energies

Review

Basic, Advanced, and Sophisticated Approaches to the Current and Forecast Challenges of Wind Energy

Paweł Ligęza

Strata Mechanics Research Institute, Polish Academy of Sciences, Reymonta 27, 30-059 Krakow, Poland; ligeza@imgpan.pl

Abstract: The article is a synthetic review of contemporary wind energy issues. It was created on the basis of a survey of literature from the last two years, with mainly review articles. This work is intended to be a source of information for a wide group of scientists and students from various fields. The aim is to interest them in a wide range of topics related to wind energy and wind turbines. This may allow for the selection of an area and the undertaking of research in this interesting and future-oriented field.

Keywords: wind energy; wind turbines; development; operation; maintenance; monitoring; challenges

check for updates

Citation: Ligęza, P. Basic, Advanced, and Sophisticated Approaches to the Current and Forecast Challenges of Wind Energy. *Energies* **2021**, *14*, 8147. https://doi.org/10.3390/en14238147

Academic Editor: Antonio Rosato

Received: 28 October 2021
Accepted: 30 November 2021
Published: 5 December 2021

1. Introduction

"Saddle the Wind" is a classic, if somewhat forgotten, western directed by Robert Parrish from the year 1958. Who could have thought then that after half a century, "saddling the wind" would become one of the key challenges for people? Certainly nowadays, no one dares to deny that the development of renewable energy is another giant leap for mankind.

This publication is intended to provide an overview of selected wind energy issues and problems. In this introduction I consciously omit the analysis of the causes and the great importance of the development of renewable energy, including wind energy, in the contemporary world. Virtually every publication in this field begins with such introductions. The number of publications on wind energy published so far is so great that it certainly exceeds the number of wind turbines currently installed all over the world. Therefore, in my review, I only included publications from the last two years. However, such an assumption is not sufficient as the number of important articles related to wind energy is still huge. Therefore, as my paper is limited mainly to the survey of the review articles, it is a kind of meta review. It also applies only to selected issues that I have arbitrarily considered representative. The aim of this review is to familiarize and interest a wide group of scientists and students from various backgrounds and thematic areas in the issues of wind energy. I discuss individual topics in terms of phrases, at a relatively general level, so they are understandable to specialists in various fields. Hence, for this reason, I resign from introducing acronyms denoting various methods, technologies, and indicators to the article. I use full names so that they are understandable to representatives of various fields. Increasingly, the same acronyms, even in similar fields, mean something else. The number of acronyms introduced in scientific publications is growing at an alarming pace. In many cases, creating new acronyms is simply unreasonable and introduces more chaos than order.

With this review article, I would like to encourage the global scientific community to find an area where they can conduct research and contribute to the development of renewable energy. The approach I propose in this review publication may be controversial for many experienced scientists, so I invite you to polemics but, above all, to share your achievements in the field of wind energy. Such an opportunity was created when I guest edited the special issue of, "Advances in Wind Energy and Wind Turbines" in the journal *Energies*.

2. Overview of Selected Basic Issues

The subjects of the article were divided into three substantive parts. The choice of topics and divisions were made on the basis of the research interests, experiences, and knowledge of the authors. Thus, these are subjective divisions based on heuristic premises aimed at introducing a certain systematic orientation of the review of research issues. This review does not pretend to be a complete review of wind power problems. However, the divisions used should be treated as conventional ones, despite other researchers being of the opinion that the hierarchy may be completely different. This section discusses the conventionally basic topics that apply to most typical wind turbines.

2.1. Wind Turbine Locations

Designing a wind farm requires determining its location and optimizing the placement of turbines in the selected area. A review of works on these issues is included in [1]. The article presents the historical background regarding the locations of wind farms. Then, a review of wind farm modeling and optimization methods are discussed, taking into account heuristic methods, artificial intelligence, and mathematical programming algorithms. The main factor of optimization in the design of wind farms is the achievement of maximum efficiency while minimizing the expenditure. The locations of the turbines should take into account the decreases in the efficiencies of the turbines placed in the aerodynamic shadows and the increases in the levels of turbulence generated by adjacent turbines. Apart from the technical and economic aspects, when locating and designing the placements of turbines, a number of other extremely important factors, such as environmental impact and sociological aspects, must of course be taken into account. It is postulated to develop wind farm optimization methods using computational fluid dynamics, deep machine learning, and image recognition and processing techniques. It is possible to further improve the efficiencies of the wind farms while reducing operating costs as well as reducing the environmental impact.

