Editorial

Worldwide Research Trends on Optimizing Wind Turbine Efficiency

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1. Introduction

In a world in which electricity is increasingly necessary, it is vitally important to ensure that the supply of this electricity is safe, reliable, sustainable, and environmentally friendly, reducing CO_2 emissions into the atmosphere and the use of fossil fuels. Renewable energies, and wind energy, in particular, make a significant contribution to this. Wind energy research dates to the last century, yet efforts to improve wind turbine performance continue around the world. Advances in blade aerodynamics and wind resource assessment are outstanding [1].

According to some authors, such as Haase et al. [2] who state that fossil fuels should be replaced and to combat climate change with renewable energies, or Yang et al. [3] who studied that three forms can be used to improve energy transmission: high voltage alternating current transmission, high voltage direct current transmission, and low-frequency alternating current. Ma et al. [4] used the Weather Research Forecasting (WRF) model to forecast the future wind potential, observing that in the next few years the potential will decrease in the center of the country and in Eastern Quebec, and in the Great Lakes it will increase; Niyomtham et al. [5] also proposed to consider electricity tariffs when evaluating the wind resource.

The aerodynamic loads must be studied as well as its design; for this, Blade Element Momentum (BEM) is indispensable to determine the aerodynamics of the wind turbine blade. However, because it is not easy to calculate, the BEM is used with the use of Computational Fluid Dynamics (CFD) in its 2D version. This was performed by Sang et al. [6], who used the classical BEM model and the modified BEM, and found that by combining them they were able to correct the aerodynamics of their model. Kavari et al. [7] demonstrated that using other variables for the evaluation of an airfoil is of great interest. In this study they used wind shear, in addition to BEM and drag and lift coefficients; the results showed that at low wind shear the power output increased, and the kinetic energy was reduced.

Several studies have been conducted on lift and drag forces. These forces are important in the aerodynamic analysis of wind turbine blades, such as the analysis performed by Oukassou et al. [8], who evaluated an airfoil with different Reynolds numbers and found the optimal chord dimension and angle of attack. An interesting proposal is hybrid blades, such as the one proposed by Yen et al. [9], who used several flows with different Reynolds numbers and different angles of attack; in this study they were able to increase the lift coefficient to twice the normally measured ones. Hasham Ali et al. [10] proposed lift and drag coefficients for low speeds on vertical axis wind turbines to identify the best airfoil; they identified that for low speeds the angle of attack should be changed from 0° to 15°.

Much more research could be enunciated; however, proposals are presented here to further improve the wind industry.

- Mini wind.
- Blade Element Momentum.
- Wind resource assessment.
- Blade diffusers.
- Mesoscale and microscale simulations.

2. Worldwide Research Trends on Optimizing Wind Turbine Efficiency

In this study, the Scopus database was used to analyze the current state of knowledge on optimizing wind turbine efficiency using bibliometric techniques.

The research starts using the following research equation: TITLE-ABS-KEY("Wind Turbine Blade") OR TITLE-ABS-KEY(Optimization Flexible Blade*) OR TITLE-ABS-KEY("wind turbine deformable profile") OR TITLE-ABS-KEY("Wind Turbine Efficiency") OR TITLE-ABS-KEY("Blade element momentum") OR TITLE-ABS-KEY("Wind turbine trends") with the objective to obtain results about documents type, scientific production, the most important scientific institutions and their scientific productions, the current collaboration between countries, the most important authors, and the use of keywords.

