sources for advancing scientific knowledge.
- **Selection of the scientific databases:** The Web of Science and Scopus databases were used to identify studies related to wind power externalities. The reason for using Scopus and Web of Science is to provide studies with extensive guidelines and access to diverse literature across various subject areas, according to previous studies [14–16].
- **Sampling procedure:** Search terms customized for each specified bibliographic database were utilized as part of the sample approach

Table 1
Criteria selection.

Search strategy	Criteria	Steps	Number of papers
Web of Science and Scopus databases (1°)	Search String	externalit* AND wind AND energ*	427
	Duplicate papers	(−) 89 papers	338
	Document type/Language	Article/English	244
	Restrictions	Title, Keywords, and Abstracts	**20**
Snowball technique (2°)	Document type/Language	Article/English	28
	Restrictions	Title, Keywords, and Abstracts	**13**
Total of the combination (1° and 2°)	–	–	33 (20 + 13)

to screen the articles. The following keywords were used for the investigation: (externalit* AND wind AND energ*).
- **Snowball technique:** The scientific database did not provide all relevant publications related to the specific research question, even considering a generic search string. In this sense, the Snowball technique [17] was adopted to improve the analysis.

3. Results

3.1. Search results

To select the most relevant articles, a preliminary search strategy was created in the Scopus and Web of Science databases, using search queries related to the study topic mentioned previously. However, this selection criteria resulted in only 20 scientific papers. As a second search strategy, the Snowball technique provided 13 additional articles indexed in Scopus or Web of Science databases, previously neglected in the search engines. Therefore, 33 studies were selected as significant. Table 1 presents the selection of criteria for combining scientific databases and the Snowball technique, pointing to the number of selected papers for each criterion.

Fig. 1 presents the PRISMA 2020 flow diagram to show the steps taken in selecting the 33 articles for this systematic review. To update with the latest literature reviews on this subject [9,10], we divided the PRISMA 2020 flow diagram model into two categories: identification of studies via databases and identification of studies via other methods [13]. In the original diagram model, "report" refers to any document type, whereas in Fig. 1, "report" means only journal paper. The first group of article identification refers to records found in the Web of Science (236) and Scopus (191), totaling 427, and the second represents the records identified using the Snowball technique (28). After removing duplicated works, titles and abstracts were used attending the eligibility and ineligibility screening process, followed by a full-text review. After this step, 33 articles were selected, 20 from the database and 13 from the Snowball technique. Of the 33 articles, 4 are indexed in the Scopus database, 1 is indexed in the Web of Science database, and 28 are indexed in both databases. Finally, from the 33 articles selected, 29 are empirical articles, and 3 are literature reviews on the externalities of wind energy.

Most of the studies on the topic were carried out in Europe. Greece, Norway, Denmark, and Germany were the leading author countries in the number of published papers, each with three publications. Meanwhile, Italy and Sweden had two each. The Netherlands, Poland, Ireland, Spain, and France had one paper published on this topic. Germany and Denmark conducted more research on this topic probably because Germany occupies the leading position in European wind energy production. Denmark has a higher percentage of wind energy in its energy mix. In 2022, Germany had the largest installed wind power fleet in Europe, with over 66 GW of capacity, while Denmark had the highest share of wind energy in their electricity mix at 55 % [18].

The studies cover 24 years, between 1998 and 2022. Each peer-reviewed paper included in the analysis received, on average, 58 citations measured by the Scopus and Web of Science citation index, with one study having a maximum of 303 citations (until September 2023, when this search was performed). The top 5 journals that publish the most are Energy Policy with 10 papers, Energy Economics and Ecological Economics with 3 each, and Renewable and Sustainable Energy Reviews and Journal of Environmental Economics and Management with 2 each. We gathered three literature reviews for this work, two of which were published in Ecological Economics. These are the most recent reviews, published in 2016 and 2017. This information suggests the need for additional and updated review studies. Table 2 provides an overview of the studies of wind energy externalities.

3.2. Publication trends

Fig. 2 shows the trend followed by the publications on wind energy externalities, based on the documents selected from Scopus and Web of Science databases from 1998 to 2022. As observed, the number of publications shows an incremental trend in most of the period but with a final decrease at the end. Indeed, in the last two decades, the average number of publications is significantly higher than in the 1990s, corresponding to a rise in the scientific interest in the subject. The decrease at the end could be associated with a greater community acceptance of wind turbines and their local effects [19–21].

