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BIBLIOMETRIC ANALYSIS OF AIRBORNE WIND ENERGY RESEARCH AND WIND SPEED ANALYSIS

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ABSTRACT

This article describes the contribution of researchers around the world about Airborne wind energy and Wind Speed analysis from 1945 to 2018. Airborne wind energy systems are devices that extract electricity from the wind stream and convert it into electricity. With the purpose of analyzing airborne wind energy systems, understand the wind, and the methods used to analyze wind speed, this research used a bibliometric approach. To analyze the scientific publications in this field of research, the Web of Science database was used with documents indexed by the Science Citation Index Extended, Social Sciences Citation Index and Conference Proceedings Citation Index-Science. It was possible to verify the main authors, research institutions, journals and countries that publish on the subject, the most cited documents and collaboration networks. It was identified that the first scientific publication on wind speed analysis occurred in 1984 by the authors Tuller, S.E. and Brett, A.C. The results indicate that the USA, Switzerland, Belgium, Germany, Italy, Netherlands, Peoples R China, Ireland, Scotland and the Brazil are the leading countries in the research on Airborne wind energy and Wind Speed analysis. The most productive author, journal, and research institution are Lorenzo Fagiano, Proceedings of the American Control Conference and the American Control Conference, both with 18 articles published and the research institution was Katholieke University Leuven. It was also possible to identify the main methods used by the authors to analyze wind speed.

Keywords: Airborne wind energy, Wind speed analysis, bibliometrics analysis.

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ANÁLISIS BIBLIOMÉTRICO DE LA INVESTIGACIÓN SOBRE ENERGÍA EÓLICA AÉREA Y ANÁLISIS DE LA VELOCIDAD DEL VIENTO

RESUMEN

Este artículo describe la contribución de los investigadores de todo el mundo sobre la energía eólica en el aire y el análisis de la velocidad del viento desde 1945 hasta 2018. Los sistemas de energía eólica en el aire son dispositivos que extraen electricidad de la corriente eólica y la convierten en electricidad. Con el propósito de analizar los sistemas de energía eólica en el aire, comprender el viento y los métodos utilizados para analizar la velocidad del viento, esta investigación utilizó un enfoque bibliometrico. Para analizar las publicaciones científicas en este campo de investigación, se utilizó la base de datos de Web of Science con documentos indexados por Science Citation Index Extended, Social Sciences Citation Index y Conference Proceedings Citation Index-Science. Fue posible verificar los principales autores, instituciones de investigación, revistas y países que publican sobre el tema, los documentos más citados y las redes de colaboración. Se identificó que la primera publicación científica sobre análisis de velocidad del viento ocurrió en 1984 por los autores Tuller, S.E. y Brett, A.C. Los resultados indican que EE. UU., Suiza, Bélgica, Alemania, Italia, Países Bajos, Pueblos R China, Irlanda, Escocia y Brasil son los países líderes en la investigación sobre energía eólica en el aire y análisis de la velocidad del viento. El autor, la revista y la institución de investigación más productivos son Lorenzo Fagiano, Proceedings of the American Control Conference y American Control Conference, ambos con 18 artículos publicados y la institución de investigación fue la Universidad de Katholieke Leuven. También fue posible identificar los principales métodos utilizados por los autores para analizar la velocidad del viento.

Palabras clave: energía eólica en el aire, análisis de la velocidad del viento, análisis bibliometrico.

ANÁLISE BIBLIOMÉTRICA DE PESQUISA DE ENERGIA EÓLICA AÉREA E ANÁLISE DE VELOCIDADE DO VENTO

RESUMO

Este artigo descreve a contribuição de pesquisadores em todo o mundo sobre *Airborne wind energy* e *Wind Speed analysis* no período de 1945 - 2018. Os sistemas de *Airborne wind energy* são dispositivos que extraem energia elétrica do fluxo de vento e a convertem em eletricidade. Com o objetivo de analisar os *airborne wind energy systems*, compreender o vento, e os métodos utilizados para analisar a velocidade do vento, está pesquisa utilizou uma abordagem bibliometrica. Para analisar as publicações científicas neste campo de pesquisa, foi utilizado a base de dados *Web of Science* com documentos indexados pelo *Science Citation Index Extended, Social Sciences Citation Index* e *Conference Proceedings Citation Index-Science*. Foi possível verificar os principais autores, instituições de pesquisa, periódicos e países que publicam sobre o assunto; os documentos mais citados; e as redes de colaboração. Identificou-se que a primeira publicação científica sobre analise da velocidade do vento ocorreu em 1984 pelos autores Tuller, S.E. and Brett, A.C. Os resultados indicam que os EUA, Suíça, Bélgica, Alemanha, Itália, Holanda, Povos R China, Irlanda, Escócia e Brasil são os principais países na pesquisa sobre *Airborne wind energy* e *Wind Speed analysis*. O autor, o periódico e a instituição de pesquisa mais produtiva são Lorenzo Fagiano, *Proceedings of the American Control Conference* e a *American Control Conference*, ambos com 18 artigos publicados e a instituição de pesquisa foi Katholieke University Leuven. Também foi possível identificar os principais métodos utilizados pelos autores para analisar a velocidade do vento.

Palavras-chave: Energia eólica aerotransportada, análise da velocidade do vento, análise bibliométrica.

1. INTRODUCTION

Energy sources have evolved over time, and to meet the great demand for electric energy different sources of primary energy has been take advantage, such as hydropower, wind, solar, biomass, tidal, nuclear and fossil sources like coal oil, natural gas, among others.

While the demand for energy increases, energy production depends almost exclusively from the combustion of fossil fuels that are polluting and limited in nature.

Due to growing concern over the last two decades with the global climate change, with the emission of greenhouse gases and energy security, accelerated the research work in the field of clean and renewable energy technologies. Among them is wind energy, whose installed global capacity reached approximately 540 GW in 2017, a 15% increase over the previous year (GWEC, 2017).

Airborne Wind Energy (AWE) or High Altitude Wind Energy (HAWE) is an innovative technology for the exploitation of renewable energy that uses aerial devices that harness the kinetic energy of the wind at high altitudes and are able to stay in the air through aerodynamic forces or aerostats, (Archer and Caldeira, 2009). These devices called tethered airfoils, may be wings like that of a paraglider or kitesurf or structures like a balloon or airplane wings (Diehl, 2014).