Currently, there are about 9315 manuscripts on optimizing wind turbine efficiency; the countries with the most research are China, the United States of America, the United Kingdom, Denmark, and Germany. Figure 1 shows the top ten countries on the topic.
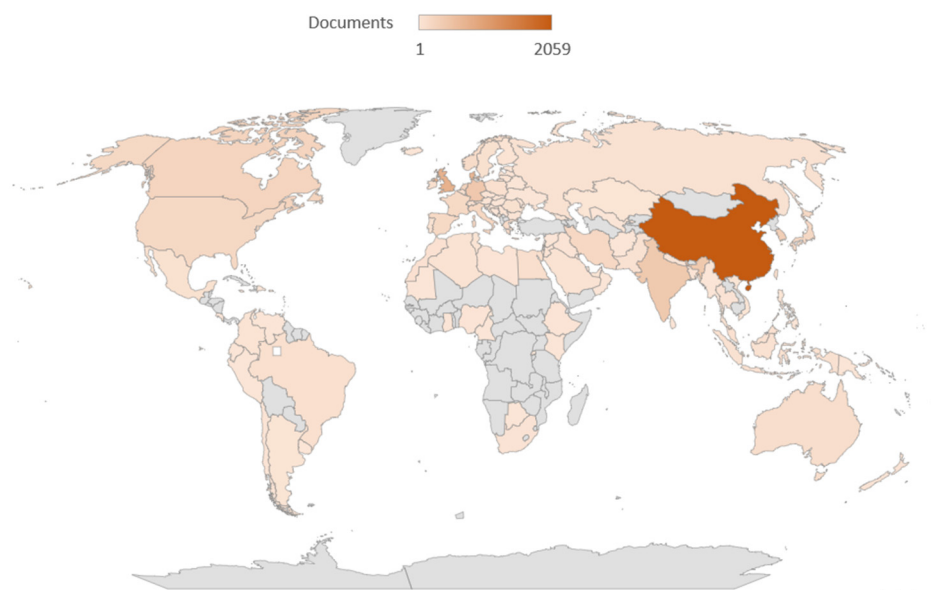

Figure 1. Worldwide top ten countries on optimizing wind turbine efficiency.

To determine the collaboration between authors from different countries related to the same subject, the application VOSviewer has been used. This application records the download data from the Scopus database and delivers a *.csv file; this relationship can be appreciated in Figure 2. The color assigned to each country determines which cluster it belongs to. The size of the circle shows the importance of the country based on the number of publications on renewable energy and agriculture, and the lines represent the collaborations in scientific documents existing between the different countries that form each cluster.
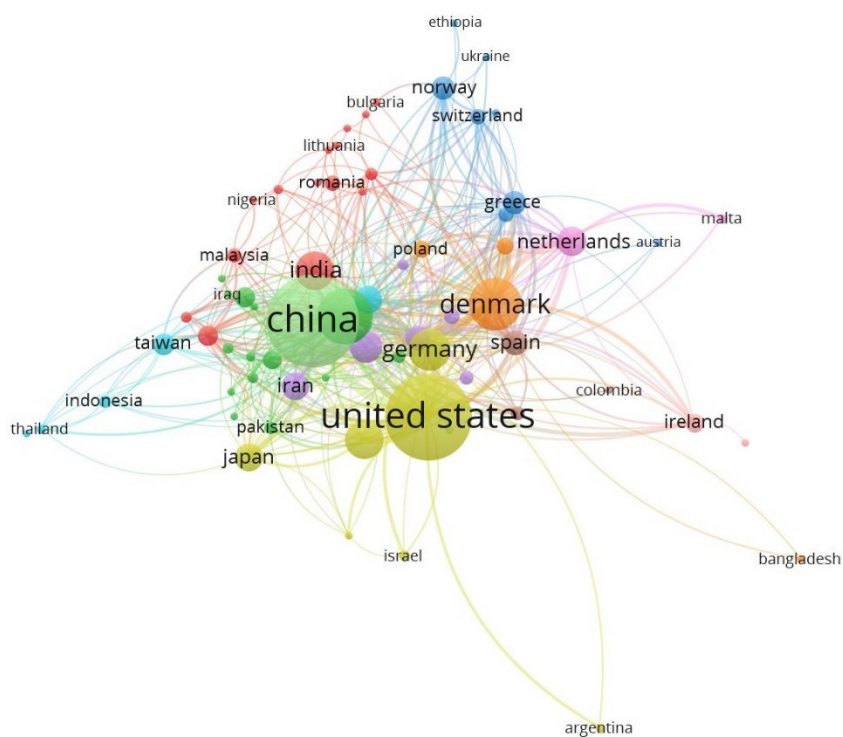
Figure 2. Worldwide collaborations between countries on optimizing wind turbine efficiency.

