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REVIEW PAPER

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Identification and analysis of impact factors on the economic feasibility of wind energy investments

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Summary

The growing energy demand in the world and the concern for environmentally damaging energy sources have led to an increased interest in seeking alternative renewable energy sources, such as wind energy. Furthermore, choosing effective locations for wind power plants has become a key issue in project planning. However, prior to implementation, such projects should be confirmed as economically viable. This article is a systematic review of the literature carried out with the aim to identify the main factors that impact the economic feasibility of wind energy investments. The search was performed in the ISI Web of Science (WoS) electronic database, from which 120 papers were extracted after a selection process, and were analyzed individually. As a result of the review analysis, 23 factors that have an impact on feasibility analysis were identified and organized in five categories: location (surface roughness, turbine location), economic (investment costs, operation and maintenance costs, avoided energy cost, depreciation, land rent), political (interest rates and taxes, energy sales price, inflation, financing conditions), climatic (wind speed, air density, temperature, air pressure), and technical (turbine height, installed wind power, lifetime, efficiency, rotor diameter, operation time, number of turbine blades, construction time). These factors can directly impact the cost of capital and/or energy production, affecting the economic viability of wind farms. In the last decade, there has been an exponential growth in publications about economic feasibility of wind investments. The wind investments growth has been accompanied by financial studies about this subject. This study provides insights on the main variables used in wind energy feasibility studies. The results may assist researchers and investors to identify the key parameters that are being examined in the literature, and to evaluate which ones should be considered in their study to ensure a sustainable development of power generation through the wind source.

KEYWORDS

economic feasibility, economic viability, risk factors, wind energy, wind potential

1 | INTRODUCTION

Excessive consumption of fossil fuels, which results in environmental crises, and the fact that fossil fuels are limited resources on the planet, underline the need to find unlimited and clean alternative sources of energy. Among these sources, solar and wind energy have made the most remarkable progress in recent years.[1,2] Nowadays, it is widely accepted that the continuing use of fossil fuels will result in irreversible damage to the environment. Thereby, many nations in the world are making efforts to provide clean and sustainable energy by 2030.[3] The benefits of producing electricity from renewable energy sources and reducing greenhouse gas emissions have been known and promoted since 1997,[4] following the activity started at the international scale with the Kyoto Protocol.

The installed wind power capacity in the world has grown significantly. Fazelpour et al.[5] argue that before installing a wind farm it is necessary to assess wind potential, feasibility, and operating cost to avoid investment risks and maximize efficiency.

Many researchers try to explore the economic characteristics that affect the electricity produced and the total costs involved in developing wind turbines. Studying these characteristics is important to know the main factors that can contribute or make unfeasible a wind energy project.[6] Therefore, it is of great academic interest to know the parameters that can be considered at risk in this type of analysis, according to the experiences of research conducted around the world, before applying them in the study of economic feasibility in a practical case.

Some parameters are seen as risk factors and can make investment in wind energy financially unviable, so they should be considered when studying the economic feasibility of such projects. Several factors have been pointed out around the world and vary among different studies. In Blanco,[7] the capital cost of the wind turbine, with grid connection and civil works, represents up to 80% of the total investment cost and is among the most influential factors, as well as the turbine capacity (efficiency) factor. According to Rocha et al.,[8] the cost of investing in turbines is also the factor that most influences the economic feasibility of wind power projects, followed by factors such as wind speed and energy price. Glassbrook et al.[9] point out that there are many advantages in the implementation of wind turbines from an environmental point of view, but the high cost of investment hinders the interest of the investors; the authors emphasize the importance of government incentives; moreover the amount of energy generated, which depends on the local wind variation, is very important to make the investment financially viable.

Wind farms are capital intensive projects that depend on the energy production potential, which is linked to technical aspects inherent to the industry's status and the local wind potential. Therefore, this study investigates variables that directly influence capital costs and energy production.

The aim of this paper is to investigate what are the main impact factors on the economic feasibility of wind energy investment. These impact factors have been identified, discussing how they are treated in economic feasibility analyses, and finally have been organized in five points of view or categories. For this purpose, a systematic literature review (SLR) has been carried out to group and examine the main publications related to the theme and indicate the parameters that affect financially and are evaluated in economic feasibility analysis studies. Thus, the extensive systematic literature review about wind investment analysis aims to provide subsidies and guidelines both for researchers and investors on the main variables that directly impact the return on investments.

This paper is organized as follows. Section 2 discusses the materials and methods used to achieve the research objective. Section 3 deals with the results and discussions, and presents the characterization of the sample of the researched literature, a data network analysis, and the main impact factors identified. Finally, Section 4 contains the concluding remarks on the study.

2 | MATERIALS AND METHOD

A methodological review of past literature contributions is a crucial effort for any academic research.[10] Finding out what is already known is necessary before starting any research study.[11] According to Webster and Watson,[10] an effective literature review creates a solid foundation for advancing knowledge, facilitates theory development, identifies areas where research is plentiful, and uncovers areas where research is needed.

This research presents an SLR, aiming to gather a sample of publications on the economic feasibility of wind energy investments, in order to understand and investigate the economic parameters that are being more analyzed in the literature.

According to Levy and Ellis,[12] the literature review is a process that systematically follows three steps: Input, Processing, and Output. Based on the model developed by Levy and Ellis,[12] for systematic reviews, the SLR process is divided into three stages: input process, with problem definition, objectives, search terms, inclusion or exclusion criteria, methods, and tools to be searched; processing stage, which includes the search for manuscripts in the databases, analysis of the search results, making desired filters, and documenting the results; and finally, the output process, in which an analysis of the articles resulting from the search and the construction of a table with the research synthesis are performed. Figure 1 presents an adaptation of the SLR driving model developed by these authors.

2.1 | Input phase

This phase consists of the construction of SLR planning. The first step is to define the problem to be studied: "What are the factors that impact the economic feasibility of wind energy?"

Along with the definition of the problem, the research objectives were aligned, to identify studies that address the topic of economic feasibility in wind energy and, in these, verify the factors that impact financially, according to their authors.

Following the steps of the input phase, search terms were defined. At the beginning of the review, a search for manuscripts focused on the theme of this study was performed, identifying the main keywords that would later be used to search for articles and database reviews.

The database selected for this review was the Web of Science (WoS), as it is a reliable database with quality studies published in impact journals in the literature. WoS includes over 10 000 journals and comprises seven different citation databases, including different information collected from journals, conferences, reports, books, and book series. As the WoS is the oldest citation database, it has strong coverage with citation data and bibliographic data, and has the highest depth and highest quality.[13]

Two searches were performed with the same search terms, alternating the place of structure where the terms should be found in the studies (between title or topic). The search terms used are presented in Table 1. The research was carried out on the database on 31 January 2020, including all works found until the end of December 2019.

After having performed the search, inclusion and/or exclusion criteria were applied in order to refine and improve the sample, focusing on the scope of this study. The main inclusion criteria of the papers in the sample were:

a. Research applied to the global context;
b. Research in the format of articles and reviews, for providing greater accessibility and dissemination of content to the academic and professional community;
c. Availability of access to full content;
d. Literature focused on the evaluation or economic feasibility of wind energy;
e. Studies available in the English language;
f. Studies that were not found in the search, but are considered important for research.

Regarding the exclusion of studies in the sample, the main criteria used were:

a. Non-access to the complete content;
b. Duplicity of the studies;
c. Studies available only in languages other than English;
d. Research with themes that are beyond the scope of this study.

The main tools and methodologies to be applied in the refinement of the research were defined. The ISI Web of Science database was used to obtain the manuscripts, the VOSviewer bibliometric software for data network analysis, and Microsoft Excel to evaluate and synthesize results and information, and to compose content analysis graphs.

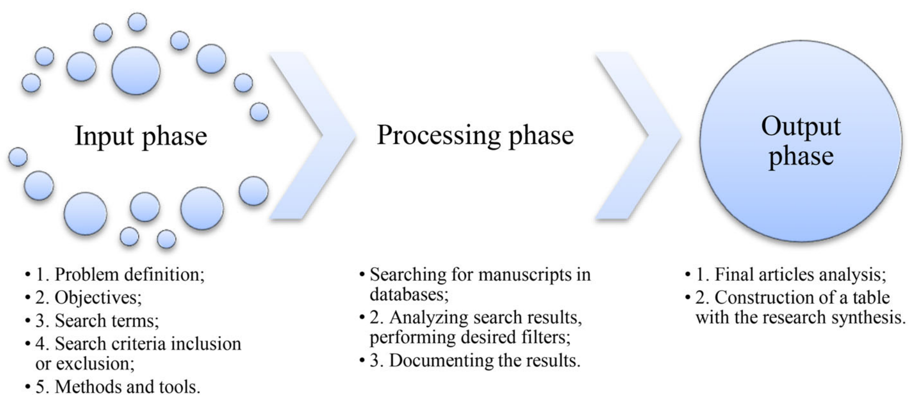


FIGURE 1 Model for conducting a systematic literature review
Source: Adapted from Levy and Ellis[12]
[Colour figure can be viewed at wileyonlinelibrary.com]

2.2 | Processing phase

In this phase, a search was performed in the database, selecting the filters that could improve this search, according to the theme to be studied. The filter in the studies was used to select those available in the format of articles and reviews, which is the only filter used in the database of this research. In the search result, after the filters, the sample number was 219 articles.

From the sample of 219 articles, by exclusion criteria, 214 studies remained. The remaining articles were subject to reading in order to further refine this research. Figure 2 shows an overview of the articles filtering in this review after readings, identifying the number of articles in each step.

Figure 2 shows that initially we had 214 articles in the search; however, after reading titles, abstracts, and keywords, the result of this search was reduced to 153 papers. It was found that some of the themes addressed in the studies were beyond the scope of this research, analyzing sources other than wind energy or articles that did not deal with the study of economic feasibility.

In the second reading step, attention was given to the results and conclusion, as it was in them that the economic feasibility was most emphasized, and it was possible to verify if the articles in fact analyzed the impact factors as expected. At this stage, the sample decreased from 153 to 130 papers, as some of the studies were excluded from the sample because they did not present the impact factors on the economy or because it was not clear how the factors influenced the economic feasibility.

