

## Investment analysis and sustainable finance: A bibliometric study of real options as a financial tool for the viability of geothermal renewable energy



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### ABSTRACT

**Introduction:** The finance/investment and Renewable Energy (RE) sectors are central to any climate change programme. The first has been identified as fundamental to the advancement of the zero-carbon energy transition, acting as a facilitator and catalyst determining this climate economic transformation (Chenet et al., 2019). The second, is the main component of any climate change mitigation strategy (aren't et al., 2011) and its associated technologies have been the target of increasing interest, becoming a reality in recent years (Dranka et al., 2020).

**Research Problem and Objective:** Financial assessments hinder the development of geothermal energy (Lukawski et al., 2016) and the real-option approach could contribute to its development (Compernelle et al., 2019; Fernandes et al., 2011). Thus, it is opportune to answer: How can the approach of real options contribute to the analysis of investments in geothermal plants? The article aims to expand the understanding of investments and real options in geothermal plants, especially by: i. Select bibliographic ref. on the subject; ii. Perform bibliometric analyses on the articles and their references.

**Theoretical Basis:** Real options theory is known to increase the value of projects under uncertainty by modeling their flexibility in response to changes in their environments. It could be used to address current environmental and energy issues by increasing the value of electricity generation

projects, especially renewable energy projects (Martínez Ceseña et al., 2013). Geothermal energy is a renewable source, derived from the thermal energy stored in the Earth's interior. Its production has a low carbon footprint and the ability to provide continuous energy and heat (Compernelle et al., 2019).

**Methodology:** The structured process was used for the selection and analysis of the ProKnow-C scientific literature (Ensslin et al., 2017). Once the Scopus and WoS databases were defined, as well as the research axes, investment analysis and renewable energy axes, articles were searched for in the databases, which systematically passed through filters of scientific recognition, alignment to the research and adherence to the proposed theme and resulted in a Bibliographic Portfolio (PB) that subsidized the bibliometric analyses.

**Analysis of Results:** As a result of the methodological process, a bibliographic portfolio was formed consisting of 25 articles, aligned with the objective of the research, adhering to the proposed theme and with scientific recognition. In the bibliometric analyses, graphs were elaborated to adequately represent the quantitative and cognitive aspects of the research, whose observable parameters are: Featured articles, their references, featured authors, number of citations, keywords and most relevant journals.

**Conclusion:** This research aimed to present a relevant theoretical bibliographic portfolio, detailing the process that resulted in 25 articles. In the bibliometric analyses, it was evidenced: a) that the highlighted journals were Energy Policy, Energy Economics and Renewable and Sustainable Energy Reviews; b) as authors the researcher Ferreira, P. was the only one who participated with 3 papers in the selected PB and Fleten S. E. had more than 10 works composing the references of the PB; and c) the articles (Boomsma et al., 2012) and (Fernandes et al., 2011) stood out in the classification of academic relevance.

**Keywords:** Investments, Real option, Geothermal.



## 1 INTRODUCTION

Recent changes in the world's climate are unprecedented and all regions of the world are already affected by extreme events such as heat waves, heavy rains, droughts and cyclones caused by global warming. This is what says the AR6 report, approved and released by the Intergovernmental Panel on Climate Change (IPCC), released in August/21 and which for the first time claims to be unequivocal that human activities caused climate change. In 2019 the concentration of carbon dioxide (CO<sup>2</sup>) in the atmosphere was higher than at any other time and the concentration of methane and nitrous oxide was the highest in 800,000 years, however, if there is a significant reduction in the emission of Greenhouse Gases (GHG), climate change can be limited (Masson-Delmotte et al., 2021).

The finance/investment and Renewable Energy (RE) sectors are central to any climate change programme. The first, although they have responded slowly to the alignment with the new demands of the sustainable economy (Ryszawska, 2016), has been identified as fundamental to the advancement of the zero-carbon energy transition, acting as a facilitator and catalyst determining this climate economic transformation (Chenet et al., 2019). The second, is the main component of any climate change mitigation strategy (aren't et al., 2011) and its associated technologies have been the target of increasing interest, becoming a reality in recent years (Dranka et al., 2020).

Despite the increase in the share of RE generation in the world (aren't et al., 2011), geothermal renewable generation, derived from thermal energy from the Earth's interior, with low carbon production and continuous supply capacity, has not gained scale and grows below the targets established for this source, with financing being pointed out as one of the main barriers and economic analyses, apparently, they have been limited to traditional Net Present Value (NPV) calculations (Lukawski et al., 2016).

Other obstacles such as high and uncertain capital investment costs contribute to geothermal remaining marginalized, but evaluations using real options would allow its progression and have already proven that they can generate better results than traditional limited techniques, differing significantly from a standard NPV calculation and offering much deeper insights into the risks associated with the development of this source (Compernelle et al., 2019; Fernandes et al., 2011). In energy investments, the real options method has proven effective for presenting a more realistic value of projects, allowing investors to add value, using flexibility in the face of unpredictable fluctuations, including greater accuracy in the calculation of subsidies and the possibility of using certificates, important for the sustainable development and viability of RE (Liu & Ronn, 2020).

