



ARTICLE

# Bibliometric Study Applied to the Overtopping Wave Energy Converter Device

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ABSTRACT

The present study aims to analyze the state of the art of scientific studies about the Overtopping device used to convert sea wave energy into electrical energy, by means the Bibliometric methodology. The development of this study took place through the selection of articles from conference proceedings, as well as national and international journals. The Bibliometric methodology consists of a statistical tool that allows quantifying the measurement of production indexes. Using selected keywords, it was conducted a survey of studies in the online databases of Science Direct, SciELO and Google Scholar. The works found then went through a filtering process, in order to limit the Bibliometric study only to studies about Overtopping devices as sea Wave Energy Converter (WEC). Finally, the investigation of these selected articles was carried out under the optics of production and authorship study, content study and study of bibliographic references. Where it was identified growth in publications related to the topic, methodologies used and, among other indicators, the authors most cited in the analyzed articles. The predominant keywords used were “Wave Energy Converter” and “Overtopping”. It was noted that Brazilian universities are leaders in the productivity, presenting more than 36% of the scientific production regarding Overtopping WECs.

## 1. Introduction

Due to the global energy demand and the growing concern to reduce greenhouse gas emissions, the interest in research for renewable sources of energy has intensified. However, renewable does not mean clean, Brazil for example has an energy matrix based on renewable sources, around 83% of the produced electricity according to *Em-*

*presa de Pesquisa Energética (EPE)*<sup>①</sup>, still most of this energy originates from hydroelectric plants, which are also responsible for the emission of methane and dioxide of carbon. As stated by <sup>[1]</sup>, the emission of greenhouse gases caused by hydroelectric plants are comparable with the emission carried out by thermoelectric plants. The authors still estimate that in certain cases the emission from hydroelectric plants is higher than some thermoelectric

① <https://www.epe.gov.br/pt/abcdenergia/matriz-energetica-e-eletrica>

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plants.

According to <sup>[2]</sup>, the ocean represents one of the largest renewable resources present on the planet, containing energy available in different forms, which can be used to generate electricity. In conjunction with that, <sup>[3]</sup> states that the ocean contains the potential to supply a significant part of the electric energy global need through the utilization of the energy provided by the sea waves.

As <sup>[4]</sup> points out, oceanic waves represent mechanical energy in transition resulting from the sum of the kinetic and surface wave potentials. It is possible to transform such energy into electrical energy through the use of Wave Energy Converters (WECs). These devices allow an alternative way to obtain energy from clean and renewable sources.

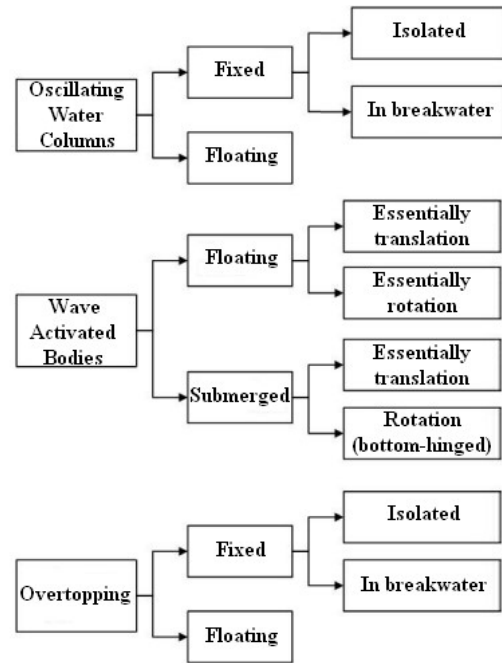
Thus, the use of renewable energy sources provides environmental gains, opening up space for technological development and the production of new knowledge on the energy field <sup>[5]</sup>. Conforming <sup>[6]</sup>, wave energy conversion has become a growing field in the renewable energy sector, since in recent decades both scientific and industrial communities have shown interest in wave energy.