TABLE 1 SLR search terms

Search	SLR search terms	Structure location
Search 1	("economic feasibility" or "economic assessment" or "economic viability") AND ("wind energy" or "wind risk" or "wind power")	Title AND Topic
Search 2		Topic AND Title

In the final reading stage, the articles were submitted to full reading. Finally, after the reading stages and the final selection of articles, the sample of papers to be analyzed in this research, with 120 manuscripts, was defined.

2.3 | Output phase

This is the synthesis and analysis phase of the research results. At this stage, all articles in the final sample were analyzed and presented in Table 2.

3 | RESULTS AND DISCUSSIONS

This section discusses the main information that characterizes the studies of the sample, presenting the profile of the articles by the number of citations and relevance in the literature, the year in which it was published, and the locations where the studies were performed. In addition, the main keywords used in the research are presented and, as the objective of the study, the main impacting factors in a feasibility analysis that were identified in the sample are finally discussed.

3.1 | Final sample characterization

Year of publication: The first article found in the research was published in the year 1984, and by mid-2010 it is noted that there was not much study on economic feasibility of wind energy. There has been a remarkable growth of publications in the last decade. This reflects the growing interest in renewable energy sources, particularly wind energy. Figure 3 presents a graph of the evolution of selected articles published over the years.

Place of publication: It was observed that the location where the study of the economic feasibility of wind energy is carried out influences the evaluation result. In fact, factors such as wind speed, electricity cost, public policies, among others that depend on the location, have a great influence on the economic impact of these studies. For this reason, it is important to know the main

FIGURE 2 Summary of articles filtering after reading [Colour figure can be viewed at wileyonlinelibrary.com]

TABLE 2 Final article sample overview

	Authors	Location	Journal
1	Qolipour et al. (2017)	Iran	Renewable and Sustainable Energy Reviews
3	Mohsin et al. (2018)	Pakistan	International Journal of Hydrogen Energy
4	Serri et al. (2018)	Italy	Renewable Energy
5	Fazelpour et al. (2017)	Iran	Renewable and Sustainable Energy Reviews
6	Jie et al. (2018)	China	Energy Sources Part B-Economics Planning and Policy
7	Blanco (2009)	Spain	Renewable and Sustainable Energy Reviews
8	Rocha et al. (2018)	Brazil	Renewable and Sustainable Energy Reviews
9	Glassbrook et al. (2014)	Thailand	Energy for Sustainable Development
14	Fang (2019)	China	International Journal of Hydrogen Energy
15	Hulio et al. (2019)	Pakistan	Energy Strategy Reviews
16	Bhattara et al. (2019)	Canada	Journal of Energy Storage
17	Samu et al. (2019)	Zimbabwe	International Journal of Green Energy
18	Lee et al. (2019)	South Korea	International Journal of Renewable Energy Research
19	Abnavi et al. (2019)	Iran	Environmental Progress and Sustainable Energy
20	De Lara et al. (2019)	Brazil	Brazilian Archives of Biology and Technology
21	Shaahid et al. (2019)	Saudi Arabia	Thermal Science
22	Adefarati and Obikoya (2019)	South Africa	International Journal of Engineering Research in Africa
23	Kassem et al. (2019)	Lebanon	Modeling Earth Systems and Environment
24	Mohsin et al. (2019)	Pakistan	Environmental Science and Pollution Research
25	Bahrami et al. (2019)	Uzbekistan	Journal of Cleaner Production
26	Rotela et al. (2019)	Brazil	Energies
27	Rodriguez-Hernandez et al. (2019)	Mexico	Energies
28	Al-Nassar et al. (2019)	Kuwait	Energy
29	Rezaei et al. (2018)	Iran	International Journal of Hydrogen Energy
30	Bina et al. (2018)	Iran	Energy
31	Olatayo et al. (2018)	South Africa	Renewable and Sustainable Energy Reviews
32	González-Aparicio et al. (2018)	Spain	Applied Energy
33	Kirmani et al. (2018)	India	IET Renewable Power Generation
34	Li et al. (2018)	China	Energy
35	Tuyet and Chou (2018)	Taiwan	Applied Energy
36	Asghar and Liu (2018)	China	Neurocomputing
37	Kassem et al. (2018)	Cyprus	Global Journal of Environmental Science and Management-GJESM
38	Babarit et al. (2018)	France	International Journal of Hydrogen Energy
39	Calderon et al. (2018)	Colombia	Tecciencia
40	Liu et al. (2018)	China	Energy Conversion and Management
41	Neto et al. (2018)	Brazil	Electric Power Components and Systems
42	Yarova et al. (2017)	Ukraine	Economic Annals—XXI
43	Hulio et al. (2017)	Pakistan	Energy Sustainability and Society
44	Ramli et al. (2017)	Saudi Arabia	Journal of Renewable and Sustainable Energy
45	Ramadan (2017)	Egypt	Journal of Cleaner Production

(Continues)

TABLE 2 (Continued)

	Authors	Location	Journal
46	Ali et al. (2017)	South Korea	Energies
47	Mattar and Guzman-Ibarra (2017)	Chile	Energy
48	Aquila et al. (2017)	Brazil	Energy Economics
49	Abdelhady et al. (2017)	Egypt	Wind Engineering
50	Waewsak et al. (2017)	Thailand	Sustainable Energy Technologies and Assessments
51	Rahman et al. (2017)	Bangladesh	International Journal of Renewable Energy Development-IJRED
52	Park et al. (2017)	South Korea	Sustainability
53	Ajayi and Ohijeagbon (2017)	Nigeria	International Journal of Ambient Energy
54	Albadi et al. (2017)	Oman	International Journal of Renewable Energy Research
55	Aquila et al. (2016)	Brazil	Journal of Cleaner Production
56	Castro-Santos et al. (2016)	Spain	Energy
57	Simons and Cheung (2016)	England	Journal of Cleaner Production
58	Watts et al. (2016)	Chile	Renewable Energy
59	Ayodele et al. (2016)	Nigeria	Journal of Cleaner Production
60	Kapsali et al. (2016)	Greece	Applied Energy
61	Qolipour et al. (2016)	Iran	Energy Conversion and Management
62	Silva et al. (2016)	Brazil	Renewable and Sustainable Energy Reviews
63	Argatov and Shafranov (2016)	Germany	Renewable Energy
64	Capellaro (2016)	Germany	Renewable Energy
65	Mohammadi et al. (2016)	Iran	Environmental Earth Sciences
66	Rasheed et al. (2016)	South Korea	International Journal of Renewable Energy Research
67	Asumadu-Sarkodie and Owusu (2016)	Ghana	Energy Sources Part A-Recovery Utilization and Environmental Effects
68	Belabes et al. (2015)	Algeria	Renewable and Sustainable Energy Reviews
69	Astariz et al. (2015)	Spain	Renewable Energy
70	Wyman and Jablonowski (2015)	United States	Wind Engineering
71	Li and DeCarolis (2015)	United States	Renewable Energy
72	De Vos and Driesen (2015)	Belgium	IET Renewable Power Generation
73	Grieser et al. (2015)	Germany	Renewable Energy
74	Saiz-Marin et al. (2015)	Spain	Wind Energy
75	Fazelpour et al. (2015)	Iran	Renewable Energy
76	Soe et al. (2015)	Myanmar	International Journal of Renewable Energy Research
77	Juarez et al. (2014)	Brazil	Renewable and Sustainable Energy Reviews
78	Pena et al. (2014)	Portugal	Energy Economics
79	Gil et al. (2014)	Spain	Applied Energy
80	Kose et al. (2014)	Turkey	International Journal of Green Energy
81	Katsigiannis and Stavrakakis (2014)	Australia	Renewable Energy
82	Olateju et al. (2014)	Canada	Applied Energy
83	Gillenwater et al. (2014)	United States	Renewable Energy
84	Nor et al. (2014)	Malaysia	Renewable Energy
85	Albani et al. (2014)	Malaysia	Energy Exploration and Exploitation

TABLE 2 (Continued)

	Authors	Location	Journal
86	Adaramola et al. (2014)	Ghana	Energy Conversion and Management
87	Mohammadi and Mostafaeipour (2013)	Iran	Energy Conversion and Management
88	Mudasser et al. (2013)	Canada	Energy Policy
89	Silva et al. (2013)	Brazil	Renewable and Sustainable Energy Reviews
90	Li et al. (2013)	China	Renewable Energy
91	Simic et al. (2013)	Croatia	Renewable Energy
92	Zhao et al. (2013)	United States	Journal of Intelligent Transportation Systems
93	Madlener and Latz (2013)	Germany	Applied Energy
94	O'Keeffe and Haggett (2012)	England	Renewable and Sustainable Energy Reviews
95	Erturk (2012)	Turkey	Energy Policy
96	Hamouda (2012)	Egypt	Renewable and Sustainable Energy Reviews
97	Saiz-Marin et al. (2012)	Spain	IEEE Transactions on Power Systems
98	Li et al. (2012)	Ireland	Applied Energy
99	Oliver and Groulx (2012)	Canada	Journal of Renewable And Sustainable Energy
100	Askari and Ameri (2012)	Iran	Energy Sources Part B-Economics Planning and Policy
101	Montes et al. (2011)	Spain	Renewable and Sustainable Energy Reviews
102	Walters and Walsh (2011)	England	Energy Policy
103	Mota et al. (2011)	Brazil	IEEE Latin America Transactions
104	Genc (2011)	Turkey	Journal of Energy Engineering-Asce
105	Wang et al. (2010)	United States	EMJ—Engineering Management Journal
106	Recalde (2010)	Argentina	International Journal of Hydrogen Energy
107	Akdag and Guler (2009)	Turkey	Energy Sources Part B-Economics Planning and Policy
108	Hrayshat (2009)	Jordan	Energy Sources Part B-Economics Planning and Policy
109	Ucar and Balo (2008)	Turkey	International Journal of Green Energy
110	Diaf et al. (2008)	Algeria	Energy Policy
111	Ngala et al. (2007)	Nigeria	Renewable Energy
112	Moran and Sherrington (2007)	Scotland	Energy Policy
113	Soderholm et al. (2007)	Sweden	Renewable and Sustainable Energy Reviews
114	Greenblatt et al. (2007)	United States	Energy Policy
115	Kissel and Krauter (2006)	Brazil	Energy Policy
116	Stockton (2004)	United States	Renewable Energy
117	Teetz et al. (2003)	South Africa	Renewable Energy
118	Wachsmann and Tolmasquim (2003)	Brazil	Renewable Energy
119	Papadopoulos and Dermentzoglou (2002)	Greece	Renewable Energy
120	Karlis et al. (2001)	Greece	Energy Conversion and Management
121	Kaldellis and Gavras (2000)	Greece	Energy Policy
122	Munksgaard and Larsen (1998)	Denmark	Energy Policy
123	Richardson and Mcnerney (1993)	United States	Proceedings of the IEEE
124	Desrochers et al. (1986)	Canada	IEEE Transactions on Energy Conversion
125	Furuya and Maekawa (1984)	United States	Journal of Solar Energy Engineering—Transactions of the ASME

places where these studies are being performed. Figure 4 illustrates the number of publications in each market. Brazilian wind market is the most studied with 12 publications, then the Iranian market with 10 publications in the sample, the US market with 9 publications, and Spanish (8 publications), Chinese (6 publications), Turkish, and Canadian (5 publications) are markets that have been investigated. In addition to these, other countries appear in the sample with a number of 1 to 4 publications, totaling 46 countries of publications. There is also a concentration in European countries and in the South Asia region. This is due to the dependence of these countries on increasingly scarce and expensive energy sources such as oil, as well as the high energy demand of these countries, and the need to meet this demand and reduce environmental impacts.