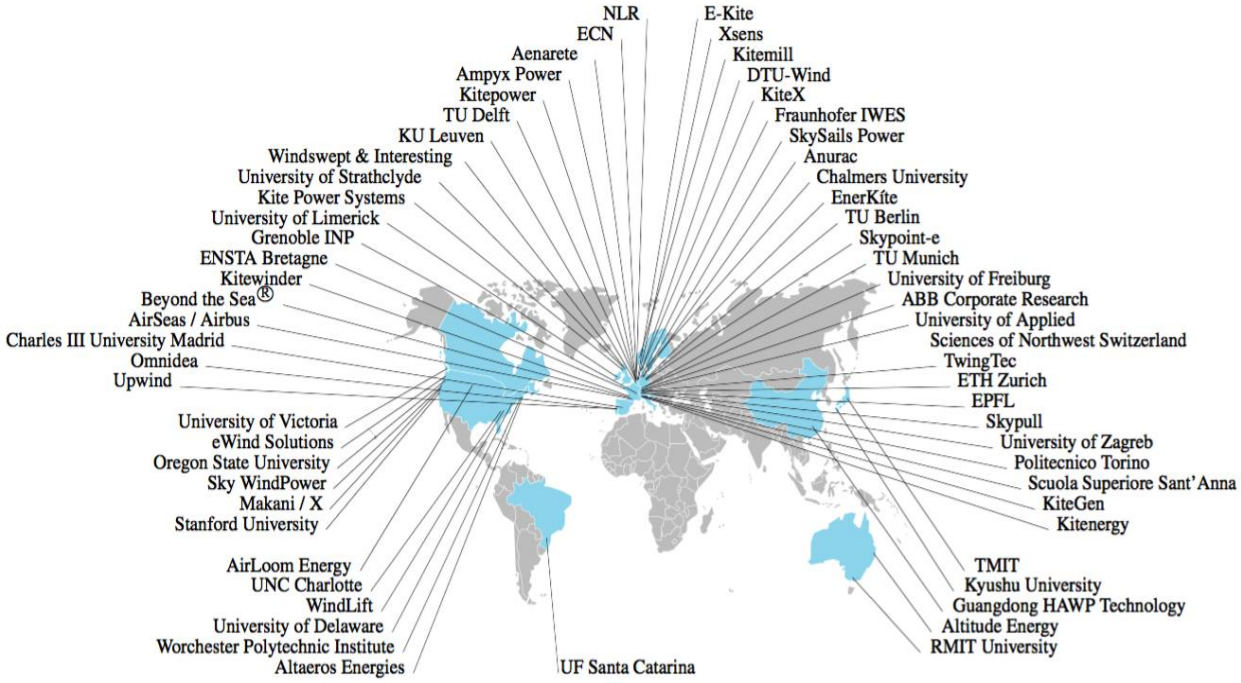
Many structures with wired airfoils have been studied for harnessing the energy of the winds at high altitudes. They can be differentiated, in relation to the type of wing, which can be rigid or flexible, as to the location of the electric generator, which can be in the ground or in flight, as for the aerodynamic force explored, *(drag)* or *(lift)*, and how to control the flight of the airfoil, which depends on the number of cables and the position of the actuators and sensors (Loyd, 1980; Archer and Jacobson, 2005; Ahrens et al., 2014; Archer et al., 2014; Cherubini et al., 2015).

This technology has begun to be intensively studied over the last decade, and although commercial products are not yet avail- able, significant research and investment is being made. An overview of the state-of-the-art technology AWE was published by (Ahrens et al., 2014) and (Cherubini et al., 2015).

Mendonça et al. (2017) made a comparison of the scientific literature of technology AWE with the development of patents for get more information about the State of the art technology. Schmehl (2018) presented a global map, Figure 1, with 63 research institutions and industrial around the world actively involved in

Research & Development (R&D) in this area.

Figure 1: Global map of academic and industrial contributors in R&D with AWE technology in 2018.



Fonte: Schmehl (2018), pg 88.

Some of the search alternatives based on wired Airfoil (rigid or flexible wings) are: Laddermill, (Ockels, 2001); Dancing Kites, (Houska, 2007); Carousel, (Canale et al., 2009); Pumping Kite – PK, (Fagiano, 2009); Rotokite, (Sequoia, 2014) and the Makani energy kite, (Makani, 2015), among others. The configuration called Pumping Kite is the most investigated in the literature, probably because of the relatively simple design of PK, making it more convenient to perform theoretical and practical experiments in the Research & Development (R&D) stage in which this technology found.Airborne wind energy are devices that extract electrical energy from the wind stream and convert it into electricity. This wind flow present in the atmosphere, becomes denser as rises in height. According to Archer and Caldeira (2009); Fagiano (2009), it has already been proved that in higher altitudes

the wind is stronger and more frequent due to the distance of the friction (dissipative actions) of the wind flow with the irregular terrain.

The main objective of this work is to quantitatively and qualitatively evaluate the global trends of research activities within the field of AWE technology and wind speed analysis, considering scientific articles published between 1945 and 2018. Statistics of the publications, geographical distribution and significant contribution of authors, research institutions, journal and countries, as well as the most frequently used keywords and citations are investigated in this study. Performance parameters are selected for the comparative assessment of the contribution of authors, research institutions and countries. This article uses a bibliometric and systemic approach to build the researcher's knowledge to guide him/her in researching AWE technology to provide an overview of the field of research and may also influence the future directions of research of other researchers. The article is divided into four sections. The research methods are briefly presented in Section 2, Section 3 covers the results and the discussion. Finally, some final observations are described in Section 4.