Long-term investments involve relevant uncertainties that can determine the behavior of investors and the market, and the influence of sustainable elements in this long-term market is complex (Ferreira et al., 2016). ER projects are often among the riskiest types and the way investors evaluate their investments requires the use of more sophisticated valuation techniques (Dranka et al., 2020).



Faced with this problem, it is opportune to establish a knowledge, with scientific recognition and in a systematized way, to answer the question: How could the approach of real options contribute to the analysis of investments in geothermal plants?

Thus, this article aims to expand the understanding of investments and real options in geothermal plants, especially by:

- i. Select bibliographic references on investment analysis and real options in geothermal plants; and
- ii. Perform bibliometric analyses on articles and their references, authors and prominent journals on this topic.

To achieve these objectives, the Knowledge Development Process – Constructivist (ProKnowC) tool was used. It is a structured process for the selection and analysis of scientific literature, with a constructivist perspective, considering the purpose of the researcher on a given theme, allowing to generate the necessary foundation for the beginning of a scientific research (Lacerda, 2021; Lacerda et al., 2012).

The construction of this knowledge in the researcher is represented here by the selection of the relevant scientific articles that will compose the bibliographic portfolio related to the analysis of investments and real options in geothermal plants, as well as the bibliometric analysis of these articles.

The concept of bibliometric analysis, popularized by Pritchard in 1969, consists of a set of methods and techniques for information visualization, with the purpose of elaborating maps that can adequately represent the quantitative and cognitive aspects of science (Macedo dos Santos & Kobashi, 2009; Vanti, 2002). The observable parameters in this research are: the selected articles, their references, authors, number of citations and most relevant journals

The remainder of this article is structured as follows: Section 2 contains the theoretical foundation; Section 3 shows the methodological framework and procedures used in this research; section 4 describes the analyses and bibliometric results; Conclusions and notes are in section 5; Finally, the last section is dedicated to bibliographic references.

## **2 THEORETICAL FOUNDATION**

Financing in RE and sustainable finance – RE financing promotes the sustainable financial system through its alignment with the long-term needs of a sustainable economy. It contemplates the aspects of climate finance, when working on GHG reduction; green finance, when pursuing regenerative environmental outcomes; and sustainable finance, by improving environmental, social and economic outcomes (Ryszawska, 2016). In addition, sustainable finance also seeks, through more robust metrics, models in which all relevant costs and benefits are properly accounted for, including,



in addition to the usual set of cash flows, the explicit recognition of incremental cash flows attributable to sustainability (Popescu et al., 2021).

The economic evaluation of energy investments - Energy investments have specific characteristics that differentiate them in relation to others such as: practically irreversible investment since the capital becomes immobilized, preventing it from being used for other areas, or companies; There is temporal flexibility, allowing the investor postpone the decision to get the best time of the investment; and there are several generation technologies that can be chosen, associated with different levels of uncertainty that must be considered. Therefore, it is mandatory for investors to provide adequate tools for investment analysis, which contemplate this matrix of risks and uncertainties (Santos et al., 2014).

Real options – Real options theory is known to increase the value of projects under uncertainty. This is achieved by modeling the flexibility that managers have to adjust projects in response to changes in their environments. Based on this, this theory could be used to deal with current environmental and energy issues by increasing the value of electricity generation projects, especially renewable energy projects (Martínez Ceseña et al., 2013).

Geothermal energy - Geothermal energy is a renewable energy source, derived from the thermal energy generated and stored inside the Earth. Geothermal energy production has a low carbon footprint and the ability to provide continuous power and heat. It is considered an abundant energy resource, but despite its environmental and economic benefits and in opposition to most other renewable energies, the development of geothermal energy is below the predicted trajectory for this source. Initial investment costs and multiple sources of uncertainty result in a large investment risk, making it difficult to mobilize the necessary capital (Compernelle et al., 2019).