Number of citations: The number of citations of each publication shows the relevance they have in the literature and the interest in studies on the subject of this research. Figure 5 shows the 15 most cited articles in the sample, representing all studies with more than 30 citations in total. It is noted that studies performed before 2010 still have great relevance in the literature. References such as Blanco,[7] Greenblatt et al.[14] and Diaf et al.[15] appear with more than 100 citations, and are the publications with the largest number of citations in the sample.

In addition, the importance of publications in the literature can be observed by the average number of citations per year of these articles, which reflects the items that these manuscripts are impacting in the literature. As an example, more recent publications, such as those by Madlener and Latz,[16] Adaramola et al.,[17] Mohammadi and Mostafaeipour,[18] Fazelpour et al.[5] and Silva et al.,[19] despite having a not very large number of citations, appear with a high average, which reveals that these studies are important in recent literature. Figure 6 illustrates the evolution of citations of the 15 most cited articles in the sample over time. It can be observed that older articles, such as the study by Desrochers et al.,[20] which was practically the only one mentioned at the beginning, has been less mentioned as new studies are emerging and gaining ground in the literature on the subject. As can also be noted that the latest literature is increasingly exploring new and varied studies, and with that comes a greater competition in citations as the years go by.

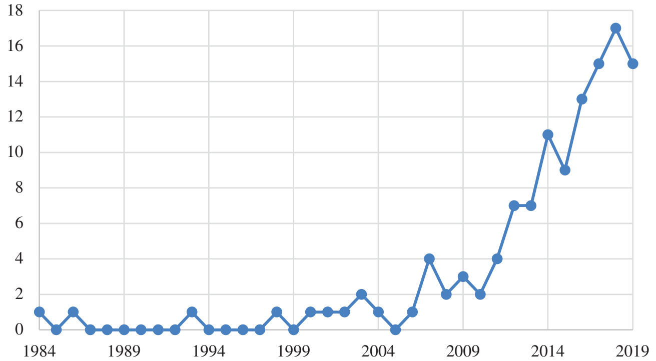


FIGURE 3 Evolution in the number of publications per year [Colour figure can be viewed at wileyonlinelibrary.com]

3.2 | Data network analysis

Using VOSviewer, a network analysis of the sample data for the main keywords was carried out in order to observe which key terms were used in the search for these articles, and the links between them. For this analysis, a map based on bibliographic data was created, selecting the data from the final sample of 120 publications. The type of analysis selected was "co-occurrence", the "full counting" counting method, and the "author keywords" analysis unit. We opted for a minimum of three keyword hits so that the map shows all terms that

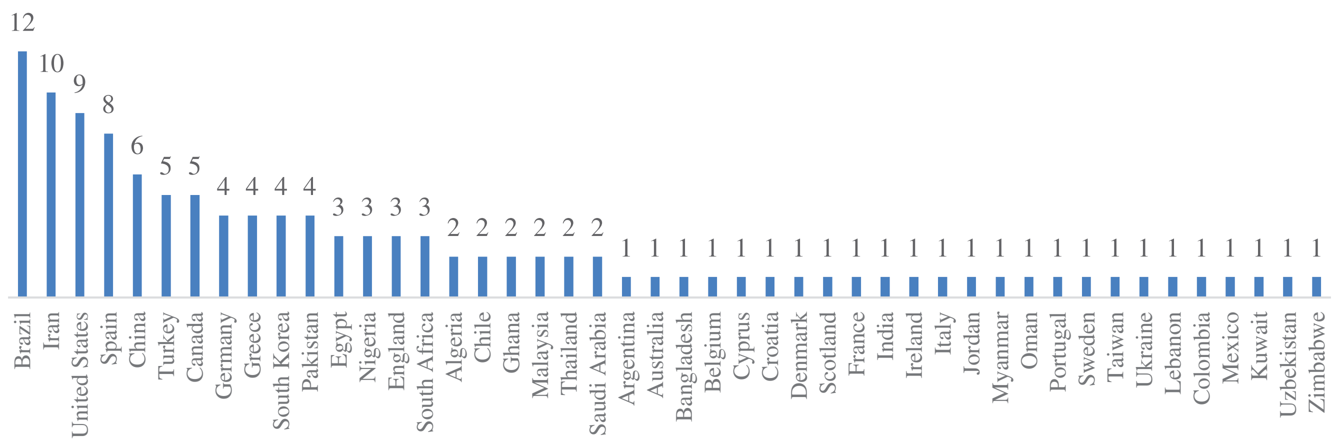


FIGURE 4 Number of published articles by country [Colour figure can be viewed at wileyonlinelibrary.com]

FIGURE 5 Number and average of citations of the most cited articles in the sample [Colour figure can be viewed at wileyonlinelibrary.com]

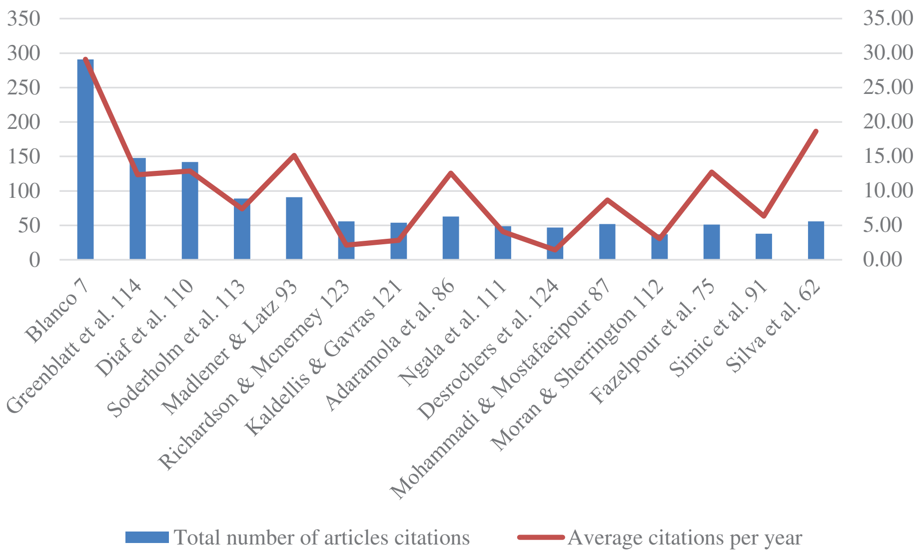
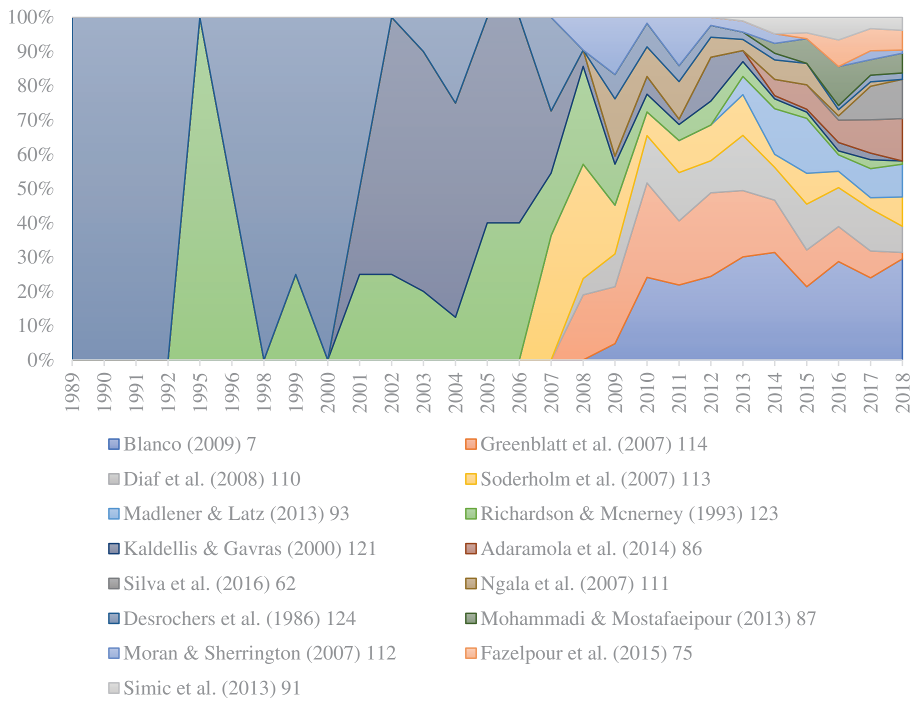


FIGURE 6 Evolution of article citations over the years [Colour figure can be viewed at wileyonlinelibrary.com]



appear in at least three posts. In the end, 22 keywords were identified and the data map was created in "overlay visualization" mode, where it is possible to analyze the evolution of the terms used over the years (Figure 7).

It can be seen that the term "wind energy" is the one that appears most often, which was expected, as this was one of the main terms used in the search of this research. In addition, it can be noted that newer terms are being used, such as "wind speed", "wind power density", "net present value", and "offshore wind energy", while terms such as "economic analysis" and "economic viability" have been used in the older literature and no longer appear frequently, meaning that they are currently being used less in the literature.

3.3 | Impact factors identified

In the SLR performed, 23 parameters were seen as impact factors on the economic feasibility of wind energy. Table 2, presented in Section 2.3, presents the references used to identify these parameters. In addition, Table 2 presents the journal of publication and the country of the market studied.