2.2. Wind Parameters Forecasting

In wind energy, forecasting wind parameters is an extremely important and key issue. This process is necessary for the management of individual components and the entire energy network, current operations, energy distribution, planning for switching systems on and off, maintenance, and repairs. Wind forecasting also allows for effective exploitation and technical–economic optimization. A review of the methods of forecasting wind parameters can be found in the article [2]. Physical and statistical issues, the use of artificial intelligence, and hybrid methods are considered here. Various prediction time scales and methods of accuracy were considered. Most often included in wind parameters are velocity, direction, fluctuations, temperature, humidity, and air pressure. The development of forecasting methods uses the huge available databases and complex algorithms such as neural networks or deep machine learning. Due to the development of offshore wind farms, wind forecasting methods apply not only to land areas but to an increasing extent of the open sea.

2.3. Low Speed Wind Turbines

One of the general factors influencing the location of wind farms is the characteristics of the wind in a given area. The optimal location is an area where winds have stable high velocity and slight fluctuations in direction. However, it is also necessary to use locations with lower wind velocities. The problem of turbines for generating electricity at low wind velocities is discussed in [3]. The design of such turbines requires optimization of the geometry, twist, and blade positioning, turbine size, number of blades, reduction of rotor inertia, selection of start characteristics, and improvement and optimization of energy conversion systems. The article presents problems related to the design of standard turbines dedicated to low wind velocities and selected unconventional solutions. These are vertical axis wind turbines, turbines with wind boosters, turbines with nozzles and diffusers, multi-wing turbines, wind concentration systems, and other solutions. An important issue is also the development of algorithms controlling the operations of the turbines in order to obtain maximum efficiency for variable wind velocity. Installing turbines in low wind velocity areas also requires economic consideration. The authors state that these types of turbines are an important complement to other energy systems, and new solutions should be constantly researched.

2.4. Bearings for Wind Turbines

Wind turbines are based on rotation movement and the associated torque transmission. Therefore, one of the important issues regarding the reliability of turbines is the issue of bearings. The review article [4] is devoted to this very issue. The operating conditions of bearings in wind turbines are extremely difficult, mainly due to the magnitude of the loads, their variability over time, and environmental conditions. At the same time, the reliability of these elements is of decisive importance for long term, uninterrupted operation and economic effects. The costs associated with the possible need to replace the bearings in the event of premature wear can have a decisive impact on the profitability of the investment. In the article, the authors present an overview of tribological solutions related to the problem of the bearing arrangement of the various elements of a wind turbine. Bearings used in the main shaft, gearbox, or generator are subject to different, but always the highest, requirements. The issues of bearing design, materials used, friction surface technology, lubrication, and condition monitoring during operations are considered. The authors emphasize the necessity of further verification of the basic causes of bearing damage, with particular emphasis on the parts of the gearboxes. It is also important to pay attention to the various environmental conditions related to the geographical locations of the turbines. It is necessary to conduct research in the field of innovative bearing structures, for example, fluid film bearings.

2.5. Vibrations Problems

The article [5] provides an overview of problems related to vibrations of wind turbines as well as control and reduction techniques. The features of six main categories of systems used are discussed and compared: advanced blade pitch control, variable rotor diameter, flow control, tuned dampers, active tendons, and piezoelectric actuators. The authors point out that many of these systems are used in other fields, but their transfer to wind energy requires solving many problems, for example, scaling. The development of wind turbines is heading towards the creation of facilities with gigantic dimensions, high slenderness and flexibility, and weight reduction. This requires both adaptation works in the field of conventional solutions as well as innovative conceptions and research.