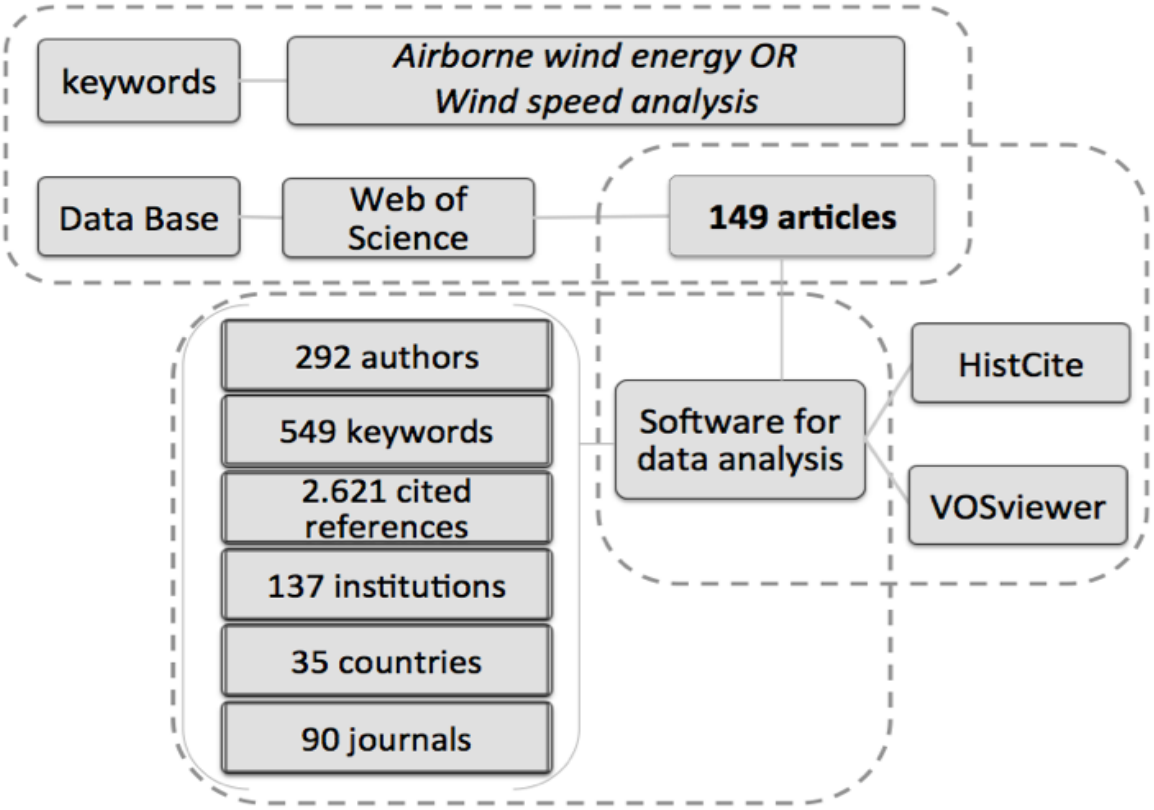
2. METHODOLOGY

Bibliometric analysis is a systematic approach to the quantitative and statistical analysis of relevant features of scientific publications in order to identify specific research phenomena (Thompson, 2008; Jacobs, 2010). In the bibliometric analysis, a set of methods is applied, where the document system and bibliometric characteristics are considered as research object, mathematical and statistical methods are used to investigate the distributed architecture, the quantitative relation, the standards, the management quantitative information of the documents as well as the information contained in the documents (Leeuwen et al., 2013; Du et al., 2014).

For the bibliometric analysis, articles are used that compose the

bibliographic portfolio and its references in order to raise the periodicity of publication, the degree of collaboration, the relevance of periodicals, authors, research institutions, the most important keywords content. The search strategy was performed by combining the keywords TS=("Airborne Wind Energy" OR "Wind speed analysis") as shown in Figure 2.

Figure 2: Methodological procedures of the research.



After the definition of the keywords, the database to be consulted was chosen from the Capes (Coordination for the Improvement of Higher Education Personnel) journal portal: *Web of Science* - (WoS) because it is widely used for the research of scientific literature, (Chadegani et al., 2013). Were used documents indexed by the Science Citation Index Extended - (SCI- Expanded), Social Sciences Citation Index - (SSCI) and Conference Proceedings Citation Index-Science - (CPCI-

S). WoS has been considered as a significant source of data for bibliometric analysis, and bibliometric analysis is widely recognized as a well-established research method, particularly for assessing the performance of scientific research, (Leeuwen, 2006). Bibliometric analysis has been used in a large scientific field, such as: climate change, (Li et al., 2011); sustainable development, (Hassan et al., 2014); progress on emergy research, (Chen et al., 2017); recent research trends, (Imran et al., 2018) and etc.

2.1. H-index and impact factor

In this research two measures of influence are adopted to ex- amine the characteristics of the publication statistics of authors, research institutions, countries and journals, the h-index and the impact factor.

The quality of the research is measured based on the impact factor. The impact factor has played an important role in the evaluation of the academic quality of journals, providing a reference on the selection of periodicals and the evaluation of scientific research results. In this research, were calculated the h-index of authors, countries and periodicals to evaluate their performance based on publications related to airborne wind energy and wind speed analysis, respectively. The impact factor is a citation metric to measure the quality and influence of journals, being used in this research to evaluate the relative influence. The impact factor of a given journal was retrieved from the Journal Citation Reports of 2016.

3. RESULTS AND DISCUSSION

3.1. General statistics

This survey was conducted in February 2018 and presented a total of 149 scientific literature documents. Among the publications obtained, proceedings (75 publications) and journal papers (70 publications) are the main contributions,

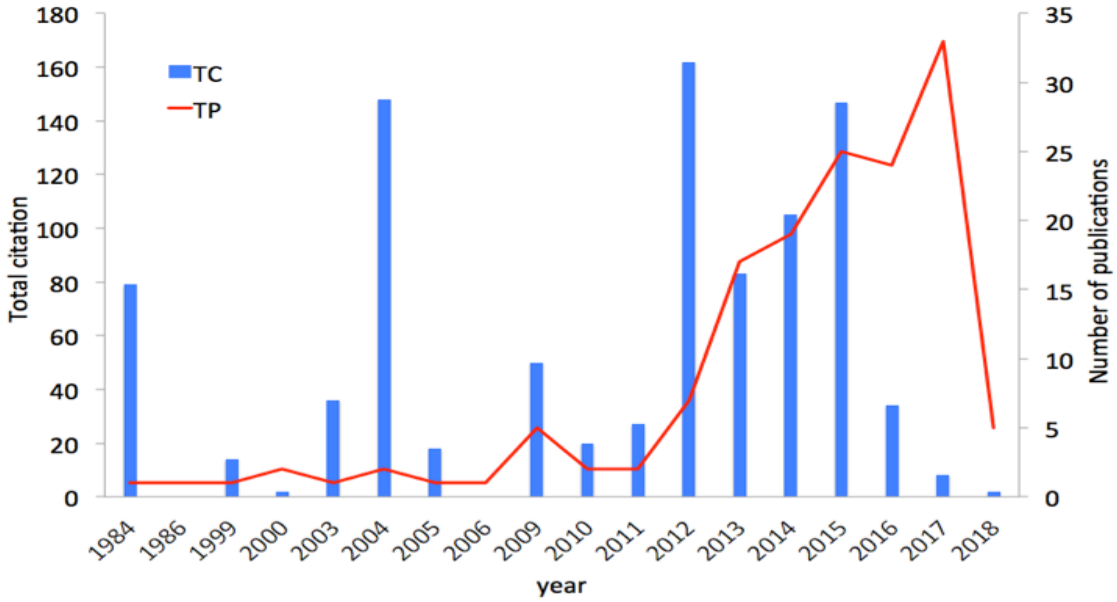
representing 50.30 % and 47.00 % of the literature, the other 4 % are attributed to review papers. The Table 1 presents the results of the distribution by document type. It can be seen that 99.30 % of the documents were published in English and Chinese (0.70 %). For this study, only the literature published in English was analyzed, since English is the universal language.