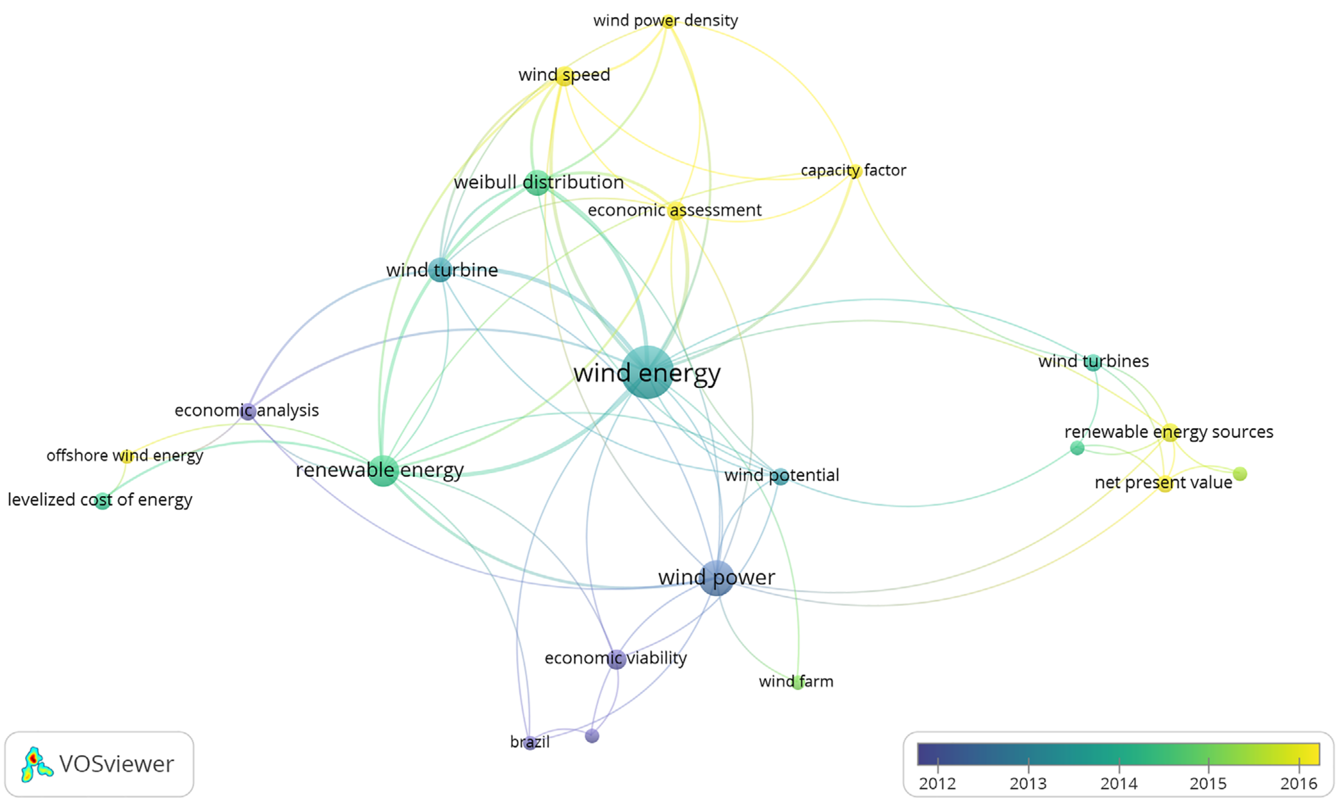


FIGURE 7 Map of bibliographic data of the main sample keywords [Colour figure can be viewed at wileyonlinelibrary.com]

Installed power, investment cost, wind speed, service life, and operating and maintenance cost were the most recurring factors that appeared in articles. In addition to the most cited factors, it is also important to pay attention to the emergence of other factors in order to decide which ones deserve to be evaluated for each case study. Figure 8 graphically shows the main factors. It can be observed that the installed power was the most cited factor, present in all articles in the sample, followed by investment cost, wind speed, useful life, and operation and maintenance, which are cited 112, 109, 103, and 100 times, respectively.

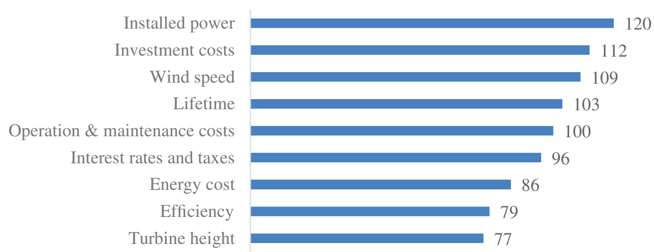


FIGURE 8 Main factors identified in the sample [Colour figure can be viewed at wileyonlinelibrary.com]

The main factors were classified according to point of view, such as location, economic, political, climate, and technical factors.[21] The investigation about these factors contributes to understanding the reasons why the technology has matured, consequently verifying the costs evolution and assessing the source competitiveness over time. In the case of wind power, it can be seen that, since 2010 (see Figure 3), when the number of studies started to increase, it is possible to observe that the Levelized Cost of Electricity (LCOE) has undergone a significant reduction, as can be seen in Figure 9 and Table 3. To wind investments, the technology maturity has a positive impact. Feasibility studies seek to analyze the variables that have a main impact for wind projects feasibility, and analyze the possible impacts, or changes, that may be proposed in order to reduce the LCOE.

Rediske et al.[21] argue that the factors for decision-making in the installation of renewable energy projects can be grouped into six points of view: (i) socioenvironmental; (ii) location; (iii) economic; (iv) political; (v) climate; and (vi) orography. In this research, according to the identified factors, four of these points of view were considered in the classification of the factors, besides the technical point of view was included. Table 4 presents the identified impact factors, the classification they fall into, and the references where they were found, based on article number (Table 2).

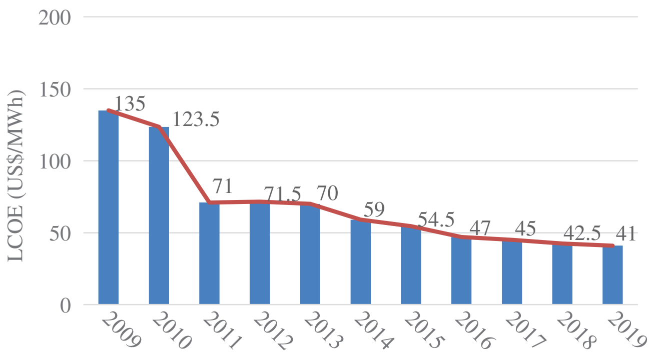


FIGURE 9 Global Average LCOE for Wind Energy (US $/MWh)
Source: Adapted from IRENA[22] [Colour figure can be viewed at wileyonlinelibrary.com]

TABLE 3 Weighted average LCOE (USD/kWh) for onshore wind projects by country or region, in 2010 and 2019.

	Year	
Region/Country	**2010**	**2019**
Africa	0.100	0.067
Other Asia	0.117	0.099
Central America and the Caribbean	0.086	0.061
Eurasia	0.108	0.064
Europe	0.107	0.067
North America	0.089	0.051
Oceania	0.117	0.054
Other South America	0.101	0.057
Brazil	0.095	0.048
China	0.072	0.046
India	0.083	0.049

Source: Adapted from IRENA.[22]

The identified factors were associated with the countries of origin of the research. When this happens, it is possible to notice the difference of the studies by region, and the importance of each factor according to the study region, and how they vary according to the country. Table 5 shows the impact factors associated with the countries where they were analyzed.

Table 5 shows that countries, such as Brazil, the United States, Spain, Iran, Turkey, and Canada, for example, analyze at least 18 of the 23 parameters in their research, which represents more than 75% of the total number of factors. This shows a diversity in studies of these regions, which are concerned with analyzing various factors involved in the economic feasibility of wind power projects. Although China is one of the countries with the most active research in this area, it concentrates on analyzing only 14 of the 23 parameters (about 60% of the total), but this is due to some standardization in research studies in the region observed during SLR. Most are concerned with factors such as installed power output, installation cost, local wind speed, operating and maintenance costs, among others common to the region.

3.3.1 | Location factors

Surface roughness

Roughness is seen as an important factor in the feasibility analysis of wind projects. Some authors argue that winds are influenced by the roughness of the terrain. When estimating the value of the average wind speed, some researchers use the value of roughness length (usually measured in meters in length), expressed in relation inversely proportional to wind speed, that is, the higher the roughness, the lower is the wind speed. In Mohsin et al.,[3] the roughness length is related to the displacement height, which is the height over the roughness elements where there is free flow.

Ramadan[33] states that wind speed and power density are strongly influenced by roughness. Their research used the average wind speed for different turbine heights with different roughness lengths.

Mattar and Guzman-Ibarra[34] analyze the terrain roughness as an impact factor on wind speed and present graphs of energy power variation varying with the surface roughness length. For the authors, the surface roughness length should be estimated according to the type of surface found at the location.

Finally, Table 6 seeks to present the values of length of roughness for each type of terrain. In addition, it is worth mentioning that the smoother surfaces are more suitable for wind farms and this variable must be considered controllable, since the investor can choose the ideal terrain for the installation.

Turbine location

Some researchers analyze where the turbine will be installed, as a major impact factor in the financial viability analysis. Asumadu-Sarkodie and Owusu[47] analyzed 11 sites in the country of Ghana, showing the difference between energy production, energy exported to the grid, or the capacity factor for each region, highlighting the importance of assessing where the wind farm will be installed.

In Soe et al.,[49] the selection of the location is the main step of the wind power project, involving mainly the evaluation of wind resources on a large scale. According to this author, large-scale wind data are needed to determine appropriate locations.