Wind turbines are mechanical constructions of considerable height and high slenderness. They are found on various bases in various geological conditions, both on land and offshore. They are subject to the wind impact of varying intensities and forces related to the rotations of the rotors with the huge blades. They are exposed to constant vibrations, which are a significant destructive factor. This issue is exacerbated by the possibility of various mechanical resonances. Counteracting this influence is difficult due to the complexity of the process of generating vibrations. The article [6] provides an overview of antivibration techniques and strategies as applied to wind turbines. Theoretical and experimental research in this field is constantly carried out. Passive, active, and hybrid vibration reduction methods are used. Passive methods focus on the optimization of the turbine design and the use of appropriate damping and ballast elements. Active methods require sensors, actuators, and complex control systems as well as other elements that adapt dynamic properties to the current conditions. In addition, an effective and comprehensive facility vibration monitoring system is essential.

2.6. Turbines Control Systems

Due to the variable nature of the air flow, wind energy requires dedicated control systems. The issues related to this problem are discussed in the article [7]. An overview of the currently used control systems for fixed speed, variable slip, doubly fed induction generator, and full converter turbines is presented here. Currently, the last two types are mainly used for large wind farms. Block diagrams and the structure of control systems for all types of turbines were presented; their characteristics and the quality of the generated power were compared. The development of control techniques and the challenges in this area mainly relate to the problems of nonlinearity of the objects and the use of adaptive techniques and state prediction to ensure reliable and effective operations.

Optimizing the efficiency of wind power requires the constant development of methods for controlling, managing, monitoring, and maintaining turbines. The use of artificial intelligence methods becomes effective here. An interesting scientometric review in this area is presented in the article [8]. It provides a critical overview of techniques utilized in the wind industry with the use of artificial intelligence. The literature on this subject in the last decade is huge. Authors in the area of network visualization present recent publications on data-driven, decision-making techniques. They focus on the verification and assessment of various artificial intelligence methods used in wind energy. Statistical methods were used here to analyze the available literature knowledge. This allows for the definition of thematic groups in this field and for setting trends and development directions. The authors indicate that deep machine learning methods in particular constitute the area of potentially the highest scope of application. According to the authors, the current level of application of artificial intelligence methods in wind energy is relatively low compared to other fields. This is a challenge for research teams and designers of renewable energy systems.

2.7. Wind Power Storage and Smoothing

An important issue in the process of wind energy generation as well as with the use of other renewable energy sources is temporary storage. A review of issues related to energy storage systems is presented in the article [9]. It provides a general overview of such systems using a variety of technologies while the mechanical systems are thoroughly discussed. The structures and comparisons of flywheel energy storage systems, pumped hydro energy storage, and compressed air energy storage are presented. The advantages and disadvantages of the applications of these systems in renewable energy storage have been considered. The authors also present their recommendations in this regard.

The generation of wind energy is characterized by a strong variation with time, depending on the current velocity of movement of air masses. The possibilities for anticipation and planning in this regard are limited. This is a severely disadvantageous feature of this energy source. Therefore, one of the important issues in this area is smoothing the energy stream with the use of its storage. A review of the developed strategies in this regard can be found in the work [10]. The process of hydrogen production, air compression, rotating massive objects, supercapacitors, and superconductor coils are used to store energy, but the basic is electrochemical batteries. Optimizing a power generation system requires an appropriate control strategy. The paper [10] reviews such strategies related to the filtration, charging, and discharging processes and wind velocity prediction. Solutions using classic proportional-integral-derivative controllers, fuzzy logic, and the predictive control model are discussed. The authors note that thus far the systems based on deep learning technology have been used to a small extent.

A comprehensive review of publications related to the problem of wind power smoothing in high power systems is included in the work [11]. The development of energy storage methods for short and long term applications is discussed here. Attention was paid to hybrid solutions and cooperation with the network. Reducing wind power fluctuations is a constant challenge that must be constantly developed. Thanks to the conducted research, the cost of energy storage systems is reduced. On the other hand, the parameters related to capacity, lifetime, and reaction speed are improving. This enables the development of complex control systems for wind turbines and the improvement of the quality of wind energy smoothing systems.

