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Bibliometrix applied to computational simulation for wind generator

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Abstract: This study presents a comprehensive bibliometric analysis of computational simulations in wind turbine projects, addressing their pivotal role amid growing demands for renewable energy and engineering project optimization. The primary objective is to discern trends, focal areas, and global collaboration networks. Utilizing Scopus and Web of Science databases, supported by CAPES, all pertinent publications on computational simulations in wind turbine projects were scrutinized. Bibliometric metrics were analyzed using the bibliometrix library in R. Findings reveal a increase in publications since 2022, particularly in aerodynamic optimization and offshore projects. Leading contributors are universities, research centers across Europe, North America, and prominently China. Co-authorship networks underscore significant collaborations among global academic institutions. Key terms such as "computational modeling," "CFD (Computational Fluid Dynamics)," and "wind turbine" predominate in literature. The analysis confirms the escalating significance of computational simulations in wind turbine projects, underscored by burgeoning publications and international partnerships. Integration of emerging technologies like artificial intelligence and machine learning into market practices is evident. This study serves as a foundational resource for future researchers and industry stakeholders, identifying promising avenues and areas necessitating further exploration.
Keywords: bibliometry; wind turbine; numerical study; aerodynamic optimization; renewable energy.

1 Introduction

In recent decades, wind power has become one of the main sources of renewable energy, playing a key role in the global energy transition to mitigate climate disasters. In this sense, expanding its use contributes to reducing greenhouse gas emissions, especially in countries where the energy matrix is predominantly based on fossil fuels, since wind energy is a clean and renewable alternative for producing electricity (Custódio, 2009).

The components of a wind generation system include wind turbines, which convert the kinetic energy of the wind into electrical energy. The wind turbine driven by the wind transmits mechanical energy to the shaft, which in turn moves the generator. Based on electromagnetic conversion,the electric generator converts the mechanical energy into electrical energy, a process that often depends on the presence of multiplier gears between the turbine and the generator to compensate for the dif- ferent speeds of the two devices Lopez 2012. Therefore, the use of computer simulation is essential for engineering projects when developing turbines of any type, whether they have a horizontal or vertical axis, with variable frequency control or not, as well as all the other important characteristics that vary according to the wind turbine.

In this way, optimizing wind turbine projects increasingly requires the use of numerical simu- lations due to their ability to predict the performance and feasibility of implementing a wind gen- eration system in practice. In order to reduce costs and operating parameters, Computational Fluid Dynamics (CFD) is becoming more robust than analytical methods and experimentation. From this perspective, according to

Cunha Júnior 2021, CFD encompasses:

The area that deals with the numerical simulation of fluid flows, heat transfer and related phenomena, making it possible to calculate operating conditions - temperature, pressure and transport properties - in three dimensional or two-dimensional space. In this way, it is possible to verify problems that a traditional simulation would not be able to map, as it works with average parameters.

In this scenario, understanding research trends and the evolution of scientific knowledge are fundamental to identifying gaps and opportunities for innovation. In order to map this effectively, bibliometric analysis is a powerful tool. According to Guedes 2012:

Bibliometrics is a statistical tool that makes it possible to map and generate different indicators for the treatment and management of information and knowledge, especially in scientific and technological information and communication systems information and communication systems, and productivity, necessary for planning, evaluating and managing of science and technology in a given scientific community or country.

The overwhelming volume of new information, conceptual developments and data is where bibliometrics comes in handy as it provides a structured analysis for a large set of facts, thereby providing the "big picture" of existing research Aria and Cuccurullo 2017 (cited in Crane 1972). In this way, bibliometrics enables a systematic, broad and transparent introduction to any scientific topic that has published material.

Therefore, this study aims to carry out a bibliometric analysis of publications on computer simulations applied to wind turbine projects, using the Scopus and Web of Science databases together and the "Bibliometrix" library of the R programming language. These databases are recognized for the breadth and quality of their records, covering a wide range of disciplines and providing a detailed overview of global scientific production.

In short, by investigating publication patterns, collaboration between authors and institutions, as well as the main areas of focus and temporal evolution, this bibliometric analysis aims to provide valuable insights into the current state of research into wind turbines and the relevance of computer simulation to the sector. It is hoped that the results will contribute to future research, direct interna- tional collaborations and encourage the creation and development of more efficient and sustainable wind power generation technologies.

The objectives of this bibliometric review are:

a) To assess the global expansion of wind power as a crucial renewable energy source amidst climate change mitigation efforts.
b) To analyze the role of computer simulations in optimizing wind turbine design and performance prediction.
c) To explore the applicability and advancements of Computational Fluid Dynamics (CFD) in wind energy projects.
d) To conduct a comprehensive bibliometric analysis using Scopus and Web of Science databases to identify trends, collaborations, and gaps in research on computer simulations in wind turbine projects.

2 Methodology

To make the research replicable in other areas of study on energy or outside this scope, we opted for a systematic review of the literature based on Catumba et al. 2023, Raman et al. 2022 and Bortoluzzi, Souza, and Furlan 2021, which are works that address the functionalities of bibliometrics to extract information from a database and the applicability of these insights to conduct future research.

Thus, from the journal portal of the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (Capes), the searches in the databases, with the signed content of the scientific publishers, were carried out as follows: ("computational simulation" OR "numerical simulation" OR "simula- tion model" OR "cfd" AND "simulation" OR "numerical" AND "study" OR "computational" AND "fluid" AND "dynamics") AND ("wind energy" OR "wind power" OR "wind turbine"). These key- words were used in the Scopus and Web of Science databases and applied to the title, abstract and keywords. In addition, the following filters were applied to the searches: (1) Works published from 2019 to May 2024. (2) English as main language. (3) Article or review-type publications. (4) Works focusing on engineering and its subfields. (5) Final stage of publication.

The two databases have been merged into a single file by the following code using RStudio. The R language will automatically delete repeated works from the two databases. Executing the last line in the

Figure 1 will open a “Bibliometrix” library tab in the device’s default browser. Figure 1 shows a general analysis of the data made by “Bibliometrix” after the upload process has been completed.

Listing 1. Algorithm for installing R packages and bibliometric analysis.

```
# Install  necessary R packages
install.packages("vctrs")
install.packages("bibliometrix")
devtools::install_github("massimoaria/pubmedR")
install.packages("pubmedR")
install.packages("rio")
install.packages("bibliometrix", dependencies = TRUE)
install.packages("jsonlite", type = "source")
# Load R libraries
library(pubmedR)
library(bibliometrix)
# Convert BibTeX files  to dataframes
wos <- convert2df("caminho_base_web_of_science/nome_arquivo.bib",dbsourc
e = 'isi', format = "bibtex")
scp <- convert2df("caminho_base_scopus/nome_arquivo.bib", dbsource ='s
copus', format = "bibtex")
# Merge databases and remove duplicates
base_total <- mergeDbSources(wos, scp, remove.duplicated = TRUE)
# Export consolidated database to Excel
rio::export(base_total,  file = "caminho_novo_arquivo/base_total.xlsx"
)
# Open the  bibliometrix interface in the default browser
biblioshiny()
```

Figure 1. General analysis of the Scopus+WOS database.

3 Results and discussion

Figure 2 shows the evolution of the number of publications on the use of computer simulation for wind turbines. This graph is important to clarify how relevant the topic is and how it is likely to grow in the coming years, making it a promising area for engineers who want to specialize in CFD. Data for 2024 only considers publications up to the month of May.

The CFD study of effect of solidity on vertical axis wind turbine with Gurney flap stood out in 2019 Zhu et al. 2019. The results indicate that the inboard, outboard, two-side Gurney flap (GF) and dimple-GF can increase the power coefficient in a given tip speed ratio (TSR) range.

