Wind power and supply chain: a bibliometric research

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ABSTRACT

In the last few decades, there has been much discussion on the relationship between energy production by means of fossil fuels and climate change, which has led to a substantial increase in research on new forms of energy production using renewable sources. Among these sources, wind energy is pointed out as one of the most prosperous, since it has been showing expressive growth, economy and guarantee of continuous supply. This article introduces a robust bibliometric research that generates important and useful information for researchers, who have the ability to analyze the evolution of conceptual, social and intellectual aspects of the research field of supply chain and wind power. In order to know these aspects, the core objective of this research was to analyze the evolution of studies related to supply chain and wind power by employing bibliometric analysis so that future study referrals can be observed. The results proved that the studies on wind power and supply chain have been consolidated since 2009, being maintained in a continuous way until the current period. It was also certified, through the analysis by keywords and qualitative evaluation of the publications, contemplating the specific proposed objectives, showing the characteristics of the publications, the most cited authors and articles, as well as the countries involved in the theme, providing directions for future research.

***Keywords*:** Wind energy. Supply chain. Renewable energy. Bibliometric research.

Energia eólica e cadeia de suprimentos: uma pesquisa bibliométrica

RESUMO

Nas últimas décadas, vem se discutindo muito a respeito da relação da produção de energia por meio de combustíveis fósseis e as alterações climáticas, o que fez com que se elevasse, substancialmente as pesquisas sobre novas formas de produção de energia, empregando fontes renováveis. Entre essas fontes, a energia eólica é apontada como uma das mais prósperas, pois vem apresentando crescimento expressivo, economicidade e garantia de suprimento contínuo. Este artigo apresenta uma pesquisa bibliométrica que têm a capacidade de analisar a evolução dos aspectos conceituais, sociais e intelectuais do campo de pesquisa da cadeia de suprimentos e energia eólica. Com intuito de conhecer esses aspectos, esta pesquisa teve como objetivo central analisar a evolução dos estudos relacionados a cadeia de suprimentos e energia eólica, empregando análise bibliométrica para que futuros encaminhamentos de estudos possam ser observados. Os resultados demonstraram que os estudos sobre energia eólica e cadeia de suprimentos cresceram a partir de 2009, conservando-se de maneira continua até o período atual. foi certificado também, por intermédio da análise por palavras-chave e avaliação qualitativa das publicações, contemplando os objetivos específicos, apresentando as características das publicações, os autores e artigos mais citados, países envolvidos na temática, propiciando direções para futuras pesquisas.

***Palavras-chave:** Energia eólica. Cadeia de suprimentos. Energias renováveis. Pesquisa bibliométrica.*

Energía eólica y cadena de suministro: una encuesta bibliométrica

RESUMEN

En las últimas décadas, se ha discutido mucho sobre la relación de la producción de energía por medio de combustibles fósiles y el cambio climático, lo que ha hecho que se elevara, sustancialmente, las investigaciones sobre nuevas formas de producción de energía, empleando fuentes renovables. Entre estas fuentes, la energía eólica es señalada como una de las más prósperas, pues presenta crecimiento expresivo, ahorro y garantía de abastecimiento continuo. Este artículo presenta una investigación bibliométrica que tiene la capacidad de analizar la evolución de los aspectos conceptuales, sociales e intelectuales del campo de investigación de la cadena de suministros y energía eólica. Con el fin de conocer estos aspectos, esta investigación tuvo como objetivo central analizar la evolución de los estudios relacionados a la cadena de abastecimiento y energía eólica, empleando análisis bibliométrico para que futuros encaminamientos de estudios puedan ser observados. Los resultados demostraron que los estudios sobre energía eólica y cadena de suministros crecieron a partir de 2009, conservándose de manera continua hasta el período actual. fue certificado también, por medio del análisis por palabras clave y evaluación cualitativa de las publicaciones, abarcando los objetivos específicos, presentando las características de las publicaciones, los autores y artículos más citados, países implicados en la temática, proporcionando direcciones para futuras investigaciones.

Palabras clave: *Energía eólica. Cadena de suministros. Energías renovables. Investigación bibliométrica.*

INTRODUCTION

Renewable energies are efficient and strategic ways to achieve sustainable development. In the period from 2010 to 2020, the enthusiasm and awakening for renewable energies has grown substantially due to global issues such as climate change, marked exploitation of the environment, the need to pursue sustainable development, as well as increased demand for energy. Nevertheless, power generation from renewable energies has not yet been able to compete economically with electricity generated by fossil fuels, as it faces situations such as political uncertainties, variability problems, low income and instability (GAO *et al.*, 2016; PURKUS *et al.*, 2018; NTANOS *et al.*, 2018; HAUSER;WERN, 2016)

Also in that period, the search for efficiency and interest in reducing environmental impacts was observed, as well as those associated with the consumption of fossil fuels, which contributed to the efforts of countries in energy production and sufficiency (WANG *et al.*, 2014; WANG *et al.*, 2018).

Still in countries like Brazil, where the performance of renewable sources in the specific supply of electricity exceeds 60% ("EPE", 2019), due to the use of hydraulic energy, other alternative sources, such as wind, sun, and biomass until then, have not solidified, essentially due to competitiveness in terms of costs involved in electricity production from conventional sources (FOGARASI; CORMOS, 2015; LINS *et al.*, 2012).

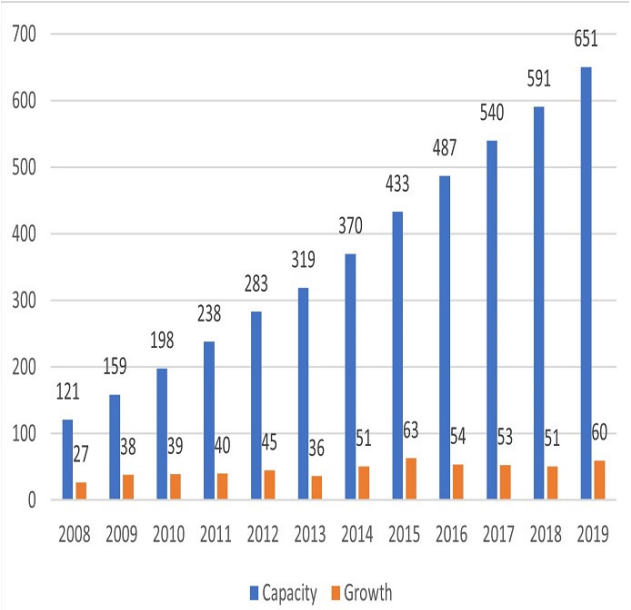
Even with the difficulties, renewable energies, due to low environmental impacts and CO2 emissions (DONG, SUN; DONG, 2018; SOAM *et al.*, 2016), were able to stand out in the socio-environmental agenda, especially since the 21st Conference of the Parties (COP 21) of the United Nations (UN) in December 2015, where the 192 nations parties agreed to provide actions for the reduction of greenhouse gas emissions (BORGES *et al.*, 2016; MARTINS *et al.*, 2019)Despite all that, Sociopolitical constraints reduce the effective space between the idealization of low carbon energy policies and the appropriate establishment of renewable energy technologies to mitigate the impacts of climate change (ABREU *et al.*, 2014).