3. Advanced Problems of Wind Turbines

This part of the article is intended by the authors to discuss more advanced and complex problems related to wind power. It is focused on certain specialized issues related to the locations of wind turbines in difficult environmental conditions as well as the issues of operations, maintenance, and repairs.

3.1. Urban Wind Turbine Locations

The issue of installing wind turbines in urbanized areas is discussed in the review [12]. The analysis of the current state of wind energy in urban areas in technical, economic, and environmental aspects was made here. The foundation of wind turbines in urban areas is a separate issue with specific features. Roofs and skyscraper, industrial, recreation, and communication areas can be used here. The undoubted advantage of urban locations is the use of energy on site without the need for long distance transmission and thus energy losses. However, winds in built-up areas are variable in direction and force and are difficult to predict. The nature of the air flows is different from that of open areas with many shadow areas and considerable levels of turbulence. The limitation is also the cost of installation and environmental nuisance. Due to the specificity of urban areas, various turbine solutions are used in terms of scale and technology. It is important to choose the optimal turbine for the available location conditions and wind characteristics. However, the authors conclude that urban distributed wind energy can be an important supplement to the constantly growing energy demand.

3.2. Offshore Wind Turbines

Offshore turbines and wind farms are both the current and future-oriented direction of renewable energy development. This area of wind energy placement has many advantages over onshore farms but poses many technological challenges. An overview of this subject is provided in the article [13]. The stage of construction and placement of both anchoring and floating turbines is decisive for the success of the project. The article provides a comprehensive overview of the methods and equipment used to install offshore turbines. It focuses on the technological, economic, legal, and environmental aspects. The types of foundations used for wind turbines and the assembly techniques of their components are presented. The authors state that while the problem of the permanent foundations is relatively well developed, the issues related to floating foundations require further work and studies. Installing turbines in the open sea is also a great challenge. Constant development of numerical computation tools at the level of project development and optimization is necessary. On the other hand, in the field of turbine installation, the subject of improving techniques and equipment is also subject to constant improvement.

The operations and maintenance of offshore wind turbines are important technological and economic problems in the field of modern wind energy. Regarding the operations of turbines, a continuous process of condition monitoring, event prediction, and making current and preventive decisions is carried out. The article [14] contains a summary of currently used conventional strategies in this field and indicates the directions of development. The use of modeling and computer simulation techniques becomes essential. This allows for the prediction of events and the use of preventive actions. An important direction of development is the use of IT methods, with particular emphasis on artificial intelligence algorithms. This will allow for the automation of decision-making processes and the introduction of autonomous systems. For this purpose, it is necessary to create operational databases, which constitute the basis for the development and improvement of operational and decision-making algorithms.

Floating offshore wind turbines are potentially the most developing direction of wind energy but also the greatest technological and research challenge. Their development allows the use of huge wind resources; hence, research in this area is very important. In the article [15], the authors reviewed the methods of testing floating turbines. This applies to computer simulations, experimental tests in laboratory pools, and in situ measurements. Thanks to the development of informatics hardware and software, numerical research is now an important tool for solving complex, nonlinear aerodynamic–hydrodynamic problems. However, numerical simulations require the determination of the boundary—initial conditions and experimental verification. In the field of laboratory tests, attention was paid to the important problem of scaling. The results of actual measurements on selected offshore facilities, available in the literature, were discussed and analyzed. The development of hybrid methods combining computer model research and experiments in a laboratory pool is also presented. This process uses a virtual–experimental feedback loop. According to the authors, this is the most promising direction of research.

3.3. Testing and Damage Detection

The rotor blades play a key role in the performance of wind turbines; however, as active elements they are susceptible to damage. The damages may be related to construction errors and defects arising in the production, transport, and assembly processes. They can occur as a result of factors during the operations process such as high loads, transients, vibrations, collisions, emergency states, and others. Therefore, the process of blade condition monitoring and damage detection is important. The article [16] presents an overview of characteristic damage to blades and the detection methods. The techniques used include strain measurement, acoustic and ultrasound emissions acquisition, vibration monitoring, thermography, and optical monitoring methods. The review presents the theoretical basis, the used physical quantities, and the methodology of damage detection for the discussed technologies. A comparison of selected features of the methods as well as prospects and development directions of damage detection techniques are also included. This problem is extremely important for the proper, safe, and reliable operations of wind turbines.