Table 1: Distribution by document type.

Document type	Count	(%)	Cumulative (%)
Proceedings papers	75	50	75
Articles	70	47	145
Review	4	3	149
Total	149	100	

The temporal evolution of the documents analyzed between the period 1945 - 2018, the total number of publication and the total citation are presented in Figure 3.

Figure 3: Relative volume of the publication per year.



Note that there was an evolution of the research with AWE and analysis of wind speed in recent years. The number of publications grew steadily, and more rapidly in the past decade. Can be observed a spike in the number of citations in 2004, 2012 and 2015, with 162 record in 2012.

The first research The Characteristics of Wind Velocity that Favor the Fitting of a Weibull Distribution in Wind Speed Analysis was developed by Tuller and Brett (1984), which demonstrated that the selection of the Weibull distribution can be often assigned your flexibility, providing a proper fit to the observed wind speed distributions, and the fact that only two parameters are required for the estimation. However, according to Tuller and Brett (1984), the use of the Weibull distribution to describe the probability of wind speed is based on empirical and non-physical justifications and is not always the most adequate distribution for the measures.

3.2. Characteristics of published journal

A total of 90 journals or conferences published articles related to AWE technology and or wind speed analysis, covering 33 research areas. The first six research areas include Automation Control Systems, Engineering Electrical Electronic, Energy Fuels, Green Sustainable Science Technology, Engineering Mechanical, Meteorology Atmospheric Sciences. The most productive journals or conferences are presented in the Table 2. The Proceedings of the American Control Conference and American Control Conference (ACC) has the highest number of publications representing 12.08 % of total publications. Renewable Energy was the most cited journal with 203 citations, mainly due to the publication of Wind speed analysis in La Ventosa, Mexico: a bimodal probability distribution case and Airborne wind energy: Optimal locations and variability. The impact factor of Renewable Sustainable Energy Reviews was the highest (IF /8.05), even though it was lower in terms of the total number of articles published.

Table 2: The 15 most produtive journal or conference in research on airborne wind energy and wind speed analysis.

Journal or Conference	TP	(%)	TC	H-index	FI
Proceedings of the American Control Conference	18	12.1	59	3	1.09
American Control Conference	18	12.1	63	3	NA
IFAC Papersonline	15	10.1	0	NA	NA
IEEE Transactions on Control Systems Technology	9	6.0	94	5	3.88
Renewable Energy	9	6.0	203	4	4.35
IEEE Conference on Decision And Control CDC	7	4.7	3	2	NA
European Control Conference	6	4.0	30	3	NA
IEEE Annual Conference on Decision and Control CDC	4	2.7	0	2	NA
Control Engineering Practice	3	2.0	25	2	2.60
Renewable Sustainable Energy Reviews	3	2.0	81	3	8.05
Energy	2	1.3	11	2	4.52
IEEE ASME Transactions on Mechatronics	2	1.3	5	1	4.35
2006 38TH Annual North American Power Symposium NAPS 2006 Proceedings	1	0.7	0	NA	NA
Agricultural and Forest Meteorology	1	0.7	67	1	3.88
Journal of Climate and Applied Meteorology	1	0.7	79	1	3.07

TP = Total publications, (%) Percentage refers to the proportion of the author's publication to the total number of publications. TC = Total citation, the H-index is based on the number of articles of an author that are collected from the 149 articles of this study and FI = Impact factor.

3.3. The analysis of research institution and countries

Table 3 presents the performance of the top 20 most productive research institutions in this area. Katholieke University Leuven, in Belgium is the research institution with the largest amount of total publications and also has the highest index h among the twenty most productive institutions. Acknowledgments References Zanon, M., Diehl, M., Vukov, M., Gros, S., Horn, G., Ahmad, H., Geebelen, K., Swevers, J., Wagner, A., Andersson, J., Meyers, J., Stuyts, J., Vandermeulen, W., Driesen, J., Gillis, J. The University of Freiburg is the second most productive research institution. The University of California, Santa Barbara in USA was the institution with the highest number of citations followed by Polytechnic University of Turin in Italy. The USA is the country of six of the most productive research institutions in this area and Switzerland is responsible for five of the institution. The Federal University of Santa Catarina is the only research institution in Latin America involved in research using AWE technology.

Table 3: The 20 most productive research institution.

Institution	TP	(%)	Country	H-index	TC
Katholieke University Leuven	13	8.72	Belgium	7	75
University of Freiburg	12	8.05	Germany	3	21
Swiss Federal Institute of Technology	10	6.71	Switzerland	4	78
Ecole Polytech Federal Lausanne	9	6.04	Switzerland	2	14
University of North Carolina	8	5.37	USA	1	2
ABB Switzerland LTD	6	4.03	Switzerland	2	27
University of California, Santa Barbara	5	3.36	USA	4	97
AMPYX Power BV	5	3.36	Netherlands	NA	NA
ETH	5	3.36	Switzerland	3	28
Polytechnic University of Turin	5	3.36	Italy	3	94
University of North Carolina at Charlotte	5	3.36	USA	NA	NA
Worcester Polytechnic Institute	5	3.36	USA	1	1
Delft University of Technology	4	2.68	Netherlands	2	17
Polytechnic University of Milan	4	2.68	Italy	2	4
Federal University of Santa Catarina	4	2.68	Brazil	1	3
University of Limerick	4	2.68	Ireland	1	4
University of Strathclyde	4	2.68	United Kingdom	1	1
Penn State University	4	2.68	USA	NA	NA
ABB Schweiz Ltd.	3	2.01	USA	1	2
ABB Switzerland	3	2.01	Switzerland	2	7

The 10 most productive countries are ranked using the following indicators: the total number of journal articles and the percentage of articles in a country. These 10 countries are made up of one from North America, six countries from Europe, two countries from Asia and one from Latin America. The USA is the country with the highest number of published scientific papers, and it is also the country with the best academic achievement (h-index = 8) as shown in Table 4.

