

# Interfaces between wind energy aspects analysis and Weibull distribution: Evidences from a bibliometric study

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**Abstract**—This paper aims to address and understand the knowledge application of Weibull distribution to analyze wind energy aspects, which is related to technical, sustainable and economic assessment, along with wind characteristics. It is structured under bibliometric analysis and reveals a panorama of 177 papers from 2007 to 2017 that presents where and how these relationships between wind energy aspects and Weibull distribution occur. This study presents six different analyses to understand these possibilities: papers by year, wordcloud, papers by author, papers by topic, papers by affiliation, papers by journal and its subjects. Main findings of this research show that the leading areas where these interfaces occur in academic research are energy, engineering and environment science. Another relevant result is that the intersection of wind energy and the Weibull distribution has been figured as a core research topic to individual or a group of researchers around the world. The main contribution of this paper to the academic community is the pioneering on presenting a view on the size and on the main characteristics of this interface through bibliometric analysis.

**Keywords**— Renewable energy, Wind energy, Weibull distribution, Bibliometrics.

## I. INTRODUCTION

The demand for energy is expected to expand continuously, more than tripled by the end of the century [1]. According to Pereira et al. [2], the world is mainly consuming fossil fuel energy and, in the case of final energy consumption, this corresponds to 79% of the world energy matrix. In this context, the conventional processes of electric power generation are among the main responsible for emissions of greenhouse gases [3].

In response to an enhanced awareness of the negative impacts of large-scale, fossil-fuel intensive energy generations, as well as the realization that the earth's resources are finite, governments, organizations and individuals are showing increasing interest in small-scale, decentralized and low-carbon energy sources [4]. As a result, policy makers, business leaders, consumers and researchers have increasingly turned their attention to the alternative energy sources such as solar, wind, and biomass [5].

Among the available renewable energy sources, wind energy is currently regarded as one of the most significant, fastest growing, and commercially attractive sources to generate electricity because of the mature and cost-effective wind energy technologies [6]–[7].

The success of the determination of the wind energy potential depends on accurate wind speed modeling and the statistical properties of wind speed are important to predict the output energy of a wind conversion system [8]. Wind characteristics and power potential of various locations have been studied in many countries worldwide, in order to fully describe the mathematical procedures useful to perform analysis in sites with the potential for wind farm installation [9].

The Weibull function is one of the most used distribution functions for different purposes such as modeling, reliability analysis, life time data analysis, and many applied science areas such as mechanic, bio system, nuclear, and energy system engineering [10]. In studies, it is seen that two-parameter Weibull distribution is used for the determination of wind energy potential in the different regions in the world [11]–[12]. Therefore, much consideration has been given to the Weibull two-parameter – k, shape parameter and c, scale parameter –

function because it has been found to fit a wide collection of wind data [13].

According to Archambault et al. [14], the increased availability of data such as bibliographic impact returns to more importance as a publication activity and citations can be included as part of a more holistic review of the literature. Zupic and Cater [15] pointed out that bibliometric methods employ a quantitative approach to a description and evaluation of published research. Indeed, bibliometric techniques have become an indispensable instrument to measure the scientific progress in various fields [16].

This paper aims to quantitatively and qualitatively map the scientific research about the studies on wind energy that used the Weibull Distribution as an analysis method. Using bibliometric method, various publication characteristics will be obtained such as publication year, authors, institution affiliation, knowledge topics, main journals and its subjects as well as a database content analysis by wordcloud, to measure the its consistency.

These results not only provide a better understanding of global hotspots in the research related to the wind energy analysis, but may also influence researchers' future research directions.

## II. METHODOLOGY

This paper is structured under bibliographic analysis. It intends to analyze quantitative data about papers and allocating them in categories in order to make a good comprehension about the interface between wind energy and the Weibull statistical distribution.

This type of analysis facilitates a cross-referencing, resulting in a previous study composed by the works that will integrate the so-called starting nucleus, where the researcher will have sufficient background for the bibliographic study. For this, bibliometric techniques are used, which employ quantitative methods in the search for an objective evaluation of scientific production.

The researches carried out in the Scopus database were carried out in order to find papers related to the Weibull function and wind energy source. In addition, no exclusion filters were used in order to avoid the reduction of results, choosing a return with the widest possible

In order to better track the scientific papers that relate the Weibull function to wind as an energy source, the search terms should be defined. Due to some different approaches, the same subject has evaluated with various expressions in researches. So, in some papers this energy source is known as wind power and, in other, it is known as wind energy. It is possible to say that wind power is more directly applied to problems related with the power plants issues. Wind energy is a more diversified term and is related to power generation processes, which can occur

in industrial plants, but also in public investments, domestic use, discussions on renewable energy and sustainability.