### 3 METHODOLOGY

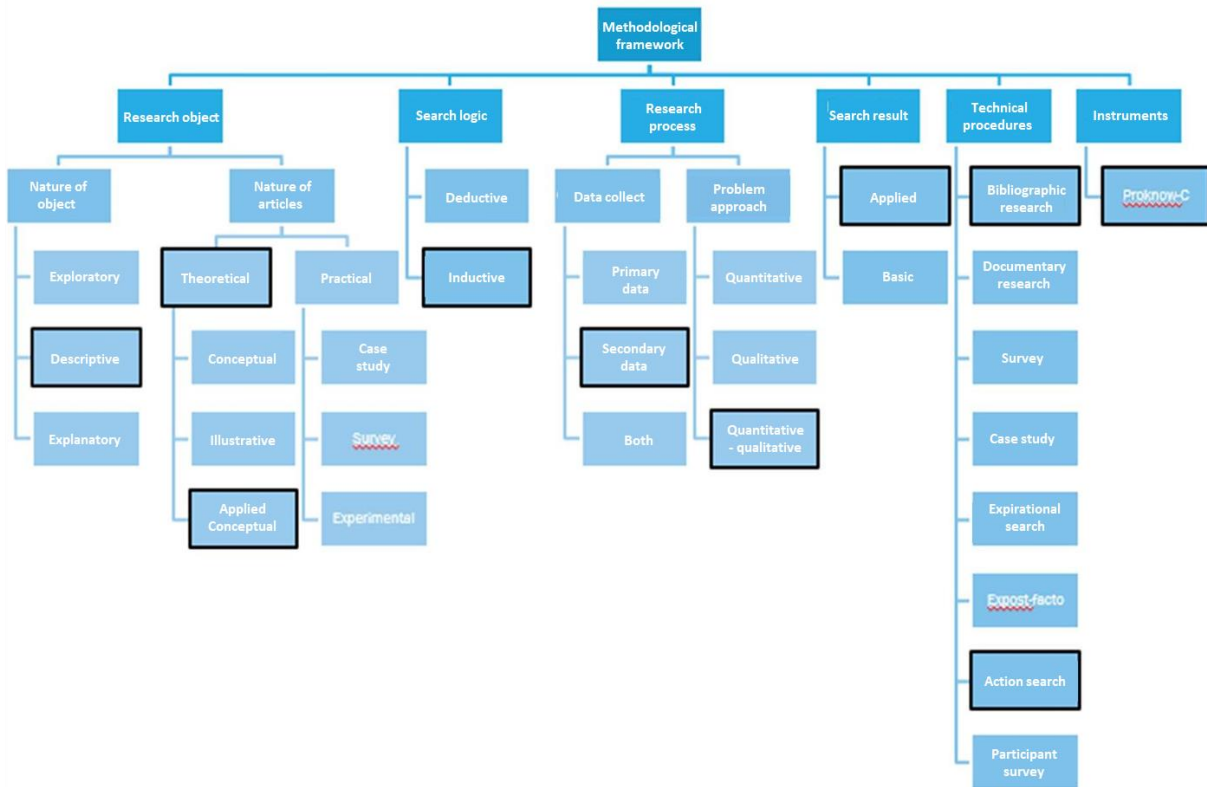
Considering that there is no better way to conduct all research, that methodological choices have an impact on discovery, that the most appropriate approaches, strategies and methods for research relate to the problem addressed (Calvetti, 2019; SAUNDERS, 2009), this section aims to provide the reader with sufficient information to make an estimate of the reliability and validity of the methods used in this research

#### 3.1 METHODOLOGICAL FRAMEWORK

The options selected regarding the methods, techniques and procedures applied in this research are arranged in .



Figure 1 - Methodological Framework



Source: Adaptation of (Lacerda et al., 2012)

### 3.2 INTERVENTION INSTRUMENT

The literature review is an initial step to provide the foundation on which a research is built, having as main objectives to help develop a good understanding and insight into previous research, trends and to review the most relevant and significant research on the topic of interest. Also according to the author, an effective analysis allows familiarity with the current state of knowledge on a given subject and the respective limitations in research (SAUNDERS, 2009).

Thus, aiming to establish a reference that portrays a representative sample of the theme, we used as an intervention instrument the structured process for the selection and analysis of the scientific literature called Knowledge Development Process-Constructivist - ProKnow-C, conceived at the Laboratory of Multicriteria Methodology for Decision Support (LabMCDA) of the Federal University of Santa Catarina (UFSC) (Ensslin et al., 2017).

Among the processes of ProKnow-C, this research is limited to addressing the corresponding stages of the selection of the bibliographic portfolio and the steps that involve bibliometric analysis. Below we will characterize in detail the procedures adopted, with this instrument, in each of the phases of the investigation.



### 3.3 INITIAL SURVEY FOR PORTFOLIO SELECTION

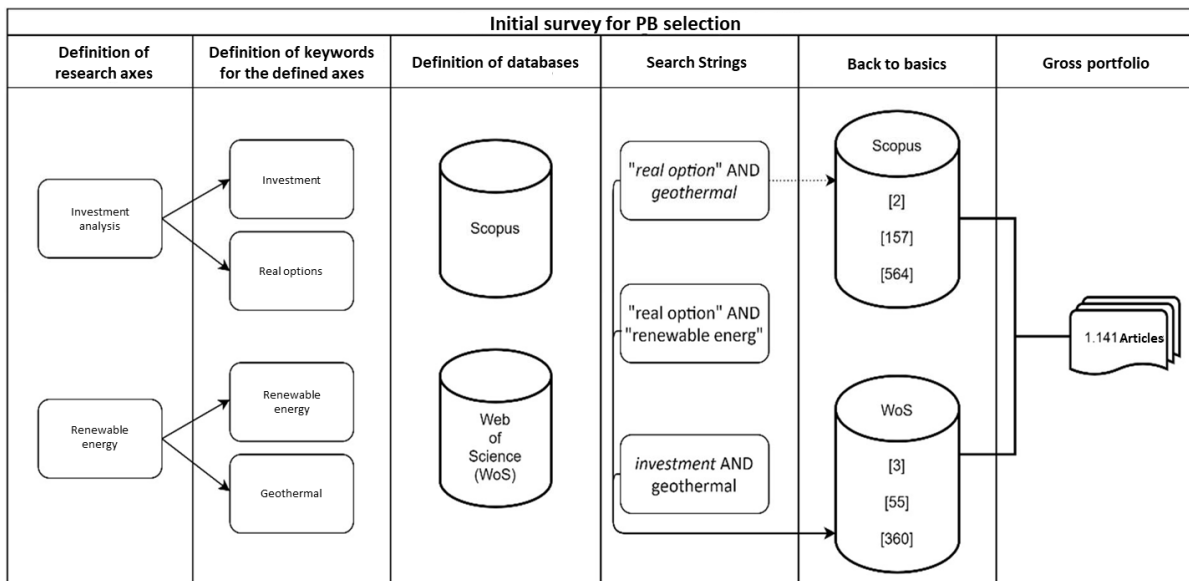
The initial survey is composed of the stage of selection of articles that will form a raw database, remaining later, only articles judged of greater expressiveness in the area of knowledge to the theme of the research.