The article [17] provides an extension to the review of nondestructive diagnostic methods for wind turbine blades. In addition to those already mentioned, radiographic and electromagnetic testing methods and shearography are also discussed. The strengths and weaknesses of diagnostic methods are presented, with references to the relevant literature items. Particular attention was paid to the technical, utilitarian, economic, and logistical aspects of applying the discussed methods and the criteria for their selection.

3.4. Advanced Techniques of Air Velocity Measurement

Wind energy requires anemometric measurements, [18] both at the turbine design stage and during the operations. The variety of methods of measuring the air flow velocity, depending on the metrological requirements, is significant. Laboratory studies often require the measurement of three-dimensional velocity fields around objects. It is also important to measure the level of turbulence and the frequency energy spectrum of the flow [19]. Optical methods are used in such measurements—laser doppler anemometry and particle image velocimetry. Hot-wire anemometry is also used in this area. However, tachometric, pressure, and ultrasonic anemometers are used in situ during turbine exploitation. Anemometric measurements always require the selection of an optimal measurement method and instrument that ensure the required measurement parameters [20].

3.5. Increasing the Efficiency of Turbines

One of the interesting directions of wind energy development are diffuser augmented wind turbines. This solution, which uses a specially constructed aerodynamic turbine casing, allows for the optimization of the energy production process. The theoretical analysis and a review of the mathematical models of this solution are discussed in [21]. The developed models are used to design and optimize the performance of such turbines.

The analysis presented in [21] is of a critical nature, paying attention to the simplifying assumptions adopted and the shortcomings of the models used thus far. This allows for the opening of new research directions in this field. An important problem indicated is estimating the maximum power that can be obtained from these types of turbines for specific dimensions. This is one of the key issues associated with optimizing the performance of these turbines.

4. Some Sophisticated Challenges

The last substantive part discusses selected issues related to wind power that do not directly relate to energy production. They were referred to as sophisticated by the authors. Although theoretically without considering these issues, the operations of wind farms are possible, the development of civilization requires the consideration of these issues on par with technological issues. The examples of issues selected in this part of the article represent this matter.

4.1. Effects on Human Health

The impact of wind turbines on the health of the inhabitants of nearby areas is subject to monitoring and constant research. A review of the literature on this subject has been compiled in [22]. The main factor to be analyzed is the low frequency sounds and infrasound generated by the turbines' rotors. Additionally, the visual impact is considered as a disturbing landscape element and other potential threats. The influence on the emotional state of people, irritation and irritability, sleep disturbance, and metabolism and blood circulation as well as on mental disorders and behavioral disorders is investigated. The literature review mainly points to the irritation and irritability of people as a result of the acoustic emissions of turbines. Other health effects are not convincingly and unequivocally confirmed. Rather, they are a derivative of the emotional, mental, and personal attitudes of residents exposed to the acoustic impact of wind farms. In the process of planning wind farms, attention should be paid to relations with local communities, their participation in the project, reliable information and compliance with ethical requirements, and respect for local customs and traditions.

An extensive literature review on the impact of wind turbine noise on sleep disturbance and insomnia [23] does not confirm a direct relationship between these elements. The conducted comprehensive meta-analysis of the available sources did not show any confirmation in the form of objective indicators of the impact of turbine noise on the sleep patterns of the local inhabitants. However, due to the variety of research methodologies, the use of nonobjective indicators and the lack of a uniform methodology of conducting research to date, the authors leave the final solution as an open problem. Well-prepared and objectified research on the influence of turbines on the organisms of people living in the immediate vicinity is a scientific challenge for the future.

4.2. Social Perception

In addition to technological, economic, and legal issues, social perception is an important aspect of development, evolution, and expansion of wind energy. A review of the literature in this area is included in [24]. The authors point out that despite the widespread support for the idea of renewable energy, local acceptance is at a very low level. This is a significant barrier to the development of this branch of energy. The article analyzes specific case studies in various regions of Europe described in the literature. Comparative and both qualitative and quantitative analyses were carried out. It was indicated that an important factor in the development of renewable energy is gaining social trust. It is necessary to implement information strategies based on high quality technical, economic, legal, social, environmental and health data.