Among the renewable sources available on the market, wind power is evaluated as one of the most promising, as it shows exceptional development and greater guarantee of continuous flow in supply (DING *et al.*, 2019; MADLENER; LATZ, 2013).

With regard to global wind power production capacity, it grew by 530 GW, i.e., from 121 GW in 2008 to 651 GW in 2019, as GWEC made available in Renewables 2020 global status report – REN 21. In the five-year period between 2009 and 2014, wind power generation more than doubled, and the global wind market expanded 19% in 2019, with about 60 GW (54 GW onshore and 06 GW offshore) added to the power grid (REN21, 2020). In the survey period, the average yearly evolution rate was 16.7% (figure 1). Accordingly, in order to make wind power even more feasible for political, economic and social reasons, promoted by the recent sustainable development agenda (COSTANZA *et al.*, 2016), there is a need for integration between the method of electricity generation based on wind power together with energy transmission lines, better energy planning of the countries and advances in studies for the implementation of offshore wind farms, since, among the greatest environmental and economic difficulties for generating wind power, it should be mentioned the need to use large areas for maintenance of its operation (HUBLER *et al.*, 2020; VAVATSIKOS; ARVANITIDOU; PETSAS, 2019).

When observing this context, it becomes relevant to define a base of understanding on the primordial factors that compose the wind power supply chain, which operate, influence and amplify its growth, trying to investigate and understand if the perspectives of cost reduction and technological advance of equipment, such as, for example, storage process, cost reduction of wind turbines will be achieved (ADEMULEGUN *et al.*, 2020; REZAEI; NAGHDI-KHOZANI; JAFARI, 2020; GIANNAKOPOULOU, 2018), as well as conditions associated with the large amounts of capital spent, government public policies and relationships with suppliers, prices and demand (SILVA *et al.*, 2013; TROCHE-ESCOBAR; LEPIKSON; FREIRES, 2018).

Figure 1 – Global capacity and growth of wind power in GW



Source: REN21, 2020.

Specifically with respect to supply chain, it can be said that it is a systemic approach of reasonable complexity, which implies high interaction among participants, requiring the simultaneous consideration of several trade-offs. Supply chain goes beyond organizational boundaries and considers both internal and inter-organizational trade-offs, regarding who should be responsible for stocks and in which stage of the channel the various activities should be held. Thus, with the technological advance, it allows the reduction of the manufacturing costs of new technologies, making in fact wind power more and more competitive and interesting (DE JONG *et al.*, 2013).

In this way, many studies have emphasized various topics in the supply chain, particularly from 2003, with the first surveys, and notably from 2009, a period in which a greater number of surveys on wind energy and the supply chain appear, due especially to the large participation of the United States, China, United Kingdom and Germany, which will be better highlighted in the next section.

From 2003 to March 31, 2020, 197 researches were published, but few or no work demonstrates an organized and directed look at ways to globally understand the supply chain that is part of the electricity generation process through wind energy. No work addressed has a comprehensive and quantitative view of publications associated with the supply chain and wind energy and, in view of this, this study proposes to satisfy the gap by performing a bibliometric research.

Given the global conceptual setting, the main objective of this research is to analyze the evolution of studies related to supply chain associated with wind power, applying bibliometric research in order to understand possible or potential directions of research in this field. Specifically, the research seeks to contribute to: a) evaluate the current development of supply chain research in the wind industry worldwide, its applications and trends; b) highlight the characteristics of publications, showing the main journals, countries, articles and most cited authors; c) identify the distribution of keywords according to purposes, methods, metrics and research fields; d) analyze and discuss the results in detail, uncovering possible directions of research in this field, through specific points correlated to the content and analysis of publications.

This article is structured in three more sections, besides this introduction. The second section discusses the research methodology in detail. Section three shows the obtained results and discusses their implications. Subsequently, the fourth section shows the relevant conclusions of the bibliometric research.

METHODOLOGY

In this section, the procedures employed in the research are described. Firstly, a brief explanation of the bibliometric research was displayed. Later, the justification for the selection of the database is presented and the coding of the process, indicators and bibliometric methods and the software used were displayed, as well as the parameters determined for the generation of the outputs of results.

BIBLIOMETRIC ANALYSIS

Bibliometrics is a science whose objective is to analyze and evaluate the scientific advances produced in the different scientific or knowledge fields, essentially through the analysis of the scientific production (MARTÍNEZ-SÁNCHEZ, 2014).

Its use has emerged as a possibility to improve and enrich studies and analyses in terms of scientific production and dissemination. It can be used in a quantitative way to analyze the contribution made available to science by research institutions and also to assume the potentiality of future research. In other words, the bibliometric analyses are aimed to check the course of science in an established knowledge field (GAUTAM, 2017; ZHAO; STROTMANN, 2015).

Also according to Martínez-Sánchez (2014), bibliometrics promotes studies on the quantitative aspects of production, propagation and use of related information, for which it develops models and mathematical measures that, in turn, assist in estimates and decision making.