Table 4: Characteristics of the top 10 productive countries.

Countries	TP	(%)	C	H-index
USA	40	28.8	43	8
Switzerland	33	20.1	37	6
Belgium	16	10.7	13	7
Germany	16	10.7	13	4
Italy	16	9.4	43	6
Netherlands	11	7.4	69	3
Peoples R China	7	4.7	17	3
Ireland	6	4.0	6	2
India	5	3.4	11	2
Brazil	5	3.4	3	2

The Italy is the country that published less than half of the publications of the USA but that obtained the same number of citations. The most productive author in this area, Fagiano, L with 22 published scientific papers, being the researcher with the most cited papers (TC = 191) and one (h-index = 7) is a researcher at Polytechnic University of Turin in Italy as presented in the Table 5.

Table 5: The 20 most productive authors.

Author	TP	(TC)	% TP	H-index
Fagiano L	22	191	11.34	7
Diehl M	20	77	10.31	7
Vermillion C	14	4	7.22	2
Gros S	10	69	5.15	7
Zgraggen AU	9	72	4.64	4
Morari M	8	68	4.12	4
Zanon M	7	55	3.61	6
Costello S	6	12	3.09	2
Olinger DJ	6	0	3.09	1
Khammash M	5	56	2.58	2
Horn G	5	27	2.58	3
Francois G	5	10	2.58	2
Bonvin D	5	10	2.58	2
Schnez S	5	5	2.58	2
Coleman J	5	4	2.58	1
Demetriou MA	5	0	2.58	1
Milanese M	4	93	2.06	3
Erhard M	4	16	2.06	2
Ahmad H	4	6	2.06	2
Schmehl R	3	17	1.55	2

Diehl, M has in this research (h-index = 7), 20 documents published with 77 citations. He was a researcher at Katholieke University Leuven and now a researcher at the University of Freiburg, the first and second most productive research institution in the area.

The researches with AWE technology at the University of Freiburg, occur with the partnership of researchers Kouzoupis, D.; Quirynen, R .; Garcia, J. L .; Erhard, M.; Diehl, M.; Girrbach, F.; Horn, G.; Koenemann, J.; Licitra, G. The Nether-lands is the country that obtained the highest number of citations in the published documents, mainly as a result of the partnership of the authors "Bosch, A. Schmehl, R.; Tiso, P.; Rixen, D., Fechner, U.; van der Vlugt, R., Schreuder, E., Vire, A. " researchers at Delft University of Technology with the authors "Licitra, G.; Sieberling, S.; Engelen, S., Williams, P., Ruiterkamp, R., Koenemann, J.; Ghandchi, S" researchers at AMPYX Power, both institutions ranked as one of the 20 most productive institutions as shown in Table 3.

Milanese, M is professor of control systems theory, automotive engineering, aeronautics and mechatronics and renewable energy at Politecnico di Torino, Italy. Published in collaboration with Fagiano, L., Piga, D. and Novara, C, 4 scientific papers, receiving 93 citations being the second most cited author with (h-index=3).

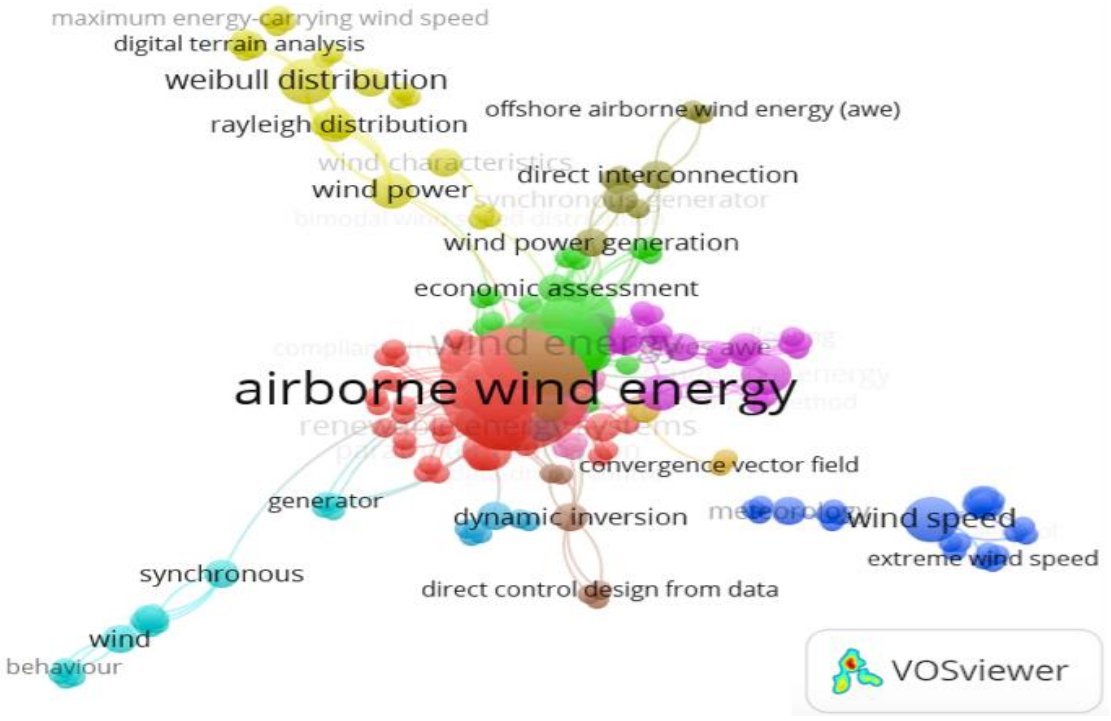
3.4. Author keywords analysis

Author's keywords describe the main topics of articles and were used to analyze trends and identify the focus of article research. Of the 149 scientific papers analyzed, 142 articles had keywords, of which the total was 549, which appeared 1,341 times. The results show that airborne wind energy is the most used category appearing 83 times, followed by wind energy (67 times), wind speed (48 times), weibull distribution (26), wind characteristics (11) and 362 keywords appeared only once.