The procedures described in this study were carried out in June 2021 and only articles published in the aforementioned databases in the last 10 years (from 2011 to 2021) were considered.

Two scientific databases were defined, Scopus and Web of Science, both because they are considered relevant exponents in the international scientific community, in addition to offering search possibilities and advanced filters, using Boolean expressions. Because of this, the authors understand that the selected bases are adequate for the proposal of this research.

Two research axes were combined, analysis of investments and renewable energy, and defined the keywords that subsidized the searches in the selected databases. The combinations of words, performed through the search strings, and the number of articles found in each database, can be seen in Figure 2.

Figure 2 - Initial Survey for BP selection



As a result of this stage, 1,141 articles were obtained, which now compose the Gross Article Bank.

### 3.4 CHOICE OF ARTICLES TO COMPOSE THE BIBLIOGRAPHIC PORTFOLIO

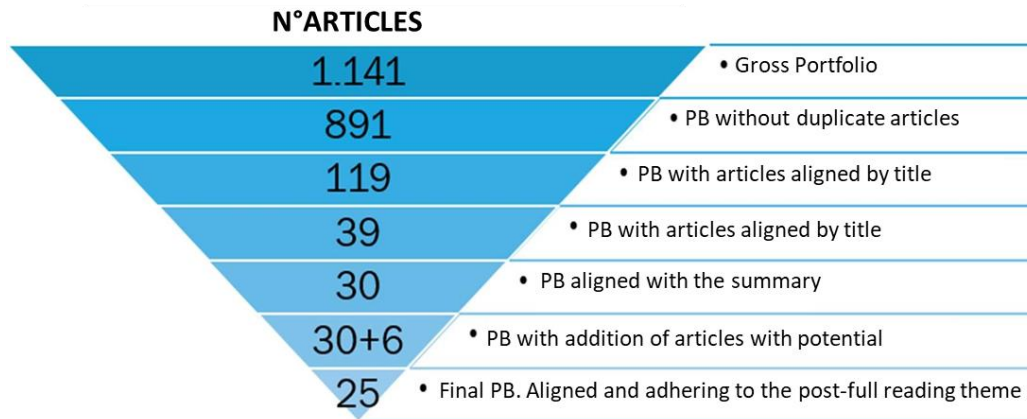
Continuing with the ProKnow-C process, with the help of the EndNote20 software, the next step was the identification and exclusion of duplicate articles, resulting in the elimination of 250



references. Of the remaining 891 documents, the titles of the articles were read to eliminate those that were not aligned with the research axes initially defined, resulting in 119 articles.

The process with the filtering steps of the articles of the raw bibliographic portfolio, is illustrated in Figure 3.

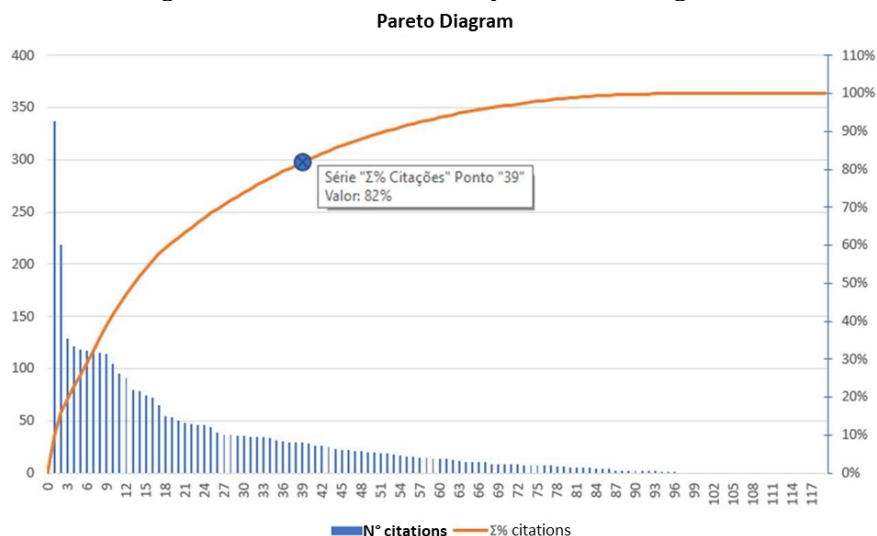
Figure 3 - Filtering Steps



The next step included the analysis of the scientific recognition of these 119 articles, based on the number of citations of each one, with the help of the online tool identified by Google Scholar (Google, 2021) and with the support of the ZOTERO software. These articles were classified in descending order, allowing the identification of the most relevant ones.