TABLE 4 Factors identified in references

Classification	Factors	References
Location	a) Surface roughness	3,23-40
	b) Turbine location	23-28,35,39-58
Economic	c) Investment costs	1,3-5,7-9,14-19,23-53,55-122
	d) Operation and maintenance costs	1,3-5,7,9,14-18,20,23-39,41-53,55-61,64,67,68,70-95,97-101,103-107, 109-111, 114-119,121,122
	e) Avoided energy cost	1,4,6,9,10,14,16,18-20,23,28-41,43-47,50-56,60,61,63,64,66-69,72,73,75-79,81-85, 87,88,90,91,93,94,96,98,101-103,105,107-114,118-125
	f) Depreciation	3,9,14,16,29-31,41,45,59,63,70,73,74,83,87,100,102,103,107,114,117,121
	g) Land rent	5,7,14,31,35,37,47,48,52,74,81,83,88,95,117,119
Political	h) Interest rates and taxes	3-5,7-9,14,16-18,23,25-53,55-58,60-65,67,69-82,84-95,97,98,100, 102-107,110,112,114-119,121,122
	i) Energy sales price	1,3,4,8,9,29,30,32,34,37,42,43,46-48,52,53,55-60,63,66,69,71,73,74,78,79, 81,89,91,94,95,97,100-102,104,105,108,109,118,123,125
	j) Inflation	3,7,8,14,17,18,25-27,29,32,36,41,47,49,52,56-58,69,73,74,77,78,81,85,89,91, 92,98,101,102,105-107,109,110,115,118,119
	k) Financing conditions	7,8,14,24,27,29-31,37,41,43,49,50,52,55-57,60,62,63,66,74,80,81,100-103,106, 107,109,112,114,118-120
Climate	l) Wind speed	1,3-6,8,9,14,15,17-20,23-39,41-54,56,57,59-79,81-96,98-101,103-105,107-109, 111-116,118-127
	m) Air density	3,5,8,9,14,17,18,20,23-30,33-35,39,43,44,46,49,54,63,64,67-70,72-75,81,83-85, 88,89,95,101,105,121-123,126,127
	n) Temperature	1,5,15,20,23-25,29,30,33-35,39,49,59,61,64,69,72,73,75,84,95
	o) Air pressure	1,5,23,25,28,33,34,49,64,72,73,75,84,95
Technical	p) Turbine Height	3-6,9,14,17,18,23-37,39,41-44,47,49-55,61,62,64,65,67-70,72-79,81-85,88-92,94, 96,101,103,104,109,114-116,118-120,123,126,127
	q) Installed wind power	1,3-9,14-20,23-127
	r) Lifetime	1,3-9,14-18,23-53,55-59,61,63-87,89-95,97-100,103-105,107,109-121
	s) Efficiency	1,3,5-9,14,16,17,24-30,33-35,42-45,47-54,57-59,61,63-65,67-73,75,76,80,83-85, 88,89,91-93,95,97,99,100,104,106-108,110,111,113,114,116-119, 121-126
	t) Rotor diameter	3,5,8,9,14,17,23,24,28-30,32-35,41-43,47,49-53,61-64,67,69,70,72-77,79,81-83, 85,88-92,94,95,98,104,115,119,122,123,126
	u) Operation time	7,9,14,15,20,28,37,39,49,52,59,60,69,74,79-81,87,93,98,108,111,122,125,127
	v) Number of turbine blades	43,46,61,91,95,119,121,122
	w) Construction time	14,31,57,103,117

Some authors argue that public policies and local population characteristics should be evaluated to meet the main objectives of wind energy investment. Soderholm et al.[55] state that two issues are of concern when choosing the optimal installation location: the location selected should be appropriate with respect to the objectives of the environmental code and resource management provisions; and for all activities and measures, locations should be selected to achieve the objective with minimal damage or harm to the environment. The choice of location is probably one of the most significant legal obstacles in wind power production.

It is worth mentioning that the location where the turbine is installed is a controllable variable, since the investor can choose the ideal location for installing the wind farm. Finally, Aquila et al.[128] evidenced the existence of the interaction between turbine brand characteristics and the wind speed behavior in specific location, confirming the importance of the combined assessment of technical aspects of the equipment and location.

TABLE 5 Identified impact factors by country

	Impact factors																						
Country	**a**	**b**	**c**	**d**	**e**	**f**	**g**	**h**	**i**	**j**	**k**	**l**	**m**	**n**	**o**	**p**	**q**	**r**	**s**	**t**	**u**	**v**	**w**
Brazil	X		X	X	X	X	X	X	X	X	X	X	X			X	X	X	X	X	X		X
United States			X	X	X	X	X	X	X	X	X	X	X			X	X	X	X	X	X	X	X
Spain	X	X	X	X	X		X	X	X	X	X	X				X	X	X	X	X	X		
Iran	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	
China			X	X	X	X		X			X	X	X			X	X	X	X	X			X
Turkey	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X		
Germany			X	X	X	X	X	X	X			X	X			X	X	X	X	X			
Canada		X	X	X	X		X	X	X	X	X	X	X	X		X	X	X	X	X	X		
Greece		X	X	X	X			X	X	X	X	X					X	X	X				X
South Korea			X	X	X	X		X	X	X		X	X	X	X	X	X	X	X	X			
Egypt	X		X	X	X			X		X		X	X	X	X	X	X	X	X	X			
Nigeria			X	X				X	X	X		X	X			X	X	X	X	X	X		
England			X	X	X	X	X	X		X	X	X	X			X	X	X	X	X			
Algeria			X	X				X	X	X		X		X		X	X	X	X	X	X	X	
Chile	X		X	X	X			X	X			X	X	X	X	X	X	X	X	X			
Ghana		X	X	X	X		X	X	X	X		X	X			X	X	X	X	X			
Malaysia		X	X	X	X			X	X	X	X	X	X			X	X	X	X	X			
Pakistan	X	X	X	X	X	X		X	X	X		X	X	X	X	X	X	X	X	X			
Thailand			X	X	X	X		X	X			X	X			X	X	X	X	X	X		
South Africa	X	X	X	X	X			X	X			X	X	X		X	X	X			X	X	
Saudi Arabia	X		X	X	X			X	X	X		X				X	X	X		X			
Argentina	X		X	X				X				X					X	X					
Australia		X	X	X				X			X	X				X	X	X	X	X			
Bangladesh			X	X	X			X		X		X				X	X	X		X			
Belgium					X							X					X		X				
Cyprus	X		X	X	X	X		X	X		X	X	X	X		X	X	X	X	X			
Croatia			X	X	X			X	X			X				X	X	X	X	X			
Denmark	X	X	X		X			X									X	X					
Scotland			X	X	X	X	X	X									X	X	X				X
France			X	X	X							X	X			X	X	X	X				
India			X		X				X		X	X					X	X					
Ireland			X	X	X				X	X	X	X				X	X	X					
Italy			X	X				X	X			X				X	X	X					
Jordan			X	X	X			X		X		X				X	X	X		X			
Myanmar		X	X	X	X			X		X	X	X	X	X	X	X	X	X	X	X	X		
Oman			X	X	X			X			X						X	X	X		X		
Portugal			X	X	X			X	X								X	X	X				
Sweden		X	X	X	X			X	X		X					X	X	X					
Taiwan	X		X	X		X		X	X	X	X	X	X	X		X	X	X	X	X			
Ukraine			X	X	X			X	X			X					X	X	X				
Lebanon	X	X	X	X				X		X		X	X	X	X	X	X	X	X				
Uzbekistan		X	X	X	X			X				X	X			X	X	X	X				

(Continues)

TABLE 5 (Continued)

	Impact factors																						
Country	**a**	**b**	**c**	**d**	**e**	**f**	**g**	**h**	**i**	**j**	**k**	**l**	**m**	**n**	**o**	**p**	**q**	**r**	**s**	**t**	**u**	**v**	**w**
Mexico		X	X	X		X		X				X					X	X	X				
Kuwait	X	X	X	X	X			X		X	X	X	X			X	X	X	X				
Colombia			X		X			X	X	X		X	X	X		X	X	X	X	X	X		
Zimbabwe		X			X	X		X		X	X					X		X		X			

TABLE 6 Roughness length values for different terrains

Land description	**Z_0 (mm)**
Smooth, ice, mud	0.01
Open and calm sea	0.20
Rough sea	0.50
Snow	3.00
Grass	8.00
Rugged pasture	10.00
Downhill fields	30.00
Cultivated fields	50.00
Few trees	100.00
Many trees, few buildings, fences	250.00
Forests	500.00
Residential areas	1500.00
Urban areas with tall buildings	3000.00

Source: Adapted from Fadigas.[130]

TABLE 7 Average values (USD/kW) of total installed cost for onshore wind projects by country or region, in 2010 and 2019

	Year	
Region/Country	**2010**	**2019**
Africa	2291	1952
Other Asia	2501	2368
Central America and the Caribbean	2664	1737
Eurasia	2432	1633
Europe	2405	1800
North America	2407	1636
Oceania	3501	1555
Other South America	2644	1718
Brazil	2539	1559
China	1491	1223
India	1412	1055

Source: Adapted from IRENA.[22]

3.3.2 | Economic factors

Investment costs

The investment cost is one of the factors that most impact the economic feasibility of wind energy projects. Much of the investment cost is due to the wind turbines chosen. This cost may include the project, wind turbine, civil and electrical infrastructure, installation, and transportation. According to Neto et al.,[31] the investment cost consists of several expenses that depend on the size of the plant, difficulties presented by the land, equipment sophistication, and others, having a strong impact on the wind project cash flow.

In the economic viability analysis, the main criteria use the investment cost as an analysis parameter, to compare the cash flow generated over the project's lifetime with the amount initially invested and to verify the project's financial return or loss. The main financial analysis criterion, known as the Net Present Value (NPV) criterion,[74,112] quantifies how much the project will impact the position of the capital originally invested.[129]

The investment cost depends a lot on the supplier and the technology that will be installed, so it is important to have a market research that compares the prices and qualities of the products, comparing the cost benefit. In addition, many authors consider investment cost as a parameter for estimating other costs. For Belabes et al.,[91] the investment cost is among the most important parameters of the wind project and depends on the manufacturers, varying greatly from one manufacturer to another. According to Ali et al.,[73] one of the parameters that can affect wind turbine selection is the initial investment, and choosing a more sophisticated turbine model implies not only a higher initial capital cost, but also the operation and maintenance cost will be higher.

