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Reveiw Article

Methods of wind energy harnessing: A state of the art and bibliometric analysis

Métodos de aprovechamiento de energía eólica: Estado del arte y análisis bibliométrico

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Abstract

Wind energy is one of the most promising alternatives for obtaining a sustainable electricity generation model with low greenhouse gas emissions. The maturity of this technology, coupled with its low investment costs and good performance, makes it highly interesting for countries to develop projects within this field. However, its high operation intermittency caused by the natural behavior of wind requires preliminary research on the technical conditions (Installation, Capacity, Environmental, Legal, Administrative and Logistics) of the geographical area wherein the wind energy project is planned. This paper provides an overview of the state-of-the-art research studies on the potential of wind energy within a territory. This review describes current methodological alternatives for assessing wind energy generation projects and potential energy studies in different geographical areas globally. Therefore, a bibliometric analysis is included, examining the scientific research trends in the field of wind energy in addition to the different technologies and innovations that have contributed to the viability of a greater wind energy generation project. Finally, the study discusses the technical restriction criteria faced by any such project. This paper also seeks to become a point of reference for future reviews and decision-making in wind projects.

Resumen

La energía eólica es parte de las alternativas más prometedoras para la obtención de un modelo de generación eléctrica sustentable y de baja emisiones de gases de efecto invernadero. La madurez de la tecnología sumado a su bajo costo de inversión y buen rendimiento hace que esta tecnología presente alto interés para los países que deseen desarrollar proyectos en este campo. Sin embargo, la alta intermitencia de su operación causada por los comportamientos naturales del viento requiere investigaciones de manera preliminar de las condiciones técnicas (Instalación, Capacidad, Ambientales, Legales, Administrativas y Logísticas) en las áreas geográficas donde se presume un posible proyecto eólico. El presente trabajo pretende aportar una visión general del estado de las técnicas relacionadas con el estudio del potencial energético eólico de un territorio. Se pretende mediante este abordaje identificar las alternativas metodológicas existentes para la evaluación de proyectos de generación de energía eólica y los estudios del potencial energético en zonas geográficas del mundo. Asimismo, presentar un análisis bibliométrico donde se analizan las tendencias de investigación científica en el campo de la energía eólica, además de las distintas tecnologías e innovaciones que han contribuido a una mayor viabilidad de los proyectos en esta rama del conocimiento. Finalmente, se muestra los criterios de restricción técnicas con las que se enfrentan un proyecto eólico. Este documento pretende convertirse en punto de referencias para revisiones futuras y la toma de decesiones en proyectos eólicos.

Keywords: wind Energy, Multicriteria Project Assessment, Energy Potential.

Palabras clave: energía Eólica, Evaluación Multicriterio de Proyectos, Potencial Energético.

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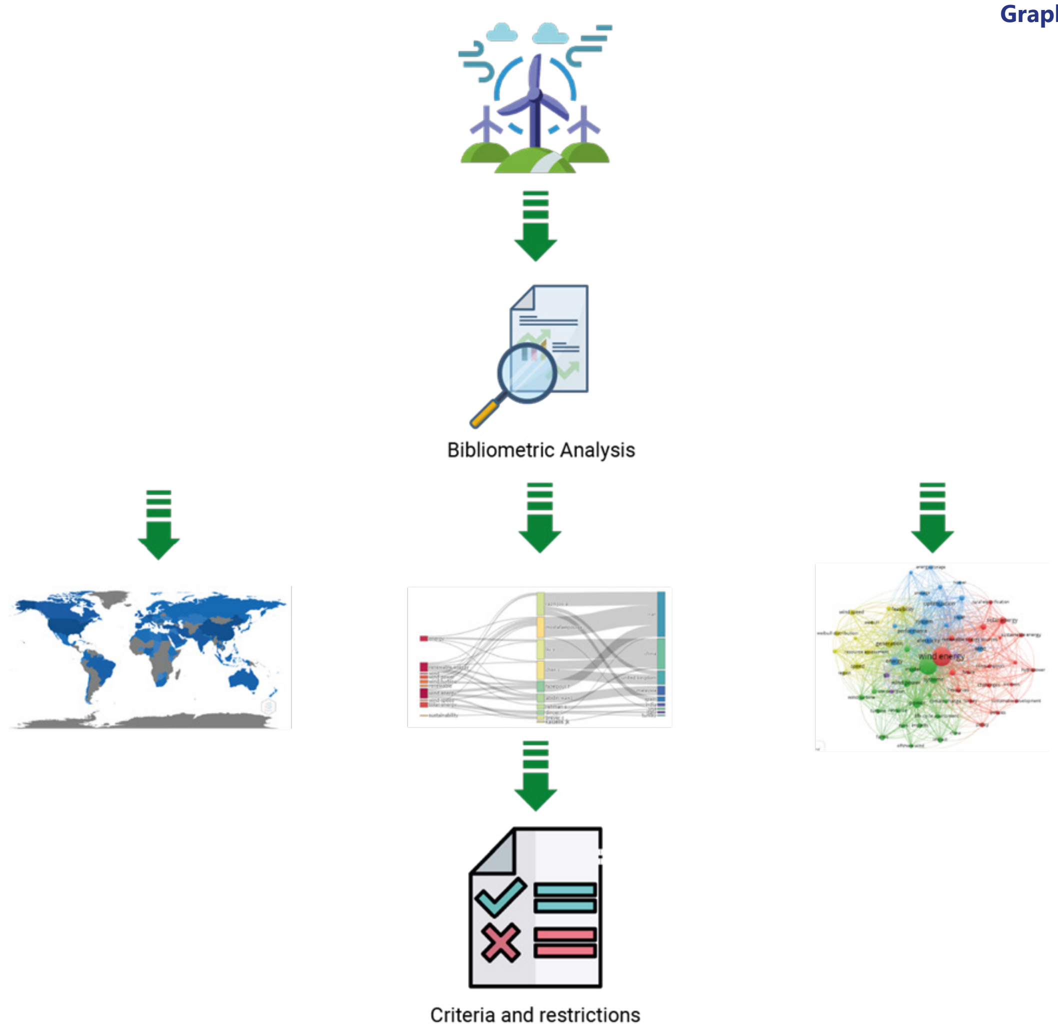
Why was it conducted?:
This study provides an evaluation of the most used methodologies for assessing the wind energy generation potential in various geographical regions. The research focused on identifying and analyzing the technical, environmental, legal, administrative, and logistical conditions necessary for the successful implementation of wind energy projects. Due to the inherent high intermittency of wind energy, it is crucial to conduct preliminary investigations to understand the technical and economic feasibility, as well as the energy potential, of such projects in specific areas. This approach helps reduce uncertainty and optimize the planning and execution of wind energy projects, thereby contributing to sustainable development and the global energy transition.

What were the most relevant results?
The study determined that although wind energy has significant potential for sustainable electricity generation, its successful implementation depends on various factors. These factors include the availability of favorable wind conditions; the minimization of environmental and aeronautical restrictions; optimal site conditions; and robust economic and logistical support. The bibliometric analysis revealed a growing trend in wind energy research, with notable contributions from countries such as the United States, China, Turkey, and Iran. Additionally, the importance of integrating multiple renewable energy sources to mitigate the intermittency issues associated with wind energy was identified. This approach allows for a more precise evaluation and more efficient planning of wind energy projects, optimizing their technical and economic feasibility.

What do these results contribute?
The results provide crucial information on the optimal conditions and methodologies for the implementation of wind energy projects. They highlight the need for preliminary studies to assess site suitability and the potential benefits of integrating wind energy with other renewable sources. The findings of the study will help guide policymakers, researchers, and investors in decision-making for the development and investment in wind energy projects. Additionally, the bibliometric analysis offers a detailed view of current research trends, enriching the global knowledge base and facilitating future studies in the field.