Among the papers published in 2023, the period with the highest number of publications, is Tong et al. 2023, which discusses how the relationship between the length of the airfoil chord and the circumference of the rotor influences the aerodynamics of vertical axis wind turbines using numerical simulation. Another relevant article for studies on this type of turbine is Benmoussa and Páscoa 2023. Still for the year 2023, Ahmad et al. 2023 presented the potential of using Machine Learning to optimize energy capture from floating wind turbines, a prospect that is likely to receive more attention in the coming decades.

Regarding the publications in 2024 that this article addresses, Hijazi, ElCheikh, and Elkhoury 2024 is relevant for using computational fluid dynamics (CFD) and design of experiments (DOE) simulations to evaluate the aerodynamics of using flexible blades in vertical axis wind turbines.

The most discussed topics are represented by the Figure 3, which is a word cloud. The magni- tude of each term represents its importance and recurrence for the research area in question Alhassan et al. (2022).

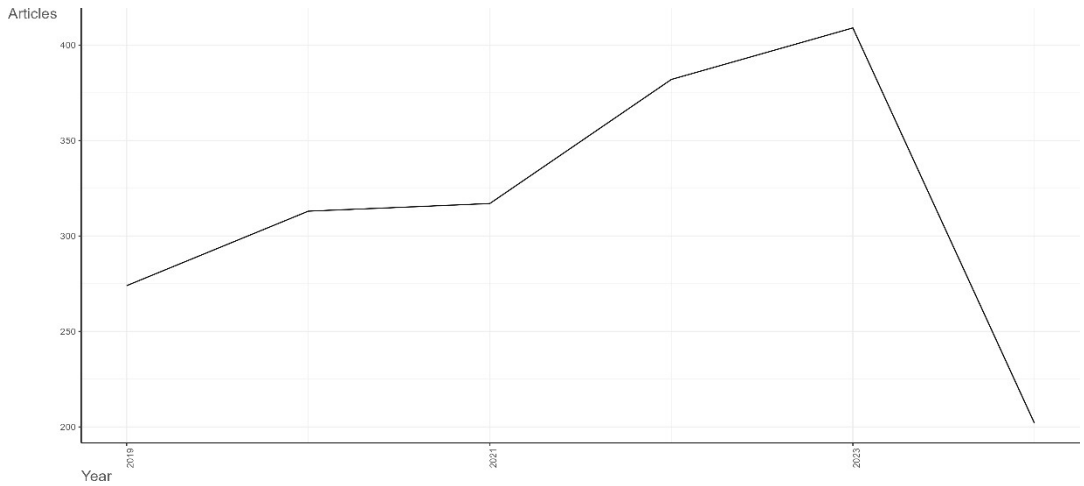

Figure 2. Total annual scientific production.

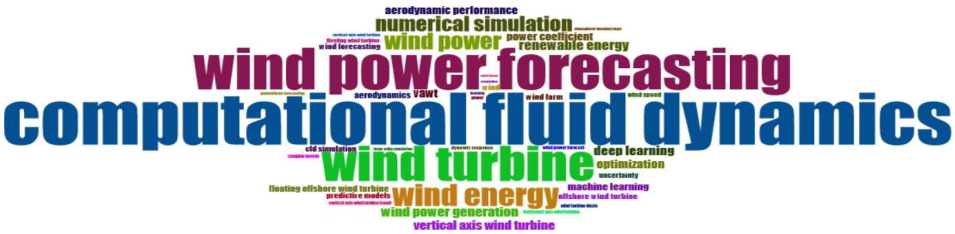

Figure 3. Cloud of words.

3.1 Analysis of published works

With the high growth in the number of published works on computer simulation for wind turbines, some productions stand out for their influence. The Table 1 shows the top 25 works, indicating how many times they have been cited in research in any area of knowledge. All of these works have more than 100 citations, which indicates their relevance. Y. Wang et al. 2021 is a study on the application of various Deep Learning techniques to optimize the forecasting of wind speed and wind power (WS/WP), and is a highly relevant piece of research because it uses real wind data and presents conclusions on factors that interfere with the accurate forecasting of WS/WP. The keywords of this work are “Wind speed forecasting”, “Wind power forecasting”, “Deep neural network”, “Data pre-processing”, “Feature extraction” and “Relationship learning”.

Clustering is an efficient method of grouping information, allowing us to understand how a field of research manifests itself and develops Donthu et al. 2021. The Figure 4 shows a grouping of documents in which the similarity calculation is based on the number of keywords shared by the authors. The metric used to assess the impact of the documents was the “Global Citation Score” (GCS), which counts the number of citations a work receives when it is cited in research in any area of knowledge, i.e. the most cited documents are considered the most influential. The clusters are labeled using the terms provided in the abstracts of the documents. These terms help to describe the content and focus of each cluster, making it easier to understand the predominant themes or topics in each group. The clustering is based on the top 750 works.

As can be seen in Figure 4, one of the groups of documents focuses on offshore wind turbines, a sector that is studied for the effects of operating conditions with irregular waves, blade mass discrepancy and non-uniform velocity field Cao et al. 2021. C. Yang et al. 2023 presents the growing research into the role of aerodynamic damping in floating wind turbines to suppress tower and blade vibration and platform movements.

Among the main trending topics in the database titles for 2024 are “Machine Learning” and “Digital Twin”, which although different concepts, the combination of the two can result in extremely powerful

and efficient systems. Digital Twins provide a rich database and a platform for simulation, while Machine Learning can analyze this data to generate knowledge, make predictions and automate decisions Eder and Chen 2020, Ponkumar, Jayaprakash, and Kanagarathinam 2023 and Marinšek and Bajt 2020.

Table 1. 25 most relevant works.

Ranking	Citation	Mentions
1	Wang et al. (2021)	305
2	Rezaeiha, Montazeri and Blocken (2019)	225
3	Luo et al. (2020)	220
4	Demolli et al. (2019)	203
5	Ju et al. (2019)	190
6	Hong and Rioflorido (2019)	180
7	Hao and Tian (2019)	164
8	Niu et al. (2020)	162
9	Hanifi et al. (2020)	150
10	Tian (2020)	150
11	Kisvari, Lin and Liu (2021)	149
12	Ti, Deng and Yang (2020)	148
13	Wang et al. (2019)	134
14	Cheng et al. (2021)	133
15	Yildiz et al. (2021)	129
16	Domínguez et al. (2019)	126
17	Duan et al. (2021)	124
18	Lin and Liu (2020)	122
19	Abedinia et al. (2020)	118
20	Zhang, Yanting Li and Zhang (2020)	115
21	Cheng, Huang and Wan (2019)	113
22	Kheirabadi and Nagamune (2019)	105
23	Qin et al. (2019)	105
24	Mehrjerdi and Hemmati (2020)	104
25	Alom and Saha (2019)	103