4. Discussion

The concept of externalities goes beyond the neoclassical concept that the production of a certain good harms the production of another specific good [10]. It may be extended, considering the secondary effects on an agent's welfare beyond market transactions [19]. The definition of externality is quite vast and varied. However, for this particular research, the main focus will be on the community's acceptance of wind

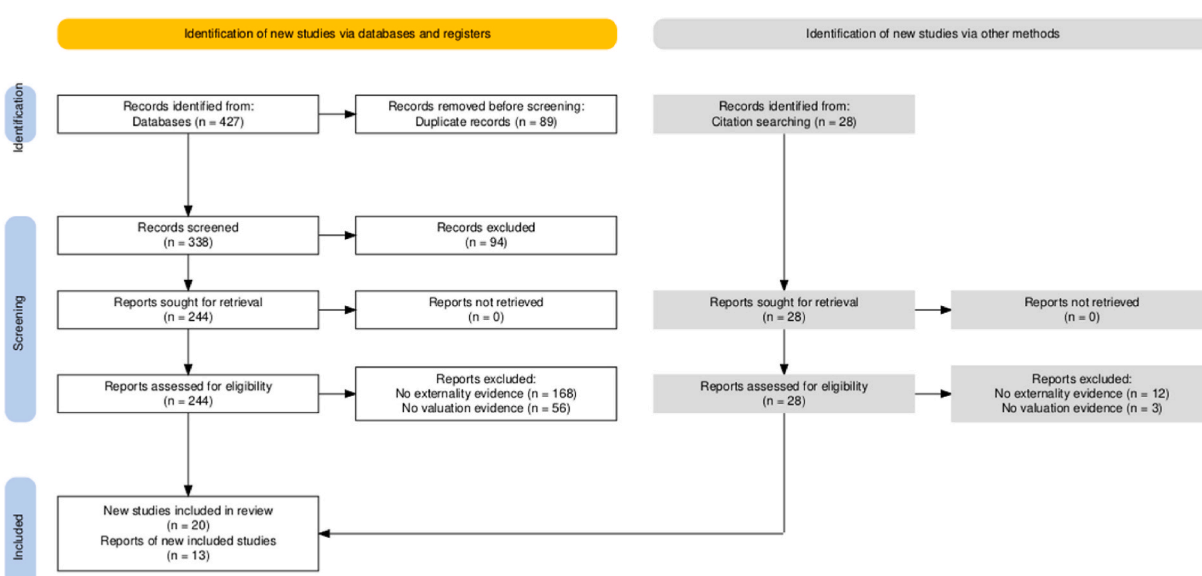

Fig. 1. Prisma flow diagram.

Table 2
Works related to wind energy externalities.

Study ID	Reference	Journal	Country	WOS citations	Scopus citations
1	(Fooks et al., 2017)	Agricultural and Resource Economics Review	USA	9	10
2	(Skenteris et al., 2019)	Economic Analysis and Policy	Greece	12	12
3	(Meyerhoff et al., 2010)	Energy Policy	Germany	156	160
4	(Trapp & Rodrigues, 2016)	Gestão & Produção	Brazil		5
5	(du Preez et al., 2012)	Journal of Energy in Southern Africa	South Africa	11	13
6	(Krekel & Zerrahn, 2017)	Journal of Environmental Economics and Management	Germany		52
7	(Dröes & Koster, 2016)	Journal of Urban Economics	Netherlands	62	62
8	(De Salvo et al., 2021)	Sustainability (Switzerland)	Italy	4	4
9	(Munksgaard & Larsen, 1998)	Energy Policy	Denmark	11	12
10	(Lang et al., 2014)	Energy Economics	USA	68	64
11	(Dugstad et al., 2020)	Energy Policy	Norway	17	20
12	(Polinori, 2019)	Energy Economics	Italy	4	6
13	(Faulques et al., 2022)	Energy Policy	France	4	5
14	(Bartczak et al., 2017)	Energy Economics	Poland	25	26
15	(Kipperberg et al., 2019)	Journal of Outdoor Recreation and Tourism	Norway	12	13
16	(Brennan & Van Rensburg, 2016)	Energy Policy	Ireland	49	53
17	(Jensen et al., 2018)	Energy Policy	Denmark	42	40
18	(Vecchiato Daniel, 2014)	Aestimum	Italy		26
19	(Landry et al., 2012)	Resource and Energy Economics	USA	72	79
20	(Ek & Persson, 2014)	Ecological Economics	Sweden		95
21	(Mirasgedis et al., 2014)	Renewable and Sustainable Energy Reviews	Greece	36	35
22	(Ek & Matti, 2015)	Journal of Environmental Planning and Management	Sweden	28	30
23	(Koundouri et al., 2009)	Energy Policy	Greece	60	65
24	(Álvarez-Farizo & Hanley, 2002)	Energy Policy	Spain	208	223
25	(Westerberg et al., 2013)	Tourism Management	France	107	115
26	(Ladenburg & Dubgaard, 2009)	Ocean and Coastal Management	Denmark	63	68
27	(Mariel et al., 2015)	Renewable and Sustainable Energy Reviews	Germany	68	71
28	(Borchers et al., 2007)	Energy Policy	USA	267	303
29	(Navrud & Bråten, 2007)	Revue d'Economie Politique	Norway	43	46
30	(Hanley & Nevin, 1999)	Energy Policy	Scotland	72	81
Literature review studies					
31	(Van Kooten, 2016)	Annual Review of Resource Economics	Literature review	11	15
32	(Zerrahn, 2017)	Ecological Economics	Literature review	66	70
33	(Mattmann et al., 2016)	Ecological Economics	Literature review	45	49