Graphical Abstract



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Introduction

The excessive use of fossil fuels as the energy source and the resulting high pollution levels harming the environment have led several countries to start developing energy transition policies, invest in their care, and foster green economies (1, 2). Wind energy is the most popular and successful technology to generate alternative renewable energy worldwide (3). Its popularity has risen since the cost gaps between conventional energies and wind energy have diminished. The generation cost of 1 megawatt-hour (MWh) wind energy in large wind farms lies between USD$30 and USD$60, while that of 1 MWh of the cheapest fossil fuel (natural gas) ranges from USD$42 to USD$78 (4). Currently, the installed capacity of global wind power is 743 gigawatts (GW), which saves the emission of 1.1 billion tons of CO2 (5). Although the benefits of wind energy are indisputable, its greatest limitations are related to the geographical locations of the generation systems, since their operation is closely linked to the quantities of air mass displaced through the environment and favorable topographical and meteorological conditions for optimal energy generation. Intermittency is a significant weakness of this leading technology (6), prompting the implementation of several methodologies to mitigate it, including the application of storage systems for the simultaneous integration of several renewable generation sources, etc. (7).

A hybrid wind power forecasting model that combines data mining techniques and wavelet analysis has been proposed to enhance prediction accuracy, which is crucial for the effective integration of wind energy into power grids (8). Additionally, a novel approach to harness wind energy from the air displaced by moving trains has been presented, utilizing vertical axis wind turbines and optimizing their placement through GIS and FEM simulations, contributing to energy efficiency in railway infrastructures (9). Furthermore, a hybrid forecasting method combining singular spectrum analysis and Laguerre neural networks has been developed, significantly improving wind power prediction accuracy, which is essential for managing the intermittency and variability of wind resources (10). Comparative analyses of Maximum Power Point Tracking (MPPT) techniques have demonstrated that optimized MPPT algorithms can significantly enhance the performance of wind energy conversion systems by ensuring turbines operate at maximum efficiency (11). Comprehensive reviews of the impact of seismic activities on wind turbines have highlighted the need for robust design and operational strategies to mitigate these risks (12). The importance of advanced forecasting technologies for improving the accuracy and reliability of wind energy production forecasts has been emphasized, thereby supporting better grid integration and operational planning (13). Practical power analysis approaches in wind energy have focused on the implementation of lasso regression and Weibull distribution to optimize wind turbine performance (14). The application of artificial neural networks in wind energy systems has been increasingly used to predict and manage wind power generation efficiently (15). Additionally, the combined use of geothermal and solar power systems with wind energy has been explored to create more stable and reliable renewable energy systems (16). Likewise, wind projects are generally based on the preliminary phases supporting their viability based on important aspects, such as wind conditions throughout the year, institutional restrictions (natural parks, airports, etc.), laws, logistic complexity, and economic and financial matters. Hence, the energy potential, the technical and legal suitability, and the economic benefits from these projects are validated from the standpoints of government officials, investors, and communities.

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Therefore, this document is aimed at deepening current wind energy generation knowledge through four scenarios. The first scenario is a state-of-the-art assessment of the methodologies proposed for the evaluation of wind energy generation projects and matters related to their execution. The second scenario is a bibliometric analysis, including technical and environmental references within the global context. The third is an assessment of the technical and geographical contexts of knowledge applicable to the development of studies on energy potential estimation and the design of wind farms. The fourth scenario is a definition of the criteria and technical restrictions that a wind project may eventually face.

This paper is organized as follows: Section 2 provides the state-of-the-art evaluation methodologies for wind power generation projects and potential energy studies, focusing on specific geographical areas. Section 3 offers a bibliometric analysis of the current knowledge regarding the development of wind power generation projects worldwide. Section 4 defines the general criteria and restrictions for the assessment of wind energy projects. Finally, Section 5 discusses the conclusions drawn from the study.

Comprehensive review of methodologies and regional assessments in wind energy projects

The assessment of wind energy generation projects involves selecting appropriate methodologies, techniques, and tools for design, assembly, installation, operation, maintenance, and optimization. Evaluating the most relevant scientific approaches provides insights into various perspectives, technologies, techniques, measurement mechanisms, and execution methods, establishing a state-of-the-art assessment that identifies key knowledge clusters in wind energy research and development. Dr. David B. Richardson, one of the most cited authors in this field, has focused his research on identifying the benefits of the relationship between wind energy and the increasing demand for electric vehicles (EVs) to mitigate the effects of polluting gases and foster the economy and integrity of the electrical system (17). Dr. Richardson mentions different research perspectives on the subject, including the model and dimensioning of the electrical capacity in Brazil for 2030 with a projection of 1.6 million electric vehicles, along with assessing the hourly interaction between wind power and electric cars in the United States. His research highlights the importance of promoting the use of EVs worldwide to reduce CO2 emissions, increase the capacity and quality of non-conventional alternative energy infrastructure, and integrate a more efficient and low-negative impact, multi-source, renewable energy grid. An approach proposed by other authors states that a disadvantage of using renewable resources is the impossibility of continuous energy production, since they depend on special environmental and meteorological conditions (18). The authors propose that the best way to overcome this disadvantage is to integrate two or more complementing renewable technologies to maximize their utilization during adverse natural conditions. These authors propose a methodology for selecting suitable sites for the development of hybrid projects based on literature wherein legal aspects, environmental acceptability, and economic viability were assessed for a hybrid wind–solar photovoltaic energy generation project in Turkey.

A multi-objective decision algorithm was proposed, obtaining results according to the hybrid nature of the system. Finally, the selection of a favorable geographical location for the development of this project was highlighted, studying both technologies individually using the geographic information system and superimposing the associated information. Meanwhile, other studies conducted reviews on the contemporary literature to assess

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the potential of nine renewable energy technologies, including wind energy, in Indonesia (19). Consequently, the authors discovered that the country hosts enormous renewable energy resources, both on the land and in the sea, potentially meeting the current energy demands. However, some knowledge gaps must be addressed through research to further support this theory. For example: (i) lack of identification of economic potentials, (ii) research on spatial mapping, and (iii) research on empirical data. Additionally, other researchers conducted a study supported by documentary information, which assessed the highest levels of optimization achieved by hybrid electric power generation systems, thus allowing the artificial intelligence algorithms to emerge as the best optimization tool due to their precision and less computational time (20).

The authors also highlighted the importance of achieving precise optimizations, since they provide better system dimensioning, thus making a positive impact on both the energy performance and the economic aspects. Finally, the authors reviewed decades of scientific research related to the optimization of hybrid power generation systems, thus identifying the problems and solutions as well as the importance of artificial intelligence in these projects. Another literature review provided an overview of the global wind energy scenarios, the current state of the development of wind turbines, the development trends for offshore wind farms, and the environmental and climatic impact of wind power from these farms (21). This work also discussed the possible deterioration to the environment that may exist from installing and operating wind turbines. In addition, the review discussed different global scenarios dominated by clean energy. The development of onshore and offshore technologies and their impacts on climate change were also highlighted. The conclusions highlighted the leading role of European countries in the implementation of offshore wind technology and discussed the relationship between the negative effects of noise pollution and its impact on the life quality of both humans and animals. Thus, the authors recommended the implementation of adequate and supportive policies regarding wind energy by understanding its environmental impact. In another study, a thorough literature review was conducted to establish the best sizing methodologies for battery-powered storage systems (22).

This study was motivated by the need to establish compensation mechanisms for the intermittent and fluctuating characteristics of renewable technologies, including wind-based energy. This review listed the similarities and differences between the size of the storage system and the alternative power generation system, in terms of the existing methodologies, criteria, categorizations, and approaches. Consequently, a direct correspondence between the size of the generation system and the storage system was demonstrated. This study concluded that for the design processes in renewable energy generation systems and their dimensioning, battery sizes must be considered, since depending on the opted battery size, an adequate sizing methodology could improve the overall system efficiency. Furthermore, studies proposed a methodology based on counteracting intermittency in alternative energies using storage systems (23). The authors listed the economic and technical difficulties in implementing batteries for wind power applications and demonstrated that a Compressed Air Energy Storage (CAES) system is an economically appropriate system by employing a technical and thermodynamic approach, along with mathematical models, simulations, and experimental validation. The CAES system can support up to 80% of the electric grid by solely using wind technology. This is possible because during low-demand periods, the generated electrical power is used to compress air and transport it to underground tanks sealed at high pressure. When required, the stored air is used to drive a turbine, thus enabling energy generation. The results from this study revealed that CAES is only used in some countries, thus, developed

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at a small scale, despite exhibiting great results in improving wind power systems. These storage systems can be extended to smart microgrids to avoid the frequent blackouts reported in developing countries. The authors further claimed that in the future, energy storage technologies will play an important role in smart grids and polygeneration due to their capability for stable energy delivery from wind sources. Nevertheless, the rotational efficiency of CAES is affected while dissipating heat during compression and delivering cold energy during expansion. However, this efficiency can be improved by the integration of polygeneration through industrial heating processes. Hence, the future challenge is combining the air energy storage systems with cascading polygeneration to improve the system efficiency. In addition, researchers studied the optimization techniques in power generation systems based on numerical and mathematical models (24).