In order to improve research related to the extraction of sea wave energy, the present research seeks to survey the state of the art of the one specific WEC type, the Overtopping device. Therefore, the present study is carried out through the methodological perspective of Bibliometry, applied to studies of production and authorship, content and bibliographic references of articles selected from national and international conference proceedings and journals available in online databases. Therefore, this study can assist researchers in making decisions to implement new research, in addition to identifying studies already carried out that may come to serve as a theoretical reference in future researches.

## 1.1 Wave Energy Converter Classifications

After decades of research and development regarding the wave energy extraction technologies, there are different proposed WEC devices. According to <sup>[7]</sup>, the usual method of classifying the WECs is based upon their main operating principle, but it is also possible to add another qualifier to specify the device accordingly to their location.

Although there are several conversion techniques patented, the different concepts for WECs can be divided into some distinct types, established on its operating principle <sup>[8]</sup>. Figure 1 illustrates the categorization approach used by International Energy Agency (IEA)-Ocean Energy Systems<sup>②</sup>.



**Figure 1.** Categorization of wave energy technologies (adapted from <sup>[3]</sup>)

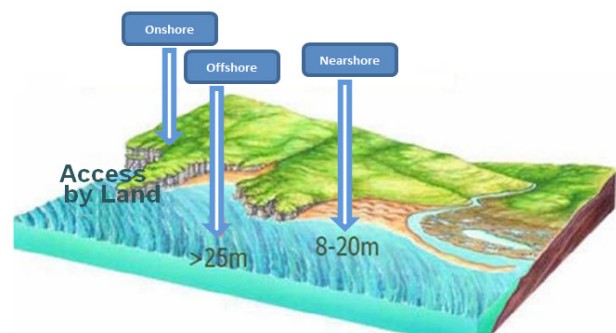
Concerning the location, according to <sup>[9]</sup> the WECs can be classified in agreement with their installation depth: onshore, when accessible by land; nearshore, installed near the coast; offshore, devices installed away from the coast. Figure 2 illustrates the classification conforming to the location.

It is also worth noting that each of these locations have advantages and disadvantages over the others:

(1) In accordance with <sup>[10]</sup>, onshore devices have immediate advantages as easier installation and maintenance, absence of large submarine cables extension and absence of complex fastening systems.

(2) On the other hand, the nearshore devices are used to extract the potency directly from the wave breaking zone <sup>[11]</sup>.

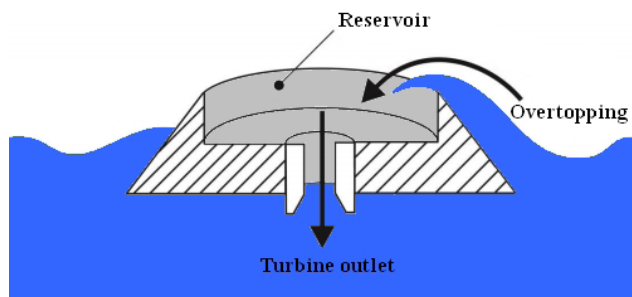
(3) Offshore devices are located in high depth areas and thus benefit from the most energetic waves and present a lower visual impact <sup>[12]</sup>.



**Figure 2.** Classification regarding the WEC location (from <sup>[13]</sup>)

② <https://www.ocean-energy-systems.org/index.php>

The target of the present study is the Overtopping WEC, regardless of device location. The operating principle of the Overtopping WEC is based on the accumulation of water in an elevated reservoir in relation to the average level of the free surface of the sea. The accumulated water, when returned to the sea, activates low-fall hydraulic turbines coupled to electrical generators of common manufacture. The accumulation of water in the elevated reservoir occurs through the incident waves that climb and exceed the top of the ramp<sup>[14-15]</sup>. Figure 3 shows the operating principle of the Overtopping device.