The authors of this research adopted the indicator of 82% of the most cited articles, for cutoff value, which correspond to 39 articles, totaling 2,909 citations, as shown in Figure 4. The 80 non-selected articles, with scientific recognition not yet confirmed, in line with ProKnow-C, will undergo further analysis and evaluation.

Figure 4 - Selection of Articles by Scientific Recognition





Regarding the 39 selected articles, they were analyzed regarding the alignment to the research and adherence to the proposed theme, from the reading of the respective abstracts, being eliminated 9 articles in this phase, leaving 30 articles selected.

In the next stage, the 80 articles were retrieved, representing 18% of the citations, with probable potential for scientific recognition and pending confirmation. Of these, those who had their publication carried out in the last two years (post 2019), because they understood that they had little possibility of being cited, had their abstract read to check the alignment to the theme. For documents older than two years, the author of the work was confronted with the database of authors who composed the articles selected in the previous stage, If there was no coincidence between any of the authors, the article was eliminated, otherwise, the abstract was also read to confirm adherence. In this stage, 6 articles were selected.

All 36 selected articles had the full reading performed, to identify alignment to the research and adherence to the proposed theme, having been eliminated 11 documents in this phase, resulting in a bibliographic portfolio composed of 25 articles, which formed the PB of this research. From this PB, the bibliometric analyses that supported the results and the description of this report were carried out.

#### **4 FINDINGS**

As a result of the methodological process presented in the previous stage, a PB was formed composed of 25 articles, which are arranged in descending order of citations, as shown in Figure 5





Figure 5 -Table of Articles of the PB

Seq.	Authors	Title	Year	N° citations
1	T. K. Boomsma, N. Meade and S. E. Fleten	Renewable energy investments under different support schemes: A real options approach	2012	337
2	B. Fernandes, J. Cunha and P. Ferreira	The use of real options approach in energy sector investments	2011	219
3	E. A. Martínez Ceseña, J. Mutale and F. Rivas-Dávalos	Real options theory applied to electricity generation projects: A review	2013	121
4	S. Fuss, J. Szolgayová, N. Khabarov and M. Obersteiner	Renewables and climate change mitigation: Irreversible energy investment under uncertainty and portfolio effects	2012	118
5	E. A. Martínez-Ceseña and J. Mutale	Application of an advanced real options approach for renewable energy generation projects planning	2011	115
6	L. Santos, I. Soares, C. Mendes and P. Ferreira	Real Options versus Traditional Methods to assess Renewable Energy Projects	2014	115
7	K. Kim, H. Park and H. Kim	Real options analysis for renewable energy investment decisions in developing countries	2017	114
8	I. Pitzenhofen and S. Spinler	Optimal design of feed-in-tariffs to stimulate renewable energy investments under regulatory uncertainty - A real options analysis	2016	105
9	S. Bruno, S. Ahmed, A. Shapiro and A. Street	Risk neutral and risk averse approaches to multistage renewable investment planning under uncertainty	2016	80
10	J. A. Schachter and P. Mancarella	A critical review of Real Options thinking for valuing investment flexibility in Smart Grids and low carbon energy systems	2016	74
11	N. Detert and K. Kotani	Real options approach to renewable energy investments in Mongolia	2013	72
12	P. K. Wesseh, Jr. and B. Lin	Renewable energy technologies as beacon of cleaner production: A real options valuation analysis for Liberia	2015	65
13	M. Kozlova	Real option valuation in renewable energy literature: Research focus, trends and design	2017	55
14	T. K. Boomsma and K. Linnerud	Market and policy risk under different renewable electricity support schemes	2015	53
15	M. Z. Lukawski, R. L. Silverman and J. W. Tester	Uncertainty analysis of geothermal well drilling and completion costs	2016	48
16	S. E. Fleten, K. Linnerud, P. Molnár and M. Tandberg Nygaard	Green electricity investment timing in practice: Real options or net present value?	2016	47
17	M. M. Zhang, D. Q. Zhou, P. Zhou and H. T. Chen	Optimal design of subsidy to stimulate renewable energy investments: The case of China	2017	46
18	H. X. Li, D. J. Edwards, M. R. Hosseini and G. P. Costin	A review on renewable energy transition in Australia: An updated depiction	2020	44
19	C. Y. Chang	A critical analysis of recent advances in the techniques for the evaluation of renewable energy projects	2013	39
20	M. Cárdenas Rodríguez, I. Hašiči, N. Johnstone, J. Silva and A. Ferey	Renewable Energy Policies and Private Sector Investment: Evidence from Financial Microdata	2015	37
21	M. M. Zhang, Q. Wang, D. Zhou and H. Ding	Evaluating uncertain investment decisions in low-carbon transition toward renewable energy	2019	26
22	A. C. Passos, A. Street and L. A. Barroso	A Dynamic Real Option-Based Investment Model for Renewable Energy Portfolios	2017	15
23	G. G. Dranka, J. Cunha, J. D. de Lima and P. Ferreira	Economic evaluation methodologies for renewable energy projects	2020	9
24	T. Compernelle, K. Welkenhuysen, E. Petitclerc, D. Maes and K.	The impact of policy measures on profitability and risk in geothermal energy investments	2019	9
25	X. Liu and E. I. Ronn	Using the binomial model for the valuation of real options in computing optimal subsidies for Chinese renewable energy investments	2020	8

#### 4.1 BIBLIOMETRIC ANALYSIS OF BP

Bibliometrics is a quantitative and statistical technique to measure indices of production and dissemination of knowledge, as well as to monitor the development of various scientific areas and the patterns of authorship, publication and use of research results (Costa, 2012). This section aims to present the analyses and bibliometric studies performed on BP.