At investment cost, some authors consider the possibility of energy storage systems, which may increase the initial capital cost, but with a probable greater possibility of viability. According to Bhattara et al.,[60] energy storage systems are recognized as viable solutions to alleviate wind energy challenges. In addition, the literature also deals with the issue of storage as an alternative to generate energy from different renewable sources, using the

TABLE 8 O&M costs (USD/kW) of wind projects by country or region in 2019

	Range	
Region/Country	**min**	**max**
Africa	23.03	64.42
Other Asia	27.94	78.14
Central America and the Caribbean	20.50	57.32
Eurasia	19.27	53.89
Europe	21.24	59.40
North America	19.30	53.99
Oceania	18.35	51.32
Other South America	20.27	56.69
Brazil	18.40	51.45
China	14.43	40.36
India	12.45	34.82

Source: IRENA[22] and NREL[132]

hybrid energy technique, and making the best of the potential of each one. According to Madlener and Latz,[16] a variety of operational strategies are compared with three different energy storage systems, with the most profitable storage medium being the compressed air energy storage system (CAES). Silva et al.[19] state that, despite its rapid installation and reduced environmental impacts, the lack of storage capacity and the generation of intermittent energy are seen as the main problems for the greater exploitation of wind energy.

Looking at regional or country data, Table 7 shows the average values of total installed cost (USD/kW) for onshore wind projects. The table shows the values for the period between 2010 and 2019. Regarding the countries presented, it is possible to observe that Brazil, China, and India have more mature markets and lower cost than their neighbors.

Finally, it is important to note that this is a variable that the investor cannot control, although he can negotiate for better equipment prices. The behavior of this variable has uncertainties that are impacted by macroeconomic factors and the development of technology. In addition, investments in wind farms are capital intensive.[131]

Operation and maintenance costs

Generally, the cost of operation and maintenance (O&M) is calculated by the researchers as a percentage of the investment cost. Hulio et al.[23] consider the cost of O&M as 2% of the cost of wind turbine. For Grieser et al.,[94] O&M costs are estimated at 0.5% of total installation costs. For Zhao et al.,[105] over a 15-year period (considered in their research), the total assumed cost for O&M was 5% of the cost of the wind turbine. For Aquila et al.[81] this cost is calculated as 12% of the gross revenue generated from the wind project. Therefore, it is common to consider the value with operation and maintenance as a percentage of the project value, which varies according to the research of each project, so one must take into consideration the type of equipment offered by the manufacturer and the O&M cost of the equipment.

O&M costs are considered to ensure proper operation of the plant until the end of its useful life, and they depend heavily on the types of equipment that will be installed on the wind turbine. For Blanco,[7] like any industrial equipment, wind turbines require an operation and maintenance cost that constitutes a considerable part of the total annual costs, including repairs and spare parts, as well as maintenance of the electrical installation.

Finally, annual O&M costs are often estimated as a percentage of the investment cost per kW per year, as can be seen in Table 8. Typically, it is estimated that such values vary between 1.18% and 3.30%.[132] According to IRENA,[22] an average O&M cost was found that was less than 2% of the total installed costs per year, with a variation between 1% and 3% of the total installed costs per year. However, for larger projects, O&M costs are estimated below the average of 2%, while smaller projects approach the maximum estimated value. Despite being a variable that also has uncertainties and that can be influenced by non-systematic factors, it is a low representativeness cost for the LCOE of wind farms when compared with capital expenditures (CAPEX).

3.4 | Avoided energy cost

The conventional avoided energy cost is considered to measure the savings generated in the project when using wind energy, leading to positive cash flow revenue. This cost usually varies by location. For example, Mohsin et al.[26] state that, in Pakistan, the price of electricity per unit and energy tariffs vary across states in relation to the purpose of consumption, so price changes at the final stage of supply are local to each other. Furthermore, Mohsin et al.[26] also indicate the need to compare renewable energy prices with conventional energy prices, searching for grid parity conditions.

The energy tariff is taken as a value that directly affects the economy of wind farms and is dependent on location and public energy policies. Rocha et al.[8] state that, among the variables that influence cash flow in a wind project, the residential electricity tariff and its interaction with wind distribution are fundamental to calculate the energy savings obtained from the wind generator installation. In some locations, the price of local energy can be so high that it often makes wind projects profitable without the need for government subsidies. Watts et al.[84] state that, in Chile, local energy prices are higher and these characteristics make the country a very attractive place for the development of renewable energy projects. As this variable is normally impacted by the retail price (price paid by the consumer for the energy supplied by a concessionaire) practiced in each market, the investor has no influence on the behavior of this variable.

3.5 | Depreciation

Over time, with wear and tear, electronic parts and equipment depreciates and thus lose value. Some authors consider the cost of machine depreciation as an impact factor on the economic feasibility of wind projects, which is measured as a percentage of the total turbine cost per year. For example, for Aquila et al.,[74] the depreciation cost is 5% of the investment value, disregarding pre-operating costs. Liu et al.[70] consider the depreciation cost being 4% per year of the total amount invested.

To assess the cost of depreciation, the types of equipment that will be used in the project and how much value they lose over time should be known. Researchers recommend searching the literature based on equipment history or directly with the manufacturer. According to Tuyet and Chou,[29] depreciation impacts the annual income tax, and some of the most commonly used methods of calculating its value (acceptable to the authorities) are as follows: straight-line depreciation method, declining balance method, sum of years digit method, production quantity, and machine/working hours, in which the most used is the straight-line depreciation method (linear method). The straight-line depreciation method consists of dividing the total value of the equipment by the number of years of its useful life, so this will be the depreciation share per year.

Finally, as in each country the accounting rules determine the depreciation method, as well as the depreciation rates and terms, it becomes a difficult variable to be generalized and compared between different locations.

3.6 | Land rent

In some research cases, an additional entry was considered for renting land for wind power installation. Blanco[7] considers land rent as one of the most important variable costs of wind energy investment, adding this value to the cost of O&M. In Montes et al.,[37] land rent is included in the O&M cost and represents around 16% of that cost. Neto et al.[31] adopt the amount of land rent being equal to 1% of the gross revenue of the project. In all cases, to consider the amount of land rent, it is necessary to know the local cost of land rent per area and the area that will be required for wind farm installation.

According to Kose et al.,[35] the wind energy, when compared to other energy production methods, is economically usable because a wind farm uses only 1% of the total land area, which allows agricultural and other activities to be carried out on around the wind turbines, and this reduces the land cost of wind farms.

Finally, here we present a non-convergence of criteria, since some authors consider land rent as a variable not related to fixed O&M costs, while others consider this variable with total O&M costs.[130,132]

3.6.1 | Political factors

Interest rates and taxes

The interest rate and taxes established by local policy are calculated on the annual values of the wind project revenue, and are considered as a parameter that impacts the economic feasibility study. These rates may vary by region and may favor or detract from the feasibility of the project. The authors of Rocha et al.,[8] in their studies in Brazil, comment on the importance of the government's involvement in the creation of tax incentives to support the growth of the wind industry, and that it should consider a reduction in the high import taxes, since the main technology used in Brazil is manufactured by foreign companies in the country. According to Ali et al.,[73] the discount rate, coupled with the electric tariff, and the corporate tax rate are the factors that greatly affect the viability of wind farms.

According to Ramadan,[33] accurate forecasting of the discount and interest rate is not a straightforward process and should be estimated and assumed to be consistent with local reality. Serri et al.[4] define the interest rate value by considering the interest rate applied to most local banks, and uses the value 6% as a rate. For Gil et al.,[98] the interest rate considered is an average of the market interest rate and, in their research, it was adopted a rate of 4.5%, considering a SD of 0.2. Therefore, the interest rate varies by region and should be estimated as an average percentage of what is charged locally.

Furthermore, with respect to interest rate, a number of authors based on finance principles advocate the use of weighted average cost of capital (WACC) as the best model for estimating the discount rate.[8,63,74,81,82,107] The WACC is the rate that a company is expected to pay, on average, to all its security holders to finance its assets. The WACC is commonly referred to as the firm's cost of capital and used as a discount rate.[133] Bjarne[133] reviewed the spectrum of estimation methods for the private cost of capital for renewable energy projects and sought to discuss the appropriate use of the parameters to yield unbiased results. To achieve these goals, the author presents a systematic review of the global empirical evidence on renewable energy cost of capital.

Moreover, as a prerequisite for calculating the discount rate, the use of the capital asset pricing model (CAPM) for calculating the cost of equity is well regarded in the finance literature.[8,63,74,81,82,107]

Finally, it is worth noting that the WACC is the most popular method for estimating the discount rate. The parameters for estimating the WACC should preferably be based on the market and economic context of each location.[134] Still, this variable is seen as partially controllable, since financing decisions can be controlled, but the rate parameters cannot.

Energy sales price

In some studies, depending on the public policy of the region, it is interesting to research the price at which the generated wind energy can be sold to the local grid. Some factors that generate revenue are considered in wind power generation linked to the local connection grid, such as the sale to the grid of the potential energy that is not consumed, as well as the sale of carbon credit. These values serve as public policy incentives to enable renewable energy projects. Qolipour et al.[1] state that initially it is necessary to price the new energy per kilowatt to calculate the revenue generated by electricity.

For Rocha et al.,[8] electricity produced in a home can be sold at a favorable price through the establishment of premium rate programs known worldwide as feed-in tariffs (FIT), a net metering system for buying and selling energy. According to Capallero,[123] the simplest method for promoting renewable energy is with feed-in tariffs, associated with the obligation of system operators, to buy renewable sources whenever they are produced. This public policy incentive can make wind energy investment viable.

Providing capital subsidies and tariffs for energy generated above market price may encourage a building owner to buy wind technology, even if the owner cannot accurately determine whether a positive financial benefit will be accrued over the lifetime of the product.[112] According to Grieser et al.,[94] the introduction of FIT, and a combination with an energy storage system, has a substantial influence on wind turbine profitability, and also says that the FIT regime plays a crucial role in the decision to invest not only in public business or private companies, as well as in private households. According to the results of their research, the power tariff scheme adopted in the studied region (Germany) significantly improves the profitability of the wind energy project.

Some authors treat LCOE as the breakeven price that would make investments feasible.[135,136] The breakeven price ends up being information for policy makers for the design of policies, such as feed-in tariffs and subsidies in the RES investments chain. The price level depends on the political, economic, and fiscal factors of each country (see that the LCOE is usually presented separately by country or region).

Inflation

The inflation rate is a result of the increase in the price of energy or other project-related costs. Some authors consider this annual percentage increase to predict the electricity and other costs involved in the wind project. Inflation rate has been one of the factors used in the financial analysis of wind projects and may impact on the economic feasibility of the project.