**Figure 3.** Schematic representation of the overtopping operating principle (adapted from<sup>[16]</sup>)

## 2. Methodology

In the present paper, the Bibliometric methodology is used to investigate the state of the art concerning the Overtopping WEC device, as suggested by<sup>[17]</sup>, under three optics: (1) production and authorship study (aiming to demonstrate the total number of publications per year, defining the authors and educational institutions of each article, in order to identify the most prolific ones); (2) content study (where the selected articles analysis occurs in regard to the research theme, the keywords and methodologies most used in their construction); (3) study of bibliographic references (identifying of the most widely disseminated papers in the studied area).

The Bibliometry, according to<sup>[18]</sup>, is a statistical tool that maps and generates different treatment indicators for information and knowledge management. Also,<sup>[19]</sup> increase that the Bibliometric study evaluates the texts of scientific production already carried out in specific areas of knowledge.

The Bibliometric methodology was used in this study since it is a tool for measuring scientific production. In consonance with<sup>[20]</sup>, the main advantage of a Bibliometric study is the standardization of procedures, facilitating the collected data measurement, unlike other research methodologies generally performed in engineering studies, such as the exhaustive search technique, for example. In

addition, this methodology reveals information about the scientific productions carried out to date, the important aspects already treated and adding knowledge to new publications that seek to study subjects that have not yet been explored.

Regarding the infrastructure for the present study development, the resources used to accomplish the Overtopping device state of art survey were computer, internet and access to online databases such as Science Direct, SciELO (Scientific Electronic Library Online) and Google Scholar. In order to improve the obtained results accuracy, it was defined that the search for each keyword in the databases should be completed on the same day that it started, avoiding changes in the search results, due to the constant changes on the online databases.

## 3. Results and Discussion

The presentation of the obtained results is divided into two stages: the first consists of surveying the articles that shall be analyzed, while the second part effectively consists of the Bibliometric analysis of the selected articles. Concerning the first stage, the keywords in Portuguese to be searched in the databases were defined as: “*Conversor de Energia das Ondas*”, “*Energia das Ondas*”, “*Galgamento*”, and “*Design Construtal*”, as well as the following corresponding English words: “Wave Energy Converter”, “Wave Energy”, “Overtopping” and “Constructal Design”.

Moreover, the initial period of the study was not limited, i.e., all articles found in the databases for these keywords until the month of April 2019 were taken in consideration. So, Table 1 shows the total of articles found by keyword investigation.

**Table 1.** Total articles found by keyword

Keywords	Files	Files without Repetitions	Articles
<i>Conversor de Energia das Ondas</i>	80	79	27
<i>Energia das Ondas</i>	186	164	130
<i>Galgamento</i>	135	114	58
<i>Design Construtal</i>	66	61	22
Wave Energy Converter	392	373	323
Wave Energy	2175	2124	2122
Overtopping	314	278	268
Constructal Design	251	215	211
<b>Total</b>	<b>3599</b>	<b>3408</b>	<b>3161</b>