##### 4.1.1 Articles

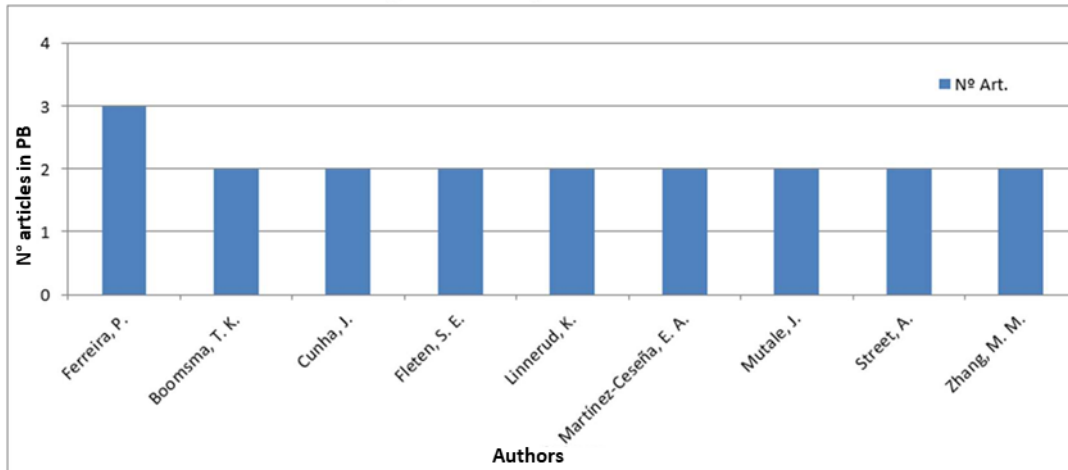
When analyzing the scientific recognition of PB articles, identified through the largest number of citations in Google Scholar in June 2020, column "Number of citations" of Figure 5, it is possible to highlight the articles (Boomsma et al., 2012) and (Fernandes et al., 2011), with 337 and 219 citations respectively, which correspond to 28% of the total citations.



#### 4.1.2 Authors

The authors of the articles that composed the selected theoretical framework, who participated in more than one article in the sample, are shown in Figure 6. Ferreira stands out, P. as the most relevant, participating with three published articles.

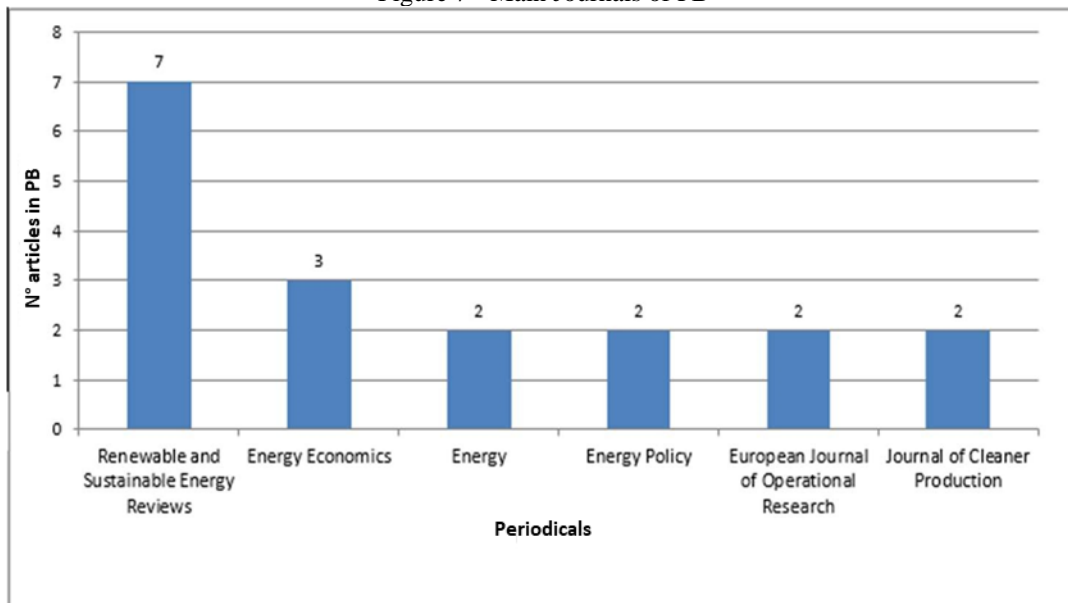
Figure 6 - Main Authors of BP



#### 4.1.3 Journals

Six journals had more than one publication in BP are shown in Figure 7. The journal Renewable and Sustainable Energy Reviews stands out as the most relevant, with seven articles published (28%), more than twice as many publications in relation to the others.