In the same way, the Vosviewer software was used to find out the different clusters of keywords that coincide simultaneously in different publications, in such a way that it helps us to find out the trend in research and the themes in which the keywords are grouped. Figure 3 shows five keyword clusters detected in the different publications obtained in Scopus on optimizing wind turbine efficiency.

Figure 3. Keyword clusters on optimizing wind turbine efficiency.

Table 1 shows for each cluster: the color, the main words, and the topic.

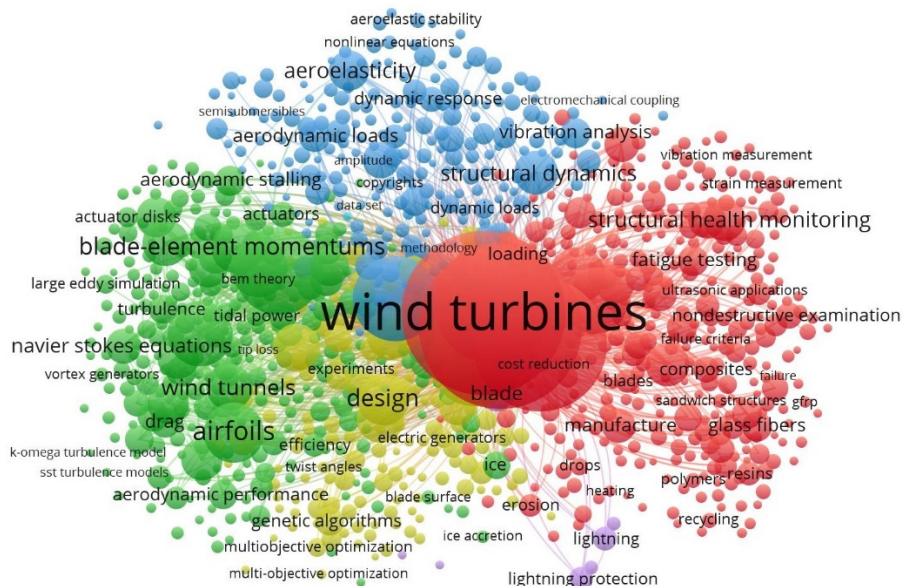**Table 1.** Main clusters obtained in the co-words analysis on the topic of wind turbine efficiency.

Cluster	Color	Main Keywords	Topic
1	Red	Wind turbine blades, finite element method, fatigue of materials, fatigue testing, composite materials, stress analysis, structural analysis, structural components.	Structural analysis of wind turbines blades
2	Green	Aerodinamics, computational fluid dynamics, wind tunnels, airfoils, Reynolds number, turbulence models, surface roughness, vorticity.	Aerodynamic performance of wind turbines
3	Blue	Offshore wind turbines, dynamic response, floating wind turbines, fluid structure interaction, thin walled structures, aeroelastic stability, aeroelasticity, vibration analysis.	Offshore wind turbines
4	Yellow	Wind, wind energy, wind power, wind speed, energy efficiency, energy productions, electricity generation, energy policy.	Wind energy
5	Purple	Electric discharges, fem, lightning, lightning protection, lightning protection systems, light strikes.	Protections in wind turbines