**Table 2.** Articles selected for the Bibliometric Investigation

Title	Index
Overtopping Device Numerical Study: Openfoam Solution Verification and Evaluation of Curved Ramps Performances	[21]
Numerical Implementation and Sensitivity Analysis of a Wave Energy Converter in a Time-Dependent Mild-Slope Equation Model	[22]
Development of a Composite Sea Wall Wave Energy Converter System	[23]
Wave Farm Impact Based on Realistic Wave-WEC Interaction	[24]
Prototype Overtopping Breakwater for Wave Energy Conversion at Port of Naples	[25]
Wave Loadings Acting on Innovative Rubble Mound Breakwater for Overtopping Wave Energy Conversion	[26]
Stability Analysis of a Non-Conventional Breakwater for Wave Energy Conversion	[27]
Numerical Study of the Effect of the Relative Depth on the Overtopping Wave Energy Converters According to Constructal Design	[28]
The new Wave Energy Converter WaveCat: Concept and Laboratory Tests	[29]
Overtopping Measurements on the Wave Dragon Nissum Bredning Prototype	[30]
Numerical Approach of the Main Physical Operational Principle of Several Wave Energy Converters: Oscillating Water Column, Overtopping and Submerged Plate	[31]
Constructal Design de um Dispositivo de Galgamento Onshore em Escala real para uma Profundidade Fixa	[32]
Numerical Study on Overtopping Performance of a Multi-Level Breakwater for Wave Energy Conversion	[33]
Energia das Ondas do Mar: Modelagem Computacional de um Dispositivo de Galgamento	[34]
Influence of Slot Width on the Performance of Multi-Stage Overtopping Wave Energy Converters	[35]
Simulation Studies of the Basic Non-Linear Effects of Wave-Energy Conversion by an Overtopping Water-Column	[36]
Prototype Testing of the Wave Energy Converter Wave Dragon	[37]
Vertical Distribution of Wave Overtopping for Design of Multi Level Overtopping Based Wave Energy Converters	[38]
Numerical Prediction for Overtopping Performance of OWEC	[39]
Experimental Study on Overtopping Performance of a Circular Ramp Wave Energy Converter	[40]
Experimental Study on Multi-Level Overtopping Wave Energy Converter Under Regular Wave Conditions	[41]
Análise Numérica da Geometria da Rampa de um Dispositivo de Galgamento Onshore em Escala Real Aplicando o Design Construtal	[42]
SSG Wave Energy Converter: Design, Reliability and Hydraulic Performance of an Innovative Overtopping Device	[43]
<i>Análise Numérica de um Dispositivo de Galgamento Onshore Comparando a Influência de uma Onda Monocromática e de um Espectro de Ondas</i>	[44]
<i>Estudo dos Procedimentos Numéricos para Simulação de um Dispositivo de Galgamento</i>	[45]
Geometric Evaluation of the Main Operational Principle of an Overtopping Wave Energy Converter by Means of Constructal Design	[46]
An Approximate Solution for the Wave Energy Shadow in the Lee of an Array of Overtopping Type Wave Energy Converters	[47]
Numerical Simulation of Wave Flow Over the Overtopping Breakwater for Energy Conversion (OBREC) Device	[48]
Wave Energy Device and Breakwater Integration: A Review	[49]
Aproveitamento da Energia do Mar Através do Espreadamento em Estruturas Costeiras	[50]
The Breakwater, From Wave Breaker to Wave Catcher	[51]
Measurements of Overtopping Flow Time Series on the Wave Dragon, Wave Energy Converter	[52]
Modelagem Computacional do Princípio de Funcionamento de um Conversor de Energia das Ondas do Mar em Energia Elétrica do Tipo Seawave Slot-Cone Generator (SSG)	[53]
The SSG Wave Energy Converter: Performance, Status and Recent Developments	[54]
Innovative Rubble Mound Breakwaters for Overtopping Wave Energy Conversion	[55]

As shown in Table 1, after completion of the data collection process, a total of 3599 articles was obtained, 191 of which were discarded due to being repeated at least once. In a second filtering, works that consisted of dissertations, thesis, patents and reports were discarded, listing only scientific articles, due to the fact that they cover the present study scope, thus leaving 3161 files.

In the next selection stage, the remaining articles were gathered in a single file folder, disregarding their keywords. Where the presence of repetitions was found again and, after excluding them, the total number of articles was reduced from 3161 to 2846. Finally, an analysis began in order to determine which articles presented studies about the Overtopping device for energy production, thus accounting for a total of 35 documents selected for the Bibliometric analysis.

