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Analyzing the growth and trends of vertical axis wind turbine research: Insight from a bibliometric study

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Abstract

Bibliometric analysis research has been done for vertical axis wind turbine (VAWT). This study aims to determine the growth of VAWT research, the number of VAWT studies in various countries and the most influential authors to find opportunities for research collaboration, and the challenges of future VAWT research. Research data was taken from Scopus in 1801 articles from 1970-2021. The software used for data interpretation was VosViewer 1.6.19 and Tableau Public 2022.2. Based on the analysis, VAWT research has tended to increase from 1970-2021, although there was a decrease from 1987-2006. The country that has conducted the most VAWT research is China, while the author with the highest number of citations is from Italy. The most dominant research topic related to VAWT research is computational fluid dynamics (CFD), which is 50.14 % of the total. A future challenge related to VAWT research is finding a suitable turbulence model for each type of VAWT or finding an airfoil optimization method so that a model with better performance is obtained. Opportunities for research collaboration can be carried out with China or an author with the highest number of citations who has expertise in the field of CFD .

Keywords: bibliometric analysis; Tableau Public 2022.2 software; vertical axis wind turbine (VAWT); VosViewer 1.6.19 software.

I. Introduction

Development of renewable energy is currently increasing rapidly [1] due to the Stated Policies Scenario (STEPS) policy which seeks to reduce carbon dioxide (CO_2) emissions by 55 % in 2030 compared to 1990 [2]. Basically, many renewable energies are produced by various sources, such as the sun, wind, ocean waves, ocean currents, and so on [3]. In the Asia Pacific region, wind energy is a renewable energy source with great potential to be developed, even from 2008–2018, the development of wind energy has continued to increase [4]. Especially in Indonesia, the implementation of wind energy has increased every year since 2017 until now. Moreover, President Jokowi installed the largest wind energy installation in Indonesia, with a capacity of 75 MW in July 2018 [5]. Not only that, studies on the implementation of wind energy have been attempted in various fields, for example, at airports [6].

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The challenge for the development of wind energy in Indonesia is the relatively low wind speed [5]. In fact, to be able to rotate horizontal axis wind turbine (HAWT) that is commonly developed in Indonesia, wind speeds of 5–7 m/s are required [7]. However, there is a type of wind turbine that can rotate at lower wind speeds, namely the vertical axis wind turbine (VAWT) [8]. According to [9], VAWT has more advantages than HAWT. However, the efficiency of VAWT is still less than HAWT. So, for VAWT development, a lot of innovation is still needed to improve its performance. And currently, research is being intensively carried out to improve the performance of the VAWT, as was done by [10][11][12].

So far, there are many methods that can be applied to determine ongoing research trends, for example, meta-analysis, literature review, mapping review, bibliometric analysis, and so on [13]. Among all these methods, bibliometric analysis has advantages. For example, it can easily provide final information on research opportunities, can provide information on collaboration opportunities easily, and so on [14]. With these various advantages, bibliometrics is one of the most popular literature review methods and has been used in various fields, for example, electric vehicle control strategy [15], food studies [16], renewable energy [17], and so on. However, so far, there has been no bibliometric analysis in the field of VAWT. Therefore, this research was conducted on the topic of bibliometric analysis for VAWT with the main objective of providing information to readers about the VAWT research growth, the country that does the most research on VAWT, opportunities for VAWT research collaboration, and challenges to future VAWT research.

II. Materials and Methods

Bibliometric analysis is a method for identifying research trends from a specific topic quantitatively [18]. There are three main stages in bibliometric study, as shown in Figure 1. Based on Figure 1, the most important thing is data visualization. The author can use many software to interpret data, but in this case, the author uses VosViewer 1.6.19 and Tableau Public 2022.2 software. Then data collection can be obtained from many sources, but in this case, the author uses Scopus.

VAWT research publication data were obtained from Scopus from the beginning until 2021. Scopus was used as the data source in this study because Scopus provides high-quality data for bibliometric analysis [19]. The keyword used to search articles on Scopus Explorer is "vertical axis wind turbine". The number of articles found is 2411. However, limitations were given to the articles to be reviewed, which are English-language articles, journals, and published articles, so that 1801 articles that met these criteria were obtained.

All data relating to the article, such as the author's name, number of citations, affiliation, keywords, abstract, and so on, are exported in CSV format. The data that has been obtained from Scopus is then processed using the OpenRefine software. The purpose of using this software is to do keyword clustering. Keywords from all articles that have similar meanings are grouped so that there is no meaning bias.