The keyword frequency of the authors indicates that most keywords are not used frequently and that only a small sample of keywords are used frequently. This

leads us to conclude that the keywords of different authors present similar ideas. To identify the link or interrelationship between keywords, we analyzed the keyword network to identify search trends using Vosviewer software, a tool for managing and viewing network maps. The most frequent keywords represent the four largest re- search groups in this domain: the red cluster, linked to Airborne Wind Energy technology, the green cluster, involving Wind Energy, the blue cluster approaching Wind Speed and the yellow cluster approaching the distribution method weibull. The Figure 4 shows a co-occurrence network of the author's keywords, with at least two occurrences.

Figure 4: Most frequently used author keywords.



The analyzed keywords are represented by the existing links between them, in this way, the most frequent keywords appear clusters, being formed by 11 clusters with 821 links.

The cluster red "airborne wind energy" is related to the technology itself, including renewable energy systems, adaptive control, aircraft control, delay

estimation, flight control, flexible cables, pumping cycle, pumping kite, wind energy economics among other items. The cluster green ”wind energy” is related to autonomous flight, autonomous takeoff, tethered aircraft, unmanned aerial vehicle, wind energy, the cluster blue ”wind speed” with wind speed distribution, extreme wind speed and meteorology, already cluster yellow, relates with wind power, rayleigh distribuition and the weibull distribution method itself.

4. DISCUSSION

4.1. The main researches found in the bibliographic portfolio

The world's wind power generation occupies a prominent position in the energy matrix, as wind energy production is increasing rapidly. For this reason, the forecast of wind power generation plays a fundamental to meet the challenges of balancing supply and consumption in any electricity system, given the uncertainty related to wind power production. Wind speed is a fundamental variable for predicting wind farm generation capacity: its knowledge reduces project risks (uncertainties) and allows an adequate planning of the balance of the electric system. However, wind forecasting based on measurements is complex because of the stochastic nature of the wind. The table 6 presents the articles in the bibliographic portfolio that discuss wind speed analysis.

Table 6: Articles that discuss wind speed analysis.

Author	Title	Journal
Tuller and Brett (1984)	The characteristics of wind velocity that favor the fitting of a weibull distribution in wind-speed analysis	Journal of Climate and Applied Meteorology
Scoon and Robinson (2000)	Meteorological and oceanographic surface roughness phenomena in the English Channel investigated using ERS synthetic aperture radar and an empirical model of backscatter	Journal of Geophysical Research-Oceans

Bivona et al. (2003)	Hourly wind speed analysis in Sicily	Renewable Energy
Jaramillo and Borja (2004)	Wind speed analysis in La Ventosa, Mexico: a bimodal probability distribution case	Renewable Energy
Perez et al. (2004)	Analysis of height variations of sodar-derived wind speeds in Northern Spain	Journal of Wind Engineeringand Industrial Aerodynamic
Aziz et al. (2005)	Effects of airsea enteraction parameters on ocean surface microwave emission at 10 and 37 GHz	IEEE Transactions on Geoscience and Remote Sensing
Wilson and Morcos (2006)	Design of an offshore wind farm on Lake Michigan: Part 1	38th Annual North American Power Symposium
Beegumet al. (2009)	Large scale modulations of spectral aerosol optical depths by atmospheric planetary waves	Geophysical Re- search Letters
Cabello and Orza (2010)	Wind speed analysis in the province of Alicante, Spain. Potential for small-scale wind turbines	Renewable & Sustainable Energy Reviews
Razali et al. (2010)	Mapping of Annual Extreme Wind Speed Analysis from 12 Stations in Peninsular Malaysia	Selected Topics in System Science and Simulation in Engineering
Xu and Levy (2011)	Analyzing potential evapotranspiration and climate drivers in China	Chinese Journal of Geophysics - Chinese Edition
Bagiorgas et al. (2011)	Weibull Parameters Estimation Using Four Different Methods And Most Energy-Carrying Wind Speed Analysis	International Journal of Green Energy
Zheng et al. (2011)	An Overview: the Development of Prediction Technology of Wind and Photovoltaic Power Generation	Proceedings of International Conference on Smart Grid and Clean Energy Technologies - ICSGCE
Foley et al. (2012)	Current methods and advances in forecasting of wind power generation	Renewable Energy
Fagiano et al. (2012)	Optimization of airborne wind energy generators	International Journal of Robust and Nonlinear Control
Gros et al. (2012)	Orbit Control for a Power Generating Airfoil Based on Nonlinear MPC	American Control Conference
Zanon et al. (2013)	Rotational Start-up of Tethered Air- planes Based on Nonlinear MPC and MHE	European Control Conference (ECC)
Zgraggenet al. (2013)	On Real-Time Optimization of Air- borne Wind Energy Generators	IEEE 52nd Annual Conference on Decision and Control
Novara et al. (2013)	Direct feedback control design for nonlinear systems	Automatica