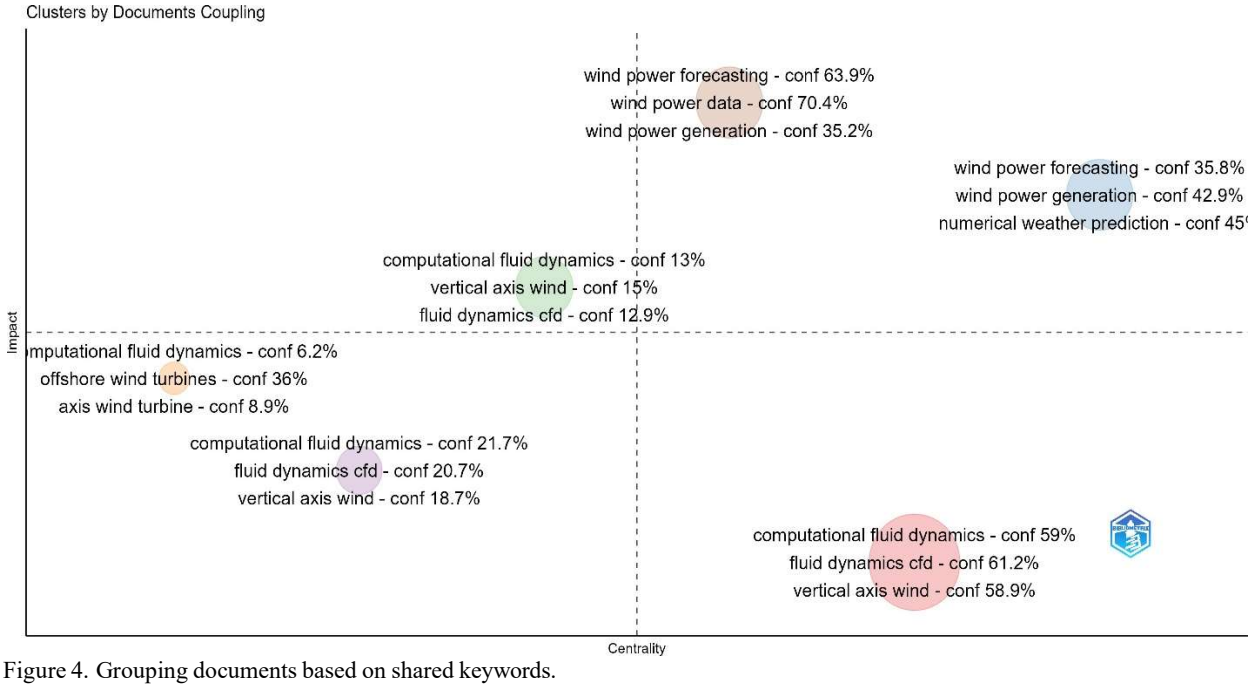

Figure 4. Grouping documents based on shared keywords.

3.2 Analysis of authors

Table 2 shows the 15 main authors of the database studied in terms of the number of articles in which they participated, the value in the "Freq" column, short for frequency. In addition, the "H-index" column is about the tool proposed by physicist Jorge Hirsch, which aims to quantify the scientific activity and measure the impact of researchers, based on their most cited papers Thomaz, Assad and Moreira (2011). Li Yan is the most relevant author in the database, having participated in 16 works. His recent work shows that the installation of a wind concentrator improves the characteristics of the inside the rotor and improves the aerodynamic performance of vertical axis straight blade wind turbines (SB-VAWTs), particularly at lower wind speeds Yan Li, Tong, et al. 2023. The same author also presents studies on SB-VAWTs using numerical simulation through CFD technology, reviewing existing methods with regard to factors such as the selection of the size of the calculation domain, the mesh creation strategy, the determination time interval, the numerical solution of the N - S equation and the selection of the Yan Li, S. Yang, et al. 2023 turbulence model. Li Yan's H-index is 8, which indicates that at least 8 works in which he participated received at least 8 citations. This same analysis is valid for the other authors.The author Bianchini Alessandro has an H-index of 10, which indicates that at least 10 of his articles have been cited at least 10 times in the observed database. Among his main works, Bianchini et al. 2019 portrays an extended numerical analysis using Computational Fluid Dynamics (CFD) with the aim of evaluating the potential of using Gurney Flaps to increase the power output of Darrieus wind turbines. Another work with great scientific contribution that Alessandro participated in is Rahmatian et al. 2022, which uses three-dimensional numerical simulation for the flow around and inside a nozzle-diffuser-flange duct with a horizontal axis wind turbine (HAWT).

Among the fundamental laws of bibliometrics is Lotka's Law, which, according to Aria and Cuccurullo 2017, "describes the frequency of publication of authors in any area as a law of the inverse of the square, in which the number of authors who publish a certain number of articles is a fixed proportion in relation to the number of authors who publish a single article". The Figure 5 shows how well this law represents the subject covered in this article, demonstrating that most of the works were produced by a small number of authors.

Table 2. 15 most relevant authors.

Ranking	Author	Freq.	H-index
1	Li Yan	16	8
2	Bianchini Alessandro	15	10
3	Liu Yongqian	13	
4	Li Chun	12	10
5	Li Li	12	7
6	Wang Tongguang	12	7
7	Meng Hang	11	6
8	Balduzzi Francesco	10	7
9	Feng Fang	10	5
10	Han Zhaolong	10	5
11	Lutz Thorsten	10	5
12	Wan Decheng	10	5
13	Chen Hamn-Ching	9	4
14	Ishihara Takeshi	9	6
15	Joo Young Hoon	9	6

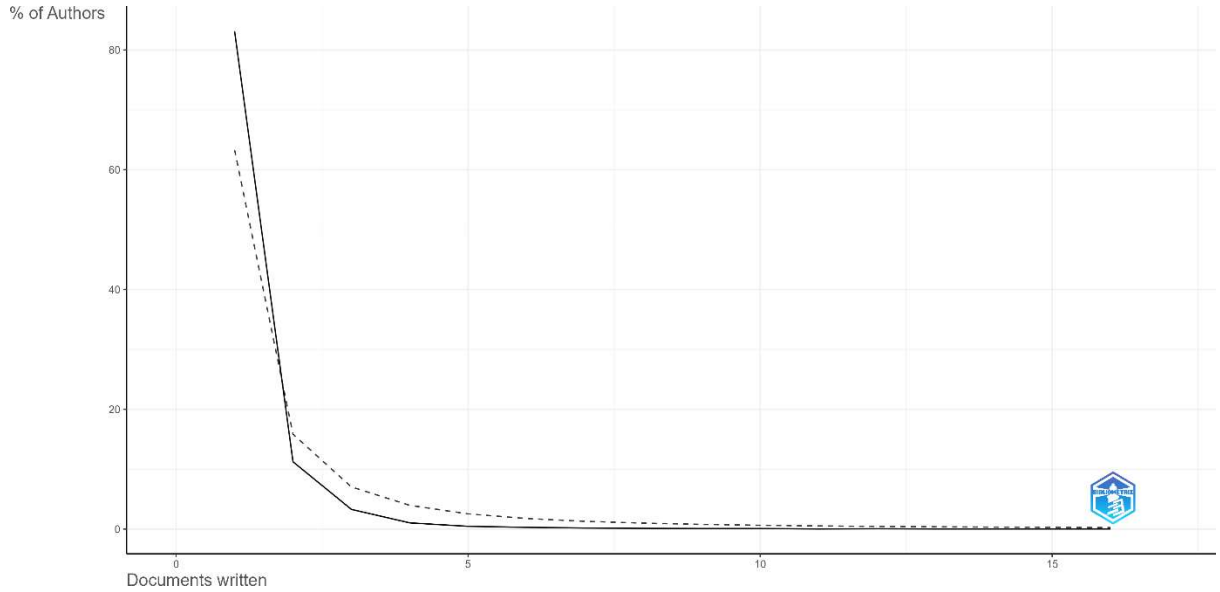

Figure 5. Author productivity according to Lotka's Law.

3.3 Analysis of sources

The 1897 documents collected were published in 372 different newspapers. The Table 3 tab shows the 10 most relevant research sources for the works studied. It can be seen that the first 5 concentrate the majority of works, with 675 articles, representing 35.58% of the total. The aforementioned H- index can also be applied to sources, such as Energy Ocean with a value of 33, which indicates that at least 33 articles published by this journal received at least 33 citations.

The journal "Energie" covers research on sustainable and renewable energy systems, energy efficiency, and energy policy, with a focus on technological advancements in electric vehicles and addressing global energy challenges. One of the recent papers published in "Energies" deals with wind energy forecasting considering time series, using a neural architecture based on stacked Re- current Neural Networks to process and combine different data sources containing spatio-temporal patterns Miele, Ludwig, and Corsini 2023. This work was able to explore the impact of meteorological variables on different spatial scales, from complete networks to cardinal point features, on wind energy forecasts.