This article is retrospective in nature and uses a bibliometric analysis of secondary data. This analysis generates important and useful information for researchers, who have the ability to analyze the evolution of conceptual, social and intellectual aspects of the research field of interest, observing its evolution (MONTERO-DÍAZ *et al.*, 2018). The bibliographic material is examined under a quantitative conception and in an objective way, making it possible to organize information in a specific thematic field (ALBORT-MORANT; RIBEIRO-SORIANO, 2016). Accordingly, a bibliometric analysis using keywords enables the analysis of particularities in the main research contents in a given field of knowledge (CHEN; XIAO, 2016) By advancing according to criteria recommended by Castillo-Vergara, Alvarez-Marin and Placencio-Hidalgo (2018), this research adopted the following steps: 1 – definition of the study field; 2 – selection of the database; 3 – adjustment of the research criteria; 4 – coding of the chosen material; 5 – analysis of the conceived information.

SELECTION OF THE DATABASE

Bibliometric methods are used in various fields for a variety of purposes, including research evaluation. Most bibliometric analyses have in common their data sources: Web of Science (WoS) from Thomson Reuters and Scopus from Elsevier (MONGEON; PAUL-HUS, 2016), for example.

Bibliometric analysis investigates a collection of publications using quantitative analysis methods (GARRIDO; SANTOS; RODRIGUEZ ANTÓN, 2019).

Scopus is a multidisciplinary database of abstracts and citations, with over 25,100 titles from over 5,000 international publishers (LEI; LIU, 2019).

The search and selection of the chosen articles, from the applied keywords, were retrieved from Elsevier's SCOPUS database. The multidisciplinary feature and the breadth of its database of abstracts and citations makes it one of the most requested in the fields of science (MARTÍN-MARTÍN *et al.*, 2018).

The research has examined publications since 2003, when the first manuscript for the surveyed terms was observed, until March 31st, 2020. The ascertainment for this period, March 2020, was due to the fact that all the analyzed articles within the theme of the current year have already been published in the proper journals, that is, with the research completed and published. The keywords included in the research were: "wind power" and "supply chain", in order to be searched only in the domains related to title and abstract, as well as the keywords themselves, using the Boolean operators "and". Only articles published in English were requested. Preliminary research returned 230 articles, which were analyzed in a qualitative way. Of these, publications that did not specifically contain the two terms were eliminated, as well as research that discussed other renewable energy sources such as biomass, oil, gas and publications that did not dialogue on wind power and supply chain.

Moreover, articles related to the theme of renewable energy were discarded but were not linked to the purpose of this research. Soon after this refining, there were 197 articles left, which were highlighted in the bibliometric analysis. Review articles were also part of the selection to integrate the database. The research and collection of articles were performed from March 2nd to March 31st, 2020.

CODING PROCESS

After the data collection, a unique structure of information was prepared, consisting of a simple file, designed in the Excel program, in "CSV" format, including a complete record of the characteristics used for analysis: Title of the article, year of publication, abstracts, author, language, type of research, country of origin, keywords, field of research and references cited in each of the publications designated in the screening stage of the database. Appropriate time intervals were also established with the number of publications for the analyzed period, with the purpose of showing the evolution and variation in the number of publications among the defined years.

A frequent difficulty in bibliometric research and systematic review is the way in which some of the authors are called. There is also an adversity tied between some keywords that have different spellings, but have the same meaning included in the studied context, such as: "wind power" and "wind energy". Thus, they were considered as one word only.

In order to avoid this adversity, all the qualitative treatment of evaluation was made in the selected articles.

CHOICE OF INDICATORS AND BIBLIOMETRIC METHODS

The choice was based from on file formatting, choice of quantitative indicators that measure the efficiency of a researcher, journal or country of the researcher, in statistical form of publications and citations of the produced work (SKALABAN; YURIK; LAZAREV, 2017; CADAVID HIGUITA; AWAD; FRANCO CARDONA, 2012).

These indicators aim to evaluate the regularity with which an article, author or journal is cited in other studies, correlating research, authors, keywords, institutions and countries according to the established method, structuring the analysis sections according to metrics.

For this study, the designated bibliometric methods were Citation Analysis, Co-citation Analysis, Co-author Analysis and Co-word Analysis. The Citation Analysis method is a technique applied using the citation as parameter of importance, understanding that authors, research and journals with higher levels and numbers of citations prove to be more influential (MERIGÓ *et al.*, 2016; ZHAO; STROTMANN, 2015). Co-citation Analysis aims to detect the intellectual structure of a field of study, where groups of researchers are methodically cited by a deliberate number of works jointly (MARTINS *et al.*, 2019).

The estimate in which the more referenced together shows that their contents are related and configures the most influential authors (ZUPIC; ČATER, 2015). The Co-citation also defines that a link between documents cited by another author and their approach allows the identification of a field of research, as well as the analysis of references can evaluate the results of the research (ETO, 2016; GARRIDO AZEVEDO; SANTOS; RODRIGUEZ ANTÓN, 2019).

Co-Author Analysis analyzes the intellectual structure and activities of researchers in a given field of research (GARRIDO AZEVEDO; SANTOS; RODRIGUEZ ANTÓN, 2019). Moreover, when a researcher cites the work of other researchers, as well as the author of the work is cited by others, important information on how an intellectual network is formed, who the main actors are, which countries discuss the subject, characterizing the measure of cooperation between published studies (BACKHAUS; LUGGER; KOCH, 2011). Co-word Analysis shows that, when words often co-occur in documents, it means that the concepts behind these words are closely related, expanding the interest in research (ZUPIC; ČATER, 2015; CASTILLO-VERGARA; ALVAREZ-MARIN; PLACENCIO-HIDALGO, 2018; LEE *et al.*, 2020; MONTERO-DÍAZ *et al.*, 2018).

These techniques used admitted the metric maps of the defined research field, or rather, the wind power supply chain, mainly through the technique Co-word Analysis that observed the current state of research and likely future paths of studies correlated to the context addressed in this work.

SOFTWARE USED AND SPREADSHEETS

In order to assist in the construction of the metric maps, the Vosviewer software was used, an open access information technology program created by Waltman and van Eck (2012) for the preparation and visualization of bibliometric maps. The advantage of Vosviewer is that it focuses on graphic reproductions of maps. With this, it is of great use because it exposes larger maps, providing understanding and can also be used to design maps with network data (ZHANG; YUAN, 2019; MUÑOZ-VILLAMIZAR *et al.*, 2019)

The maps show the frequency of occurrence of a term chosen in the search. The distance between two terms can be understood as a denotation of the connection of these terms based on the amount of co-occurrences between the terms (COBO *et al.*, 2011; CASTILLO-VERGARA; MAURICIO, ALAVAREZ-MARIN; PLACENCIO-HIDALGO, 2018). Several methodologies are used in the bibliometric analysis to visualize qualitative and quantitative changes in a specific field of research, and the analysis performed in this program identified countries, authors, Journals, most cited articles and keywords (COBO *et al.*, 2011).