4.3. Impact on the Natural Environment

The impact of wind energy on the ecosystem is subject to constant research and monitoring. One problem is the noise generated by wind turbines. This issue concerns not only the acoustic waves generated in the air but also the underwater noise produced by offshore wind farms. The article [25] discusses the most important problems related to this issue. Based on the collected literature, the results of measurements made in various locations were reviewed. This allowed for the analysis and comparison of noise parameters generated by offshore turbines. The noise level was analyzed depending on the type and number of turbines, size, wind velocity, and distance from the noise source. Based on the survey of measurements, it has been found that the level of low frequency underwater noise produced by turbines is approximately 10 to 20 dB lower than that generated by other facilities such as large cargo ships. While the noise level is relatively high near the turbines themselves, it decreases quickly with distance. The size of the turbines or the velocity of the wind have less influence here. Currently, turbine noise has a significant environmental impact in areas where the levels of other sources are low. However, the constant development of offshore wind energy will result in the intensification of underwater noise and the necessity to take action to reduce the noise impact on the environment.

One of the very important issues related to wind energy is the impact on the natural environment. One of the aspects of this topic is the mortality of flying fauna, i.e., birds and bats. This issue is studied and monitored in many areas of the world. The article [26] reviews this subject in Latin America. This is particularly interesting because most of the research is focused on Europe and North America. The authors of the article draw attention to the lack of reviews in Latin America so far and are trying to fill this gap. It is important because Latin America is potentially a region of rapid and intensive development of wind energy in the coming years. The research conducted so far in this area indicates that sparrows constitute the largest number of victims among the birds, while there are no endangered species. However, one endangered species was reported among bats. The available amount of information in this area is limited; therefore, it is difficult to make an unambiguous and complete assessment of this phenomenon. However, it is necessary to develop and intensify activities related to reducing the possibility of collisions between animals and wind turbines. It would be helpful to use the experience from other areas of the world where research in this field is more advanced.

4.4. Economic Issues and Indicators

The departure from traditional methods of electricity production based on the combustion of fossil resources has become a civilization necessity. Therefore, various methods of generating energy are being developed. It becomes imperative to compare and economically evaluate various energy sources. Levelized costs of electricity are a widely used indicator for comparing the costs of energy production. Along with the development of wind power and other modern energy technologies, it was necessary to adapt the methods of determining this indicator to the properties of these technologies. The article [27] reviews these methods as applied to renewable energy. Economic considerations related to investments, operations, performance, and risks are included here. The uncertainty in determining economic indicators was analyzed. On the basis of the literature review, the authors of the work [27] indicate the problems that should be taken into account when determining economic indicators for renewable energy sources. These include variable efficiency, location and seasonal conditions, cooperation with the grid, and renewable energy policies. The authors point out the need to take into account the uncertainty of data and parameters in the modeling of economic indicators.

An important exploitation indicator is also life cycle assessments. A systematic review of the methods for determining this indicator, based on the literature, is included in [28]. The review covers all major methods of electricity generation, including those based on the combustion of fossil fuels, nuclear energy, and renewable energy. The authors indicate that despite the development of methods for determining life cycle assessments, there are still many unresolved problems that require further development. This applies to the improvement of data processing methods, standardization, and the wide use of results by decision makers.

5. Conclusions

As a conclusion of this survey, I would like to once again encourage readers to take up challenges and undertake research in the field of broadly understood wind energy. We can see that this theme applies not only to technical and engineering sciences, but also to natural sciences, humanities, medical, social, agricultural, economic, and possibly even art. What will be the future of wind energy development and its share in global energy production? One possible answer to this question can be found in an article published in the journal *Science* [29]. However, experience shows that simple trend extrapolation does not always produce correct results. Apart from the enthusiastic development of diverse renewable energy technologies, there are also questions. I recently received a challenge to include a bold estimation of the ratio of all energy invested in wind turbines to all energy gained from wind turbines so far worldwide. I do not know a simple answer to this question and possibly someone from the younger generation of scientists will create an appropriate model and be able to estimate this parameter with acceptable uncertainty.