Among the outstanding research published in "Renewable Energy", journal focuses on renew- able energy technologies such as solar and wind power, bioenergy, energy storage solutions, and economic policies that promote the adoption of renewable energy sources, there is the presentation of a methodology for producing seasonal capacity factor forecasts for a series of turbine classes Lledó et al. 2019, as well as time series forecasts using single strengths of Discrete Wavelet Trans- form (DWT), Seasonal Autoregressive Integrated Moving Average (SARIMA) and Deep Learning- based Long-Term Memory (LSTM) W. Zhang, Lin, and X. Liu 2022.

A useful way of analyzing the data is in the Figure 6, in which there is a relationship between authors, sources and keywords, which indicates in which journals the main authors usually publish and which areas each of these sources addresses the most. In this sense, Han Zhaolong, in his contribution in Fang et al. 2020 published in the journal Energy, presented how the effects of pitch periods are linked to "numerical simulation" and "computational fluid dynamics" for "wind turbines". The same goes for Li Chun, a researcher who addresses how an integrated floating energy system made up of different types of energy devices is an ideal option for reducing the levelized cost of production Y. Yang et al. 2020, who used the journal Energy Conversion and Management to disseminate his findings, a journal focused on "wind power forecasting" that currently features topics on "deep learning".

Table 3: 10 most relevant journals.

Ranking	Font	Freq.	H-index
1	Energies	189	21
2	Renewable Energy	152	34
3	Energy	141	33
4	Ocean Engineering	130	20
5	Energy Conversion and Management	63	23
6	Wind Energy	59	15
7	Wind Energy Science	45	10
8	Applied Energy	39	23
9	Wind Engineering	38	7
10	Journal of Wind Engineering and Industrial Aerodynamics	32	14

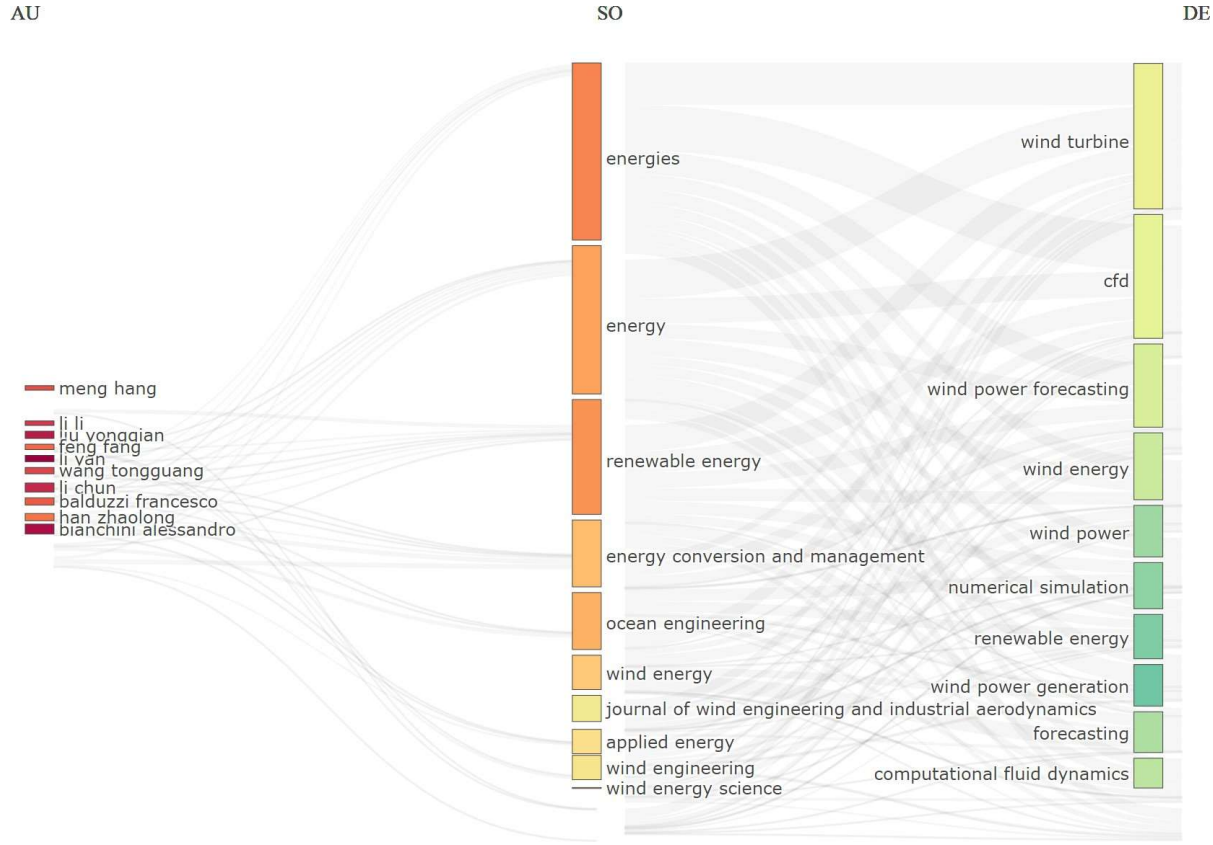

Figure 6. Analysis Author - Source - Keyword.

3.4 Analysis on affiliations

A fundamental analysis to mention is the question of the most relevant affiliations/institutions for the field of computer simulation for wind energy. Table 4 shows the top 20 institutions, with the vast majority located in Asia.

North China Electric Power University (NCEPU) is located in Beijing and is a renowned univer- sity for its research in the fields of electrical engineering, energy, and environmental technologies. Its researchers primarily focus on renewable energy, power systems, and environmental sustain- ability. In the area of renewable energy, they develop advanced technologies for solar, wind, and biomass energy. This institution participated in 59 articles in the database studied, contributing to the development of a more advanced three-dimensional wake model for wind power generation based on a multivariate Gaussian distribution, research that managed to accurately capture the asymmet- ric distribution of the vertical profile of the wake He et al. 2021. Xiaoxia et al. 2022 collaborated with North China Electric Power University and proposes a model and wake expansion data ob- served in real conditions that can provide theoretical and data support for wind farm microlocation, downstream turbine control strategy adjustment, as well as wind power prediction for hilltop wind turbines.

Kunsan National University stands out for its use of non-linear predictive control via the Yin- Yang

grey wolf optimization algorithm for maximum wind energy extraction D. Song et al. 2021, as well as for an advanced model predictive control (MPC) using a multi-step prediction model for the electric motor-based yaw system of an industrial wind turbine D. R. Song et al. 2019.

Among the institutions outside of Asia, Texas AandM University made a major contribution by analyzing a structural health monitoring (SHM) method for floating offshore wind turbines (FOWTs) using operational modal analysis (OMA) with numerical sensor signals H.-C. Kim, M.-H. Kim, and Choe 2019. The major contribution from Norwegian University of Science and Technol- ogy is the use of the systematic uncertainty components previously evaluated in hydrodynamic tests propagated to response metrics of interest using numerical simulation tools, and combined with the random uncertainty of the system to obtain the total experimental uncertainty Robertson et al. 2020.

This Danish affiliation also addresses relevant studies centered on the hydroelastic response of a large floating wind turbine in regular waves and severe sea states Leroy et al. 2022 and the process of coupling offshore wind turbine blades using a self-elevating crane vessel Bhaskaran et al. 2023.

Table 4. 15 most relevant affiliations.