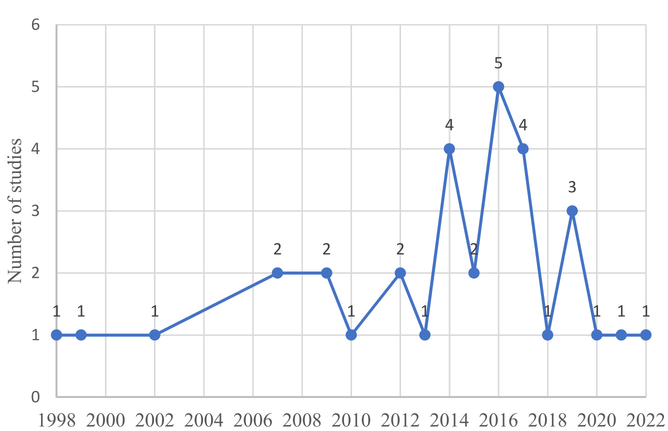

Fig. 2. Publication trends.

turbines and the local effects they may have. These studies may also involve the assessment of the monetary value, such as the willingness to pay, and how the externalities that arise from generating and using electricity may impact the environment, the economy, and society. Yet, it is recognized that the proposed approach to externality might limit the study, possibly misrepresenting a broader literature related to external impacts in terms of economic, social, and environmental aspects of wind energy projects. Nonetheless, this research provides an update that focuses on this relevant concept.

4.1. Types of wind energy externalities

The assessment of the impact of wind energy considers both its positive and negative externalities. These externalities may be revealed in various ways, such as environmental degradation, air pollution, human health, visual impacts, noise, changes in fauna, economic impacts, and social changes [1]. The externalities have been classified within three main categories of impacts, based on previous literature review studies [22]: (i) the impact on well-being, (ii) the impacts of turbines, and (iii) the impacts of avoided externalities. This categorization is a helpful tool for easily identifying and presenting the frequency with which each externality is mentioned in the literature, allowing their comparison across different studies and facilitating comprehension. Table 3 shows how this procedure works, using the same study ID as Table 1. The 'Total' column in the table is particularly significant, as it represents the number of studies that have acknowledged each specific externality and its respective category (in bold).

4.1.1. The impact on well-being

The impact on well-being is covered by the main social and economic effects related to wind energy externalities, as explained next.

The social effects refer to the impact on the quality of life of the residents, such as the impact on house values [1,23], local recreation [3], and conflicts with land use [11,24].

Regarding the economic effects, several economic activities could be impacted, such as tourism and real estate [1,23], job creation [1,21,23] and local economic growth [1,23].

The presence of wind turbines may lead to concerns related to the impact on well-being [22]. Specifically, the construction of wind turbines close to households can have significant negative effects on residential well-being, although these effects are spatially and temporally limited [19]. There has been a noticeable transition towards a more integrated methodology involving both physical attributes of the technology and the socio-economic elements intrinsic to the communities affected, including the diverse traits of the local population, thus augmenting the probability of achieving favorable project results,

Table 3
Types of wind energy externalities.