According to Ayodele et al.,[85] the inflation rate is used to calculate the current value of the turbine cost. Gil et al.[98] use the inflation rate to calculate the real interest rate and thereby calculate the cost associated with annual energy losses produced over the life of the facility. For example, in a Malaysia case, Nor et al.[101] also use the inflation rate in the present value calculation, assuming this annual rate to be 3.5% and constant over the project lifetime.

Inflation rates should be observed by location and may vary by region. Researchers have adopted an average rate based on the history of banks in the region. For Mohsin et al.,[3] the considered inflation rate was 6.9% in Pakistan over a 20-year project lifetime. Ali et al.[73] assume an inflation rate of 3% in South Korea. For Rahman et al.[77] the inflation rate considered was 7.3% using the 2014 annual average based on the Bangladesh Bank.

As can be seen, this variable depends on the local macroeconomic context, and in high inflation scenarios, it can increase the project's cost of capital.

Financing conditions

One of the factors that can most facilitate and contribute to the profitability of wind power projects by attracting investors involves the financing conditions. These conditions may involve a minimum interest rate, tax rebates or exemptions, long financing periods, and other strategies that amortize the value of the investment. Rocha et al.[8] argue that short-term policies include the strategy of direct subsidies for investment in the renewable energy project, tax incentives such as discounts or tax exemptions, and a special financing line for renewable electricity generation projects with interest rates lower than those on the market, and long repayment periods.

Without public incentive policies, the researchers comment that it is difficult to invest in wind energy, since it is an expensive investment and may have long-term return or not expected return, making the project financially unviable. Therefore, many authors propose adequate financing conditions to increase the probability of economic feasibility in wind energy projects.

For example, in Brazil, favorable financing conditions for the National Bank for Economic and Social Development (BNDES) facilitate investment in renewable energy, and lack of adequate long-term financing is a barrier to consolidating renewable sources in the Brazilian market. Creditors' aversion to risk is high as renewables have high production costs.[102] According to Aquila et al.,[74] the results obtained in their research reinforce the important role of bank loans as a complementary strategy for long-term contracts with fixed remuneration. In their study, they concluded that, in terms of financing lines, the probability of the project being viable was 86.53%, while the probability of viability rises 99.17% in the scenario that considers financing without trading carbon credits.

Public financing can be articulated as a way to subsidize RES, reducing the cost of capital. In this case, it will depend on the regulatory and political framework of each location for the RES market.

3.6.2 | Climate factors

Wind speed

The wind speed is a key factor in making wind energy project viable as it is the main source of energy for this type of project. Some authors usually consider an average local wind speed, usually measured in m/s, considering historical wind speed data to verify the wind potential of the studied region. Qolipour[87] emphasizes the attention that should be given to quantitative and qualitative changes in wind speed for wind power production. According to the author, there is no doubt that wind is the most important factor in building a wind farm, so not only the changes in wind speed but also the effect of these changes on the amount of electricity produced should be measured.

Furthermore, wind speeds vary greatly by region and attention should be paid to this variable when verifying the economic feasibility of wind projects. According to Li et al.,[67] accurate wind speed estimation is extremely important for all aspects of wind energy exploration. According to Ramadan,[33] wind characteristics and relevant wind potential have been extensively analyzed through recent studies around the world. And, the methodologies developed allow energy, power, and wind speed to be estimated, so investments and wind farm projects can be properly executed in a region with relatively small errors.

In addition to the average wind speed, the authors consider it is very important to estimate wind distribution over time. According to Jie et al.,[6] Weibull is the most commonly used probability model for distribution analysis, widely accepted and cited in the wind literature. It is considered as a standard approach due to its accuracy, simplicity, and flexibility. According to Jie et al.,[6] many studies base their statistical analyzes on wind characteristics and energy potential, believing that the Weibull distribution is an appropriate approximation to wind speed, and this is due to the easy estimation of the distribution parameters to approximate the empirical distribution of wind observations. In addition, the Weibull distribution has the best adherence to the most varied wind regime cases.

The Weibull distribution has two parameters, which are named as shape parameter "k" (dimensionless) and scale parameter "c" (in m/s), and there are several numerical methods available in the literature to estimate the value of these parameters.[126] Several methods can be used to estimate Weibull's "k" and "c" parameters, including the Graphical Method, Ordinary Least Squares, Energy Pattern Factor, Maximum-Likelihood Estimation, Modified Maximum-Likelihood Estimation, and Empirical Methods. All of these methods have the ability to estimate Weibull parameters with minimal error, but empirical methods require less computational effort and are simple to use compared to other methods. The empirical model was first proposed by Justus, and it uses the mean and variance of wind speed to determine the shape "k" and scale "c" Weibull parameters.[85]

Some authors also consider the variation of wind throughout the day as an important factor to be observed in order to verify peak times and reduction in wind speed, and to consider this variation in economic impact. Accurately forecasting production per hour can minimize system uncertainties and costs by correctly positioning turbines where they provide the greatest benefit. To predict the market value of wind turbine production, a statistical analysis of the hourly data is required.[123] For Kassem et al.,[25] the variation of wind speed during the day is very important for the integration of wind energy in the global energy supply. And, the average wind speed per hour varies over a 24-hour period, as shown by the study realized in the northern region of Cyprus.[25]

Mohammadi and Mostafaeipour[18] use daily wind speed data hourly to obtain monthly and annual values. All calculation procedures were performed based on this average data to analyze wind speed in terms of time, monthly, and annual. Kose et al.[35] analyzed average 10-minute interval data from three different days for low, medium, and high wind speeds. De Vos and Driesen[124] argue that the available wind power reserve capacity at each hour of the day is limited by the expected value of wind power next day, but the expected wind power capacity can be predicted by a model of probabilistic forecasting.

The wind direction is also another aspect that must be observed for wind farms to have a higher electricity production. The differentiated heating of the atmosphere causes gradients of atmospheric pressure, which are responsible for mass movements of air.[137] Thus, the wind direction depends on the region where the equipment will be installed and, therefore, this is an important technical aspect that must be considered during its installation. In addition, the effectiveness of the yaw control strategy, and the impact of the Coriolis and the direction of rotation of the blades on the wake of wind turbines can significantly interfere in energy production.[138]

Finally, it is important to highlight that the investor does not have control over the wind speed and direction, but can carry out studies on the location where the winds are most favorable (directly related to the turbine location).

Air density

Air density is nothing more than the mass of air per unit volume of the earth's atmosphere. This variable, usually measured in kg/m,[3] is a factor that can affect wind energy production because wind kinetic energy is directly proportional to air density.[23] According to Mohsin et al.,[3] the investigation of wind speed alone does not represent a real picture of wind potential. Normally wind energy density depends on the wind speed cube, turbine blade area, and air density.

Air density is considered to be 1.225 kg/m^3 according to the International Standard Atmosphere (ISA) at 15°C and sea level.[126] Hulio et al.[23] says that air density is higher in winter months and decreases in summer, and considers the average values of ambient temperature and air density. Some authors calculate the value of air density by a relationship between atmospheric pressure, ambient temperature, and the specific gas constant for dry air.[33,73,95]

Temperature

The ambient temperature is a factor that influences air density, thus affecting the wind energy density, so this factor is considered in the analysis of some authors. According to Abdelhady et al.,[75] air density is directly proportional to atmospheric pressure and inversely proportional to temperature. Thus, the wind energy potential is inversely proportional to temperature, that is, the energy potential is higher on colder days and lower on warmer days.

In most cases, the temperature value is considered by the researchers for the calculation basis of 15°C, which can assume the standard air density of 1.225 kg/m^3, which is measured at sea level.[5,49,84] For other authors, it is important to observe the variation in ambient temperature and consider an average local temperature, based on history, and perform the calculation of air density.[33,35,75]

Atmospheric pressure

The air density is a variable that is directly proportional to the atmospheric pressure of each location, so some authors use air pressure as an impact factor, considering the feasibility analysis. Generally, atmospheric pressure is measured in Pascal (Pa), atmosphere (atm), or millimeters of mercury (mmHg). Researchers calculate wind energy density based on air density values, which have a direct relationship to atmospheric pressure, generally considered to be 1 atm as normal atmospheric pressure.[5,34,49,84]

3.6.3 | Technical factors

Turbine height

Turbine height influences wind power density. The higher the turbine, the higher the wind speed, and the higher the power output. Serri et al.[4] state that there is an increase in power output due to the higher hub height of wind turbines, as well as better generator performance and better comprehension of wind characteristics. Fazelpour et al.[5] investigated the effect of using multi-height wind turbines and found that using multi-hub turbines can optimize energy output even when the number of wind turbines is equal. In addition, various cost models were studied, and it was found that different heights of the wind turbine hub would reduce the cost per unit of a wind farm.

For a more accurate estimate of wind speed, authors recommend that wind speed be measured from different heights to predict the average wind speed. The wind turbine hub heights have increased significantly during time. For Li et al.,[67] the heights of the wind turbine hubs are mostly from 60 to 80 m. Ramadan[33] analyzed hourly wind speed measurements at different cube heights to estimate the average wind power generation potential. Waewsak et al.[76] state that each wind turbine generator considered had different hub heights ranging from 80 to 100 m, but in the selection process the annual energy production was estimated at equivalent and extended cube heights at 110 and 120 m. For Simons and Cheung,[83] the height of the cubes considered was between 44 and 135 m. Therefore, this parameter depends on the turbine model that will be used and where it will be installed.

Currently, most modern turbines have already reached high heights, which allow the use of wind energy in places with intermediate wind speed. For more technical details, the catalog of the turbine manufacturers can be consulted in The Wind Power Database.[139]

Installed power

The installed energy potential is undoubtedly one of the factors that most impact the economy of a wind project. Cited in all references in the final survey sample, installed power is usually measured in MW or kW. It is calculated according to the required energy demand and turbine capacity, and is a choice to be made prior to investment in order to choose the manufacturer and the appropriate turbine model for the project. The price of the turbines depends largely on their model and their installation capacity. Fazelpour et al.[95] state that the main objective of the study was to improve the understanding of the use of wind power potential and, knowing this potential, it is possible to calculate the wind turbine economy and to evaluate the unit cost of electricity (per kWh) to the cities considered.

For many authors, local power must be predicted before wind farms are installed, and choosing the right turbine model depends on the power installation capacity, which can make the project more expensive. For the analysis of the economic feasibility of wind energy projects, Wyman and Jablonowski[92] studied the decision of the project energy capacity and other factors for data fixation. In this study, three project capacities and three commercially available turbine sizes were considered. The results showed economies of scale as project capacity increased within a given turbine size.