Rank.	Affiliation	Country	Freq.
1	North China Elect Power University	China	59
2	Shanghai Jiao Tong University	China	53
3	Technical University of Denmark	Denmark	46
4	North China Electric Power University	China	42
5	Dalian University of Technology	China	38
6	Wuhan University of Technology	China	27
7	Hohai University	China	26
8	Tsinghua University	China	25
9	Zhejiang University	China	25
10	Tianjin University	China	24
11	Tongji University	China	24
12	Ocean University of China	China	23
13	Kunsan National University	South Korea	21
14	Texas AandM University	USA	20
15	Wuhan University	China	20

3.5 Analysis of countries

In light of this, it is worth highlighting the proportion of in-house and collaborative publications in each country. One way of visualizing this is through Table 5, where SCP indicates "Publica- tions from a single country", MCP refers to "Publications from several countries" and “FR%” to the relative frequency of each country for the sum of SCP+MCP in relation to the total number of doc- uments. Thus, in the case of China, SCP = 637 was identified, which is the number of publications in which all the institutions and researchers who contributed to the publication are located in China. In addition, the MCP for China is 55, which means that of all the publications related to this country in the dataset analyzed, 55 are the result of international collaborations. China’s influence is notable with 36.50% in the relative frequency column.

In view of this, it can be assumed that SCP publications indicate a country’s ability to conduct research independently, without international collaborations, being a measure of self-sufficiency and the availability of resources on its own territory. MCP, on the other hand, is an indicator of a coun- try’s international research collaboration and its integration with the global scientific community. This parameter reflects several important characteristics, such as diversity of ideas, complementar- ity of resources and expertise between different nations. The same SCP and MCP analyses can be made for the other countries in the database studied.

The Table 6 shows the amount of scientific production of the 20 main countries for the research topic, outlining the degree of relevance of these nations. China stands out with total production of 1218 (64,20%), which refers to the total number of publications where at least one author is affiliated with a Chinese institution, regardless of whether they are the corresponding author or not. The corresponding author is the author designated to handle communication between the authors of the article and the journal or conference where the work will be published. So, as an example for China, the sum of SCP + MCP represents only the number of publications where the corresponding author is Chinese, divided between

national and international publications. Publications in which the corresponding author is not Chinese, but there are Chinese co-authors, are included in the total production, but do not count towards China's SCP or MCP.

A prominent African country is Egypt, which has collaborated on research into the use of long short-term memory (LSTM), a recurrent neural network (RNN) algorithm for forecasting and esti- mating wind energy Ewees et al. 2022. Karim et al. 2023 is another Egyptian-contributed article that proposes a bio-inspired prediction model with a Recurrent Neural Network (RNN) incorporating a Dynamic Fitness Al-Biruni Earth Radius (DFBER) algorithm to predict wind energy data patterns. With regard to the publications in which Brazil participated, the study on the impact of different physical parameterizations on wind speed forecasting at two onshore wind farms using the Weather and Research Forecasting (WRF) model Jacondino et al. 2021 stands out. In addition, Ribeiro et al. 2022 evaluates a joint learning model that combines bagging and stacking methods applied to time series forecasting with very short-term (10 and 30 minutes) and short-term (60 and 120 minutes) assessments of wind power generation. The most important Brazilian work is Kothe, Möller, and Petry 2020, which numerically and experimentally investigates the aerodynamic performance of a Savonius helical rotor model with 180° twisted blades.

In this sense, an important way of visualizing the global collaboration network between coun- tries is in the Figure 7, in which China plays a central role in scientific advances in the area of computer simulation and wind power generation, with collaborations with Europe, North America, Africa, Asia and Oceania, with one of the most prominent partnerships being research into a new wind power forecasting method called Temporal Collaborative Attention (TCOAT), an approach designed to capture temporal and spatial dependencies in wind power generation data, as well as discern long- and short-term patterns Hu et al. 2024. In addition, the collaboration between China, England and Scotland made a considerable scientific contribution in Y. Liu et al. 2020 by elucidating how laminar separation in a low Reynolds number airfoil flow can be eliminated by surface slots.

Still on the subject of country analysis, the Figure 8 is another way of visualizing the importance of each country, taking into account the evolution of the number of publications over time. Since 2019, the difference in the number of publications from China to the other countries has already been enormous, a proportion that evolved even further by 2024.

Table 5. Distribution of articles by country.

Ranking	Country	SCP	MCP	FR%
1	China	637	55	36.50
2	Usa	101	4	5.50
3	UK	81	7	4.60
4	India	72	4	4.00
5	Iran	67	5	3.80
6	Italy	48	5	2.80
7	Korea	50	3	2.80
8	Germany	43	2	2.40
9	Japan	44	0	2.30
10	Denmark	40	3	2.30
11	Canada	38	3	2.20
12	Norway	27	3	1.60
13	Spain	28	1	1.50
14	France	25	0	1.30
15	Brazil	23	1	1.30

Table 6. Countries with Frequencies.

Ranking	Country	Freq	FR%
1	China	1218	64.20
2	USA	189	9.96
3	UK	138	7.27
4	India	121	6.38
5	Iran	94	4.96
6	South Korea	91	4.80
7	Denmark	72	3.80

8	Italy	66	3.48
9	Germany	64	3.37
10	Japan	63	3.32
11	Canada	62	3.27
12	Norway	58	3.06
13	France	54	2.85
14	Australia	45	2.37
15	Turkey	45	2.37
16	Egypt	44	2.32
17	Spain	42	2.21
18	Brazil	39	2.06
19	Saudi Arabia	39	2.06
20	Netherlands	36	1.90

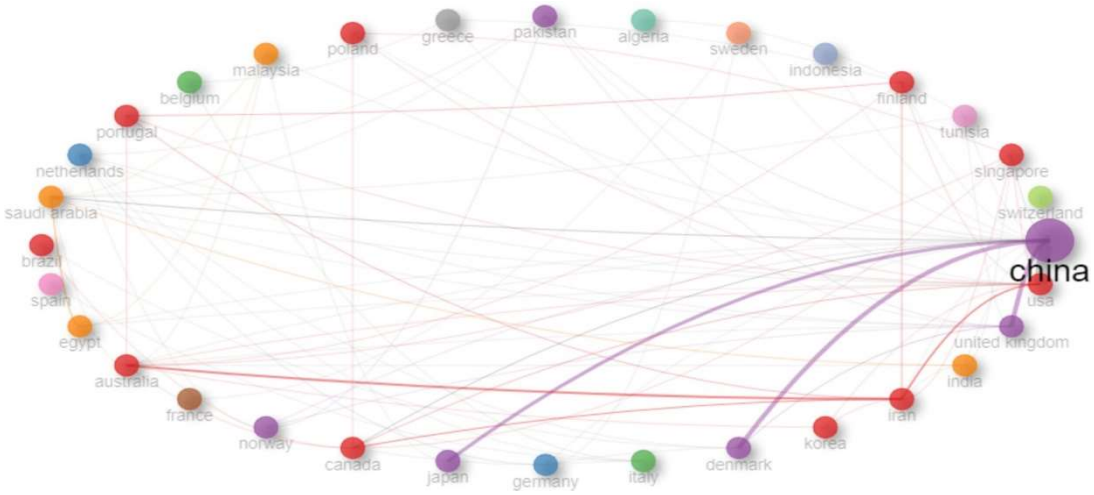

Figure 7. Global collaboration network between countries.