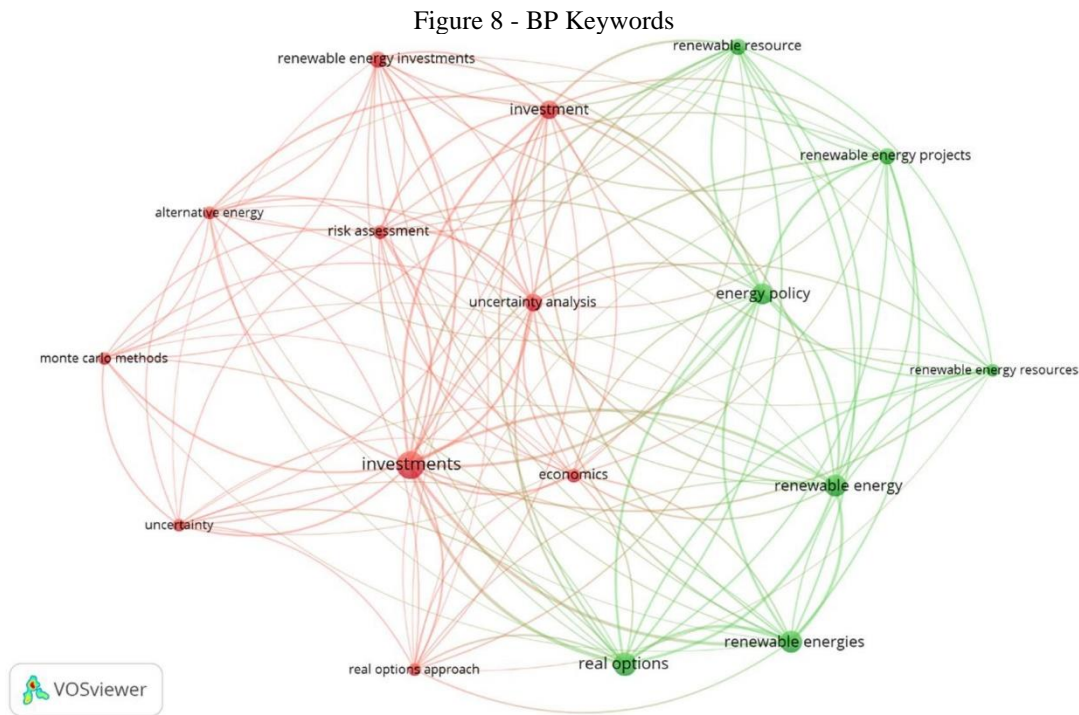
Figure 7 - Main Journals of PB





#### 4.1.4 Keywords

The analysis of the highlighted keywords was performed through a network of co-occurrences of the PB articles, with the aid of the VOSviewer software, constituting for the analysis base the sessions of the title, abstract and the list of keywords of the documents. Figure 8 shows through the size of the circle the frequency of occurrences of the keywords and the strength of association is represented by the proximity between them.



#### 4.2 BIBLIOMETRIC ANALYSIS OF BP REFERENCES

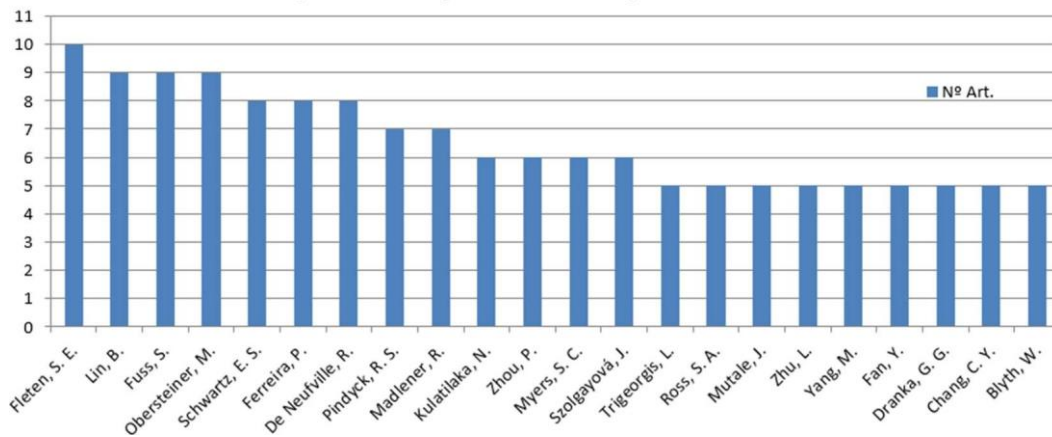
In order to improve the identification of authors, articles and journals that stand out in the context of this research, the 703 articles cited in the BP references were analyzed, whose results are described below.

##### 4.2.1 Notable authors

The author of greatest relevance among the articles that composed the references of the PB, is Fleten S. E., having published ten articles. Its position among the authors who had more than 5 publications in the BP references can be seen in Figure 9.