According to this study, the most addressed systems within renewable energies were wind and solar technologies, as well as their storage systems and energy balance models. The study concluded that to optimize a distributed energy generation system, emphasis must be laid on the design details and the risk assessment during uncertain conditions, since mathematical models can be a powerful tool for solving large-scale problems with high precision. Other researchers evaluated wind-power generation using predictions based on the Conditional Value-at-Risk optimization methodology, which assesses historical wind-power generation data for one year to subsequently evaluate its performance in terms of average energy generation and forecasting errors for multiple test regions (25).

The study concluded that by jointly assessing the generation sources in different geographical locations or technologically diverse positions, the forecasting errors may be reduced for energy production. In addition, the prediction results revealed that grouping geographically-dispersed wind-power generation sources can reduce the production forecasting errors by up to 50%. The proposed model in this study showed that with a carefully designed optimization problem, a better forecasting error can be achieved, while wind-power generation farms continue to produce electricity. Other authors evaluated Poland's potential for using different renewable technologies to generate power by considering the ecological conditions and economic aspects, such as the Internal Rate of Return, the Net Present Value, and the Return on Invested Capital (26).

Furthermore, market assessments and economic models were used to evaluate the investment profitability of these projects. Among their conclusions, the authors mentioned the importance of incorporating clean energy in the long term to improve Poland's energy efficiency. The authors also emphasized that investment profitability must be evaluated considering several dynamic indicators, i.e., indicators that vary over time. Further research compared the energy potential rates among different renewable technologies in Iran (27). The authors claimed that the regions with the greatest potential for harnessing wind energy are located in the central part of the country. In addition, they emphasized that the most profitable technology is the energy generation through an integrated system combining several technologies, such as wind power and biogas. Other authors assessed the wind energy potential and the economic aspects of Zahedan, Iran based on the data collected between 2003 and 2007 (28).

Subsequently, four different types of wind turbines were evaluated using an economic approach. The authors concluded that during the studied years, high average wind speed was detected between 9:00 a.m. and 3:00 p.m, with the maximum wind speed at noon. The authors also stated that the maximum and minimum general average speeds were 5.52 and 1.34 m/s, respectively. The latter occurred at night when the energy generation was extremely low. The maximum values of wind power were observed in 2003 with

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values of 106,525 W/m² and 933,159 kWh/m². Other studies statistically assessed the wind conditions in Hong Kong and their energy potential (29). The studies were based on the statistics collected by five weather stations in different terrains over six years. The Weibull distribution model, frequently used in wind-related studies, was used for the statistical analysis in this study. The conclusions revealed that the Weibull parameters changed throughout the four seasons of the year, with the highest and lowest values reported in autumn and summer, respectively. Additionally, the authors stated that in Hong Kong, hilltops and offshore locations are best suited for exploiting wind energy. Other authors evaluated the solar and wind energy potential in Nepal based on geospatial and economic analyses (30). This study was the first of its kind conducted in this region and revealed that Nepal's usable solar energy capacity was 47,628 MW at the production cost of around 91 USD/MWh, with the usable wind energy potential of 1,686 MW at the cost of around 46 USD/MWh. The authors called for specific policies in the development of renewable energy in Nepal. Finally, in another research study, statistical methodologies were applied to assess the degree of correlation between wind and solar resources within the Caribbean region of Colombia (31).

For this, data was collected from the Automated Satellite Meteorological Stations (EMAS) and the meteorological stations from the Institute of Hydrology, Meteorology, and Environmental Studies (IDEAM) from 2014 to 2018. The results from the individual and combined analyses of wind and solar energy data yielded the highest correlation coefficient of −1. This correlation is also observed while evaluating multiple technologies simultaneously, implying that when one resource increases, the other decreases. The conclusions stated the importance of conducting future energy studies in the Caribbean region of Colombia, considering both wind and solar energy as power sources. The following table summarizes this review considering elements such as the geographical area of the study, identified issues, applied methodologies, and main achievements obtained.

Table 1. Summary of Reviewed Studies

Geographic Zone	Identified Issue	Applied Methodologies	Main Achievements
Brazil	Interaction between wind power and EVs	Model and dimensioning of electrical capacity for future projections, specifically considering the increasing number of EVs.	Promotion of EVs to reduce CO2 emissions, enhancement of renewable energy grid infrastructure, and meeting future energy demands.
Turkey	Intermittent energy production	Multi-objective decision algorithm for hybrid wind-solar photovoltaic projects, legal and economic viability assessments, GIS for site selection.	Improved site selection for hybrid projects, integration of complementary renewable technologies to maximize utilization during adverse conditions.
Indonesia	Renewable energy potential assessment	Comprehensive literature review, identification of economic potentials, spatial mapping of renewable resources, empirical data collection and analysis.	Identification of research gaps, vast renewable energy resources both on land and sea, potential to meet current and future energy demands.

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Various regions	Optimization of hybrid power generation systems	Analysis of documentary information, application of AI algorithms for optimization of hybrid power systems, review of decades of research on hybrid systems.	Highlighted AI as a precise optimization tool, improvements in system dimensioning, positive impact on energy performance and economic aspects.
Global	Environmental and climatic impact of wind farms	Extensive literature review of global wind energy scenarios, development trends for offshore wind farms, environmental and climatic impact assessments.	Discussion on the environmental impact of wind farms, policy recommendations to mitigate negative effects, promotion of offshore wind technology, particularly in European countries.
Iran	Wind energy potential and economic analysis	Economic evaluation based on collected wind data, analysis of different wind turbine types, assessment of wind conditions over several years.	Identification of optimal wind turbine types, analysis of wind speed variations, economic viability of wind projects in specific regions, especially Zahedan.
Hong Kong	Wind conditions and energy potential assessment	Statistical analysis using Weibull distribution model, collection of data from multiple weather stations over different terrains and seasons.	Understanding seasonal variations in wind potential, identification of best locations for wind energy exploitation, such as hilltops and offshore sites.
Nepal	Solar and wind energy potential	Geospatial and economic analyses, estimation of energy capacities, production cost analysis for solar and wind energy.	Estimation of usable solar (47,628 MW) and wind energy capacities (1,686 MW), cost analysis highlighting economic viability, recommendations for renewable energy policies.
Colombia (Caribbean)	Correlation between wind and solar resources	Statistical methodologies to assess correlation, data collection from Automated Satellite Meteorological Stations and IDEAM meteorological stations.	High negative correlation between wind and solar resources, implications for combined energy studies, recommendations for future energy research considering both resources.
Poland	Economic viability of renewable technologies	Market assessments, use of economic models and dynamic indicators to evaluate long-term profitability and ecological impact of renewable energy projects.	Emphasis on long-term integration of clean energy, comprehensive profitability evaluation, identification of important dynamic indicators for renewable investments.
Central Iran	Profitability of integrated renewable systems	Comparative analysis of renewable technologies, focus on integrated systems combining wind power and biogas, assessment of central regions for potential.	Identification of most profitable regions and technologies, benefits of integrating multiple renewable technologies to enhance energy production and economic returns.

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Bibliometric analysis of wind energy generation studies

This bibliometric analysis unravels the knowledge related to the development of wind-power generation projects emerging worldwide. Moreover, it identifies the current state of the techniques associated with advanced technologies foundational for the development of detailed studies, experimental developments, technological developments, and innovations in this field. The current study applied the methodological guidelines proposed in (32), which established a pragmatic workflow for a quality bibliometric mapping based on the following steps:

Study Design: It´s the resolution of scientific questions stating the intention of a bibliometric analysis. For this work, current scientific research on the subject was identified from a technical approach. In addition, it determined the development of this field over time and in different parts of the world.