About the Weibull distribution function, the first strategy was to use the word 'Weibull' to better assimilate the results about the matter. However, it had felt it should make some more filters to the results. Hence, the terms "Weibull distribution function", "Weibull function" and "Weibull parameters" were used.

The next step was the definition of the temporal cut of research and it was decided to work with works published from 2007 to 2017, to clarify the evolution of the publications in the period of a decade. The structure of our search terms as well as the preliminary results for setting our papers database are 609 registers, and it's listed on the Table 1.

Table.1: Search keys used

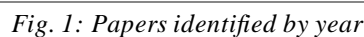
Search	Results
TITLE-ABS-KEY ("wind power" AND "Weibull distribution function") AND (PUBYEAR > 2006)	104
TITLE-ABS-KEY ("wind power" AND "Weibull function") AND (PUBYEAR > 2006)	58
TITLE-ABS-KEY ("wind power" AND "Weibull parameters") AND (PUBYEAR > 2006)	181
TITLE-ABS-KEY ("wind energy" AND "Weibull distribution function") AND (PUBYEAR > 2006)	71
TITLE-ABS-KEY ("wind energy" AND "Weibull function") AND (PUBYEAR > 2006)	43
TITLE-ABS-KEY ("wind energy" AND "Weibull parameters") AND (PUBYEAR > 2006)	152
Total of registers	609

Due to the many results found, a restriction was applied in the types of works. These were restricted to only articles published in journals, excluding conference papers, theses and reports, reducing that set to 177 records.

## III. RESULTS AND DISCUSSION

Initially, it was analyzed the papers distribution by year, represented in Fig. 1. This graph can be separated in two distinct moments: the first moment is from 2007 to 2013, when there is a tendency of publish oscillation. The

line. So, considering the data universe, we can assume the amount of published papers for the next period may continue increasing, according to the trend from 2014 to 2017.



Next, the authors and affiliation with the highest number of publications on the matter were highlighted in Fig. 3 and Fig. 4, respectively. Only those authors and affiliations with four or more records were considered, due to the considerable amount of these with only three or less related publications.

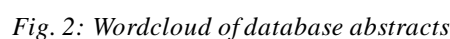
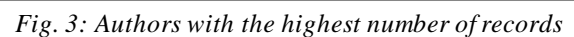


Fig. 4: Affiliations with the highest number of records

A good approach to improve comprehension about database is to evaluate the average amount of journal papers published. In this sense, the value for the average of 17.45 published papers by year indicates the matter has a good acceptance and relevance for the research worldwide, granting more than one article by month on indexed journals since 2007.

In Fig. 4, we can notice two institutions with great relevance in number of publications, King Fahd University of Petroleum and Minerals, from Saudi Arabia, and Nan Kai University of Technology, from Taiwan.

When the two analysis indicators get related, it can be observed that the most prominent authors on the subject belong to the affiliations that have the largest number of publications. Hence, there is two rising groups of scientific paper production that are called the references on the topic.

About the cover topics for the matter, all the 178 papers were related and allocated into the topics

according to the scientific database, with special emphasis on Energy, representing 50% of the registers, Engineering and Environmental Science (Fig. 5).

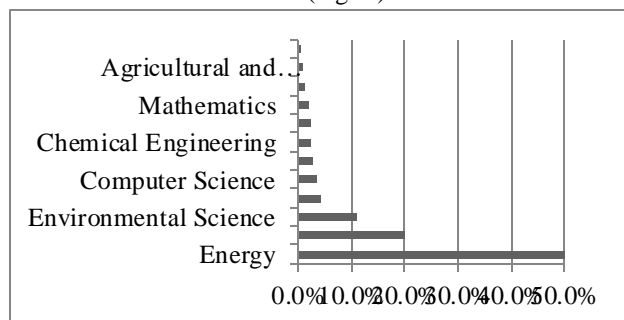


Fig. 5: Papers by topics in the database

For the most part, the papers are listed in the topic Energy, so there is an agreement with the terms used in the search keys and indicate the prominence of investigation lines related to the topic under discussion.

Nonetheless, it has been observed that the amount of articles that refers to more than one topic is relevant. We can cite as examples Costa Rocha et al. [17], allocated in Energy and Engineering, Hulio et al. [18] refers to Energy and Social Science, Fazelpour et al. [19] appointed as Environmental Science and Energy, and Gani et al. [20], allocated in three cover topics: Chemical Engineering, Energy and Environmental Science. This fact corroborates the comprehensiveness and relevance of this research.