Data visualization was performed using VosViewer 1.6.19 and Tableau Public 2022.2 open-access software. These two software make data visualization more attractive in various forms. By using two software, a graph of the growth of VAWT research publications, a map of the country with the number of VAWT research publications, and linkages between keywords from the articles obtained can be displayed. Finally, the analysis was carried out with the aim of knowing the growth of VAWT research publications, opportunities for research collaboration through data on countries and authors who conducted VAWT research, and ideas or challenges for future VAWT research.

III. Results and Discussions

Data that has been interpreted using VosViewer 1.6.19 and Tableau Public 2022.2 software is analyzed as follows.

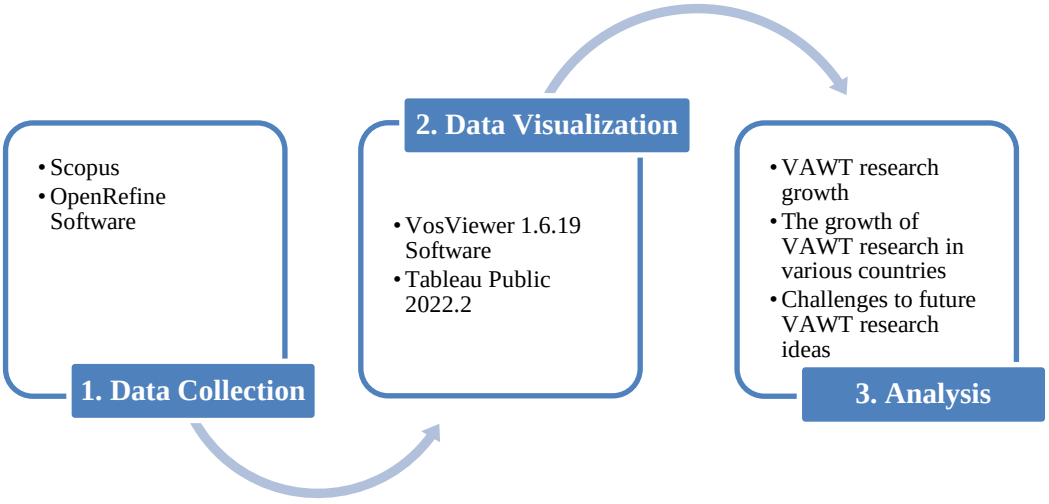

Figure 1. Stages in bibliometric analysis

A. Introduction VAWT research growth

Based on data obtained from Scopus, there have been 1801 articles on the topic of VAWT since it was first conducted in 2021. The first research published on Scopus was conducted in 1970. Until 2021, the number of studies on VAWT has fluctuated but tends to increase, as shown in Figure 2.

Research published in 1970 was conducted by Butler B. L., Blackwell B. F. with the title "the application of laminated wooden blades to a two-meter Darrieus type vertical axis wind turbine" [20]. He introduced and conducted experimental testing of Lauan plywood as a suitable material for Darrieus propellers on a small scale. Since then, until 1986, VAWT research published in Scopus has tended to increase. The dominant VAWT research studied during this period was Darrieus. During this period, most researchers focused their research on obtaining an economical Darrieus design. In fact, during this period, commercial Darrieus wind farms were also built in India [21] and Canada [22].

However, there was a decrease in VAWT research from 1987 to 2006 because it was triggered by several things, one of which was a failure in the development of a wind farm related to power transmission, which destroyed the turbine blades. Turbine prototypes that had already been built were also dismantled in the early 1990s [23]. From 2007 to 2021, VAWT research published on Scopus continued to increase. This was triggered by efforts to reduce CO_2 emissions held by various countries in the world and stated in the Kyoto Protocol [24]. Since the issuance of the Kyoto Protocol, in the period 2008–2012, industrialized countries must be able to reduce CO_2 emissions by 5 %. Therefore, one of the efforts they can make to meet this target is through the development of renewable energy, one of which is wind energy.

B. VAWT research in various countries and opportunities for research collaboration

Along with the incessant efforts to reduce CO_2 emissions, many countries in the world are starting to participate in conducting VAWT research. The number of studies on VAWT by various countries in the world is shown in Figure 3.

The country map is made using Tableau Public 2022.2 software. Tableau Public 2022.2 software has a database for country map coordinates, when combined with the number of journal publications data in each country that has been obtained, the contours in Figure 3 can be generated. In Figure 3, the number of publications is also stated in the map, for example, 26 publications for Indonesia, 86 publications for Japan, 16 publications for Australia, and so on.