RESULTS AND DISCUSSION

As detailed in the methodological section, the basic body of publications identified in the pertinent literature covered 197 articles. The distribution of publications in the period (01/2003 to 03/31/2020) is illustrated in figure 2. In 2003, the first year of the analyzed series, only one article was published on the

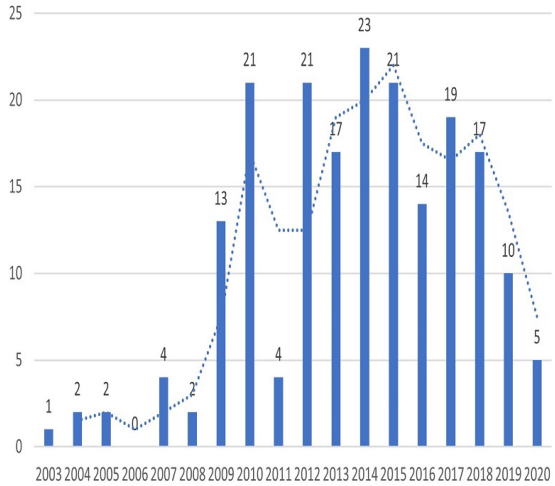
theme. Considering that the number of publications in 2020 does not consider the whole year, because this research was held in the period from March 2nd to March 31st, 2020, and there is a clear upward trend since 2009. Therefore, this is not only a topic of growing interest, but also very recent.

This section contemplated the specific proposed objectives, showing the characteristics of the publications, the most cited authors and articles, as well as the countries involved in the theme under discussion.

PERFORMANCE OF RELATED PUBLICATIONS AND PERFORMANCE PER COUNTRY

In the first six years, the average publication was only two articles. The low interest in these first six years of the study for the aspects related to the wind power supply chain can be clarified for some reasons. Firstly, an important reason to be considered is related to the technological issue (LIU; TANG; JIANG, 2010; SHERIF; VEZIROGLU, 2005) and high costs (CIANG; LEE; BANG, 2008; LINNEMANN; STEINBERGER-WILCKENS, 2007). Although the knowledge and use of winds to generate energy has been known for over 3,000 years, the effectiveness of windmills was very incipient in the early days of the 1950s. (FRAENKEL; KENNA, 1984), affecting the efficiency of this process. Subsequently, after two major world oil crises, in 1973 and 1986 respectively, with oil values very high, the predominance of fossil fuels was still prominent, but little was discussed and environmental issues were not on the agenda of priorities (GROSSMAN, 2015; LOWRY; JOSLYN, 2014; MAY; JOCHIM, 2013; NOHRSTEDT; WEIBLE, 2010).

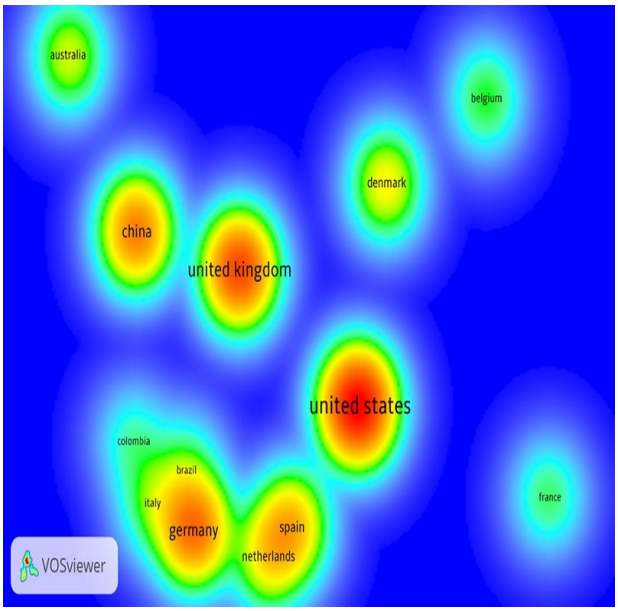
Figure 2 – Yearly distribution of publications on wind power and supply chain



Source: SCOPUS – The authors, 2020.

The country with the largest number of publications on the theme "Wind Power and Supply Chain" is the United States (37), followed by China (28), the United Kingdom (24), Germany (22) and Brazil (02), being well cited by researchers (ALÉ *et al.*, 2013; HERRERA; URIONA; DYNER, 2020; INGRAO *et al.*, 2015; SIMA; PACCA, 2014; TROCHE-ESCOBAR; LEPIKSON; FREIRES, 2018). The largest number of citations comes from the United Kingdom, with 778, which is the country that also has the largest number of connections with other countries. The map in figure 3 shows the countries that carry out research on the topic of interest. A total of 13 countries were identified, which formed four clusters.

Figure 3 – Intensity of publications per country on wind power and supply chain



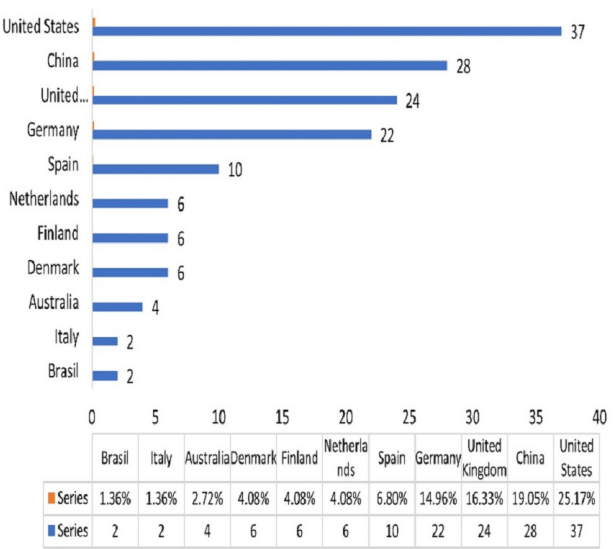
Source: Vosviewer – The authors, 2020.