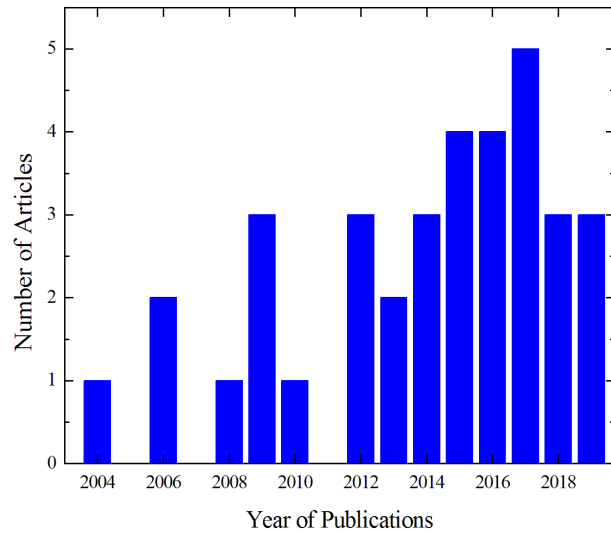
After the selection of articles on the interested topic, it was then decided to investigate these documents under the three optics of study proposed by [17]: production and authorship; content; bibliographic references. The full list of selected articles can be seen on Table 2.

### 3.1 Production and Authorship Study

This analysis aims to demonstrate the total number of publications about Overtopping WECs per year and also to define the authors of each article. Moreover, the study seeks to identify the most prolific authors and educational institutions, ordering them according to the number of publications in the period.

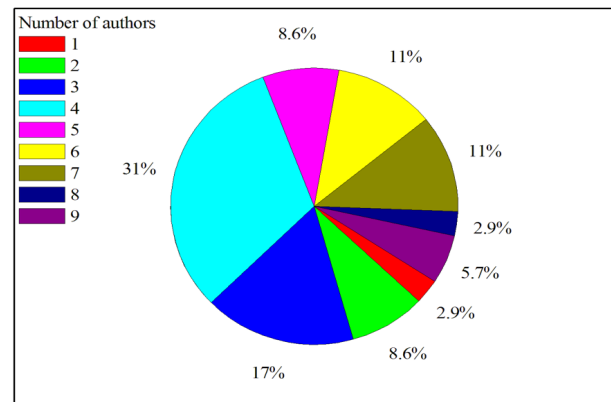
In order to demonstrate the temporal progression of scientific production, a histogram that condenses the publication data by year was elaborated. Thus, in Figure 4, it can be seen that the first article found in the databases on the generator topic was developed by [36]. The article is called “Simulation Studies of the Basic Non-Linear Effects of Wave-Energy Conversion by an Overtopping Water-Column” and aims to analyze the results of simulations of a mathematical model for this energy conversion system.

It was also observed, in Figure 4, that the year 2017 has the largest number of publications, which corresponds to approximately 14.3% of the total publications on the topic. Furthermore, one can observe that the number of publications has grown since 2013, only decreasing in 2018. It should be noted that the mentioned period corresponds to about 70% of publications in the area.



**Figure 4.** Evolution of published articles found in the databases

Figure 5 shows a classification of the sample regarding the number of authors per article, being possible to observe that articles produced by three to seven authors predominate (80%). On the other hand, 11.43% are written by two or one authors and 8.57% were elaborated by eight or more authors.



**Figure 5.** Number of authors per article

As for the authorship study of the articles, it was sought to verify the most prolific authors on the subject through an analysis that considers the largest participation in the articles sample, as indicated in Table 3. It is worth mentioning that, in this sample, all authors shown in the articles are considered, regardless of their authorship position, totaling 162 authors.

Table 4 shows the researchers with names mentioned in at least three articles, being these authors present in 48.77% of the articles in the area. It is also noticeable that 9 authors were mentioned twice and another 65 were mentioned only once. Finishing the authorship study, it is

observable in Table 4 which institutions contributed most to the scientific production of the researched theme. It is worth noting that the institutions were based on the author’s affiliation as cited in the articles.