The top ten journals that have published the highest number of articles on optimizing wind turbine efficiency are shown in Figure 4. It is worth highlighting the relevant position of the journal Energies at number 7.
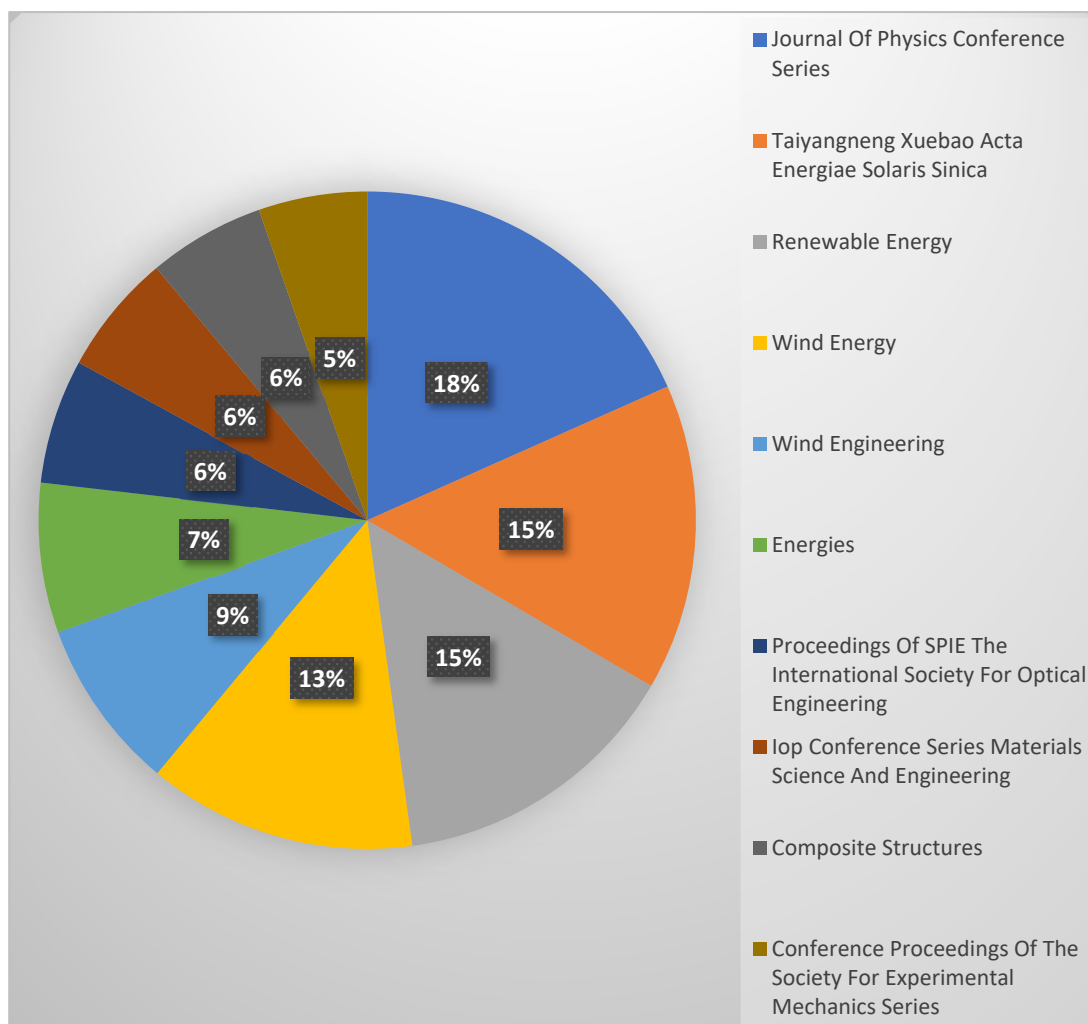

Figure 4. Worldwide top ten journals on optimizing wind turbine efficiency.

If the search equation is limited to optimizing wind turbine efficiency publications in the Energies journal (TITLE-ABS-KEY("Wind Turbine Blade") OR TITLE-ABS-KEY(Optimization Flexible Blade*) OR TITLE-ABS-KEY("wind turbine deformable profile") OR TI-TLE-ABS-KEY("Wind Turbine Efficiency") OR TITLE-ABS-KEY("Blade element mo-mentum") OR TITLE-ABS-KEY("Wind turbine trends") AND (LIMIT-TO(EXACTSRCTITLE, "Energies"))), 125 documents are obtained. Table 2 shows the top ten countries that have published the most on the topic in the Energies journal.