Impact	Type of externality	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	Total
well-being	Economic growth in local communities		X		X							X	X																						**4**
	Job Creation		X		X						X	X	X				X																		**6**
	Impact on house values and tourism		X	X	X		X	X	X		X		X	X		X	X																X		**12**
	Local Recreation			X												X										X									**3**
	Conflicts with other land uses			X									X																X						**3**
avoided externalities	Greenhouse gas emissions		X		X			X	X	X	X	X	X				X												X						**10**
	Air quality				X								X																	X					**3**
	Climate Change		X																																**1**
wind turbines	Noise pollution		X	X	X			X	X	X	X	X	X	X		X	X			X	X		X			X		X		X		X	X	X	**21**
	Visual Impact	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X		X	X	**31**
	Shadow Flicker			X					X				X				X																		**4**
	Biodiversity			X	X				X	X	X	X	X	X		X									X			X	X	X	X	X			**15**
	Radiation concerns																															X			**1**

increasing the probability of achieving favorable project results.

The impact on well-being relates to externalities associated with the satisfaction of individuals, tourists, and the general population. However, it is difficult to measure [10] and cover several aspects such as psychological stress [21], perceived health risks, social cohesion, and cultural aspects related to the presence of wind energy installations [25]. A commonly assessed externality related to well-being is the effect on the value of houses and tourism [19,26,27], as well as on local recreation [3,28].

Numerous studies have investigated the factors that influence the societal acceptance of wind energy parks considering the relationship between their impact on well-being and personal satisfaction [20]. It is apparent that there exists a relationship between measures of well-being and levels of acceptance: indeed, enhanced wind energy production enjoys greater acceptance if consumers evidence a willingness to pay for it, while conversely, people display less acceptance if they demand payment [21].

Valuation of the externalities of wind energy should also include the understanding of fundamental principles that control the positive or negative effects of any type of externality [10]. To enable the best decision-making, it is also necessary to consider the NIMBY (Not in My Back Yard) idea [19,21], hear from local communities about how implementation affects property values [29], and territorial distributive fairness [10,19].

4.1.2. *The impacts of turbines*

The primary effects of wind turbines are the consequences on wildlife, noise, and visual impact [9]. Wildlife and visual impacts are detrimental to animals [11] and tourists [30], respectively. Meanwhile, noise and shadow flicker [24] are often associated with adverse effects on human health, such as inducing stress, anxiety, and sleeping problems [2,19,23]. However, no empirical evidence proves to cause and effect between them [23].

Wind energy use may have resulted in negative local externalities that harm the fauna, flora, and particularly those people who live near such installations. Numerous research has been published in the literature on the impacts of wind turbines [24,27,31]. The impacts of wind turbines refer to externalities that directly cause changes in the physical environment and the local ecosystem [2].

In general, the literature on the externalities of wind energy places particular emphasis on the visual impact [32,33]. This is the main impact valued and frequently discussed as landscape [20,31], visual intrusion, terrestrial visual impact [34], and tourist viewshed [30], among others. The visual changes come from the physical characteristics of the turbine such as height, distance, quantity, and size [27,32]. In a study carried out in Italy, the location of the offshore wind turbine must have a minimum distance of 1000 m from the houses and the coast, a height of 120 m, and the ideal number of wind farms is 50, corresponding to common residents' preferences [34]. Large wind farms, instead of several small ones, are preferred by people to concentrate the impacts and to increase the energy generation per plant [35]. Wind turbines have a significantly reduced marginal effect on nearby properties when located 3 km or more away [27].

Nevertheless, greater importance should be given to the public's preferences and perceptions when installing wind turbines near residential areas, rather than solely considering specific attributes of the turbines [24]. The selection of sites should focus more on community characteristics like attachment to the site and prior experiences rather than the distance between wind farms and nearby communities and their effect on how risks associated with the expansion of these parks are perceived [11].

4.1.3. *The impacts of avoided externalities*

The avoided externalities refer to greenhouse gas emissions [2,6,20] climate change [9], and air quality, which are environmental negative externalities.

When measuring the impacts of avoided externalities, it is crucial to quantify how much wind energy is capable of replacing non-renewable sources of electricity, such as fossil fuels (coal, oil, and natural gas), and even nuclear [6].

4.2. Methodologies for assessing wind energy externalities

Renewable energies' positive and negative externalities have been the subject of non-market valuation research, primarily through direct valuation methods that build hypothetical markets, known as stated preference methods [24]. Although revealed preference techniques involve valuation through actual goods transactions, hypothetical markets are said to be more popular [19]. This study confirms the same result for wind energy externalities. Most studies (24 out of 33) have estimated the economic values by stated preference methods through choice experiment (CE), discrete choice experiment (DCE), and contingent valuation (CV). Nevertheless, the revealed preference methods were adopted in 5 studies using hedonic pricing and travel cost techniques. Table 4 describes the methods and techniques used to evaluate the externalities found in selected works.