Data Collection: The information was obtained through the Web of Sciences scientific database, wherein the previously defined search criteria led us to obtain the most relevant studies on the subject within a specific period. The search criteria used were **"Wind Energy", "Renewable Energy", "Study", And "Potential",** using the conditional AND in all cases. This helped us obtain the maximum possible relationships among the search criteria. The time range was limited from 2011 to 2022. In the search, we only considered documents in English, since it is the most predominant language in the scientific field.

Data Analysis: The data was extracted in BibTex (.bib) format and processed using the R STUDIO™ statistical software. Various types of analyses were conducted, including descriptive statistics to summarize the main characteristics of the data, trend analysis to identify publication patterns over time, and bibliometric indicators such as citation analysis to assess the impact and relevance of the documents.

Data Visualization: The data was processed using the R STUDIO™ software under a set of commands to generate data charts, including bar, line, and mapping charts, to organize the data for further analysis. Visualization techniques such as co-authorship networks, keyword co-occurrence networks, and geographical distribution maps were utilized to provide insights into collaborative patterns, research trends, and regional contributions in wind energy research.

Interpretation: The images were accompanied by interpretations based on the results, thus providing a greater reference, and understanding.

Discussion: A significant data sample was obtained from scientific papers. The sample was obtained by applying equation (1). Subsequently, the documents were reviewed according to the selected criteria, followed by a general discussion of the most important geographical and technical aspects. Notably, the most representative papers were cited to conduct an adequate analysis coherent with the objectives of the discussion.

Eq. (1) represents the size of a simple probabilistic sample, which was used due to its practicality and wherein all parameters of the studied population yield quite similar results (33).

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$$n = \frac{N \cdot Z_{\alpha}^{2} \cdot p \cdot q}{e^{2} \cdot (N-1) + Z_{\alpha}^{2} \cdot p \cdot q} \quad (1)$$

where n is the sample size, N is the population size or universe. Z_{α} represents the confidence level, e is the maximum accepted estimation error, p is the probability of the event occurring, and q is the probability that it does not occur, i.e., 1–p. The processed data were summarized indicating the number of documents imported into the database, year of validation, document type, number of authors, among other important variables (see Table 2). The assessment included the identification of 901 documents.

Table 2. Data Summary Table

DESCRIPTION	RESULTS
MAIN INFORMATION	
Sampling Period	2011 to 2022
Sources (Magazines, Books, etc.)	273
Documents	901
Average years of publication	3.5
Average number of citations per document	21.16
AVERAGE NUMBER OF CITATIONS PER YEAR	
References	37510
DOCUMENT TYPES	
Papers	721
Paper; data	2
Paper; recent hits	17
Papers; reports	16
Publishing materials	1
Reviews	142
Reviews; recent hits	2
DOCUMENT CONTENT	
Keywords plus (ID)	1683
Author keywords (DE)	2774
AUTHORS	
Authors	2816
Author References	3143
Single Author Documents	78
Multiple Author Document	2738
AUTHOR COLLABORATIONS	
Single Author Documents	85
Documents per Author	0.32
Authors per Document	3.13
Co-authors per Document	3.49
Collaboration Index	3.36

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Figure 1 shows the evolution of wind-power generation research studies in numerous documents published worldwide. The data reveals that research trends are increasing, with a production peak in 2021, when 146 documents were published in different journals. From 2011 to 2015, a similar number of studies were published; however, in 2016 and 2017, an increasing trend in publications was reported, thus evidencing larger scientific production on the subject matter.

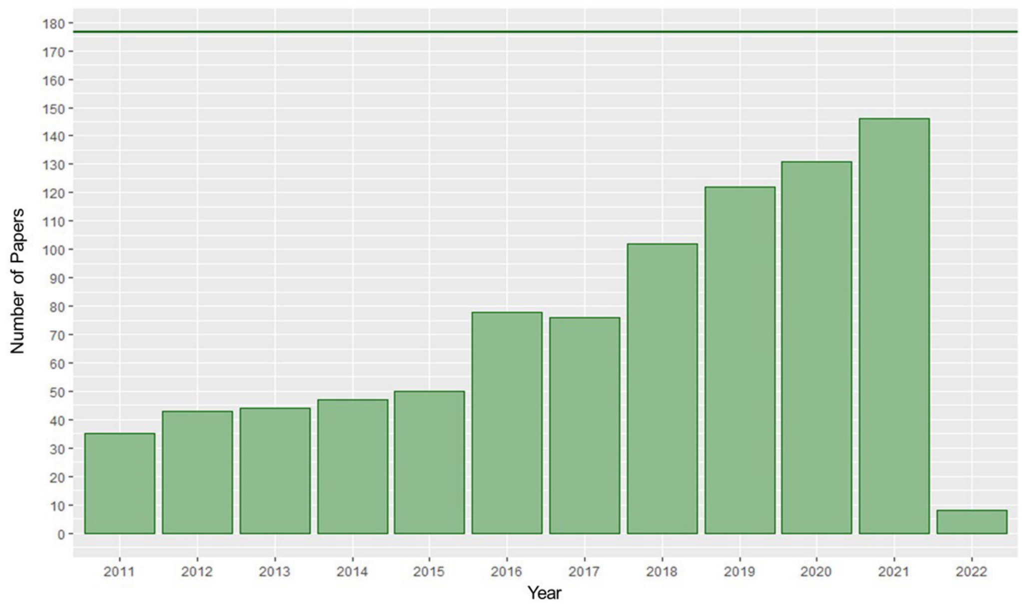

Figure 1. Number of publications from 2011–2022

Table 3 lists the most relevant authors in terms of the number of publications. Here the top author is Mostaphaeipour A., who has published eight wind-power generation papers over the last ten years. In addition, Figure 2 lists the five main authors in terms of number of publications between 2011 and 2021. As can be observed, Chen C. and Kaldellis J.K. have both been actively publishing since 2011, which grants them greater research relevance due to their continuous participation in these studies.

Table 3. Top Five Authors with Most Publications

Author	Articles
Mostafaeipour A	8
Chen C	6
Kaldellis JK	6
Breyer C	5
Liu Y	5

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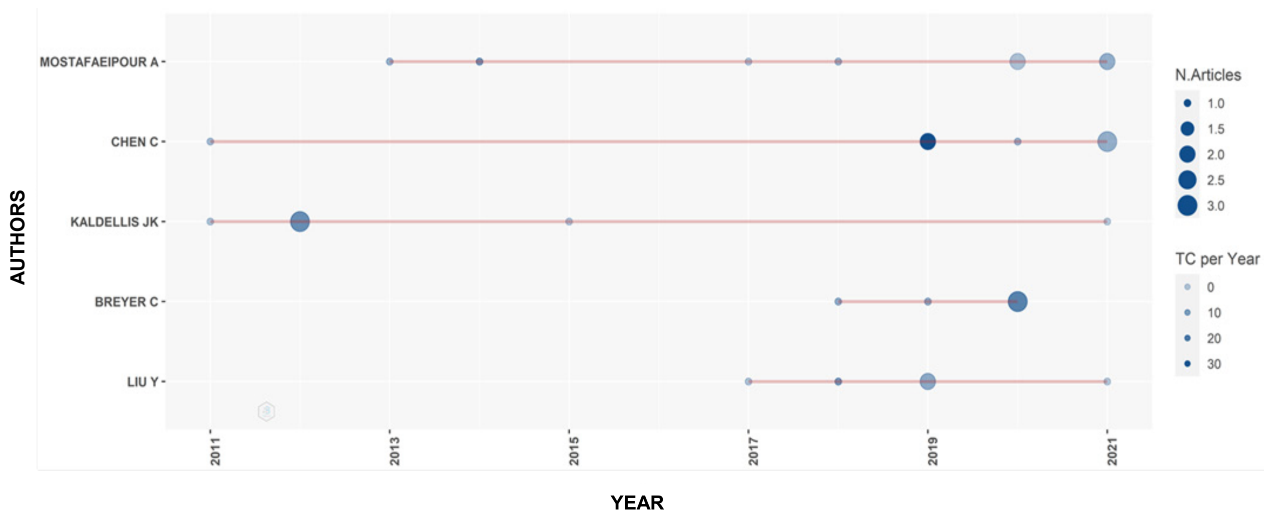

Figure 2. Publications of the top five authors from 2011-2021

This section also details the interconnection among the most common words, authors, and countries, thus providing an assessment of productivity by country and subject matter affinity. Figure 3 highlights this interconnection among three fields. This figure indicates that Iranian and Chinese authors most closely relate in terms of search keywords.