Table 2. Top ten countries that have published the most on the topic in the Energies journal.

Country	Number of Documents
China	45
Denmark	18
United Kingdom	12
South Korea	11
United States	9
Canada	7
Germany	7
Spain	7
Japan	6
Poland	5

3. Most Cited Articles in Energies Journal on Optimizing Wind Turbine Efficiency

The improvements range from acting on the cut-in-speed and rated speed to improving the design of wind turbine blades by minimizing physical, geometric, and aerodynamic constraints that improve the power coefficient and annual energy yield. In this sense Rehman et al. conducted a review of articles that focus on the different ways to improve the efficiency of wind turbines [11]. The authors' review focuses mainly on the work carried out to improve blade design through experimental and analytical methodologies. Previously, other authors have worked in the same direction.

Schubel and Crossley reviewed the design of wind turbine blades by considering parameters such as theoretical maximum efficiency, propulsion, practical efficiency, design, and blade loads, highlighting the almost exclusive use of rotors with horizontal shafts, and then detailing and reviewing the aerodynamic principles used in the design of modern turbines [12].

Hsiao et al. (2013) experimentally and numerically analyzed three blade models. For this study, they used a wind tunnel and fluid dynamics software with the k-ω type turbulent model. In both studies, they calculated the power coefficient and the velocity ratio. Given the proximity between the experimentally and numerically calculated power coefficient values, the authors suggested the numerical method as a good approximation for the full-scale study of wind turbines [13].

Tran et al. studied the aerodynamic effects on a floating offshore wind turbine with pitching motion, described as a sine function. The study was carried out by applying Reynolds average Navier-Stokes with a k-ω turbulent model. The results were compared with previous studies and it was concluded that the aerodynamic loads varied with the frequency and amplitude of the platform motion [14].

Chen et al. investigated the failure causes in the transition zone of wind turbine blades by applying a Finite Element (FE) simulation, which was performed using a global-local modeling approach and Progressive Failure Analysis (PFA) techniques to detect accumulated delamination, at the spar cap, and shear web failure, in the transition region, which were the main causes for blade collapse [15].

Masters et al. conducted a comparative study of numerical models applied to tidal stream turbines to obtain renewable energy from the ocean. The models used were blade element momentum theory (BEMT), blade element actuator disk, Reynolds averaged Navier Stokes (RANS) CFD (BEM-CFD), blade-resolved moving reference frame, and

coastal models based on shallow water equations. The results obtained, for the turbine fence case, were similar to the BEM-CFD and coastal models [16].

Gómez Muñoz and García Márquez demonstrated the use of low-cost acoustic sensors to detect failures in the microfibres of wind turbine blades. They employed a robust monitoring system (CMS) together with new signal processing software [17].

Nielsen and Sorensen proposed the use of dynamic Bayesian networks to optimize and plan maintenance tasks on wind turbine blades. They used data from previous inspections of a range of blades to calibrate a Markov model that was then applied to a particular blade model [18].

Fernández-Gámiz et al. investigated the installation of two flow control systems, vortex generators and gurney flaps, to increase the power output of a 5 MW turbine. The study was performed using the BEM method for different wind speeds and showed that the blades with the flow control systems increased the power output of the turbine [19].

Schramm et al. studied the influence of erosion on the edge of wind turbine blades. They compared eroded blades with blades protected against this phenomenon by calculating polar aerodynamics using computational fluid dynamics and load calculations using BEM. They concluded that the eroded blades caused a power loss of 9%, while the power reduction in the protected blades was only 1% [20].

Arcos Jiménez et al. focused their work on the processing of guided lamb wave signals and multiclass pattern recognition using machine learning to detect, at an early stage, the delamination of wind turbine blade material, which is the source of cracks and partial or total breakage. To test the approach, the delamination phenomenon was provoked using wavelet transforms, which are effective in eliminating noise and extracting the characteristics of the measured signal [21].

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