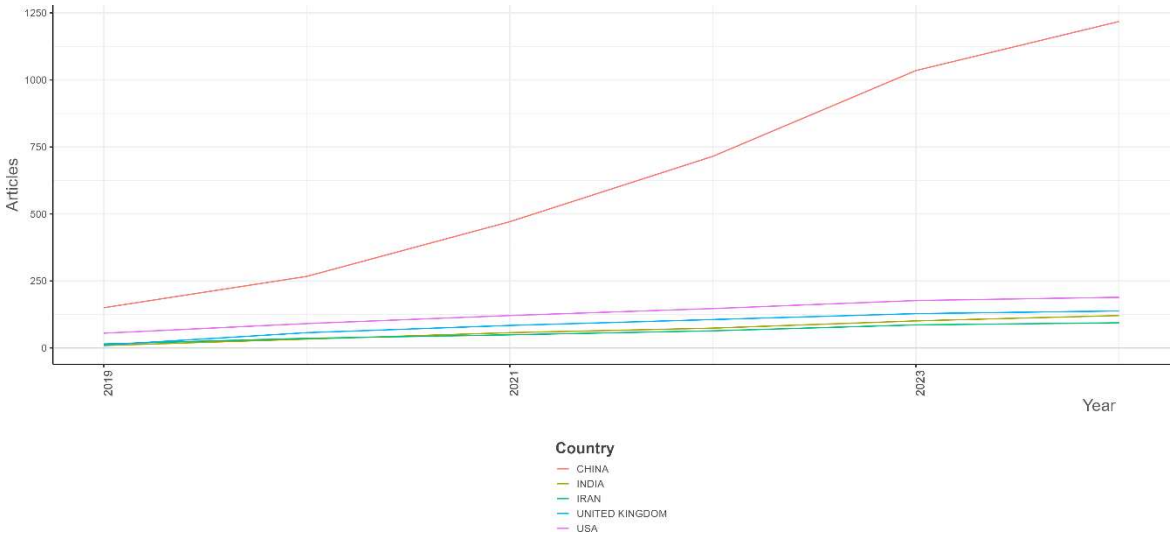

Figure 8. Number of countries' productions over time.

4 Conclusions

a) The study successfully achieved its objectives by providing transparent and clear analyses of the importance of computer simulations in wind farm projects.
b) The global collaboration network among researchers has significantly expanded since the early 21st century, reflecting a decentralized distribution of publication sources and journals.
c) Bibliometrics has proven instrumental in gaining valuable insights into scientific production within this field, highlighting its broader applicability beyond renewable energy sectors.

d) The methodology detailed in Section 2, utilizing the R algorithm and Bibliometrix library, en- hances accessibility to statistical analysis tools for researchers across disciplines, including those without programming expertise.
e) China emerges as a dominant force in computer simulation, leading both in quantity and impact of productions, particularly evident in rankings of influential authors and local impact.
f) Despite China's prominence, significant contributions in wind energy simulation research also emanate from non-Asian journals, indicating a global interest and potential job market expansion for engineers.
g) Future research directions should explore the integration of Machine Learning, particularly Deep Learning, to optimize simulation processes and enhance wind energy production efficiency, thereby reducing reliance on fossil fuels.

Bibliographic references

Abedinia, O., Oveis, M., et al. (2020). 'Improved EMD-Based Complex Prediction Model for Wind Power Forecasting'. *IEEE Transactions on Sustainable Energy*, 11(4), pp. 2790–2802. https://doi.org/10.1109/T-STE.2020.2976038.

Ahmad, I., et al. (2023). 'Fuzzy logic control of an artificial neural network-based floating offshore wind turbine model integrated with four oscillating water columns'. *Ocean Engineering*, 269, p. 113578. ISSN: 0029-8018. Available at: https://doi.org/10.1016/j.oceaneng.2022.113578.

Alhassan, M., et al. (2022). 'Bibliometric studies and impediments to valorization of dry reforming of methane for hydrogen production'. *Fuel*, 328, p. 125240. ISSN: 0016-2361. Available at: https://doi.org/10.1016/j.fuel.2022.125240.

Alom, N. and Saha, U.K. (2019). 'Influence of blade profiles on Savonius rotor performance: Numerical simulation and experimental validation'. *Energy Conversion and Management*, 186, pp. 267–277. ISSN: 0196-8904. Available at: https://doi.org/10.1016/j.enconman.2019.02.058.

Aria, M. and Cuccurullo, C. (2017). 'Bibliometrix: An R-tool for comprehensive science mapping analysis'. *Journal of Informetrics*, 11(4), pp. 959–975. Available at: https://doi.org/10.1016/j.joi.2017.08.007.

Benmoussa, A. and Páscoa, J.C. (2023). 'Enhancement of a cycloidal self-pitch vertical axis wind turbine performance through DBD plasma actuators at low tip speed ratio'. *International Journal of Thermofluids*, 17, p. 100258. ISSN: 2666-2027. Available at: https://doi.org/10.1016/j.ijft.2022.100258.

Bhaskaran, S., et al. (2023). 'A Code-to-Code Comparison for Dynamic Modeling and Response Analysis of Offshore Wind Turbine Blade Mating Process'. *Journal of Offshore Mechanics and Arctic Engineering*, 145(6), p. 062003. ISSN: 0892-7219. https://doi.org/10.1115/1.4056617.

Bianchini, A., et al. (2019). 'On the use of Gurney Flaps for the aerodynamic performance augmentation of Darrieus wind turbines'. *Energy Conversion and Management*, 184, pp. 402–415. ISSN: 0196-8904. Available at: https://doi.org/10.1016/j.enconman.2019.01.068.

Bortoluzzi, M., Souza, C.C., and Furlan, M. (2021). 'Bibliometric analysis of renewable energy types using key performance indicators and multicriteria decision models'. *Renewable and Sustainable Energy Reviews*, 143, p. 110958. ISSN: 1364-0321. https://doi.org/10.1016/j.rser.2021.110958.

Cao, Q., et al. (2021). 'Dynamic responses of a 10 MW semi-submersible wind turbine at an intermediate water depth: A comprehensive numerical and experimental comparison'. *Ocean Engineering*, 232, p. 109138. ISSN: 0029-8018. Available at: https://doi.org/10.1016/j.oceaneng.2021.109138.

Catumba, B.D., et al. (2023). 'Sustainability and challenges in hydrogen production: An advanced bibliometric analysis'. *International Journal of Hydrogen Energy*, 48(22), pp. 7975–7992. ISSN: 0360-3199. https://doi.org/10.1016/j.ijhydene.2022.11.215.

Cheng, H., et al. (2021). 'A new Euler-Lagrangian cavitation model for tip-vortex cavitation with the effect of non-condensable gas'. *International Journal of Multiphase Flow*, 134, p. 103441. ISSN: 0301-9322. Available at: https://doi.org/10.1016/j.ijmultiphaseflow.2020.103441.

Cheng, P., Huang, Y., and Wan, D. (2019). 'A numerical model for fully coupled aero-hydrodynamic

analysis of floating offshore wind turbine'. *Ocean Engineering*, 173, pp. 183–196. ISSN: 0029-8018. Available at: https://doi.org/10.1016/j.oceaneng.2018.12.021.

Crane, D. (1972). *Invisible Colleges; Diffusion of Knowledge in Scientific Communities*. 1st edn. Chicago: University of Chicago Press.

Cunha Júnior, A.A. da (2021). *Estudo sobre a Dinâmica de Fluidos Computacional* [Study on Computational Fluid Dynamics].

Custódio, R. dos S. (2009). *Energia Eólica para Produção de Energia Elétrica* [Wind Energy for Electricity Production]. 1st edn. Rio de Janeiro: Eletrobras, pp. 15–16. ISBN: 978-85-87083-09-8.

Demolli, H., et al. (2019). 'Wind power forecasting based on daily wind speed data using machine learning algorithms'. *Energy Conversion and Management*, 198, p. 111823. ISSN: 0196-8904. Available at: https://doi.org/10.1016/j.enconman.2019.111823.

Domínguez, J.M., et al. (2019). 'SPH simulation of floating structures with moorings'. *Coastal Engineering*, 153, p. 103560. ISSN: 0378-3839. Available at: https://doi.org/10.1016/j.coastaleng.2019.103560.