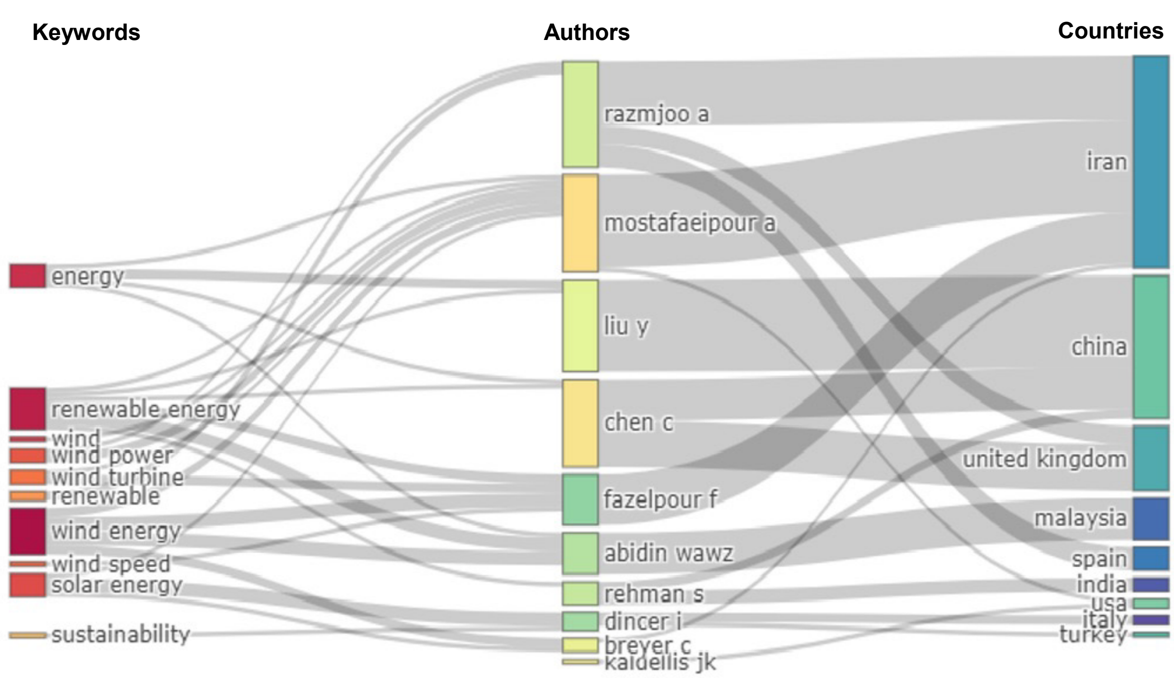

Figure 3. Interconnection between keywords, authors, and the countries of the main authors

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However, this differs when we analyze scientific production by country, as shown in Figure 4 above. As evident, the USA, China, Turkey, the United Kingdom, and Iran have the highest scie

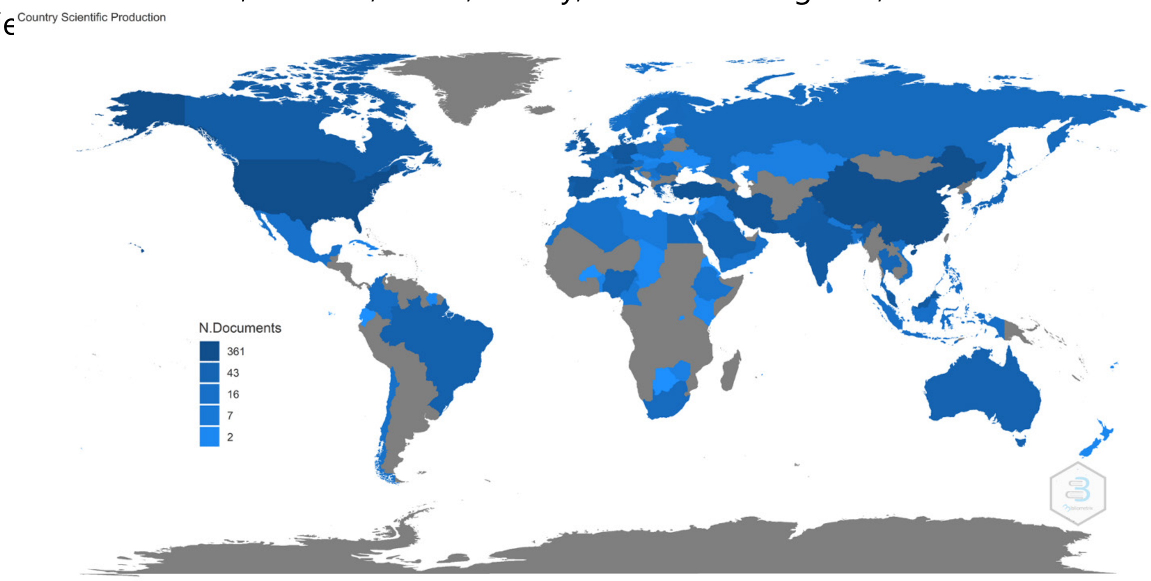

Figure 4. The Map of Scientific Production by Country from 2011-2022

Table 4 provides a summary of the top ten countries contributing the highest number of documents on issues related to wind energy generation.

Table 4. Top Ten Countries by Paper Publications

COUNTRIES	TOTAL PRODUCTION
USA	361
China	291
Turkey	202
United Kingdom	172
Iran	154
Germany	138
Spain	120
Malaysia	105
India	98
Italy	90

This study also assesses the relationship among the correlated keywords in scientific documents. This allows us to identify the terms and theme clusters, which allow us to better approach the knowledge themes and/or trends. Figure 5 (generated via the Vosviewer software) shows the different terms assessed and their thematic correlation. Therein, four large, color-coded word clusters can be appreciated: Group 1 is red; Group 2 is blue; Group 3 is yellow; Group 4 is green. The term denoted by the biggest solid circle is "WIND ENERGY", which has the greatest coexistence among all papers in the database. Other predominating terms are "MODEL", "GENERATION", and "ELECTRICITY".

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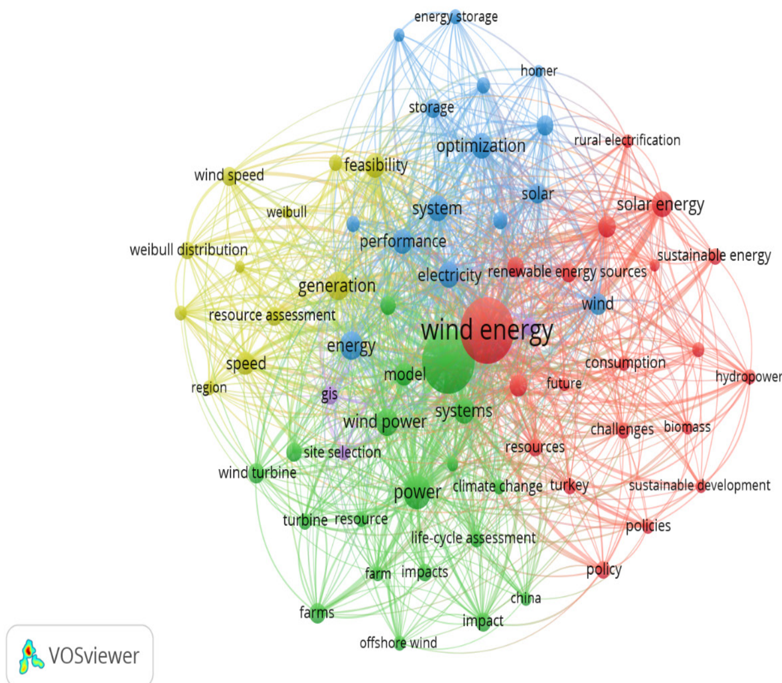