Table 5 shows the techniques to assess the externalities of wind turbines and when they are used in the 33 works analyzed, providing an overview of those most frequently used. The two most common methods are revealed preference methods and stated preference methods. However, alternative approaches such as the life satisfaction approach [22] and the system dynamics approach [1] provide different perspectives, focusing on the broader impacts on individual well-being and system interactions, respectively.

In addition to the methods for valuing externalities, three literature reviews have been identified about the externalities of wind energy. They explore the benefits and costs of integrating electricity generated from intermittent wind sources into an existing electricity grid [37].

Table 4
Methodological approaches for externalities assessment from selected studies.

Methods	Techniques	Description
Stated preference	Choice experiment	It monetizes the externality by evaluating individuals' preferences and how they make decisions when presented with different scenarios and attributes [24].
	Discrete choice experiment	It is a type of choice experiment that concentrates on participants' discrete choice sets that consist of different alternatives with varying levels of attributes and then asks them to choose their preferred alternative [21].
	Contingent valuation	It is commonly employed to estimate the value individuals place on externalities by directly asking individuals how much they would be willing to pay for an externality [36].
Revealed preference	Hedonic pricing	It estimates the value of the externality by analyzing the behavior of consumers in the real estate market. It is based on the idea that a person's willingness to pay for a property reflects its attributes, including environmental aspects, such as the visual impact of wind turbines [23].
	Travel cost	It captures the value of the externality through individuals when traveling to a particular destination, e.g. local recreation [3].
Alternative methods	Life satisfaction approach	It modifies the microeconometric function that links self-reported life satisfaction to the environmental disamenity to be valued, income, and other variables [22].
	System dynamics approach	Mathematical models with strong frameworks that effectively simulate and help comprehend external factors' intricate interactions and effects [1].

Table 5
Valuation techniques of wind energy externalities.

Valuation Techniques	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	Total
Travel Cost															X																			1
Hedonic Pricing		X					X			X							X																	4
Choice Experiment	X		X											X				X	X	X		X		X	X	X		X	X					12
Discrete Choice											X		X			X											X							4
Contingent Valuation					X			X	X			X			X						X		X							X				8
Life satisfaction approach						X																												1
System dynamics approach				X																														1
Literature Review																															X	X	X	3

Moreover, they offer a meta-analysis of non-market valuation studies on wind power's external effects [9]. The literature review conducted by Ref. [38] offers a comprehensive analysis of wind power and its externalities, encompassing multiple perspectives: (i) externalities and indirect costs of wind electricity; (ii) externalities of wind turbines; and (iii) economic and security-related side effects [10].

The most used technique for valuing wind energy externalities is the choice experiment ([5,24,28–30,34,35,39–43]), followed by the contingent valuation ([3,6,11,20,31,33,36,44]).

Studies using choice experiments have focused on the externalities associated with the physical attributes of wind farms, such as setback distance and turbine height [25].

The contingent valuation technique employs willingness-to-pay or willingness-to-accept questions to get individual answers [36]. Four elicitation methods can be employed in contingent valuation studies: open-ended questions, payment cards, single-bounded dichotomous choice, and double-bounded dichotomous choice [9].

In a recent study in Germany, the authors point out the disadvantages of contingent valuation techniques and hedonic prices because they believe that the life satisfaction approach technique is better at valuing the well-being related to satisfaction with life than the traditional models based on utility [22]. Indeed, the life satisfaction approach states that life satisfaction is a valid approximation of consumer utility, measuring how environmental issues affect people's self-reported happiness. Life satisfaction differs from traditional methods, which ask people to evaluate these issues in monetary terms directly or observe their actual market choices, not accurately reflecting their true usefulness or happiness. Another approach to environmental economics techniques may be through dynamic systems. These methods simulate specific realities and their behaviors over time, assessing and suggesting solutions for external costs and benefits linked to various energy production methods [1].