Wind energy is one of the areas of renewable energy; however, it is important to realize that there are no perfect, unlimited sources of usable energy. Contemporary energy based on solar nuclear fusion, i.e., wind energy, hydropower, and photovoltaic, are not a panacea for the risks associated with traditional energy based on raw materials [30,31]. In addition to the development and improvement of renewable energy sources, an equally important issue is to prevent unnecessary dissipation of utility energy. Let us remember this and consciously use the available energy by treating it not as a commodity but as a common good.

Funding: This research received no external funding.

Conflicts of Interest: The author declare no conflict of interest.

References

1. Azlan, F.; Kurnia, J.C.; Tan, B.T.; Ismadi, M.-Z. Review on optimization methods of wind farm array under three classical wind condition problems. *Renew. Sustain. Energy Rev.* **2021**, *135*, 110047. [CrossRef]
2. Hanifi, S.; Liu, X.; Lin, Z.; Lotfian, S. A Critical Review of Wind Power Forecasting Methods—Past, Present and Future. *Energies* **2020**, *13*, 3764. [CrossRef]
3. Venkatramakrishnan, S.R.; Pandey, J.K.; Mondal, A.K.; Karn, A. Low Speed Wind Turbines for Power Generation: A Review. *J. Adv. Res. Fluid Mech. Therm. Sci.* **2020**, *67*, 146–169.
4. Dhanola, A.; Garg, H.C. Tribological challenges and advancements in wind turbine bearings: A review. *Eng. Fail. Anal.* **2020**, *118*, 104885. [CrossRef]
5. Awada, A.; Younes, R.; Ilinca, A. Review of Vibration Control Methods for Wind Turbines. *Energies* **2021**, *14*, 3058. [CrossRef]
6. Zuo, H.; Bi, K.; Hao, H. A state-of-the-art review on the vibration mitigation of wind turbines. *Renew. Sustain. Energy Rev.* **2020**, *121*, 109710. [CrossRef]
7. Ghaffarzadeh, H.; Mehrizi-Sani, A. Review of Control Techniques for Wind Energy Systems. *Energies* **2020**, *13*, 6666. [CrossRef]
8. Chatterjee, J.; Dethlefs, N. Scientometric review of artificial intelligence for operations & maintenance of wind turbines: The past, present and future. *Renew. Sustain. Energy Rev.* **2021**, *144*, 111051.
9. Mahmoud, M.; Ramadan, M.; Olabi, A.G.; Pullen, K.; Naher, S. A review of mechanical energy storage systems combined with wind and solar applications. *Energy Convers. Manag.* **2020**, *210*, 112670. [CrossRef]
10. Silva de Siqueira, L.M.; Peng, W. Control strategy to smooth wind power output using battery energy storage system: A review. *J. Energy Storage* **2021**, *35*, 102252. [CrossRef]
11. Barra, P.H.A.; Carvalho, W.C.; Menezes, T.S.; Fernandes, R.A.S.; Coury, D.V. A review on wind power smoothing using high-power energy storage systems. *Renew. Sustain. Energy Rev.* **2021**, *137*, 110455. [CrossRef]
12. Tasneem, Z.; Noman, A.A.; Das, S.K.; Saha, D.K.; Islam Md, R.; Ali Md, F.; Badal Md, F.R.; Ahamed Md, H.; Moyeen, S.I.; Alam, F. An analytical review on the evaluation of wind resource and wind turbine for urban application: Prospect and challenges. *Dev. Built Environ.* **2020**, *4*, 100033. [CrossRef]
13. Jiang, Z. Installation of offshore wind turbines: A technical review. *Renew. Sustain. Energy Rev.* **2021**, *139*, 110576. [CrossRef]