The country that has developed the most VAWT research is China, with a total of 15.27 % Scopus publications. China ranks second in the world regarding energy consumption [25]. China is determined to reduce CO_2 emissions by 40–45 % from 2005 to 2020 [26]. Because wind energy is the most mature and economical renewable energy in China, it has great potential to be developed [27]. It is estimated that wind power installation in China is 66.9 GW in 2030 [28]. In fact, since February 2010, the Chinese government has issued a policy that every coastal province must make an offshore wind power development plan under the supervision of the National Energy Bureau and National Marine Bureau [27].

Then, based on the number of publications in all countries, data on the ten authors with the most citations are shown in Table 1. The number of citations relates to how influential the author is on the research topic. Based on the data in Table 1, the two authors with the highest number of citations are

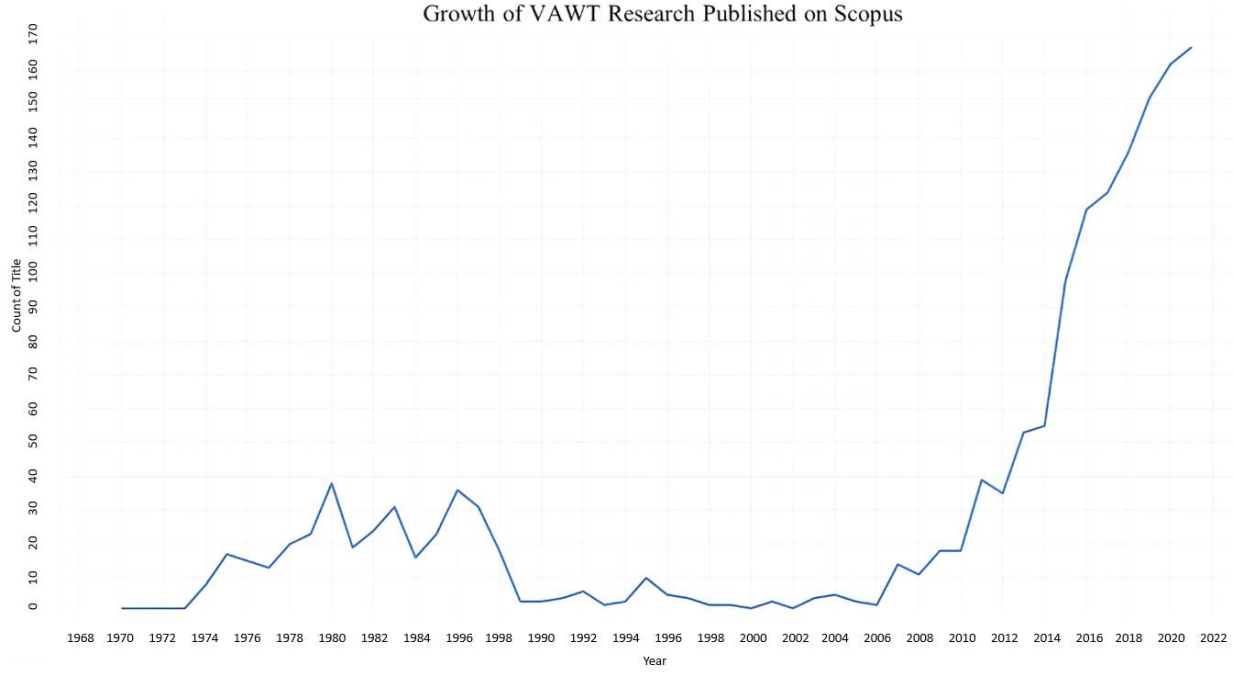

Figure 2. Growth of VAWT research published on Scopus

at the same institution, namely Università degli Studi di Firenze. Bianchini, A. is an Assistant Professor at the Department of Industrial Engineering, Università degli Studi Firenze, Florence, Italy. He has a research interest in the field of setup and control of measurement systems, particularly concerning dynamic pressure and temperature measurement, wind tunnel external aerodynamics, and performance tests of turbomachines. Meanwhile, Balduzzi, F. is a Research Fellow at the Department of Industrial Engineering of the University of Florence. He works in the field of computational fluid dynamics (CFD) analysis of fluid machines and energy systems. The laboratories of these two authors provide renewable energy applications which are supported by adequate energy conversion machines and CFD software. However, the implementation of VAWT development is not much done in Italy because Italy is currently hampered by several concurrent problems, the length of the authorization process being the most significant. Due in large part to the environmental impact assessment (EIA's) legally binding conclusion, the approval process for wind farms typically takes five and a half years [29]. So CFD simulation research on wind energy began to be started and studied by the most cited author as a preliminary study of VAWT development in his country.