One of the main factors that affect the performance of a wind turbine is its power capacity at different wind speeds, typically specified by the turbine manufacturer's power curve.[89] According to Watts et al.,[84] the power generation of a wind turbine is strongly dependent on the technology used, so an adequate selection of technology according to the wind regime is required. Proper choice of turbine model is essential.

According to the power curves of the turbines, it is possible to increase production to the same wind level, increasing capacity utilization, and making the project more viable.[84] In general, projects with higher power have greater economies of scale (lower investment per kW installed).

Equipment lifetime

The project lifetime indicates the length of time that the facilities will be operating in a standard state. It is a factor that can be considered as technical, since it is a data obtained directly from the manufacturer, depending on the characteristics, quality, and technology of the installed turbine. This time, considered to be the effective operating time of the turbines, is used to know how long the project will last and to build cash flow over this period. In general, the wind farm lifetime lasts around 20 years.[4] However, due to the development of technology, the project's lifetime can be from 15 to 35 years.[132]

This factor is usually offered by the turbine manufacturer and depends on their model and quality. Neto et al.[31] state that the longer the project life, the more attractive the business becomes, as the longer the turbine operation, the more income enters the cash flow. Belabes et al.[91] performed a sensitivity analysis and found that the project NPV is sensitive, among other factors, to the project lifetime.

Efficiency

For a more realistic estimate of energy production caused by local wind potential, researchers consider the generator efficiency, relating the effective production of energy to the maximum production capacity. Usually, the authors analyze this efficiency in terms of capacity factor (percentage value). According to Mattar and Guzman-Ibarra,[34] the technical feasibility analysis is the estimated wind energy potential and its relation to the effective energy production, based on the wind turbine power curve. From the power curve model, the capacity factor is calculated, which is defined as the ratio between the actual wind power generation produced by the turbine and the total generation it generates at full capacity over a period of time.

According to Blanco,[7] the indicator that best characterizes the electricity generation capacity of a wind farm is the capacity factor, which expresses the percentage of time that a wind farm produces electricity during a representative year. And, for the author, the capacity factor is one of the variables that most influence the overall cost of a wind energy investment.

The capacity factor can be obtained by dividing the total energy generated of a wind turbine over a period of time by the energy that would be generated by exploiting the total wind turbine capacity in the same period of time.[5] It is also seen as the ratio between the average power and the peak power determined in a given time period. For Glassbrook et al.,[9] decreasing wind turbine efficiency results in reduced annual energy production.

Table 9 shows the evolution of the capacity factor over 10 years for different countries. It is observed that

TABLE 9 Country-specific average capacity factors, 2010 and 2019

	2010	2019	Percentage change 2010-2019
Brazil	36	51	42%
Canada	32	39	21%
China	26	32	24%
Denmark	27	39	44%
France	27	33	25%
Germany	24	31	30%
India	25	32	30%
Italy	26	33	30%
Japan	24	25	4%
Spain	27	39	44%
Sweden	29	38	33%
Turkey	26	34	33%
United Kingdom	30	33	9%
United States	33	44	33%

Source: Adapted from IRENA.[22]

between countries there is a difference in the capacity factor due to differences in wind potential. And, from one period to another, within the same country, the increase was due to the development of technology.

Rotor diameter

Rotor diameter is a parameter that defines the sweep area of the turbines, which defines the turbine's ability to capture wind, so it is considered by many to be an impact factor on the economic viability of wind energy. According to Mohsin et al.,[3] larger diameter rotor wind turbines can be used to produce the maximum energy. Annual wind power production can be calculated in a ratio using the number of hours in a year to turbine efficiency and sweeping area.[9]

According to Furuya and Maekawa,[122] there are two basic methods of operating a wind turbine rotor: Rotations per minute (RPM) and constant speed ratio. From an economic standpoint, the wind turbine is typically designed at a specific or nominal wind speed. These authors argue that the reduction in the cost of capital was observed by reducing the number of turbine rotors.

It is possible to note that such a variable depends on technological developments. Currently, turbines with different rotor diameters exist in the market, and for more technical details, the catalog of the turbine manufacturers can be consulted.[139]

Operation time

Operating time is the time that turbines spend effectively operating for energy production, usually measured in hours per year. This time defines the amount of time the turbine will be running producing energy, and this number of hours is considered to calculate the total capacity of energy generated over a period of time.[9,49,125]

Some authors consider that turbines will not work every hour of the year, for some reasons like maintenance, for example. Albadi et al.[80] considered the generator working only 6 hours a day to calculate turbine efficiency. Saiz-Marin et al.[125] considered scenarios that represent an estimated daily energy output of a wind turbine working 438 hours per year. Montes et al.[37] considered 2350 hours per year of production. Other authors, for simplicity, consider that the turbines will work nonstop during the year, ie, 8760 hours per year.[48,55,71,100,140] It is also worth highlighting the possibility of losses due to failures and maintenance, whether preventive or corrective (around 2%).[132]

Number of turbine blades

The number of turbine blades is a technical characteristic of the manufacturer that influences the sweeping area of the turbines, thus impacting wind energy production. Some authors include the number of blades of the wind turbines as an economic factor.[43,46,61,91,95,119,121,122]

According to Furuya and Maekawa,[122] there are two basic methods of operating a wind turbine rotor: the rotor operating at constant revolutions per minute (RPM) (CRS); and the rotor with constant speed ratio (CVR). The choice of the turbine operating mode must take several factors into account, including the number of blades. The number of blades of the turbine directly affects the operating mode, and the blades must work at an adequate speed to keep the nominal power constant.

For Richardson and Mcnerney,[121] turbine models involve the use of a horizontal or vertical axis and the use of two or three blades. Belabes et al.,[91] Abnavi et al.,[61] Adefarati and Obikoya,[43] Olatayo et al.[46] and Stockton[119] used a set of wind turbines operating with three blades, while Fazelpour et al.[95] used a turbine operating with two wind blades. However, onshore wind turbines are usually horizontal-axis turbines, predominantly using three blades and with blades upwind.[130] Other significant types of wind turbines are commercially available and may be considered.[139]

The number of blades on a wind turbine, while apparently an easy design choice, is subtle. Two blades cost less than three blades, but two-bladed wind turbines need to operate at higher rotational speeds than three-bladed wind turbines. As a result, individual blades need to be lighter and stiffer and, therefore, more expensive in a two-bladed wind turbine.[121]

Construction time

The construction time is the time taken from the start of the project to the effective operation of the wind energy system. This time is considered by some researchers mainly due to the amount invested at the start of the project until it starts operating. Construction time varies according to investor needs or the willingness of suppliers. Usually, in onshore cases, the authors consider a period of 12 to 36 months of construction, from design to complete turbine installation.[14,57,70,104,117] In case of delays, this can result in a lower NPV of the project, since it causes delay in the start of the operation, and consequently in the receipt of revenues.

4 | CONCLUSIONS

This paper proposes the realization of an SLR, which uses an initial sample collected from the ISI Web of Science database, with 219 studies on the economic feasibility of wind energy investment. After the full reading of the papers, the final sample was defined with 120 articles, which were synthesized and examined in order to identify the impact factors in the financial analysis and achieve the research objective.

The final sample defined was characterized with the main information from the articles contained in it, so we can see the growth of publications in the study area, through the number of publications per year, as well as a greater interest of this research sample by regions, such as Brazil, the United States, Europe, and South Asia. The relevance of the studies by the number and average of citations per year was also shown.

At the end of the research, a total of 23 parameters were identified as impact factors on the economic feasibility of wind energy investment. Analyzing these studies and observing the identified factors, it was evident that these factors depend greatly on the place from which it is being evaluated.

There are factors that may be interesting to evaluate in some locations, for example, we have seen that, in some studies, it is important to evaluate the wind variation throughout the day (peak and slow wind times), while for other authors it is important to know only the overall average wind speed. This diversity in studies makes it interesting for the economic evaluation of wind energy to know all the parameters being examined and to evaluate which ones should be considered in your study.

The installed power was identified in all articles present in the sample, which may already be a result expected by many, as this factor directly influences other factors related to investment costs, such as installation cost, energy savings generated by wind energy production, financing conditions, among others. Despite being a factor that can be seen as an investor choice (and not as a risk of economic viability), depending on this choice the investment may become less or more viable because higher power generates more energy and costs more. In contrast, a project with a lower installed capacity makes the investment cost lower but produces less electricity. The existing economy of scale cannot be discarded, that is, larger projects tend to have a better cost-benefit ratio.

In addition to installed power, the cost of investment, wind speed, equipment lifetime, and the cost of operation and maintenance were factors identified in more than 80% of the articles. The investment cost is a factor that depends on other project characteristics, such as the power to be installed and, in some cases, the distance from the distributors to the place where it will be installed, adding installation and transportation costs. Wind speed directly influences the economic feasibility of the project, as it is what characterizes the wind potential of the place where wind energy will be generated. The equipment lifetime is a factor that directly impacts the economy because it indicates the effective operation of the turbines to define, among other things, how long the project will last and how far cash flow will be considered. The cost of operation and maintenance, as well as other factors, depends on other parameters, such as project duration and project size (installed energy potential). Generally, this cost is considered as a percentage of the total investment cost and should be taken into account to ensure the smooth running of the project until the end of its useful life.

Other factors were identified less frequently in the studies, but not less important. Some of the authors, for example, have been paying attention to financing conditions through public policies, such as the interest rate charged, the term of financing, and the amount financed by the government. Such conditions may offer advantages in financing the investment cost, which may help to make the project viable. Finally, other factors that can be studied are noise and vibration. For example, the wake effect, which is a technical aspect characterized when wind passes through a turbine and goes towards another one behind. This phenomenon causes a reduction in wind speed and an increase in the turbulence. Such factors can be considered in future analysis.

Based on these findings, future works may (i) select the best locations for wind power installation according to the identified impact factors (ii) perform an analysis of each factor in isolation, studying how these factors impact the economic feasibility of wind energy; (iii) relate the identified parameters to economic feasibility and compare the degree of risk between them; (iv) perform a sensitivity analysis between the factors with the criteria used in feasibility studies (NPV, IRR, payback, and others) to compare the degree of risk of the factors in the financial viability of the project.

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CONFLICT OF INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

DATA AVAILABILITY STATEMENT

Data sharing not applicable to this article as no datasets were generated or analyzed during the current study.

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