Figure 5. Keyword Data Correlations, 2011–2022

For Group 1, we can infer that the cluster is related to the efforts and concerns regarding renewable energy, both in present and future situations, since there are correlations with words, including challenges, policies, resources, consumption, energy sources, future, etc. This can be explained by the nature of the research studies, since they are based on current experimentations seeking to interpret, determine, and validate theories, discoveries, and the operational trends of these technologies. Conversely, Group 2 is more focused on resource optimization, storage, and system operation. This can be interpreted by the intentions of continuously improving the different systems constituting the generation of non-conventional alternative energy. Group 3 is focused on the qualities offered by the medium. This explanation is based on keywords, including wind speed, resource, generation, feasibility, and Weibull, the latter being a distribution method used to describe wind variation. The foregoing may be a consequence of more specific research studies focusing on better leveraging wind based on its quality. Finally, Cluster 4 is focused on the operation and the positive and negative consequences for both wind turbines and the environment. Hence, we may infer that these issues associate the level of operation or efficiency with its environmental impact.

Criteria and restrictions for the assessment of wind energy harnessing projects

This section discusses the aspects that must be considered in decision-making related to wind energy generation investment projects. The evaluation criteria, the economic aspects, and the financial aspects are detailed below.

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Assessment Criteria

Determination of Site Conditions: the conditions to identify and select an appropriate site with wind resources are given by an extension of available land without relevant obstacles. If the site assessed does not contain these obstacles, the roughness of the terrain is assessed in all geographical directions. Obstacles in the path of the wind, before reaching the wind turbine, change the wind flow from unobstructed (laminar) to turbulent (34). Some of the commonly identified obstacles are:

Turbulent flow: due to its internal instabilities in the direction of the flow, it does not allow aerodynamic forces to appear in the profiles of the wind turbine blades, thus making them inefficiently convert the kinetic energy of the wind into rotational mechanical power.

Ground Roughness: ground surface irregularities which produce wind turbulence, that tend to disappear when the flow separates from the ground at a greater height. This factor directly affects the viability of a wind generation project, since useful winds are only found at higher altitudes, thus requiring taller and more robust wind turbines, which are more expensive and require a more complex installation. In this sense, forests, and conurbations in the same direction of the wind become an obstacle for effectively harnessing wind energy.

Assessment of Environmental Restrictions: in general, environmental restrictions are related to the national regulations from the corresponding country, or from regional or local environmental protection entities. These entities must comply with national sustainability guidelines, guarantee that projects comply with their obligation to protect water bodies, and assess the impact that a project may have on the flora, fauna, soil, and water resources. Protected areas are also clearly delimited in each country, and wind generation projects must avoid them in order not to change the natural dynamics of the local flora, fauna, water resources, and their supply to human communities that depend on them for daily sustenance. From its onset, project planning can timely identify area locations and their relationship with the environment to restrict the location and expansion of the project initiative and mitigate the risks of natural activity displacement within the site.

Assessment of Aeronautical Restrictions: international aeronautical regulations restrict civil works in aircraft approach and operation areas, especially when within the limiting surfaces of airport maneuvers (35). Any wind energy generation project must contemplate aeronautical easements, which are surfaces whose coordinates limit the heights and presence of urban planning. At this point, both distance determination and air safety evaluations in accordance with national regulations must be considered. Likewise, the wind farm location pre-study indicates the restriction distances of the aeronautical aids, which will safely restrict the installation areas of wind turbines.

Assessment of Administrative Restrictions: for any territorial entity in any country, land use is an aspect that is clearly managed by local entities. Regulations generally define programs, actions, and standards adopted to guide and manage the physical development of the territory and the use of the land. In general, wind energy projects must be located outside current urban or industrial expansion areas. Rural land is allocated for agriculture, livestock, forestry, exploitation of natural resources and other similar activities, such wind energy harnessing. Likewise, land use for wind turbine installations is restricted to the exploitation of mineral ore, hydrocarbons, and construction materials from the subsoil, which are subjected to state concessions. Hence, this possibility is becoming an additional restriction for effectively harnessing wind energy.

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Assessment of Logistic Restrictions: wind turbines are oversized for conventional transportation routes which mean that they will normally require adaptations for different transportation logistics. Port maneuvers must also be specialized for ship and docking configurations, as well as for the logistics of unloading cargo (36). The docks used for unloading wind turbine sections and parts must have a draft of over 20 meters and wide evacuation routes for initial transportation maneuvers. Likewise, experienced transportations teams may be required according to load volumes and lengths. It is also important to perform a detailed route study, considering restrictions due to width, bridge capacity, pronounced curves, slopes, and pavement conditions (see Figure 6 below).

Figure 6. (A) Maritime transport of wind turbine blades (37), (B - C) Land transport of wind (38).

Evaluation of the Energy Evacuation Capacity: if the conditions for installing a wind farm are favorable, the energy generated by it must be integrated into the power system planning. From the operational standpoint, wind farms must be based on a detailed review of the intrinsic impacts from the operation on the maximum load level of the existing distribution grid components. In both developed and developing countries, power generation is an essential need, thus forming an important part of public service for which the government encourages the development of free production initiatives.

Economic Aspects

The assessment of economic aspects will determine whether the project is economically viable and thus, the development of future projects. The main economic aspects that must be considered are supply and demand of the equipment, raw material costs, reference fuels for the generation of conventional thermal energy, the exchange rate, the projects, the class of wind supported by the turbine, the number of wind turbines, location logistics, the connection distance, the transportation route, and the country of origin. Based on similar aspects, an average project costs around 1,391 USD per rated kW installed in the United States before the pandemic (39). In South America, wind energy projects can reach up to 1,500 USD per kW and higher if the size and logistic conditions of the project are inadequate (40). These amounts determine the capital expenditures (CAPEX) of the project, which forecasts the return of investment through energy sales, which also depends on

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market conditions. The specificities of the economic assessment of each country and its macro and microeconomic variables include the location of the manufacturer ultimately delivering the equipment on the required date, and the energy costs in the country of installation, considering currency volatility, since CAPEX must be settled in local currency. CAPEX capital cost includes the price of the wind turbine itself plus "Plant Balance," which are the infrastructure expenses required for the construction and installation of the wind turbines, including foundations, roads, substations, and transmission lines. This also includes developmental costs, such as project design fees, the technical and environmental studies, and the wind resource itself. Energy sales is the input variable that must offset CAPEX investments. To sustain the operation, operating expenses (OPEX) must be managed, since they support the scheduled operation of the wind turbine and, without them, a reliable operation cannot be achieved. The sum of both cost components coupled with the lifespan of the installation produces the Levelized Cost of Energy. These energy costs have experienced a downward trend in the last 10 years (41). Wind energy costs for terrestrial installations have decreased by 68% since 2010, the second largest cost decreases only surpassed by solar photovoltaic energy (42). The following table lists the CAPEX, OPEX and their variations from 2010 to 2020:

Table 5. Trends in Total Installation Costs, Capacity Factors, and Levelized Costs of Electricity by Technology, 2010–2020

	Installation Cost			**Capacity Factor**			**Installation Cost**		
	2020 - USD/kW			**%**			**2020 - USD/kW**		
	2010	**2020**	**Variation**	**2010**	**2020**	**Variation**	**2010**	**2020**	**Variation**
Bioenergy	2619	2543	−3%	72	70	−2%	$ 0.076	$ 0.076	0%
Geothermal	2620	4468	71%	87	83	−5%	$ 0.049	$ 0.071	45%
Hydroelectric Power	1269	1870	47%	44	46	4%	$ 0.038	$ 0.044	18%
Solar PV	4731	883	81%	14	16	17%	$ 0.381	$ 0.057	−85%
CSP	995	4581	−50%	30	42	40%	$ 0.340	$ 0.108	−68%
Onshore Wind Power	1971	1355	−31%	27	36	31%	$ 0.089	$ 0.039	−56%
Offshore Wind Power	4706	3185	−32%	38	40	6%	$ 0.162	$ 0.084	−48%