Thus, based on an analysis of the number of countries that have implemented the most VAWT development, the greatest opportunities for research collaboration can be carried out in China because it has easier policies for VAWT development and good technology. As for CFD research for VAWT, there is an opportunity to collaborate with Bianchini, A. and Balduzzi, F. because both have high expertise in VAWT CFD, as evidenced by the high number of citations to their articles.

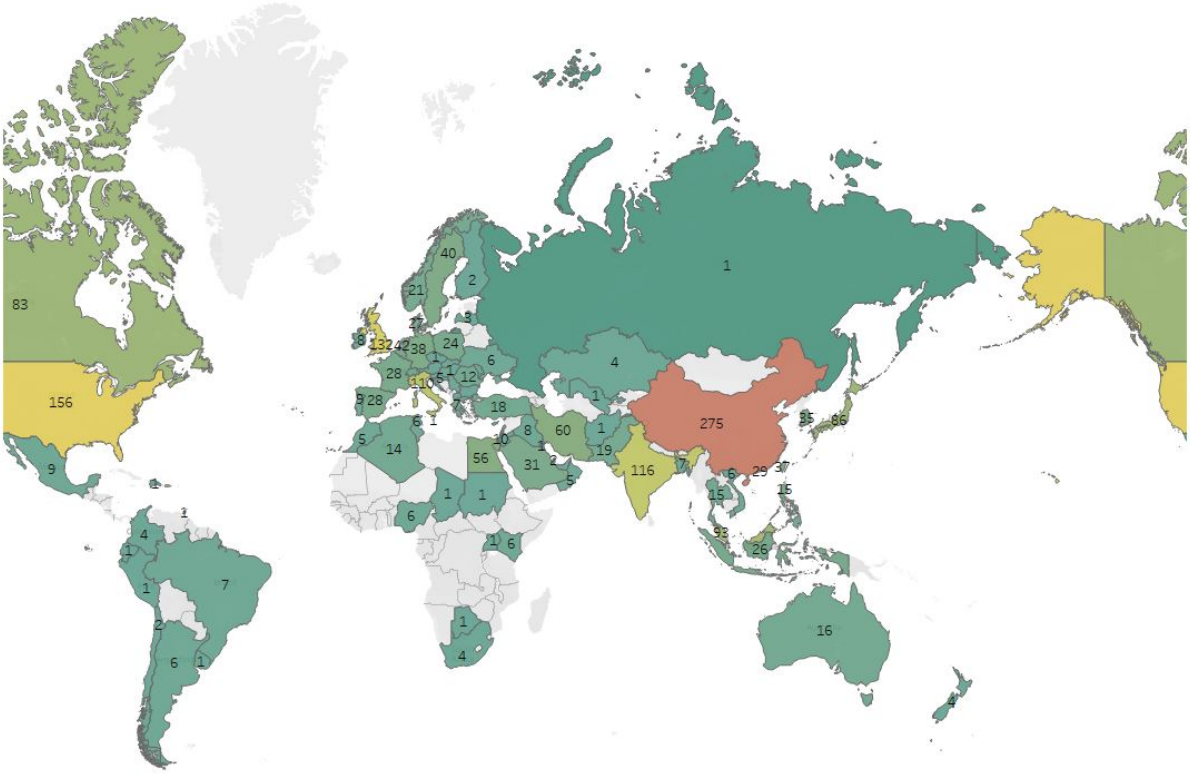

Figure 3. Country map of VAWT research publications

Table 1.
Top 10 authors with the number of citations

No.	Author	Number of citation	Affiliation	Scopus ID
1.	Bianchini, A.	467	Università degli Studi Firenze, Florence, Italy	50560948100
2.	Balduzzi, F.	397	Università degli Studi Firenze, Florence, Italy	54792610900
3.	Blocken, B.	378	Technische Universiteit Eindhoven, Eindhoven, Netherlands	55906535400
4.	Rezaeiha, A..	368	KU Leuvendisabled, 3000 Leuven, Belgium	55602401600
5.	Ferrara, G..	359	Università degli Studi di Firenzedisabled, Florence, Italy	36720039300
6.	Ferrari, I.	299	Department of Energy, Systems, Territory and Construction Engineering, The University of Pisa, Largo Lucio Lazzarino, Pisa 56122, Italy	7101737239
7.	Paraschivoiu, I.	269	Polytechnique Montréaldisabled, Montreal, Canada	7003702851
8.	Kamada, Y.	246	Mie Universitydisabled, Tsu, Japan	7102943566
9.	Maeda, T.	239	Mie Universitydisabled, Tsu, Japan	7404540215
10.	Dabiri, J.O.	227	California Institute of Technologydisabled, Pasadena, United States	6602215129