14. Rinaldi, G.; Thies, P.R.; Johanning, L. Current Status and Future Trends in the Operation and Maintenance of Offshore Wind Turbines: A Review. *Energies* **2021**, *14*, 2484. [CrossRef]
15. Chen, P.; Chen, J.; Hu, Z. Review of Experimental-Numerical Methodologies and Challenges for Floating Offshore Wind Turbines. *J. Mar. Sci. Appl.* **2020**, *19*, 339–361. [CrossRef]
16. Du, Y.; Zhou, S.; Jing, X.; Peng, Y.; Wu, H.; Kwok, N. Damage detection techniques for wind turbine blades: A review. *Mech. Syst. Signal Process.* **2020**, *141*, 106445. [CrossRef]
17. Marquez FP, G.; Chacon AM, P. A review of non-destructive testing on wind turbines blades. *Renew. Energy* **2020**, *161*, 998–1010. [CrossRef]
18. Ligęza, P.; Jamróz, P.; Ostrogórski, P. Methods for dynamic behavior improvement of tachometric and thermal anemometers by active control. *Measurement* **2020**, *166*, 108147. [CrossRef]
19. Ligęza, P. Constant-Temperature Anemometer Bandwidth Shape Determination for Energy Spectrum Study of Turbulent Flows. *Energies* **2021**, *14*, 4495. [CrossRef]
20. Ligęza, P. Static and dynamic parameters of hot-wire sensors in a wide range of filament diameters as a criterion for optimal sensor selection in measurement process. *Measurement* **2020**, *151*, 107177. [CrossRef]
21. Bontempo, R.; Manna, M. Diffuser augmented wind turbines: Review and assessment of theoretical models. *Appl. Energy* **2020**, *280*, 115867. [CrossRef]
22. Van Kamp, I.; Van den Berg, F. Health Effects Related to Wind Turbine Sound: An Update. *Int. J. Environ. Res. Public Health* **2021**, *18*, 9133. [CrossRef]
23. Liebich, T.; Lack, L.; Hansen, K.; Zajamšek, B.; Lovato, N.; Catcheside, P.; Micic, G. A systematic review and meta-analysis of wind turbine noise effects on sleep using validated objective and subjective sleep assessments. *J. Sleep Res.* **2020**, *30*, e13228. [CrossRef]
24. Segreto, M.; Principe, L.; Desormeaux, A.; Torre, M.; Tomassetti, L.; Tratzi, P.; Paolini, V.; Petracchini, F. Trends in Social Acceptance of Renewable Energy across Europe—A Literature Review. *Int. J. Environ. Res. Public Health* **2020**, *17*, 9161. [CrossRef]
25. Tougaarda, J.; Hermannsen, L.; Madsenb, P.T. How loud is the underwater noise from operating offshore wind turbines? *J. Acoust. Soc. Am.* **2020**, *148*, 2885. [CrossRef]
26. Agudelo, M.S.; Mabee, T.J.; Palmer, R.; Anderson, R. Post-construction bird and bat fatality monitoring studies at wind energy projects in Latin America: A summary and review. *Heliyon* **2021**, *7*, e07251. [CrossRef] [PubMed]
27. Shen, W.; Chen, X.; Qiu, J.; Hayward, J.A.; Sayeef, S.; Osman, P.; Meng, K.; Dong, Z.Y. A comprehensive review of variable renewable energy levelized cost of electricity. *Renew. Sustain. Energy Rev.* **2020**, *133*, 110301. [CrossRef]
28. Jordaan, S.M.; Combs, C.; Guenther, E. Life cycle assessment of electricity generation: A systematic review of spatiotemporal methods. *Adv. Appl. Energy* **2021**, *3*, 100058. [CrossRef]
29. Veers, P.; Dykes, K.; Lantz, E.; Barth, S.; Bottasso, C.L.; Carlson, O.; Clifton, A.; Green, J.; Green, P.; Holttinen, H.; et al. Grand challenges in the science of wind energy. *Science* **2019**, *366*, 6464. [CrossRef] [PubMed]
30. Skotniczny, P. Aerological factors favouring the occurrence of endogenous fires on coal waste stockpiles. *Arch. Min. Sci.* **2020**, *64*, 901–916.
31. Dutka, B.; Godyń, K. Coalification as a Process Determining the Methane Adsorption Ability of Coal Seams. *Arch. Min. Sci.* **2021**, *66*, 181–195.