Rehman (2013)	Long-Term Wind Speed Analysis and Detection of its Trends Using Mann-Kendall Test and Linear Regression Method	Arabian Journal for Science and Engineering
Li et al. (2013)	Guishan Off-Shore Wind Power Farm Interconnection: A Real Project Study	IEEE Pes Asia - Pacific Power and Energy Engineering Conference
Lynch et al. (2014)	Simplified method to derive the Kalman Filter covariance matrices to predict wind speeds from a NWP model	6th International Conference on Sustainabilityin Energy and Buildings
Mahmoudian and Mohammadzadeh (2014)	A spatio-temporal dynamic regression model for extreme wind speeds	Extremes
Archer et al. (2014)	Airborne wind energy: Optimal locations and variability	Renewable Energy
Zanon et al. (2014)	Airborne Wind Energy: Airfoil - Airmass Interaction	The International Federation of Automatic Control (IFAC)
Zgraggenet al. (2015)	Real-Time Optimization and Adaptation of the Crosswind Flight of Tethered Wings for Airborne Wind Energy	IEEE Transactions on Control Systems Technology
Komleh et al. (2015)	Wind speed and power density analysis based on Weibull and Rayleigh distributions (a case study: Firouzkooh county of Iran)	Renewable & Sustainable Energy Reviews
Wagemann et al. (2015)	Regionalization Of Wind-Speed Data To Analyse Tree-Line Wind Conditions In The Eastern Andes of Southern Ecuador	Journal Erdkunde
Mishraand Kumar (2015)	Application of brushless excitation system in Wind power generation	4th International Conference on Renewable Energy Research and Applications
Fechner et al. (2015)	Dynamic model of a pumping kite power system	Renewable Energy
De Lellis et al. (2016)	Electric power generation in wind farms with pumping kites - An economical analysis	Renewable Energy
Rajapaksha and Perera (2016)	Wind speed analysis and energy calculation based on mixture distributions in Narakkalliya, Sri Lanka	Journal of the National Science Foundation of Sri Lanka
Van et al. (2016)	On the Autonomous Take-Off and Landing of Tethered Wings for Airborne Wind Energy	American Control Conference (ACC)
Kako et al. (2017)	Effectiveness of Using Multisatellite Wind Speed Estimates to Construct Hourly Wind Speed Datasets with Diurnal Variations	Journal of Atmospheric and Oceanic Technology
Pishgar Komlehand Akram	Evaluation of wind energy potential for different turbine models based on the wind	Sustainable Energy Technologies and

(2017)	speed data of Zabol region, Iran	Assessments
Kantar et al. (2018)	Wind speed analysis using the Extended Generalized Lindley Distribution	Renewable Energy

It can be observed in the bibliographic portfolio that 36 articles deal with methods and models for wind speed analysis, however, it was verified that only 15 articles effectively developed a wind speed model as presented in Table 7. It should also be noted that of the 15 articles that developed wind models, 13 articles were developed in the last decade, reinforcing the importance of wind speed analysis for the prediction of wind power generation.

Table 7: Models of wind speed analysis found in the portfolio analyzed.

Author	Title	Journal
Tuller and Brett (1984)	The characteristics of wind velocity that favor the fitting of a weibull distribution in wind-speed analysis	Journal of Climate and Applied Meteorology
Scoon and Robinson (2000)	Meteorological and oceanographic surface roughness phenomena in the English Channel investigated using ERS synthetic aperture radar and an empirical model of backscatter	Journal of Geophysical Research- Oceans
Fagiano et al. (2012)	Optimization of airborne wind energy generators	International Journal of Robust and Nonlinear Control
Gros et al. (2012)	Orbit Control for a Power Generating Airfoil Based on Nonlinear MPC	American Control Conference
Zanon et al. (2013)	Rotational Start-up of Tethered Airplanes Based on Nonlinear MPC and MHE	European Control Conference (ECC)
Novara et al. (2013)	Direct feedback control design for nonlinear systems	Automatica
Zgraggen et al. (2013)	On Real-Time Optimization of Airborne Wind Energy Genera- tors	IEEE 52nd Annual Conference on Decision and Control
Lynch et al. (2014)	Simplified method to derive the Kalman Filter covariance matrices to predict wind speeds from a NWP model	6th International Conference on Sustainability in Energy and Buildings
Zanon et al. (2014)	Airborne Wind Energy: Airfoil - Airmass Interaction	The International Federation of Automatic Control (IFAC)
Zgraggen et al. (2015)	Real-Time Optimization and Adaptation of the Crosswind Flight of Tethered Wings for Airborne Wind Energy	IEEE Transactions on Control Systems Technology
Fechner et al. (2015)	Dynamic model of a pumping kite power system	Renewable Energy
De Lellis et al. (2016)	Electric power generation in wind farms with pumping kites- An economical analysis	Renewable Energy

Kako et al. (2017)	Effectiveness of Using Multi- satellite Wind Speed Estimates to Construct Hourly Wind Speed Datasets with Diurnal Variations	Journal of Atmospheric and Oceanic Technology
Pishgar - Komleh and Akram (2017)	Evaluation of wind energy potential for different turbine models based on the wind speed data of Zabol region, Iran	Sustainable Energy Technologies and Assessments
Kantar et al. (2018)	Wind speed analysis using the Extended Generalized Lindley Distribution	Renewable Energy

Although few articles have effectively developed a model of wind speed, this theme is not new and began with the article developed by (Tuller and Brett, 1984). The authors addressed the derivation of the Weilbull distribution from the normal distribution, providing a suitable adjustment to the wind speed distributions, providing a theoretical justification for their use in wind speed analysis. This justification is based on the premise that wind velocity components are normally distributed, have zero means, have equal variances and are not correlated.

The articles published by Fagiano et al. (2012), Novara et al. (2013), Zgraggen et al. (2013), Zgraggen et al. (2015) use the logarithmic model of the wind proposed by Manwell et al. (2009) and Fagiano (2009) where it is estimated that the altitude of the atmosphere layer in which the roughness of the ground influences the wind speed extends up to 600 meters in height. In these references the authors investigated important theoretical aspects: the evaluation of the performance achieved by the logarithmic model and the control law used for wind speed modeling, the optimization of the generator operating cycle, the possibility of continuously generating maximum power, and to the analysis of a project based on data of finalized controllers in the solution of tracking problems, and analysis of the impact of the traction force of the cable, thus generating a greater amount of wind energy.

The authors Gros et al. (2012); Zanon et al. (2014) and Zanon et al. (2013) formulated a Moving Horizon Estimation (MHE) to estimate the wind speed and direction in the absence of direct measurements based on the logarithmic wind model proposed by Manwell et al. (2009), increasing the robustness of suggested model. The authors investigate a 6-DOF control model computationally, where a

large-scale, high-performance rigid aerodynamic profile was proposed. They applied to the model, a control scheme based on predispositive control of the nonlinear model to trace the reference trajectories and to make a real-time application of the predictive control of the nonlinear model, using a real-time iteration scheme.

In Lynch et al. (2014) described an approach to predict the wind speed for a time horizon of 1 hour ahead through post-processing of a Numerical Weather Prediction model (NWP) using Kalman filter. The NWP method aims to solve equations of atmospheric processes and describe how the atmosphere changes over time, being widely used among physical methods of forecasting.