C. VAWT research trends and challenges

Research challenges can be analyzed through ongoing research trends. This trend can be seen from the relevance and number of keywords that are mostly used by researchers. Linkage data between VAWT research topic keywords from 2012 to 2021 is shown in Figure 4. The data is analyzed in the last ten years to learn the latest ongoing research.

The keywords linkage map was created using VosViewer 1.6.19 software. By inputting the data obtained from Scopus, the map can be interpreted as Figure 4 through the tools available in the software. The size of the circle indicates how many keywords are used. The bigger the circle, the more keywords are used. Based on that data, the three most used keywords were vertical axis wind turbine with 799 usages, computational fluid dynamics with 346 usages, and wind turbine with 163 usages. In contrast, the least used keyword is aerodynamic loads, with seven usages.

When reviewed by year, the yellow keywords are the most recent research keywords. One of the most recent research keywords is airfoil optimization. Along with the development of society in the 5.0 era, artificial intelligence (AI) technology is also used in VAWT research. Many researchers optimize airfoil geometry using AI. For example, [30], performs airfoil geometry optimization using a Genetic Algorithm. He optimized the S809. As a result, the optimized S809 can increase the power coefficient (CP) by 128 %. Another research regarding airfoil optimization using AI was also carried out by [31]. He optimized NACA0012 using Machine Learning. The result is that the optimized NACA0012 can increase the lift coefficient (CL) by 86.44 % and reduce the drag coefficient (CD) by 0.80 %. Of all the airfoil optimization studies that have been carried out, the challenge is the optimization method used to produce better performance.

Regarding airfoil optimization, the performance of the optimized airfoil needs to be tested. Since the existence of VAWT research, the most widely used VAWT performance testing method is computational fluid dynamics (CFD). As much as 51.14 % of the total Scopus-published documents conducted CFD research. The popular software used by researchers to do CFD is Ansys Fluent. The first published VAWT numerical research on Scopus was conducted by [32] in 2013. He used the commercial software ANSYS 11.0. At that time, he had considered design parameters such as solidity, aspect ratio, pressure coefficient, and so on to achieve a power output of 1 kW, and the tests were carried out in extreme wind conditions where the maximum deflection and bending stress values were determined at maximum aerodynamics and centrifugal forces. Thus, he obtained a design that has high strength and lower material consumption. Since then, numerical research has become popular among researchers.

CFD research is the main concern for researchers because CFD is a very useful tool for evaluating the aerodynamic performance of VAWTs. Several CFD studies have focused on evaluating ways to improve the performance of a VAWT, such as pitch angle optimization, airfoil optimization, solidity optimization, and so on. However, the biggest