The number of publications in a country proves its level of engagement with the field of study. The 11 most productive countries, considering the entire historical series (2003 to March 31st, 2020) considering only the nationality of the first author, are illustrated by figure 4. These 11 preponderant countries published 147 articles, representing 74.62% of the total number of publications. The United States are topping the list, with 37 articles (25.17%); followed by China, with 28 articles (19.05%); the United Kingdom, with 24 publications (16.33%); and Germany, with 22 articles (14.96%). In the middle of the list, Spain, Denmark, the Netherlands and Finland emerge, which have 10 (6.8%), 06 (4.08%), 06 (4.08%) and 06 (4.08%) publications, respectively. Finally, Australia, Italy and Brazil, which have 04 articles (2.72%), 02 articles (1.36%) and 02 articles, respectively each country, of the total publications in relation to the total number of publications.

It is important to emphasize that, of the 11 countries that most research on the performance and characteristics of the wind power supply chain, 05 also have the largest production capacity (REN21, 2020).

China, one of the largest producers in research on the subject under analysis, has the largest cumulative capacity in wind power (WANG; LONGYAN *et al.*, 2018; GAO *et al.*, 2016), reflecting the development in research. The United States in 2019 had its third largest year in capacity additions, increasing 20% over 2018, covering a total currently installed capacity of 105.6 GW (REN21, 2020). The country ranks first in publications, and is also the country with the largest range of investments, around US$ 300 billion in 2018 (GWEC, 2018; GIANNAKOPOULOU, 2018). The participation of European countries in research related to the surveyed topic should also be highlighted: of the 11 countries present in the list of major research producers in this field, 7 are European.

Figure 4 – The 11 most productive countries on wind power and supply chain



Source: Vosviewer – The authors, 2020.

With respect to cooperation among countries, academically classified as a relevant aspect, because it allows the association among different authors and research providing processes of technology transfer and commitment to innovative solutions for the research field, it can be seen from figure 5 that German researchers have published most of their works in co-authorship with their collaborators in Italy, Belgium and France.

For this research, a minimum of four joint publications for the countries were parameterized in the Vosviewer tool.

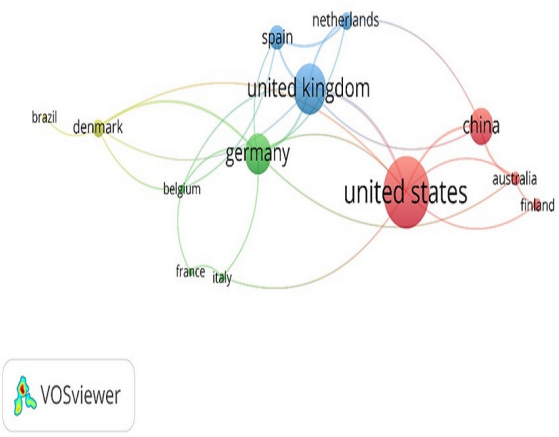
Relevant works discuss the impact of the supply chain operationalization and the operational and maintenance performance of wind turbines, observing the extension of the equipment life cycle and involves a perfect organization and coordination among maintenance, monitoring, operation (LE CADRE; PAPAVASILIOU; SMEERS, 2015; DAHANE *et al.*, 2017), as well as on the characteristics of the sector and which factors are affecting its competitiveness, seeking to identify and discuss the main strengths and weaknesses, threats and opportunities of the wind industry (FREY; SQUILLACE, 2010).

The United States is also an important country in research in this field. Its main collaborators are China, Australia and Finland. The research shown was varied, such as "The energy and water nexus in Chinese electricity production: A hybrid life cycle analysis", which has included studies on energy and water in electricity production, hybrid life cycle analysis, showing that a shift to low-carbon renewable electricity generation technologies, such as wind, could save more than 79% of the total life cycle of CO2 and more than 50% of water consumption per kWh of electricity generation compared to the current fuel mix and technology for electricity generation (FENG *et al.*, 2014); research such as the "Economic input-output based sustainability analysis of onshore and offshore wind energy systems", which seeks to quantify the indirect environmental impacts of onshore and offshore wind power technologies related to direct and supply chain (NOORI; KUCUKVAR; TATARI, 2015; SLATTERY; LANTZ; JOHNSON, 2011; QIU; ANADON, 2012; SARAN; GOENTZEL; SIEGERT, 2010); and even research that discusses GHG mitigation capacity in the energy sector (SAFDARNEJAD; HEDENGREN; BAXTER, 2015; DELARUE; LUICKX; D'HAESELEER, 2009; DENHOLM *et al.*, 2012).

The United Kingdom also holds significant and robust collaborations with other countries, especially Spain and the Netherlands. The main collaborative work, according to the article "Maintenance logistics organization for offshore wind energy: Current progress and future perspectives" has been concerned with research on maintenance logistics in offshore wind power, which proposes a classification involving three levels of strategic, tactical and operational decision-making (SHAFIEE, 2015; SULTAN; MATIVENGA; LOU, 2018), reducing operating costs, through learning curves and supply chain improvements, in order to sustain the competitiveness of the offshore wind industry in relation to other renewable energy sources (DALGIC; LAZAKIS; TURAN, 2015).

China is also highlighted in international academic partnerships. The main partner is the United States, but it also has joint research with Australia and Finland. The relevant joint themes discussed converged on developing plans to promote the optimization of the Chinese energy industry structure and achieve the emission reduction goals (LI *et al.*, 2015; YUAN *et al.* 2014; LI *et al.*, 2017)figure 5 shows and summarizes the status of international partnerships among the authors, highlighting the cooperation of the United States, the United Kingdom, Germany and China.

Figure 5 – Relationships of academic cooperation among countries on the topic of wind power and supply chain



Source: The authors, 2020.

PERFORMANCE OF THE MAIN JOURNALS

As for the 197 articles are distributed in 11 fields of Scopus' knowledge (already including the class "others"), the main fields are Energy (32.0%), Engineering (24.4%) and Environmental Science (12.1%). They have been published in 113 different journals or conference proceedings, highlighting the heterogeneous nature of the research that discuss supply chain factors and wind power. The 11 main journals are responsible for 29.95% of the total publications selected in the study. Their peculiarities are specifically appreciated through Table 1. The most influential journal in this research field is Energy Policy, with 10 publications (5.08%) and a total of 351 citations of its articles. Energy Policy is a peer-reviewed international journal that depicts the political, technical, economic and social implications of energy use and its planning. With an impact factor of 5.042, the articles cover global and national topics, according to the application and political direction undertaken by the findings. Another outstanding journal is the Renewable and Sustainable Energy Reviews, which from 2003 to March 2020 had 9 publications on the context under discussion, or 4,57%, with a total of 680 citations of its articles. In 2019, the journal's impact factor was 12.110 and it covers studies on sharing solutions, new ideas and technologies, in order to support the transition to a low-carbon future and the achievement of emission goals.