Source: (33)

Financial Aspects

With reference to CAPEX, the unit costs per MW installed offers more competitive values due to logistical advantages in large wind farm projects. In turn, the application of an economy of scale to the supply chain can be used to assess impacts and make decisions that can directly affect cost reduction. The attractive values for obtaining the lowest capital unit cost can be found in projects of 50 to 100 MW. In monetary terms, a 100-MW project would represent between 139 and 175 million USD (43), depending on the supplier location and the corresponding installation features. Nowadays, electrical energy from renewable resources, such as wind, is considered a response to future energy demand and not to an emergency or instantaneous energy requirement. Long-term low-risk investments have become the most manageable alternative for these projects, both for energy market agents and investors. Depending on their origin, project resources are generally financed by local investors, external investors, and banks. Thus, local resources are invested in the development studies that demonstrate project viability. The resources

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from the external investors can be programmed to diminish the investment risks and can be used to optimally cover the equipment production costs considering economies of scale, lower transportation costs, and meeting the expectations from local resources for project development, backed by own resources and bank loans. Also, investors usually rely on the efficiency from national governments to evaluate trade agreements and economic cooperation programs. For large-scale projects, Project Finance has become a good funding alternative. Project Finance is mainly characterized by the creation of a legally-independent company, whose sole objective is to manage investments for large-scale projects (44-46). Finally, the external investor is the owner of a Special Purpose Vehicle and becomes accountable for the debt. Even before the construction, Project Finance supports the configuration of all project stages, debt equity, energy production, and sale prices through long-term contracts or sales on the energy exchange. Only a steady income from energy sales will assure the project to proceed as expected (47-49). Hence, securing this income through contracts represents the real financial closure of the project. Thus, the product ultimately sold will no longer be energy, but the project itself (50).

Conclusions

The present study provided an overview of the scientific dynamics related to wind energy potential from 2011 to 2022, focusing on technical and geographical aspects, as well as new wind technology trends and methodologies. Through a comprehensive bibliometric analysis, key insights into the most cited articles, leading contributing countries, prominent authors, and recurring keywords in wind energy research were identified. The analysis highlights a growing research trend in wind energy, with significant contributions from countries such as China and the United States. Emerging countries also show high interest in this research topic, reflecting a commitment to developing alternative energy generation projects, particularly in regions with favorable economic, political, natural, and cultural conditions. The technical and geographical context of knowledge applicable to potential energy estimation studies and wind farm design was thoroughly examined. Additionally, the study evaluated financial and economic criteria, alongside technical restrictions, which may impact wind energy generation projects. The results reveal varying energy potential rates by geographical area, considering natural, legal, and economic conditions. There is a notable interest among many countries in assessing their territories' suitability for implementing renewable energy projects, and in exploring optimization methodologies and applied techniques over the study period. This research aims to serve as an international benchmark for future reviews in the wind energy field, contributing valuable insights for decision-making processes in wind energy harnessing projects.

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References

1. Tian J, Yu L, Xue R, Zhuang S and Shan Y. Global low-carbon energy transition in the post-COVID-19 era. Appl. Energy [Internet]. 2022 Feb; 307(1):118205. Available in: https://doi.org/10.1016/J.APENERGY.2021.118205
2. Pegels A and Altenburg T. Latecomer development in a "greening" world: Introduction to the Special Issue. World Dev [Internet]. 2020 Nov; 135:105084. Available in: https://doi.org/10.1016/J.WORLDDEV.2020.105084
3. Ezhiljenekkha GB and Marsalinebeno M. Review of Power Quality Issues in Solar and Wind Energy. Mater. Today Proc [Internet]. 2020. 24(4):2137–2143. Available in: https://doi.org/10.1016/J.MATPR.2020.03.670
4. Deloitte Insights [Internet]. Global trends in renewable energies; [cited January 01, 2022] Available in: https://www2.deloitte.com/content/dam/Deloitte/es/Documents/energia/Deloitte-ES-tendencias-globales-energias-renovables.pdf
5. Global Wind Energy Council [Internet]. Global Wind Report 2021; [cited April 6, 2022] Available in: https://gwec.net/global-wind-report-2021/
6. Sun Y, Pei W, Jia D, Zhang G, Wang H, Zhao L and Feng Z. Application of integrated energy storage system in wind power fluctuation mitigation. J. Energy Storage. 2020 December; 32:101835. Available in: https://doi.org/10.1016/J.EST.2020.101835
7. Carvajal-Romo G, Valderrama-Mendoza M, Rodríguez-Urrego D and Rodríguez-Urrego L. Assessment of solar and wind energy potential in La Guajira, Colombia: Current Status, and future prospects. Sustain. Energy Technol. Assess [Internet]. 2019 December; 36:100531. Available in: https://doi.org/10.1016/J.SETA.2019.100531
8. Richardson DB. Electric vehicles and the electric grid: A review of modeling approaches, Impacts, and renewable energy integration. Renew. Sust. Energ. Rev [Internet]. 2013 March; 19:247–254. Available in: https://doi.org/10.1016/J.RSER.2012.11.042
9. Azimi, R., Ghofrani, M., & Ghayekhloo, M. (2016). A hybrid wind power forecasting model based on data mining and wavelets analysis. Energy Conversion and Management, 127, 208-225.
10. Asensio, F. J., Martín, J. I., Zamora, I., Oñederra, O., Saldaña, G., & Eguía, P. (2018). A system approach to harnessing wind energy in a railway infrastructure. IECON 2018 - 44th Annual Conference of the IEEE Industrial Electronics Society, 1646-1651.
11. Wang, C., Zhang, H., & Ma, P. (2020). Wind power forecasting based on singular spectrum analysis and a new hybrid Laguerre neural network. Applied Energy, 259, 114139.
12. Gaied, H., Naoui, M., Kraiem, H., Goud, B. S., Flah, A., Alghaythi, M. L., Kotb, H., & Ali, S. G. (2022). Comparative analysis of MPPT techniques for enhancing a wind energy conversion system. Frontiers in Energy Research, 10, 975134.
13. Katsanos, E., Thöns, S., & Georgakis, C. (2016). Wind turbines and seismic hazard: A state-of-the-art review. Wind Energy, 19, 2113-2133.
14. Yang, B., Zhong, L., Wang, J., Shu, H., Zhang, X., Yu, T., & Sun, L. (2021). State-of-the-art one-stop handbook on wind forecasting technologies: An overview of classifications, methodologies, and analysis. Journal of Cleaner Production, 124628.
15. Khan, F. H., Pal, T., Kundu, B., & Roy, R. (2021). Wind Energy: A Practical Power Analysis Approach. 2021 Innovations in Energy Management and Renewable Resources.
16. Marugán, A. P., Márquez, F., Pinar Pérez, J. M., & Ruiz-Hernández, D. (2018). A survey of artificial neural network in wind energy systems. Applied Energy.
17. Azimi, R., Ghofrani, M., & Ghayekhloo, M. (2018). Research and application of a combined model based on variable weight for short-term wind speed forecasting. Renewable Energy, 116, 669-684.