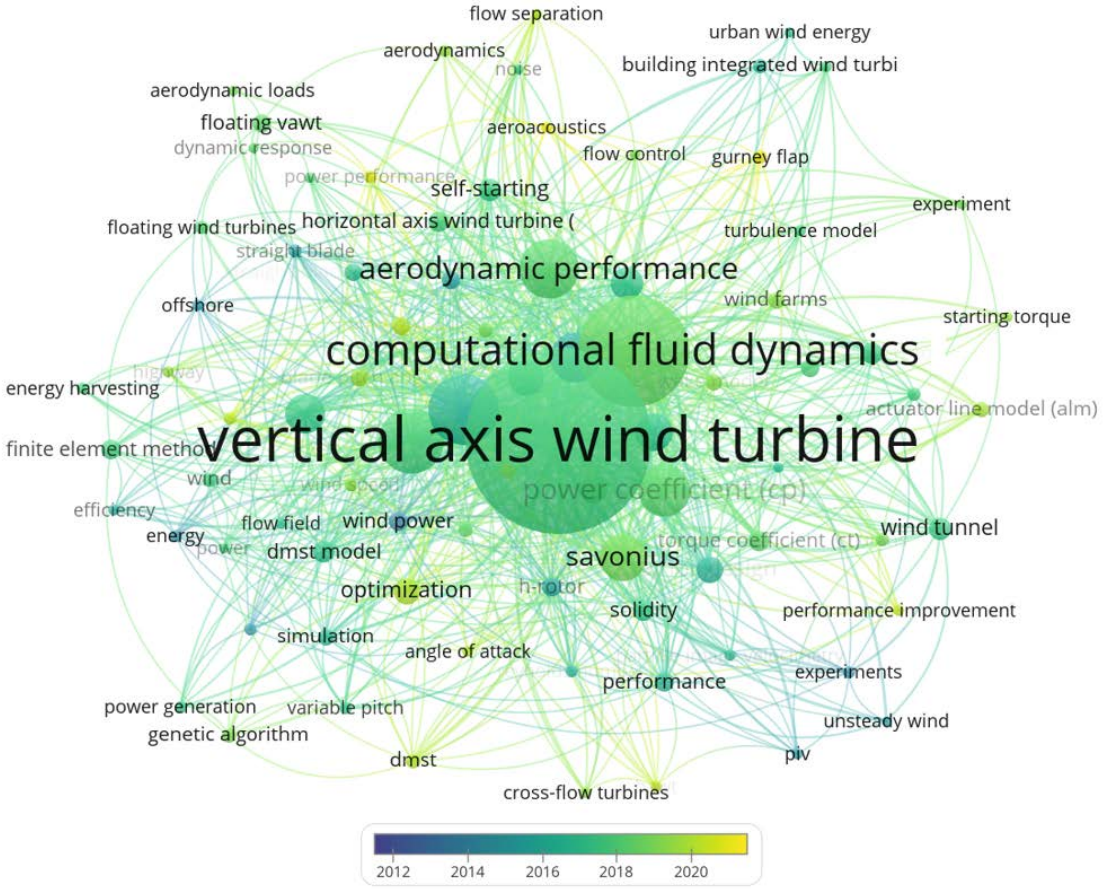

Figure 4. Keywords on the VAWT research

challenge in doing CFD is finding configurations in the CFD process so that accurate results are obtained. What researchers are currently doing to improve CFD accuracy includes determining the increment angle, domain size, and turbine revolutions.

Research on the effect of increment angle on CFD accuracy has been carried out by [33][34][35]. These studies have examined the effect of increment angles from 0.03° to 10°. As a result, the smaller the increment angle, the more accurate the results, but it will also take a long computation time. Based on research [35], CFD with an increment angle of 1° has been able to produce good accuracy and does not take longer computation time compared to an increment angle of less than 1°. Research on the effect of domain size has also been carried out by [36][37][38]. These studies examine the effect of domain size on the accuracy of CFD results. The downstream domain size tested ranges from less than 10D to more than 50D, and D is turbine diameter. While the upstream domain sizes tested varied from less than 5D to 15D. Research on the effect of turbine revolutions has been carried out [39]. This study examines the effect of turbine revolutions on CFD accuracy, starting from the fourth turbine rotation up to the 100th. As a result, the fifth turbine rotation can provide sufficiently accurate results without taking so long computation time.

Regarding the study of CFD in VAWT, the biggest challenge is determining the turbulence model to use because, basically, the turbulence model for each VAWT case can provide different accuracy. When using Ansys Fluent software, there are lots of turbulence models. Therefore, there is an opportunity to conduct research on the suitability of the turbulence model for each type of VAWT so that when someone wants to do a CFD VAWT, they can easily find references regarding what turbulence model is suitable for their VAWT type. This was conveyed because although there have been many CFD studies in the field of VAWT, so far, there has not been an article that examines the tubule CFD model that is suitable for each VAWT model.

IV. Conclusion

The growth of VAWT research from the beginning to 2021 has been analyzed using a bibliometric method. The results show that VAWT research tends to increase from the beginning to 2021, even though it experienced a decline in the 1987–2006 range. In its growth, the country that conducted the most VAWT research was China, while the authors with the highest number of citations came from Italy. Based on all articles conducting VAWT research, CFD research dominates 51.14 % of the total. Based on the analysis that has been done, the challenge for future VAWT research is to determine the suitability of the turbulence model for each type of VAWT or to find optimization methods to obtain airfoils with better performance. Research collaborations have the potential to be carried out in China or by collaborating with the author with the highest number of citations with expertise in the CFD field.

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Declarations

Author contribution

All authors contributed equally as the main contributor of this paper. All authors read and approved the final paper.

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Competing interest

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

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