The only Journal without a correlated impact factor is Applied Mechanics and Materials. This journal had four related publications on wind power and supply chain from 2012 to 2014, the articles were not cited by other authors, and an issue dedicated to the 2013 International Conference on Precision Mechanics Instruments and Measurement Technology (ICPMIMT). A large part of the articles analyzed the characteristics of supply chains and competitiveness in relation to the availability of winds from certain regions, using different models to measure speed, occurrence and periodicity of winds, and also the studies provide some ideas on supply chain in the wind power sector, where they are discussed under the aspects of policy and technology (LIU, 2013; NIU *et al.*, 2012).

Table 1 – The 11 important journals listed and their main attributes on the topic of wind power and supply chain

Journals	TP	%	I F
Energy Policy	10	5.08	5.042
Renewable and Sustainable Energy Reviews	9	4.57	12.11
Applied Energy	7	3.55	8.848
Renewable Energy	7	3.55	6.274
Energy	6	3.04	6.082
Journal Of Cleaner Production	5	2.54	7.246
Applied Mechanics and Materials	4	2.03	0
Advanced Materials Research	3	1.52	0.87
International Journal of Energy Sector Management	3	1.52	0.9
International Journal of Hidrogen Energy	3	1.52	4.939
Sustainability	2	1.01	2.576

Source: The authors, 2020.

By reflecting the analysis further, moving on to topics of interest to the journals, taking into account a minimum of two publications per Journal, it was feasible to identify three main clusters (figure 6). The first cluster, conducted by Energy Policy, together with the Journals Renewable and Sustainable Energy Reviews, Applied Energy and Sustainability, was responsible for 28 publications on the topic under study, or 14.21% of all publications.

The most cited article was "The economics of wind energy" (BLANCO, 2009), published in Renewable and Sustainable Energy Reviews, with 395 citations, where the article introduces the results of a study conducted among wind power manufacturers and developers on the costs of generating wind power projects in Europe, the factors that most influence them, as well as the reasons behind their recent increase and their future evolution.

The next most cited article was published in the journal Applied Energy and computed 89 citations. The article "Modeling of financial incentives for investments in energy storage systems that promote the large-scale integration of wind energy" (ZAFIRAKIS *et al.*, 2013) sought to emphasize the role of energy storage in the electricity supply chain. Nonetheless, the absence of an integrated evaluation framework for services provided by energy storage technologies hinders investments in capital-intensive systems. For this purpose, the feasibility of an alternative operation strategy for energy storage systems is investigated. In general, the cluster paid attention to factors related to the economic and environmental impacts of the development of wind power and energy costs (JENNICHES; WORRELL; FUMAGALLI, 2019; HEPTONSTALL *et al.*, 2012; SLATTERY; LANTZ; JOHNSON, 2011) and identified key stakeholders throughout supply chain and their concerns (YUAN; SUN, 2013), as well as studies on the role and development of supply chain and its performance in renewable energies (POULSEN; LEMA, 2017; ASLANI *et al.*, 2013).

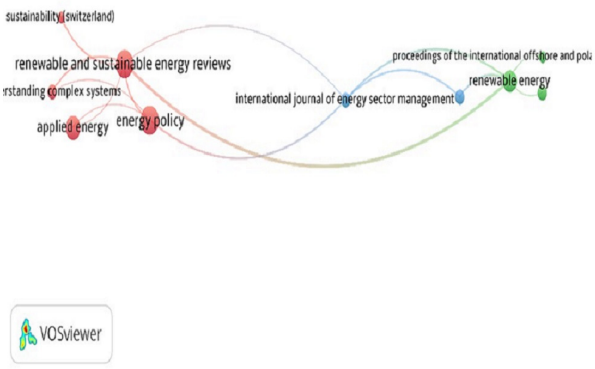
The second cluster, coordinated by the journal "Renewable Energy", and by the publications of the European wind energy conference and exhibition and Proceedings of the International Offshore and Polar Engineering Conference, which included 12 articles (6.09% of the total publications). The article with the highest number of citations in this cluster was "Wind turbine generator systems. The supply chain in China: Status and problems" (HE; CHEN, 2009), which analyzed the status of the manufacture of wind turbine generator systems from the wind turbine generator systems-WTGS, besides supply chain problems, from a macroscopic view. The other publications in the cluster also focused on topics related to the sustainable development of the clean energy industry chain and its challenges, which discussed the lack of flexibility, as well as the globalization of the wind power sector with a focus on contributions among companies and their economic impacts.

And also addressing the manufacturing infrastructure and the domestic level of supply chain (HAMILTON, 2012; LI *et al.*, 2015; LACAL-ARÁNTEGUI, 2019) The journals "Journal of Cleaner Production" and "International Journal of Energy Sector Management" comprised the third cluster, with eight publications, (4.06% of the total publications), five from the first and three from the second. The articles discuss the wind energy industry, depicting rapid growth, and that wind turbines are perceived as a low-impact energy generation technology, mainly because they have a relatively long lifespan (20-40 years); and, in order to recover the maximum value of these turbines, it is essential to perform the environmental life cycle evaluations of the turbines (ORTEGON; NIES; SUTHERLAND, 2013; LUNDIE *et al.*, 2019).

Regarding the economic and strategic aspects of the implementation and development of wind power, there is the perception that the availability of the equipment is determined by the joint efforts of both partners, i.e., the effort of the equipment manufacturer to improve quality and the effort of the client company in having better services, so that it discusses the sharing of packaged revenue with cost sharing of quality improvement and better performance (LIU *et al.*, 2020).