**Table 3.** The most prolific authors in the sample

Author	Articles	Percentage (%)
Elizaldo Domingues dos Santos	9	5.56
Liércio André Isoldi	9	5.56
Diego Vicinanza	7	4.32
Mateus das Neves Gomes	7	4.32
Luiz Alberto Oliveira Rocha	6	3.70
Jens Peter Kofoed	5	3.09
Marcelo Moraes Goulart	5	3.09
Jaífer Corrêa Martins	4	2.47
Jeferson Avila Souza	4	2.47
Pasquali Contestabile	4	2.47
Zhen Liu	4	2.47
Bianca Neves Machado	3	1.85
Enrico Di Lauro	3	1.85
Gregorio Iglesias	3	1.85
Hongda Shi	3	1.85
Peter Bak Frigaard	3	1.85

**Table 4.** Institutions of authors of the articles

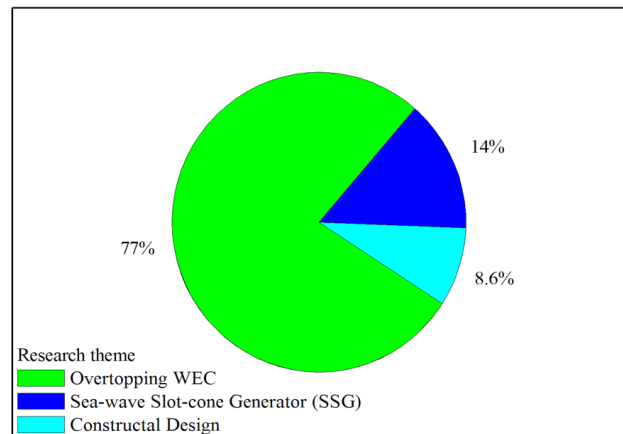
Institution	Articles	Percentage (%)
Federal University of Rio Grande, Brazil	48	29.63
Aalborg University, Denmark	12	7.41
University of Campania Luigi Vanvitelli, Italy	12	7.41
Federal University of Rio Grande do Sul, Brazil	11	6.79
Ocean University of China, China	10	6.17
University of Plymouth, England	6	3.70

Out of 37 institutions that participated in this sample of articles published in conference proceedings or journals (see Table 2), the first seven universities correspond to just over 61% of published articles, as can be seen in Table 4. In this analysis, Federal University of Rio Grande, Aalborg University, University of Campania Luigi Vanvitelli and Federal University of Rio Grande do Sul stand out as the institutions with the greatest production of scientific articles regarding the study of Overtopping WECs.

### 3.2 Content Study

As previously announced, the Bibliometric study performed in this paper is composed of different optics of analysis, among them, the Content Study. In this stage, the content of the selected articles was investigated, carrying out an analysis about the research theme, keywords and methodologies most used in their elaboration.

Although the articles selected for this analysis had been filtered so only researches about Overtopping WEC remain, they may also present different themes. As may be seen in Figure 6, there are studies that deal with the physical principle of operation of Overtopping device, while others are more specific, such as studies regarding the Sea-wave Slot-cone Generator (SSG), an Overtopping device with multiple stages, or even the Constructural Design (a method applied for the geometric evaluation of the Overtopping WECs).



**Figure 6.** Articles theme

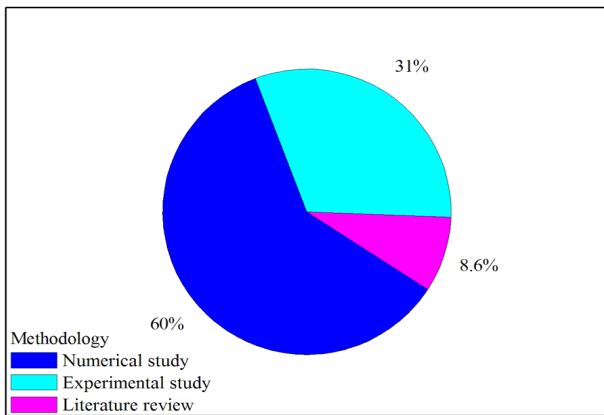
In sequence, Table 5 exhibits the five keywords most frequently presented in the analyzed articles, it is possible to recognize that all are presented in English and have been cited at least six times. It should also be highlighted that “Wave Energy Converter”, “Overtopping”, “Wave Dragon”, “Numerical Model” and “Overtopping Device” represent 31.74% of the keywords used.