In Fechner et al. (2015) was used to determine the wind speed at the reference height, the power law methodology presented in Stull (2000) and the logarithmic wind model presented in (Burton et al., 2002). Already the wind speed model presented by De Lellis et al. (2016), make use of the logarithmic model of wind proposed by (Manwell et al., 2009) and (Fagiano, 2009).

Kako et al. (2017) used an optimum interpolation method (IOM) to build a set of wind speed data with hourly resolution based on data of combined wind speed analysis of four satellites. The authors validated the hourly wind speed data set by comparing the IOM dataset with observations obtained from moored buoys. They also compared data from each of the four satellites individually with buoy observations.

Kantar et al. (2018) introduced the Extended Generalized Lindley distribution (EGLD) as an alternative to wind speed distribution. The authors tested the performance of the EGLD on actual wind speed data and indicated that the EGLD is suitable for most cases of wind speed data examined when compared to Weibull distribution, according to the tuning quality tests.

Pishgar-Komleh and Akram (2017) used Weibull distribution functions and Rayleigh to investigate the potential for generating electricity from the wind. According to the authors the probability distributions of Rayleigh and Weibull are the most accurate and adequate in the wind analysis, being necessary to calculate

two parameters, the scale parameter and the dimensionless form factor.

4.2. Main methods discussed in the literature

The main concepts approached in the portfolio articles point to a large number of models of wind speed analysis. However, models for long-term analysis were lower than those proposed for the short term. One can identify several categories of methods for analysis of wind speed: methods based on weibull distribution, in time series of the wind speed, methods of numerical weather prediction (NWP), decomposition, dynamic regression between others. In the Table 8 are presented the methods and models of wind speed analysis found in the literature.

Table 8: Methods and Models of wind speed analysis found in the articles.

Methods/Models	Author
Weibull Probability Distribution	Tuller and Brett (1984); Bivona et al. (2003); Jaramillo and Borja (2004); Perez et al. (2004); Wilson and Morcos (2006); Razali et al. (2010); Bagiorgas et al. (2011); Wagemann et al. (2015); Pishgar-Komleh et al. (2015); Rajapaksha and Per- era (2016); Pishgar-Komleh and Akram (2017)
Logarithmic wind shear model	Fagiano et al. (2012); Novara et al. (2013); Zgraggen et al. (2015); Zgraggen et al. (2013); Gros et al. (2012); Zanon et al. (2013); Zanon et al. (2014); Fechner et al. (2015); De Lellis et al. (2016) Cabello and Orza (2010); Rehman (2013); Archer et al. (2014); Mishra and Kumar (2015);
Numerical Weather Prediction (NWP)	Foley et al. (2012); Lynch et al. (2014)
Measurementsof spectral Aerosol Optical Depth (AOD)	Beegum et al. (2009)
Empirical Orthogonal Function analy- sis (EOF)	Xu and Levy (2011), Zheng et al. (2011)
Dynamic Regression Model	Mahmoudian and Mohammadzadeh (2014)
Model of basic wind component, gust, ramp and noise	Li et al. (2013)
ERS scatterometer model (CMOD4)	Scoon and Robinson (2000)
Extended Generalized Lindley Distribuition (EGLD)	Kantar et al. (2018)
Optimum Interpolation Method (OIM)	Kako et al. (2017)

The Weibull distribution method was initially proposed in the 1930 for the interpretation of material fatigue, but has been used in several studies to analyze wind speed frequency and its probability density function. The Weibull distribution function is widely used in several investigations related to wind energy (Chang, 2011), (Lima and Bezerra Filho, 2012), (Diaf and Notton, 2013). There are several methods for estimating Weibull parameters, such as graph, standard deviation, maximum likelihood, and power density method.

The Logarithmic wind shear model is used to estimate the variation of the wind speed with the altitude Manwell et al. (2009), therefore, it allows the calculation of the horizontal wind speed at a certain elevation on the earth's surface. Logarithmic Law and Power variables are important for a consistent and reliable extrapolation of wind speed from one height to another.

The Numerical Weather Prediction model is a set of computer programs Lopes et al. (2004) that contain equations and algorithms that describe the atmosphere and how it changes over time, producing weather forecasts. The initial condition of a wind speed forecast comes from the analysis, which is projected by the assimilation of the amount of meteorological observations within the model. A difficulty encountered in this model is to define metrics that allow the evaluation of the quality of a forecast, (Moreira et al., 2006).

5. CONCLUSION

Due to rapid economic growth and growing concern about climate change, the search for resources from renewable sources has been stimulated worldwide. With the goal of making wind energy a competitive source of energy in relation to fossil fuels, a new paradigm of this renewable source has been investigated, Airborne wind energy (AWE) technology. Air- borne wind energy is currently a very promising resource for the sustainable production of wind energy. The main idea of AWE technology is to make the device that draws energy from the wind stay in the

air, either through aerostatic or aerodynamic forces, attaching such a device to the ground through one or more cables, thus eliminating the elements not directly involved in power generation. With the intention of raising the results of existing research and providing a direction for future work, a comprehensive review of AWE technology literature and wind speed analysis published from 1945 to 2018 was conducted to describe the characteristics of the documents, publication, the degree of collaboration, the relevance of journals, authors, research institutions, the most frequently used keywords and the content addressed, in order to evaluate the performance of scientific research. The results show that most studies related to airborne wind energy and wind speed analysis are concentrated in the research areas of Automation Control Systems, Engineering Electrical Electronic, Energy Fuels, Green Sustainable Science Technology, Engineering Mechanical and Meteorology Atmospheric Sciences. Proceedings of the American Control Conference and American Control Conference (ACC) are the most influential journals or conferences. In addition, the countries most active in research (USA, Switzerlan, Belgium, Germany and Italy) have academic collaboration. Especially the Katholieke University Leuven in Belgium, the University of Freiburg in Germany, the Swiss Federal Institute of Technology and the Ecole Polytech Federal Lausanne in Swtzerland contributed to the development of the AWE Technology among the 20 most productive research institutions in this area; The most active authors were Fagiano, L and Diehl, M. In general, this paper provides a globalized overview of literature related to AWE technology and future directions for research, such as combining with wind speed energy at high altitude. These results may be helpful in providing references for future studies.

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