Other articles in this cluster discussed the need to expand research and identify academic findings that could provide offshore wind projects with the means to overcome their current supply chain challenges, as well as concepts from a supply chain management perspective to promote cost reduction in the offshore wind energy industry (MARTINEZ NERI, 2016; STENTOFT; NARASIMHAN; POULSEN, 2016; BAAGOE-ENGELS; STENTOFT, 2016). figure 6 illustrates the most frequently cited journals in relation to the topic of interest, highlighting the links between/among them.

Figure 6 – Most cited journals



Source: The authors, 2020.

AUTHORS' PERFORMANCE AND COLLABORATIVE RELATIONSHIPS

The content of interest proved to be quite specific. Thus, in accordance with the study data, the authors with the largest number of publications were Dyner, I. and Helo, P., with three articles published. It is important to note that these three publications by the author Dyner, I. were worked together with the author Herrera, M. M, always having him as the main author. The most cited article in the partnership was "Alternative energy policy for mitigating the asynchrony of the wind-power industry's supply chain in Brazil, published in Understanding Complex Systems, in 2018, with 04 citations.

In this article, the authors discuss how the high dependence on hydroelectricity reveals disadvantages in the security of energy supply as a consequence of climatic variability in South America. Accordingly, Brazil starts to consider new alternative renewable sources for energy production, promoting clean technologies (HERRERA; DYNER; COSENZ, 2018).

The most cited author was Blanco, M.I., who shares only one publication on the topic covered in the research, with this article having a total of 395 citations by the author in this segment. The research called "The economics of wind energy", published in 2009 in the journal Renewable and Sustainable Energy Reviews. In this article, the author introduces a study on the costs of generating wind energy projects, as well as the factors that most influence them. A comparative of onshore and offshore wind energy costs, and in the long run, production costs are expected to decrease, but it will depend to a large extent on the application of appropriate policies (BLANCO, 2009)[9]. Table 2 summarizes the important authors, highlighting the total number of publications, citations and average citations on wind power and supply chain.

Table 2 – Main authors

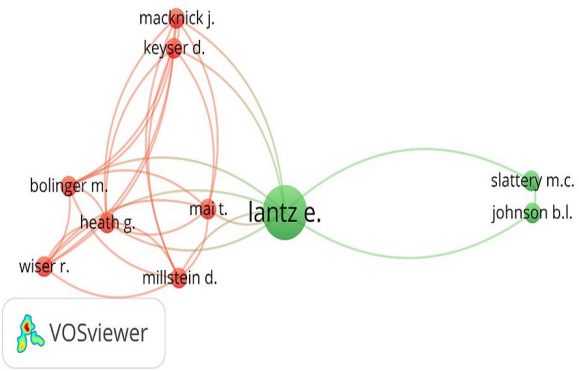
Authors	Publications	Citations	Average
Dyner, I.	3	4	1.3
Helo, P.	3	17	5.7
Lantz, E.	3	82	27.3
Ahmad, T, J.	2	3	1.5
Allman, A.	2	24	12.0
Badea, A.	2	0	0.0
Da Ros, V.	2	0	0.0
Daoutidis, P.	2	24	12.0
De Castro, R.	2	2	1.0
Goudarzi, N.	2	4	2.0
Herrera, M, M.	2	4	2.0
Kucukvar, M.	2	77	38.5

Source: The authors, 2020.

The significant characteristics of scientific production regarding supply chain and wind power are the links of collaboration, marked by being very limited. Taking into account the minimum number of one publication per author and a minimum of two citations by these authors, it is observed that they operate in two main clusters (figure 7), responsible for 12 publications, which represents only about 6.10% of the total articles in the entire series and 334 citations. The information shows that most authors work in isolation, not interacting with each other, that is, most of the works are of unique authorship. The first cluster, formed by Bolinger, Millstein, Heath, Keizer, Macknick, Mai and Wiser has 07 publications and a total of 140 citations. The main topic of relevance for the group is the aspects in which wind generation can reach a percentage of electricity demand, and achieving certain levels of penetration, could have significant implications for the wind industry and the electricity sector in general. In order to achieve these penetrations, it imposes an incremental cost for consumers (WISER *et al.*, 2016).

Formed by three authors (SLATTERY; LANTZ; JOHNSON, 2011), cluster two consists of five publications, with a total of 194 citations. The main article, "State and local economic impacts from wind energy projects: Texas case study", from 2011, had 58 citations, and uses the Jobs and Economic Development Impacts (JEDI) model to estimate the economic impacts on wind energy development in four counties in western Texas. The specific impacts of the project are estimated at the local and state levels. The main economic policy issue addressed is how investment in wind energy affects the state and local communities where wind farms are constructed. These impacts were mostly perceived in the construction phase and in the supply chain itself, with regard to employability (SLATTERY; LANTZ; JOHNSON, 2011).

Figure 7 – Cluster of scientific collaboration among authors



Source: The authors, 2020.

KEYWORD ANALYSIS

The 197 articles that comprised the body of analysis of this research provided 992 keywords. On average, there were approximately five keywords for each publication. They symbolize the basic units of an established field of study, depicting an overview of the researched field of knowledge, as well as future research trends (GARRIDO AZEVEDO; SANTOS; RODRIGUEZ ANTÓN, 2019).

By applying the keyword co-occurrence analysis, modeling in Vosviewer a minimum number of occurrences of 10 keywords, figure 8 was generated, which characterizes a keyword co-occurrence network. Each word represents a link in the network and their co-occurrence integrates the borders between the links. These mapped keywords come from an analysis that instituted characteristic indicators of connection between them, such as centralization, degree, density and inclusion. Density is determined as the relationship between the number of relationships actually constituted and the total number of likely relationships, while centralization refers to the degree to which relationships are centralized in some individuals. In turn, inclusion means the number of links connected to each other in the network.

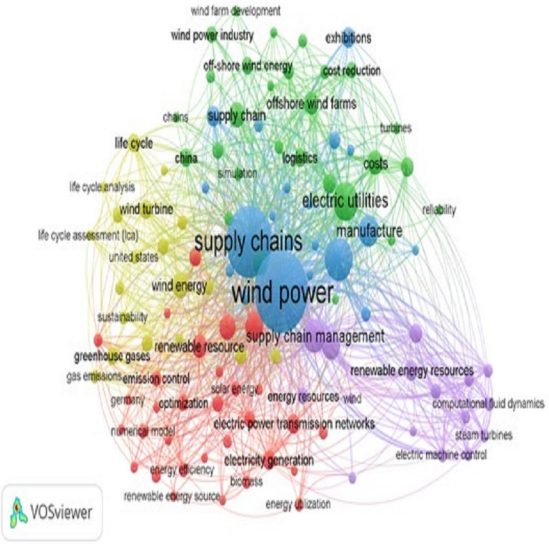
The centrality checking was focused on unveiling relevant links in the network and with the purpose of finding which keyword is positioned in the middle of the network, having the ability to influence most keywords (KIM; JANG; LEE, 2018; KIM; HASTAK, 2018).