**Table 5.** Keywords most present in the articles

Keywords	Articles	Percentage (%)
Wave Energy Converter	13	8.97
Overtopping	12	8.28
Wave Dragon	9	6.21
Numerical model	6	4.14
Overtopping Device	6	4.14

In addition to the keywords presented in Table 5, it is worth noting that another 76 words were found, of which: 7 keywords were presented three times (2.07%); 9 keywords present in two articles each (1.38%); 60 keywords cited only once (0.69%). Totaling 81 different keywords present on the 35 investigated articles.

Finally, concluding the content study, Figure 7 shows the research methodologies used in the analyzed articles.



**Figure 7.** Methodologies used in the articles

Among the 3 research methodologies observed in the investigated articles, the Numerical Study stands out as the most frequently utilized, being present at 21 articles (60%). This methodology is often used to computationally simulate the working principle of the Overtopping WEC aiming to evaluate its performance under particular conditions, defined by the researchers, such as distinctive geometries for the device or different wave climates.

### 3.3 Study of Bibliographic References

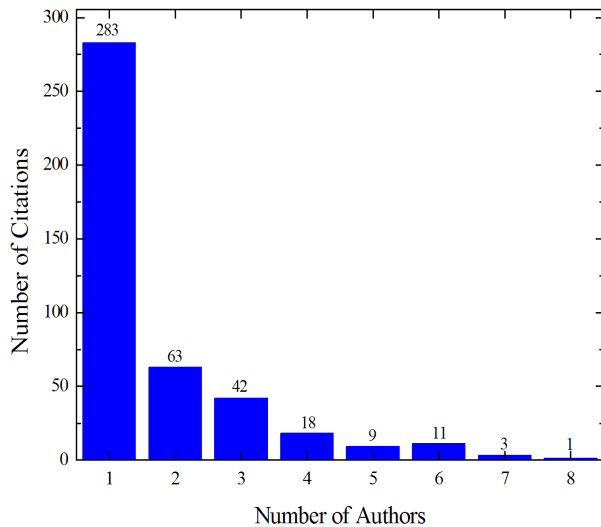
The State of the Art Bibliometric investigation of the Overtopping WEC device proposed in this study also aims to identify the most widely disseminated papers in the area and their authors. Then, there is the Study of Bibliographic References, which consists of the analysis of

the references presented in the investigated articles.

Therefore, the references present in the 35 articles were analyzed, which totalize 1147 productions by 450 different authors. Table 6 illustrates the 20 most cited authors, who were referenced at least nine times each, representing 34.87% of the citations in the investigated articles. Note that another 430 authors are not present in the Table 6. In order to illustrate the relationship among these authors and the amount of citations made to them a histogram was elaborated, which is shown in Figure 8.

**Table 6.** Most cited authors

Cited Name	Full Name	Citations	Percentage (%)
Kofoed, J. P.	Jens Peter Kofoed	71	6.19
Vicinanza, D.	Diego Vicinanza	51	4.45
Contestabile, P.	Pasquale Contestabile	25	2.18
Margheritini, L.	Lucia Margheritini	25	2.18
Liu, Z.	Zhen Liu	24	2.09
Buccino, M.	Mariano Buccino	21	1.83
Iglesias, G.	Gregorio Iglesias	21	1.83
Falcao, A. F. de O.	António F. de Oliveira Falcão	20	1.74
Beels, C.	Charlotte Beels	17	1.48
Bejan, A.	Adrian Bejan	16	1.39
Van der Meer, J. W.	Jentsje W. Van der Meer	16	1.39
Bergillos, R. J.	Rafael J. Bergillos	12	1.05
Iuppa, C.	Claudio Iuppa	12	1.05
Gomes, M das N	Mateus das Neves Gomes	11	0.96
López, I.	Iraide López	11	0.96
Takahashi, S.	Shigeo Takahashi	10	0.87
Tedd, J.	James Tedd	10	0.87
Goda, Y.	Yoshimi Goda	9	0.78
Santos, E. D. dos	Elizaldo Domingues dos Santos	9	0.78
Victor, L.	Lander Victor	9	0.78