Another aspect noted is that the article with the highest number of citations is allocated only in the Energy topic. Akdağ and Dinler [21], cited by 202 papers, developed a method to estimate Weibull distribution parameters for wind energy applications, called power density (PD) method. To demonstrate the accuracy of this method, they had made comparisons based on power density and mean wind estimation results of previous studies. Results of this study indicate that PD method is adequate method estimate Weibull parameters and it might have better suitability than other methods. The analysis showed some superiority of the PD method, because it has simple formulation, it does not require binning and solving linear least square problem or iterative procedure. According to them, it is very simple to estimate Weibull parameters, if power density and mean wind speed are available.

Some of papers following this line are Azad et al. [22], which analyzed seven different methods, including the Power Density method, to determine the best one to estimate the Weibull parameters, however, the results found did not indicate the said method as the most efficient one, Zhou and Smith [23], that estimated global variation in wind parameters, by using the PD method, as fitted to a Weibull density function using NCEP/climate forecast system reanalysis (CFSR) data over land areas,

and Akdağ and Güler [12], which presented a novel method, considered by them better than standard methods, to estimate Weibull parameters, being compared with another eight methods, including the Power Density method, presented by one of this paper's authors in 2009.

We can have some other analysis by looking to the journals that lead the ranking of papers related to our search terms. Fig. 6 shows the papers arranged by journals. For a better viewing, we have put on this graph only journals that count on four papers or more.

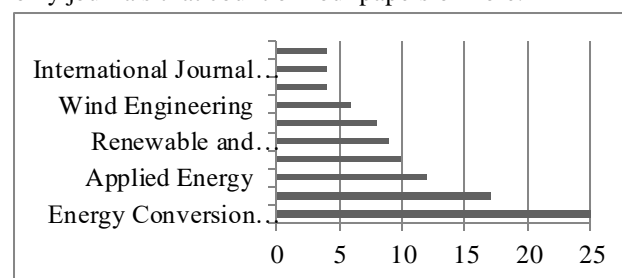


Fig. 6: Papers by journal

First of all, we can note that the leader journal is “Energy Conversion and Management”. The focus of this journal is the research on all important energy aspects, including energy generation, utilization, conversion, storage, transmission, conservation, management and sustainability. The far leadership of this journal is in line with the previous results we have got analyzing the graphic of papers by topic. Most of the papers published by this journal are associated with Energy. So, this journal is an important scientific vehicle to spread knowledge on energy in which concern the intersection between renewable resources, such as wind energy and the processes, operation and performance prospects, like the Weibull function.

The second one, “Renewable Energy”, is a journal that has the purpose of discussing various topics and technologies of renewable energy systems and components. It includes discussion about the wind energy and to apply alternative energy solutions to current practices. On the set of journals plotted in this graphic, we can identify two groups of journals. The first one, which encompasses “Energy Conversion and Management”, “Applied Energy”, “Energy” and “Energies”, is associated with all of energy types, including wind energy.

Another group consists of journals with a more concise range of subjects like “Renewable Energy”, “Renewable and Sustainable Energy Reviews”, “International Journal of Green Energy”, “International Journal of Renewable Energy” and “Energy Sources, Part A: Recovery, Utilization and Environmental Effects”. At this group, kinds of papers we will find vary and can have many different approaches and points of view about renewable

energy and sustainability.

Besides that, we can highlight the journal “Wind Engineering”, as the one more focused on a lot of wind aspects, such as the aerodynamics of rotors and blades, machine subsystems and components, power generation and transmission, measuring and recording techniques, installations and applications, and economic, environmental and legal aspects involved with wind as a source of energy.

#### IV. CONCLUSION

Combining the six different analyses we have done – papers by year, wordcloud, papers by author, papers by topic, papers by affiliation, papers by journal and its subjects, the main conclusion of this work is that the intersection of wind energy and the Weibull distribution has been figured as a core research topic to individual or a group of researchers around the world.

As a formal research topic, papers continue to be written on issues involving wind as energy source or power generation, and Weibull distribution, along with its function and parameters. From 2007 to 2017, 177 articles were produced by using two-parameter Weibull distribution for the determination of wind energy potential.

Inside the topics covered by our database of 177 papers, we can note that technical, sustainable and economic assessment or Wind power characteristics of a determined place are the major subtopics in which the Weibull distribution method can be useful. These results are supported by the journal analysis that demonstrates “Energy Conversion and Management”, which is strictly associated with environmental issues on energy systems, is the journal that has the biggest amount of papers on our database.

Energy, Engineering and Environment Science are the research topics in which collaborations of this kind of assessment can be more easily tracked and perceived, which remains as a subject for future studies.

In general, the study demonstrates that bibliometric study is a methodology that is capable of providing a knowledge base that is useful in the development of research, and is supported in scientific papers of great relevance and credibility.

We believe that this work can be useful to the scientific community on pointing out there are many ways an estimation method, like Weibull distribution, can contribute on analyzing wind aspects as energy source. Therefore, this paper may also be useful to the public entities and meteorological analysis bodies, and the community of engineering around the world.

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