4.3. Critical analysis of the results

When evaluating the externalities of wind energy, the objective is to assign a monetary value to it. The monetary value of externalities depends on the type of externality being assessed, which in turn can take various forms, including environmental degradation, air pollution, human health effects, visual impacts, noise pollution, and economic and social changes. This study defined three possible ways externalities manifest: the impacts of avoided externalities, the impact on well-being, and the impacts of turbines. The first category involves environmental effects that are relatively easier to estimate, such as the costs of greenhouse gas emissions, which can be measured by the quantity or price of carbon dioxide (CO_2). These correspond to the most common externality type (see Table 1). The price of CO_2 is used to quantify the avoided externalities regarding GHG emissions and air quality, possibly denoting an overlap between these two sub-categories within the avoided emission category that quantify, in an economic value, the impacts at different policy levels (national vs local). The second category covers qualitative or quantitative social and economic effects involving the activities of individuals or society and market transactions. Finally, the third category is directly related to changes in the physical environment and the local ecosystem. These externalities, specific to the location where wind energy facilities are implemented, are not economically quantified and require assessment techniques for measurement. This is the case of job creation and the value of housing and farmland. These externalities are often focused together locally (e.g. studies 2 and 10 in Table 1).

The assessment techniques mainly involve assigning a value to externalities through surveys. Upon analyzing the surveys from the selected article base, it becomes evident that the primary information in each survey is related to environmental and economic issues [45]. For instance, studies that focus on the impacts of wind turbines, such as noise, visual impact, and biodiversity (e.g., 3 in Table 1). These surveys aim to capture the respondents' understanding of energy and environmental matters and the significance of renewable energy sources in energy generation systems. They also gather demographic details such as gender, age, location of residence, marital status, number of family members, level of education, occupation, house size, and income [46]. This information is the foundation for applying the valuation methodology, be it Revealed or Stated preference.

Understanding local perceptions of the implementation of wind energy and its associated impacts will vary depending on the methodology applied, as explained previously [47]. Each approach has advantages and limitations, and using several of them together is often useful to gain a more comprehensive understanding of externalities.

Thus, assessing the externalities linked to wind energy is a multifaceted undertaking that entails examining various consequences, including environmental deterioration, economic transformations, and societal implications. The intricacy of evaluating these impacts is underscored by the three main categories in which externalities materialize: the impacts of avoided externalities, the impact on well-being, and the impacts of turbines.

This classification differs from previous review studies and can be taken as a fit parameter for comparison purposes with prior reviews. For instance, a study by Ref. [37] examines the benefits and costs of integrating electricity from an intermittent wind source into an existing grid. However, the mentioned classification does not account for the externalities of wind turbines from an economic and electricity systems perspective, as demonstrated by Ref. [10], which defines three categories of externalities.

Nevertheless, the classification of externalities in the study by Ref. [9] is similar to the one used in this study, but the approach is different. The [9] study takes a quantitative approach to analyzing identified externalities. The advantage of this current study lies in systematically capturing unquantified externalities, demonstrating the methods, and updating new impact measurement methodologies (e.g., the System Dynamics approach and Life Satisfaction approach in Table 4, which were not previously emphasized).

The studies [9,10] seem to converge, considering visual impacts, biodiversity, and land use as relevant impacts for wind power deployment, regardless of the externality concept/approach adopted. Meanwhile, the impacts of wind turbines are often localized, potentially reversible, and directly affect individual well-being [10]. For example, the visual impact, consistently valued in the literature, is an externality that significantly affects well-being measures and holds great political relevance [9]. However, the impact on well-being, such as local recreation and job creation, cannot always be captured by conventional methods, as discussed in Table 3. They do not evaluate the effects on individuals' quality of life and general happiness.

Prior studies ([9,10,37]) are also cautious regarding comparison between study results, in virtue of different methodologies and classifications adopted. This perspective is in keeping with the study, that views externalities as site-specific, not universal.

In their literature review, they found both points of agreement and disagreement with previous studies on the topic of wind energy. They agree with prior research that emphasizes the importance of the visual impact of wind power for its public acceptance, recognizing that visual aspects play a pivotal role in shaping public perception. They also agree with empirical evidence indicating that the negative effects of wind power on biodiversity do not substantially influence welfare measures, regardless of whether improvements or deteriorations in biodiversity are valued. Additionally, they acknowledge the common impact of noise on local communities' acceptance of wind power projects, emphasizing its importance in project planning and implementation.