Donthu, N., et al. (2021). 'How to conduct a bibliometric analysis: An overview and guidelines'. *Journal of Business Research*, 133, pp. 285–296. ISSN: 0148-2963. Available at: https://doi.org/10.1016/j.jbusres.2021.04.070.

Duan, J., et al. (2021). 'Short-term wind power forecasting using the hybrid model of improved variational mode decomposition and Correntropy Long Short-term memory neural network'. *Energy*, 214, p. 118980. ISSN: 0360-5442. Available at: https://doi.org/10.1016/j.energy.2020.118980.

Eder, M.A. and Chen, X. (2020). 'FASTIGUE: A computationally efficient approach for simulating discrete fatigue crack growth in large-scale structures'. *Engineering Fracture Mechanics*, 233, p. 107075. ISSN: 0013-7944. Available at: https://doi.org/10.1016/j.engfracmech.2020.107075.

Ewees, A.A., et al. (2022). 'HBO-LSTM: Optimized long short term memory with heap-based optimizer for wind power forecasting'. *Energy Conversion and Management*, 268, p. 116022. ISSN: 0196-8904. Available at: https://doi.org/10.1016/j.enconman.2022.116022.

Fang, Y., et al. (2020). 'Numerical analysis of aerodynamic performance of a floating offshore wind turbine under pitch motion'. *Energy*, 192, p. 116621. ISSN: 0360-5442. Available at: https://doi.org/10.1016/j.energy.2019.116621.

Gao, X., et al. (2022) 'LiDAR-based observation and derivation of large-scale wind turbine's wake expansion model downstream of a hill', *Energy*, 259, p. 125051. ISSN: 0360-5442. Available at: https://doi.org/10.1016/j.energy.2022.125051.

Guedes, V.L.S. da S. (2012). 'A Bibliometria e a Gestão da Informação e do Conhecimento Científico e Tecnológico: uma revisão da literatura' [Bibliometrics and the Management of Information and Scientific and Technological Knowledge: a literature review]. *Pontodeacesso*, 6(2), p. 74. ISSN: 1981-6766.

Hanifi, S., et al. (2020). 'A Critical Review of Wind Power Forecasting Methods—Past, Present and Future'. *Energies*, 13(15). ISSN: 1996-1073. https://doi.org/10.3390/en13153764.

Hao, Y. and Tian, C. (2019). 'A novel two-stage forecasting model based on error factor and ensemble method for multi-step wind power forecasting'. *Applied Energy*, 238, pp. 368–383. ISSN: 0306-2619. Available at: https://doi.org/10.1016/j.apenergy.2019.01.063.

He, R., et al. (2021). 'A novel three-dimensional wake model based on anisotropic Gaussian distribution for wind turbine wakes'. *Applied Energy*, 296, p. 117059. ISSN: 0306-2619. Available at: https://doi.org/10.1016/j.apenergy.2021.117059.

Hijazi, A., ElCheikh, A. and Elkhoury, M. (2024). 'Numerical investigation of the use of flexible blades for vertical axis wind turbines'. *Energy Conversion and Management*, 299, p. 117867. ISSN: 0196-8904. Available at: https://doi.org/10.1016/j.enconman.2023.117867.

Hong, Y.-Y. and Rioflorido, C.L.P. (2019). 'A hybrid deep learning-based neural network for 24-h ahead wind power forecasting'. *Applied Energy*, 250, pp. 530–539. ISSN: 0306-2619. Available at: https://doi.org/10.1016/j.apenergy.2019.05.044.

Hu, Y., et al. (2024). 'Temporal collaborative attention for wind power forecasting'. *Applied Energy*, 357, p. 122502. ISSN: 0306-2619. Available at: https://doi.org/10.1016/j.apenergy.2023.122502.

Jacondino, W.D., et al. (2021). 'Hourly day-ahead wind power forecasting at two wind farms in northeast Brazil using WRF model'. *Energy*, 230, p. 120841. ISSN: 0360-5442. Available at: https://doi.org/10.1016/j.energy.2021.120841.

Ju, Y., et al. (2019). 'A Model Combining Convolutional Neural Network and LightGBM Algorithm for Ultra-Short-Term Wind Power Forecasting'. *IEEE Access*, 7, pp. 28309–28318. Available at: https://doi.org/10.1109/ACCESS.2019.2901920.

Karim, F.K., et al. (2023). 'A Novel Bio-Inspired Optimization Algorithm Design for Wind Power Engineering Applications Time-Series Forecasting'. *Biomimetics*, 8(3). ISSN: 2313-7673.

Kheirabadi, A.C. and Nagamune, R. (2019). 'A quantitative review of wind farm control with the objective of wind farm power maximization'. *Journal of Wind Engineering and Industrial Aerodynamics*, 192, pp. 45–73. ISSN: 0167-6105. Available at: https://doi.org/10.1016/j.jweia.2019.06.015.

Kim, H.-C., Kim, M.-H. and Choe, D.-E. (2019). 'Structural health monitoring of towers and blades for floating offshore wind turbines using operational modal analysis and modal properties with numerical-sensor signals'. *Ocean Engineering*, 188, p. 106226. ISSN: 0029-8018. Available at: https://doi.org/10.1016/j.oceaneng.2019.106226.

Kisvari, A., Lin, Z. and Liu, X. (2021). 'Wind power forecasting – A data-driven method along with gated recurrent neural network'. *Renewable Energy*, 163, pp. 1895–1909. ISSN: 0960-1481. Available at: https://doi.org/10.1016/j.renene.2020.10.119.

Kothe, L.B., Möller, S.V. and Petry, A.P. (2020) 'Numerical and experimental study of a helical Savonius wind turbine and a comparison with a two-stage Savonius turbine', *Renewable Energy*, 148, pp. 627–638. ISSN: 0960-1481. Available at: https://doi.org/10.1016/j.renene.2019.10.151.

Leroy, V., et al. (2022) 'Experimental investigation of the hydro-elastic response of a spar-type floating offshore wind turbine', *Ocean Engineering*, 255, p. 111430. ISSN: 0029-8018. Available at: https://doi.org/10.1016/j.oceaneng.2022.111430.

Li, Y., Tong, G., et al. (2023) 'Numerical study on aerodynamic performance improvement of the straight-bladed vertical axis wind turbine by using wind concentrators', *Renewable Energy*, 219, p. 119545. ISSN: 0960-1481. Available at: https://doi.org/10.1016/j.renene.2023.119545.

Li, Y., Yang, S., et al. (2023) 'A review on numerical simulation based on CFD technology of aerodynamic characteristics of straight-bladed vertical axis wind turbines', *Energy Reports*, 9, pp. 4360–4379. ISSN: 2352-4847. Available at: https://doi.org/10.1016/j.egyr.2023.03.082.

Lin, Z. and Liu, X. (2020) 'Wind power forecasting of an offshore wind turbine based on high-frequency SCADA data and deep learning neural network', *Energy*, 201, p. 117693. ISSN: 0360-5442. Available at: https://doi.org/10.1016/j.energy.2020.117693.

Liu, Y., et al. (2020) 'Numerical study of the effect of surface grooves on the aerodynamic performance of a NACA 4415 airfoil for small wind turbines', *Journal of Wind Engineering and Industrial Aerodynamics*, 206, p. 104263. ISSN: 0167-6105. Available at: https://doi.org/10.1016/j.jweia.2020.104263.

Lledó, Ll., et al. (2019) 'Seasonal forecasts of wind power generation', *Renewable Energy*, 143, pp. 91–100. ISSN: 0960-1481. Available at: https://doi.org/10.1016/j.renene.2019.04.135.

Lopez, R.A. (2012) *Energia Eólica [Wind Energy]*. 2nd ed. São Paulo: Artliber, pp. 115–116. ISBN: 978-85-88098-70-1.