New keywords are usually attributed to each publication, and the differentiation of those keywords can indicate the most active areas of publications (COBO; HERRERA, 2011).

The use of this analysis distinguished five fundamental sets of keywords. The smaller subnet, purple in color, is a cluster that discusses, fundamentally, issues related to supply chain management at the macro-level, such as generation and transmission infrastructure, which affects the performance of wind power, the supply chain of the renewable energy market and the analysis of countries' wind industry, especially China, besides attaching importance to innovation and technological performance. It is a cluster closely linked with the blue cluster, according to the links that overlap between them. The blue cluster is dedicated to research in the field of competitiveness of wind power based on supply chain, energy market, international energy trade and innovation, and mainly on the wind power industries.

Conversely, the green cluster preferably discusses content related to the use of electricity, offshore wind energy, offshore wind energy supply chain, observing and evaluating turbines and operations based on maintenance. The yellow cluster, which has a strong connection to the red cluster, discusses a lot on life cycle evaluation and its analysis of the wind energy industry, as well as on sustainability and its environmental impacts and gas emissions. The red cluster, the most relevant in terms of number of keywords (31 in total) is mainly responsible for issues related to energy policy, energy efficiency, risk evaluation and economic feasibility and research on energy generation structures.

Figure 8 – Keyword co-occurrence network



Source: The authors, 2020.

The most important keywords in the pertinent literature are wind power, supply chains, wind turbines, supply chain management, manufacture, logistic, costs, offshore wind, electricity generation, wind power industry, wind energy turbines, economic analyses and renewable energy resources. Therefore, this analysis shows the fundamental terms and concerns associated with wind power and supply chain, subsidizing the identification of these terms and correlating with the main points linked to supply chain performance, which focuses strongly on the processes of decision making and supply chain design.

Moreover, the analysis identified some trends and perspectives for future research regarding the study of wind power and supply chain, shown in the article Cournot oligopoly game-based local energy trading considering renewable energy uncertainty, published in October 2020 in the journal Renewable Energy, which reports that, facilitated by advanced information and communication technologies, local wind energy trade develops rapidly, playing an important role in the energy supply chain, and thus it is essential to develop local business models and strategies that can benefit participants, not only by stimulating local

balance, but also by proposing a new local energy trade decision-making model for suppliers, considering the uncertainty costs of renewable energy.

The revenue from these technologies is largely formulated according to their operating cost, investment cost and income from energy sales. The uncertainty cost of renewable generation is integrated into the negotiation, modeled as a penalty for the shortage of potential energy, which is derived from the probability distribution function of output (ZHANG *et al.*, 2020).

Another future trend observed in the analysis was found in the article "Energy storage on a distribution network for self-consumption of wind energy and market value", which shows a new trend that requires further studies, where wind energy can be generated and captured with a storage device at the customer's premises for local use, providing services across the power supply chain, as well as observing the effects of adding the storage device to the network. Thus, a technical analysis is performed using a tool modeling (ADEMULEGUN *et al.*, 2020).

FINAL CONSIDERATIONS

This study investigates the connection between renewable wind power, strategic structures and supply chain performance by conducting a bibliometric research focused essentially on the performance of publications, academic cooperation among countries, performance of the main journals, authors' performance and relationships of collaboration, main authors and keyword analysis, among other analyzes.

The bibliometric research has revealed that the themes of Wind Power and Supply Chain examined together, are pertinent, essentially from 2009, being mainly concerned with external issues related to new technologies for power and electricity generation, as well as topics associated with the evaluation of financial costs of wind projects, since they require a series of investments to start their operations.

The study also made it possible to prove the development of research under a quantitative conception, showing the performance of publications and the main countries interested in the addressed topic.

Here, it should be highlighted the example of United States, which have productivity in line with studies and advances in the sector, with 37 articles, that is (25.52%) of all productions in the surveyed period, followed and not least by China, which in recent years has become one of the largest producers in research on the theme under analysis, and this has been reflected in the development of research. It is also worth underlining the fact that the largest number of citations comes from the United Kingdom, with 778, which is the country that also has the largest number of connections with other countries. Of the 10 countries most engaged in the connection between supply chain and wind power, seven are from Europe.

The research also highlighted the performance of the main ways of propagating academic works, having been produced, in its great majority, by scientific journals. The most influential journal in this field of research is Energy Policy, with 10 publications (5.08%).

Another journal that stands out is Renewable and Sustainable Energy Reviews, which is the journal that covers the most cited article in this research, with 395 citations. The main lines of research of the journals converge in analyzing the characteristics of supply chains and competitiveness in relation to infrastructure, availability of winds from certain regions, using different models to measure wind speed, occurrence and periodicity, and analysis of public policies on the wind sector, economic feasibility of investment projects, inclusion of new technologies, especially energy storage processes and procedures and generation from clean sources, environmental impacts and sustainability.

The importance of the main researchers was also analyzed, highlighting their publications on the addressed topic, as well as the number of citations. It has been shown that, synchronously in which they have collaborative groups that work with more specific aspects of supply chain and that researchers work mostly in isolation, they also have some clusters that hold similar positions and probably do not exchange knowledge on their investigations. After this last occurrence, it would be able to increase research, through information socialization, technology transfer pacts and exchange between/ among researchers from different countries.

Finally, a co-occurrence keyword analysis was performed, which showed the fundamental current concerns of the researchers, where they deal with supply chain in the scope of production and generation of wind power and argued that the articles were considered according to properly correlated conceptions to supply chain.

It is hoped that this research will assist researchers and facilitate their future research directions, whether in the topic under discussion in this research now discussed, wind power and supply chain, or in related matters, in order that they may be contemplated with new ideas and gratified with important information for decision-making, academic or market, through the recognition of the most important journals, authors and research groups.

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