On the other hand, they disagree with the narrow conception of externalities often confined to their economic perspective, advocating for a more comprehensive approach that considers social, environmental, and health-related aspects. They also disagree with the exclusion of wind electricity system externalities in some previous analyses, arguing that their inclusion is essential for a holistic assessment of wind energy impacts across the entire value chain. Furthermore, they dissent from the lack of attention given to developing methodologies for assessing externalities in new wind power projects, this review survey provides the basis for the development of methodology for the assessment of the externalities for new wind power projects within project R3EA (Renewable Energy: Economic and Externalities Assessment). This comparative analysis enables them to identify areas of consensus and divergence with prior studies, underscoring the importance of more comprehensive and methodologically robust approaches to understanding wind energy impacts.

While methodologies for evaluation commonly involve the attribution of values to externalities via surveys, it is imperative to recognize the constraints of such approaches and the necessity for a thorough comprehension of local attitudes. By integrating diverse methodologies and considering various demographic variables, scholars can endeavor to achieve a more refined and precise assessment of the externalities associated with the deployment of wind energy.

4.4. Practical implications

Based on this comprehensive analysis of externalities related to wind farms found in the analyzed articles, this study proposes a framework that provides practical implications for researchers and policymakers, which can be summarized in Table 6. These practical implications are factors that may significantly influence the willingness to accept (WTA) and willingness to pay (WTP) for wind energy initiatives. Practical implications play a critical role in the decision-making process for developing wind energy projects. Ensuring environmental preservation and gaining local community support is crucial in completing a successful and worthwhile project [21,48]. Table 6 highlights the factors that increase social acceptance. However, further attention from researchers and policymakers is necessary to assess externalities related to wind generation projects, alleviating the negative and enhancing the positive ones. Recently [49], pointed out that experiences of existing wind farms affect residents' acceptance of new projects, being acceptance reinforced by perceived local socioeconomic/environmental benefits. Moreover, the authors point out that trust in information from liaison officers has lasting ramifications for support. Thus, transparency in communication and community engagement during all stages should guide policymakers in their decision-making processes.

Table 6
The framework of externalities related to the installation of wind farms.

Factors of greater acceptance	References
Include a community representative in decision-making	Brennan & Van Rensburg, 2016
Improve communication with residents	Brennan & Van Rensburg, 2016; Faulques et al., 2022 Vecchiato Daniel, 2014
Adjustments to setback distances (distance between wind turbines and residential areas)	Brennan & Van Rensburg, 2016; De Salvo et al., 2021; Dröes & Koster, 2016; Ek & Persson, 2014; Jensen et al., 2018; Kipperberg et al., 2019; Krekel & Zerrahn, 2017; Landry et al., 2012; Lang et al., 2014; Skenteris et al., 2019 and Westerberg et al., 2013
Turbines gathered in larger wind farms rather than installed as single turbines	Jensen et al., 2018
Financial compensation	Brennan & Van Rensburg, 2016; du Preez et al., 2012; Faulques et al., 2022 and Kipperberg et al., 2019
Targeting awareness and education campaigns towards communities	Faulques et al., 2022 and Vecchiato Daniel, 2014
Protection of natural resources	Kipperberg et al., 2019
Explore the heterogeneity in attitudes, beliefs, and preferences of citizens that can increase social acceptance.	Álvarez-Farizo & Hanley, 2002; Bartczak et al., 2017; De Salvo et al., 2021; Dugstad et al., 2020; du Preez et al., 2012; Ek & Matti, 2015; Ek & Persson, 2014; Koundouri et al., 2009; Landry et al., 2012; Skenteris et al., 2019 and Westerberg et al., 2013

Implementing wind energy is a complicated process that requires carefully considering several potential external factors that may impact residents. To evaluate these factors effectively, estimating the "willingness to accept" of the local community is crucial. This means understanding how much inconvenience or change people are willing to tolerate in exchange for the advantages that wind energy can bring. The results revealed that the presence of a community representative increases project acceptance [25]. Another factor that may improve acceptance is also improving communication by highlighting the importance of better explanation and co-construction of new renewable energy projects ([19,25,34]).

To minimize negative effects and increase public acceptance, it's generally better to implement wind energy in more remote areas. Research has shown that clustering wind turbines together is also preferable, as the negative impact on property prices decreases with distance but increases with the number of turbines [27].

The importance of offering private compensation, such as discounted utility bills in the form of lower electricity costs, to residents is a means of incentivizing their acceptance of wind farm projects ([3,19,25,36]).

4.5. Research directions and unexplored areas

In the previous section, we have elucidated three primary categories of impacts resulting from wind energy externalities and their corresponding valuation techniques. Through a comprehensive descriptive analysis, we have assessed the prevalence of these externalities in the literature. Based on that, this section identifies avenues for future research and addresses critical gaps in the field of wind energy externalities. The forthcoming analyses could include the following focal points.