Luo, L., et al. (2020) 'Optimal scheduling of a renewable-based microgrid considering photovoltaic system and battery energy storage under uncertainty', *Journal of Energy Storage*, 28, p. 101306. ISSN: 2352-152X. Available at: https://doi.org/10.1016/j.est.2020.101306.

Marinšek, A. and Bajt, G. (2020) 'Demystifying the use of ERA5-land and machine learning for wind power forecasting', *IET Renewable Power Generation*, 14(19), pp. 4159–4168. Available at: https://doi.org/10.1049/iet-rpg.2020.0576.

Mehrjerdi, H. and Hemmati, R. (2020) 'Coordination of vehicle-to-home and renewable capacity resources for energy management in resilience and self-healing buildings', *Renewable Energy*, 146, pp. 568–579. ISSN: 0960-1481. Available at: https://doi.org/10.1016/j.renene.2019.07.004.

Miele, E.S., Ludwig, N. and Corsini, A. (2023) 'Multi-Horizon Wind Power Forecasting Using Multi-Modal Spatio-Temporal Neural Networks', *Energies*, 16(8), p. 3522. ISSN: 1996-1073. Available at: https://doi.org/10.3390/en16083522.

Niu, Z., et al. (2020) 'Wind power forecasting using attention-based gated recurrent unit network', *Energy*, 196, p. 117081. ISSN: 0360-5442. Available at: https://doi.org/10.1016/j.energy.2020.117081.

Ponkumar, G., Jayaprakash, S. and Kanagarathinam, K. (2023) 'Advanced Machine Learning Techniques for Accurate Very-Short-Term Wind Power Forecasting in Wind Energy Systems Using Historical Data Analysis', *Energies*, 16(14). ISSN: 1996-1073. Available at: https://doi.org/10.3390/en16145459.

Qin, Y., et al. (2019) 'Hybrid forecasting model based on long short term memory network and deep learning neural network for wind signal', *Applied Energy*, 236, pp. 262–272. ISSN: 0306-2619. Available at: https://doi.org/10.1016/j.apenergy.2018.11.063.

Rahmatian, M.A., et al. (2022) 'Numerical and experimental study of the ducted diffuser effect on improving the aerodynamic performance of a micro horizontal axis wind turbine', *Energy*, 245, p. 123267. ISSN: 0360-5442. Available at: https://doi.org/10.1016/j.energy.2022.123267.

Raman, R., et al. (2022) 'Green-hydrogen research: What have we achieved, and where are we going? Bibliometrics analysis', *Energy Reports*, 8, pp. 9242–9260. ISSN: 2352-4847. Available at: https://doi.org/10.1016/j.egyr.2022.07.058.

Rezaeiha, A., Montazeri, H. and Blocken, B. (2019) 'On the accuracy of turbulence models for CFD simulations of vertical axis wind turbines', *Energy*, 180, pp. 838–857. ISSN: 0360-5442. Available at: https://doi.org/10.1016/j.energy.2019.05.053.

Ribeiro, M.H.D.M., et al. (2022) 'Efficient bootstrap stacking ensemble learning model applied to wind power generation forecasting', *International Journal of Electrical Power & Energy Systems*, 136, p. 107712. ISSN: 0142-0615. Available at: https://doi.org/10.1016/j.ijepes.2021.107712.

Robertson, A., et al. (2020) 'Total experimental uncertainty in hydrodynamic testing of a semisubmersible wind turbine, considering numerical propagation of systematic uncertainty', *Ocean Engineering*, 195, p. 106605. ISSN: 0029-8018. Available at: https://doi.org/10.1016/j.oceaneng.2019.106605.

Song, D., et al. (2021) 'Maximum wind energy extraction of large-scale wind turbines using nonlinear model predictive control via Yin-Yang grey wolf optimization algorithm', *Energy*, 221, p. 119866. ISSN: 0360-5442. Available at: https://doi.org/10.1016/j.energy.2021.119866.

Song, D.R., et al. (2019) 'Model Predictive Control Using Multi-Step Prediction Model for Electrical Yaw System of Horizontal-Axis Wind Turbines', *IEEE Transactions on Sustainable Energy*, 10(4), pp. 2084–2093. Available at: https://doi.org/10.1109/TSTE.2018.2878624.

Thomaz, P.G., Assad, R.S. and Moreira, L.F.P. (2011) 'Uso do Fator de impacto e do índice H para avaliar pesquisadores e publicações', *Arquivos Brasileiros de Cardiologia*, 96(2), pp. 90–93. ISSN: 0066-782X. Available at: https://doi.org/10.1590/S0066-782X2011000200001.

Ti, Z., Deng, X.W. and Yang, H. (2020) 'Wake modeling of wind turbines using machine learning', *Applied Energy*, 257, p. 114025. ISSN: 0306-2619. Available at: https://doi.org/10.1016/j.apenergy.2019.114025.

Tian, Z. (2020) 'Short-term wind speed prediction based on LMD and improved FA optimized combined kernel function LSSVM', *Engineering Applications of Artificial Intelligence*, 91, p. 103573. ISSN: 0952-1976. Available at: https://doi.org/10.1016/j.engappai.2020.103573.

Tong, G., et al. (2023) 'Effects of blade airfoil chord length and rotor diameter on aerodynamic performance of straight-bladed vertical axis wind turbines by numerical simulation', *Energy*, 265, p. 126325. ISSN: 0360-5442. Available at: https://doi.org/10.1016/j.energy.2022.126325.

Wang, H., et al. (2019) 'Sequence transfer correction algorithm for numerical weather prediction wind speed and its application in a wind power forecasting system', *Applied Energy*, 237, pp. 1–10. ISSN: 0306-2619. Available at: https://doi.org/10.1016/j.apenergy.2018.12.076.

Wang, Y., et al. (2021) 'A review of wind speed and wind power forecasting with deep neural networks', *Applied Energy*, 304, p. 117766. ISSN: 0306-2619. Available at: https://doi.org/10.1016/j.apenergy.2021.117766.

Yang, C., et al. (2023) 'Aerodynamic damping of a semi-submersible floating wind turbine: An analytical, numerical and experimental study', *Ocean Engineering*, 281, p. 114826. ISSN: 0029-8018. Available at: https://doi.org/10.1016/j.oceaneng.2023.114826.

Yang, Y., et al. (2020) 'Performance evaluation of an integrated floating energy system based on coupled analysis', *Energy Conversion and Management*, 223, p. 113308. ISSN: 0196-8904. Available at: https://doi.org/10.1016/j.enconman.2020.113308.

Yildiz, C., et al. (2021) 'An improved residual-based convolutional neural network for very short-term wind power forecasting', *Energy Conversion and Management*, 228, p. 113731. ISSN: 0196-8904. Available at: https://doi.org/10.1016/j.enconman.2020.113731.

Zhang, W., Lin, Z. and Liu, X. (2022) 'Short-term offshore wind power forecasting - A hybrid model based on Discrete Wavelet Transform (DWT), Seasonal Autoregressive Integrated Moving Average (SARIMA), and deep-learning-based Long Short-Term Memory (LSTM)', *Renewable Energy*, 185, pp. 611–628. ISSN: 0960-1481. Available at: https://doi.org/10.1016/j.renene.2021.12.100.

Zhang, Y., Li, Y. and Zhang, G. (2020) 'Short-term wind power forecasting approach based on Seq2Seq model using NWP data', *Energy*, 213, p. 118371. ISSN: 0360-5442. Available at: https://doi.org/10.1016/j.energy.2020.118371.

Zhu, H., et al. (2019) 'Numerical study of effect of solidity on vertical axis wind turbine with Gurney flap', *Journal of Wind Engineering and Industrial Aerodynamics*, 186, pp. 17–31. ISSN: 0167-6105. Available at: https://doi.org/10.1016/j.jweia.2018.12.016.