doi: 10.25100/iyc.v26i1.13503

18. Aydin NY, Kentel E and Sebnem Duzgun H. GIS-based site selection methodology for hybrid renewable energy systems: A case study from western Turkey. Energy Convers. Manag [Internet]. 2013 June; 70:90–106. Available in: https://doi.org/10.1016/J.ENCONMAN.2013.02.004
19. Langer J, Quist J and Blok K. Review of Renewable Energy Potentials in Indonesia and Their Contribution to a 100% Renewable Electricity System. Energies [Internet]. 2021;14(21):7033. Available in: https://doi.org/10.3390/EN14217033
20. Zahraee SM, Khalaji Assadi M and Saidur R. Application of Artificial Intelligence Methods for Hybrid Energy System Optimization. Renew. Sust. Energ. Rev [Internet]. 2016; 66:617–630. Available in: https://doi.org/10.1016/J.RSER.2016.08.028
21. Leung DYC and Yang Y. Wind energy development and its environmental impact: A review. Renew. Sust. Energ. Rev [Internet]. 2012 January; 16(1):1031–1039. Available in: https://doi.org/10.1016/J.RSER.2011.09.024
22. Yang Y, Bremner S, Menictas C and Kay M. Battery energy storage system size determination in renewable energy systems: A review. Renew. Sust. Energ. Rev [Internet]. 2018 August; 91:109–125. Available in: https://doi.org/10.1016/J.RSER.2018.03.047
23. Venkataramani G, Parankusam P, Ramalingam V and Wang J. A review on compressed air energy storage–A pathway for smart grid and polygeneration. Renew. Sust. Energ. Rev [Internet]. 2016 September; 62:895–907. Available in: https://doi.org/10.1016/J.RSER.2016.05.002
24. Theo WL, Lim JS, Ho WS, Hashim H and Lee CT. Review of distributed generation (DG) system planning and optimisation techniques: Comparison of numerical and mathematical modelling methods. Renew. Sust. Energ. Rev [Internet]. 2017 January; 67(1):531–573. Available in: https://doi.org/10.1016/J.RSER.2016.09.063
25. Han C and Vinel A. Reducing forecasting error by optimally pooling wind energy generation sources through portfolio optimization. Energy [Internet]. 2022 January; 239(1):122099. Available in: https://doi.org/10.1016/J.ENERGY.2021.122099
26. Niekurzak M. The Potential of Using Renewable Energy Sources in Poland Taking into Account the Economic and Ecological Conditions. Energies [Internet]. 2021 November; 14(22):7525. Available in: https://doi.org/10.3390/EN14227525
27. Hosseini SE, Andwari AM, Wahid MA and Bagheri G. A review on green energy potentials in Iran. Renew. Sust. Energ. Rev [Internet]. 2013 November; 27:533–545. Available in: https://doi.org/10.1016/J.RSER.2013.07.015
28. Mostafaeipour A, Jadidi M, Mohammadi K and Sedaghat A. An analysis of wind energy potential and economic evaluation in Zahedan, Iran. Renew. Sust. Energ. Rev [Internet]. 2014 February; 30:641–650. Available in: https://doi.org/10.1016/J.RSER.2013.11.016
29. Shu ZR, Li QS and Chan PW. Statistical analysis of wind characteristics and wind energy potential in Hong Kong. Energy Convers. Manag [Internet]. 2015 September; 101:644–657. Available in: https://doi.org/10.1016/J.ENCONMAN.2015.05.070
30. Neupane D, Kafle S, Karki KR, Kim DH and Pradhan P. Solar and wind energy potential assessment at provincial level in Nepal: Geospatial and economic analysis. Renew. Energ [Internet]. 2022 January; 181(1):278–291. Available in: https://doi.org/10.1016/J.RENENE.2021.09.027
31. Bonilla Prado GA, Ruíz Mendoza BJ and Salazar Gil JL. Energy correlation between global solar radiation and wind speed in the Colombian Caribbean. INGE CUC [Internet]. 2021; 17(1):256–284. DOI: 10.17981/ingecuc.17.1.2021.20
32. Aria M and Cuccurullo C. Bibliometrix: An R-tool for comprehensive science mapping analysis. J. Informetr. [Internet]. 2017 November; 11(4):959–975. Available in: https://doi.org/https://doi.org/10.1016/j.joi.2017.08.007

doi: 10.25100/iyc.v26i1.13503

33. Murray RS and Larry JS. Statistics. 6a ed. McGraw-Hill Interamericana; 2020. ISBN: 9786071514639
34. Mott R. Fluid Mechanics. Mexico: PEARSON Education. 2006. ISBN: 970-26-0805-8.
35. International Civil Aviation Organization (ICAO). Aerodrome Design Manual. 3rd edition. 2006
36. Cotrell J, Stehly T, Johnson J, Roberts JO, Parker Z, Scott G and Heimiller D. Analysis of Transportation and Logistics Challenges Affecting the Deployment of Larger Wind Turbines: Summary of Results. 2014 January. Technical Report: NREL/TP-5000-61063. Available in: https://www.nrel.gov/docs/fy14osti/61063.pdf
37. Fernández Mungía S. The journey of 156 wind turbine blades on their way to Spain by boat. Diario Renovables; [cited September 12, 2019]. Available in: https://www.diariorenovables.com/2019/02/transporte-barco-palas-aerogenerador.html
38. FAYMONVILLE. The Wind and Energy Sector. [cited September 12, 2022. Available in: https://www.faymonville.com/areas-de-actividad/energia-eolica-y-sector-energetico/
39. U.S. Energy Information Administration (EIA). Average U.S. construction cost for onshore wind generation decreased by 27% since 2013. [cited October 1, 2021. Available in: https://www.eia.gov/todayinenergy/detail.php?id=49176
40. Revista Semana. El costo de la energía eólica. [citado el 22 de octubre de 2021: Disponible en: https://www.semana.com/pais/articulo/el-costo-energia-eolica/209799/
41. Stehly T, Beiter P and Duffy P. 2019 Cost of Wind Energy Review. [cited January 15, 2022] Available in: https://www.nrel.gov/docs/fy21osti/78471.pdf
42. IRENA. Renewable Power Generation Costs in 2020. [cited June 9, 2022. Available in: https://www.irena.org/publications/2021/Jun/Renewable-Power-Costs-in-2020
43. g-Advisory. Energía eólica: Principales características y riesgos técnicos. [citado el 02 de agosto de 2022]. Disponible en: https://www.fiapinternacional.org/wp-content/uploads/2016/04/sofia_lazcano-1.pdf
44. Solsona A. Análisis de la viabilidad económica de un parque eólico a través de un Project Finance. [citado el 11 de noviembre de 2021]. Disponible en: https://repositorio.comillas.edu/jspui/bitstream/11531/25870/1/TFM000927.pdf
45. Ceballos J, Villalobos B, García D y Palomino K. Economía Circular: visionando un enfoque para la gestión de residuos sólidos municipales - Caso de estudio en 5 municipios de la subregión Dique del departamento de Bolívar, Colombia. Revista El Arrendajo Escarlata. 2021 Julio; 10(2):56-67

46. Mendoza Fandiño JM, González Doria YE, Doria Oviedo M, Pedroza Urueta A y Ruiz Garcés AF. Fabricación de biocombustibles sólidos densificados (briquetas) a base de serrín de acacia y estiércol de bovinos en el departamento de Córdoba. Ingeniare. Rev. chil. Ing [Internet]. 2020 septiembre; 28(3):448-460. Disponible en: http://dx.doi.org/10.4067/S0718-33052020000300448

47. Ceballos Sandoval J, Villalobos Toro B, Bolívar Anillo H, Martínez Consuegra D., et al. Residuos Sólidos: una alternativa de aprovechamiento para los municipios de bolívar. Barranquilla, Colombia.: Ediciones Universidad Simón Bolívar; 2020. ISBN: 978-958-53184-4-1

48. López Juvinao DD, Ginete Siosi LM y Iguaran Montaño YY. Optimización de las acciones ambientales en empresa que explota agregados pétreos en La Guajira, Colombia. Ingeniare. Rev. chil. Ing [Internet]. 2022 septiembre; 30(3):455-465. Disponible en: http://dx.doi.org/10.4067/S0718-33052022000300455.

49. Poveda-Orjuela P, García-Díaz JC, Pulido-Rojano A and Cañón-Zabala G. Parameterization, Analysis, and Risk Management in a Comprehensive Management

doi: 10.25100/iyc.v26i1.13503

System with Emphasis on Energy and Performance (ISO 50001: 2018). Energies. 2020 October; 13(21). Available in: https://doi.org/10.3390/en13215579

50. Pulido-Rojano A, Sanchez-Sanchez P and Melamed-Varela E. Nuevas tendencias en Investigación de Operaciones y Ciencias Administrativas: Un enfoque desde estudios iberoamericanos. Barranquilla, Colombia: Ediciones Universidad Simón Bolívar. 2018. Disponible en: http://hdl.handle.net/20.500.12442/2601.

doi: 10.25100/iyc.v26i1.13503