- Geographical Variation and Cultural Factors: While this study covers 24 years with a predominant focus on Europe, a promising direction for future investigations would involve an in-depth exploration of how wind energy externalities manifest across diverse geographical regions and cultural contexts. Understanding the interplay between local customs, societal values, and perceptions could provide nuanced insights into these externalities' differential impacts and valuation.
- Comparative Analysis with Other Energy Sources: While this study emphasizes wind energy externalities, future investigations could conduct an extensive comparative analysis by encompassing a broader spectrum of energy sources. The next step would be to explore the externalities associated with photovoltaic energy and conduct a comparative study between both technologies through the lens of this methodology. By scrutinizing the environmental, social, and economic trade-offs associated with different energy options, such research could offer valuable insights for informed decision-making.
- Public Perception and Acceptance: In this study has mentioned the concept of NIMBY and local discretion. However, a deeper exploration of public perception and acceptance in the context of wind energy projects remains a promising frontier. Investigating the multifaceted factors influencing public attitudes, such as information dissemination, communication strategies, and community engagement, could significantly enhance policy formulation and project implementation.
- Health Impacts and Mitigation Strategies: While we have shed light on health-related externalities, a more thorough investigation into this domain is warranted. Future research could delve into the intricate health effects, potential mitigation measures, and the complexities inherent in quantifying and valuing health-related externalities associated with wind energy.

- Emerging Technologies and Innovations: While this study predominantly addressed conventional wind energy technologies, an intriguing avenue for further exploration lies in emerging innovations. This encompasses technologies like offshore wind farms, floating wind turbines, and advanced noise-reduction techniques. In addition, a large integration of solar and wind renewable generation requires massive storage availability, which may evolve significantly in the future. Investigating how these innovations might influence externalities, and their valuation would provide timely insights into the evolving landscape of wind energy. Moreover, the fast pace of technological progress highlights the importance of ongoing research into emerging technologies. We can anticipate potential opportunities and challenges by staying updated on these new advancements, informing policy decisions, and driving sustainable growth in the renewable energy sector. Thus, focusing on emerging technologies is crucial to ensure that this research remains forward-looking and relevant to the evolving needs of the wind energy industry.
- Temporal Changes and Future Outlook: Our study includes the literature up to 2022. However, future studies could extrapolate the findings to speculate on the evolving trajectory of wind energy externalities to enhance its relevance and applicability. By considering advancements in technology, shifting public opinions, and evolving policy frameworks, a forward-looking perspective can be offered to guide future research endeavours and policy formulation.
- Energy poverty-fighting: Considering the identification of externalities, taking advantage of the positive ones in terms of energy communities in developing economies could help mitigate energy needs and contribute to energy poverty reduction, which could offer a promising research opportunity and enhance economic growth while improving social and health conditions.

5. Conclusion

Our study has contributed to identifying the main wind energy externalities and the methodologies for its assessment, laying the ground for further research and exploration in this field, and providing insights to policymakers to support or promote wind energy projects while reducing the negative externalities. In this sense, our findings emphasize the importance of considering both positive and negative externalities in such decision-making processes.

Understanding public perceptions and acceptance, addressing health impacts, and exploring emerging technologies is crucial to refining our understanding of wind energy externalities. Furthermore, anticipating temporal changes and projecting the future outlook of these externalities will assist policymakers and researchers in making informed decisions.

This review has, though, some limitations to address. First, the selection criteria for gathering the related works may be insufficient or too restrictive, and relevant studies may be left out of this process. Note also that results found refer mainly to European wind energy installations, leading to a geographic gap that may limit the generalization of the results to other regions with distinct environmental and regulatory contexts and cultures. In this sense, it may be concluded that updated review studies are needed since the latest ones found during the review were published in 2016 and 2017. Given the rapid evolution of the renewable energy field, this time frame may only partially encompass the most recent developments and alterations in methodologies or externalities associated with wind energy.

Lastly, it is important to notice that there are several avenues for future research and analysis. The geographical and cultural variations in wind energy externalities warrant in-depth investigations to unveil region-specific nuances. A holistic assessment of the long-term effects and lifecycle considerations is essential to inform sustainable energy practices. Furthermore, comparative studies with other energy sources will provide valuable insights into the broader energy landscape.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Edimar Ramalho reports financial support was provided by Foundation for Science and Technology. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

No data was used for the research described in the article.

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