**Figure 8.** Relation between the citations and authors not shown in Table 6

At the end of the Study of Bibliographic References, it is possible to highlight the papers with the greatest dissemination within the research area. Therefore, Table 7 presents the studies with the highest citation index within the analyzed articles. Finally, after conducting a search for the most cited studies, it was inferred that only the one entitled “Wave Overtopping of Marine Structures Utilization of Wave Energy” is not a scientific article, but a doctoral thesis <sup>[56]</sup>.

#### 4. Conclusions

The present study aimed to characterize the scientific production regarding the application of Overtopping devices in the conversion of wave energy into electricity. Therefore, it was performed an analysis of articles available in the online databases Science Direct, SciELO and Google Scholar through the Bibliometric study of articles published in conference proceedings and journals, under the perspective of Production and Authorship Study, Content Study and Study of Bibliographic References.

As a result of this research, it was possible to identify the Brazilian Federal University of Rio Grande as the main content generator on the subject, followed by the Danish Aalborg University, the Italian University of Campania Luigi Vanvitelli and the Brazilian Federal University of Rio Grande do Sul. It is notable that these Brazilian universities are leaders in productivity regarding the researched topic, containing affiliated authors present in more than 36% of the scientific production related to the subject.

Furthermore, the most used keywords by the authors of the area were identified, being “Wave Energy Converter” and “Overtopping” the predominant ones. While, with regard to scientific research methodologies, it was found that the most used is the Numerical Methodology. Finally, regarding bibliographic references, the Danish author Jens Peter Kofoed stands out as the most cited, as well as his work “Wave Overtopping of Marine Structures Utilization

**Table 7.** Most cited studies in the analyzed articles

Authors	Title [index]	Citations (percentage)
Jens Peter Kofoed	Wave Overtopping of Marine Structures Utilization of Wave Energy <sup>[56]</sup>	18 (4.83 %)
Jens Peter Kofoed, Peter Bak Frigaard, Erik Friis-Madsen, Hans Chr. Sørensen.	Prototype Testing of the Wave Energy Converter Wave Dragon <sup>[37]</sup>	17 (4.56 %)
Lucia Margheritini, Diego Vicinanza, Peter Bak Frigaard.	SSG Wave Energy Converter: Design, Reliability and Hydraulic Performance of an Innovative Overtopping Device <sup>[43]</sup>	15 (4.02 %)
Antônio F. de Oliveira Falcão	Wave Energy Utilization: a Review of the Technologies <sup>[57]</sup>	11 (2.95 %)
Charlotte Beels, Peter Troch, Kenneth De Visch, Jens Peter Kofoed, Griet De Backe.	Application of Time-Dependent Mild Slope Equations for the Simulation of Wake Effects in the Lee of a Farm of Wave Dragon Wave Energy <sup>[58]</sup>	11 (2.95 %)



of Wave Energy”.

Given the greater accuracy of the results obtained through this statistical analysis when compared to the results coming, for example, from the exhaustive search technique, most commonly used to survey state of the art in engineering, it concludes that the Bibliometric technique effectively contributed to the survey of the state of the art of the Overtopping devices applied to wave energy conversion. In future works the intention is to apply the Bibliometric methodology to other types of WEC, for instance the Oscillating Water Column (OWC) device.

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