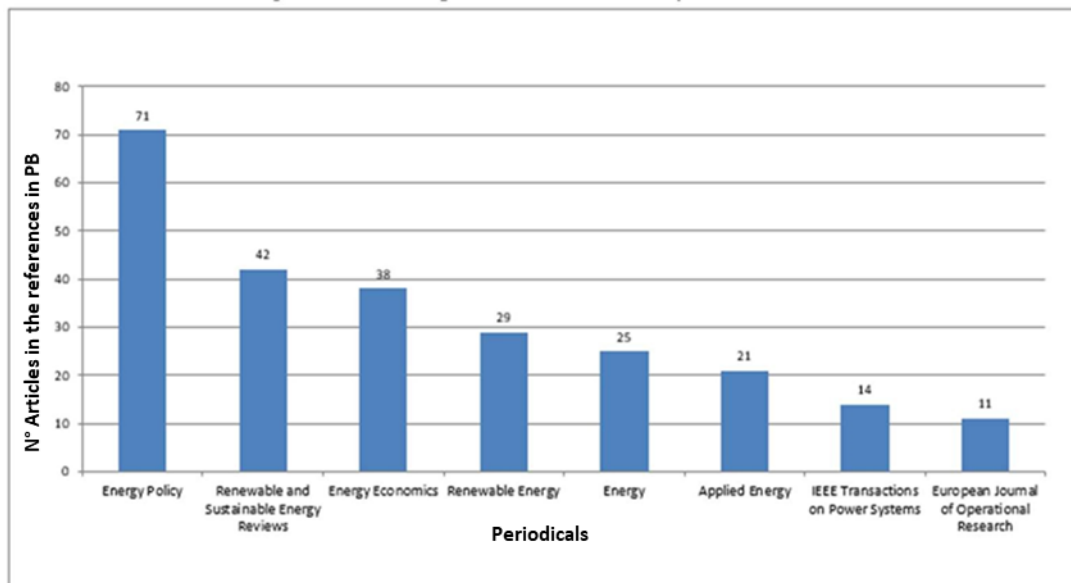
Figure 9 – Main Authors in the PB References



#### 4.2.2 Journals

The journals that published more than ten articles cited in the BP references are shown in Figure 10. The Energy Policy journal stands out with the publication of seventy-one articles, representing more than twice the average publication among the highlighted journals.

Figure 10 – Main Journals in the PB References



#### 4.3 BIBLIOMETRIC ANALYSIS, BP VERSUS BP REFERENCES

Proceeding with the objective of electing a relevant set of articles, authors and prominent journals on the subject, through bibliometrics, the BP data were compared with those of its references, improving the analyses.

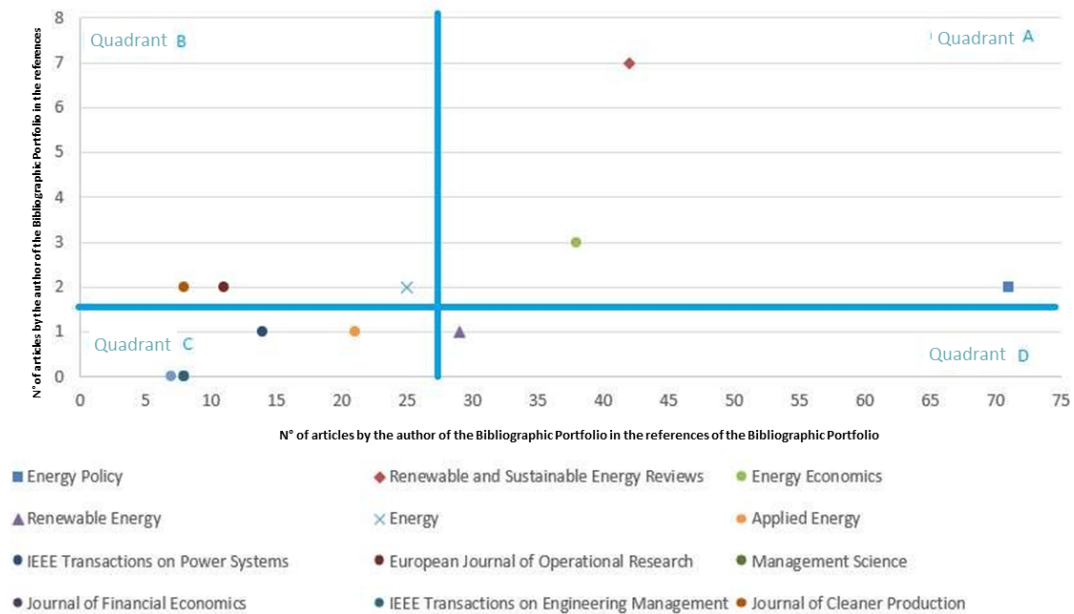
##### 4.3.1 Journals

The journals with more than six publications of articles related to the BP references were compared with the PB journals, as illustrated in Figure 11. The journals positioned in quadrant A,



Energy Policy, Energy Economics and Renewable and Sustainable Energy Reviews stood out, which stood out both in PB and in their references.

Figure 11 - PB Featured Journals and PB References

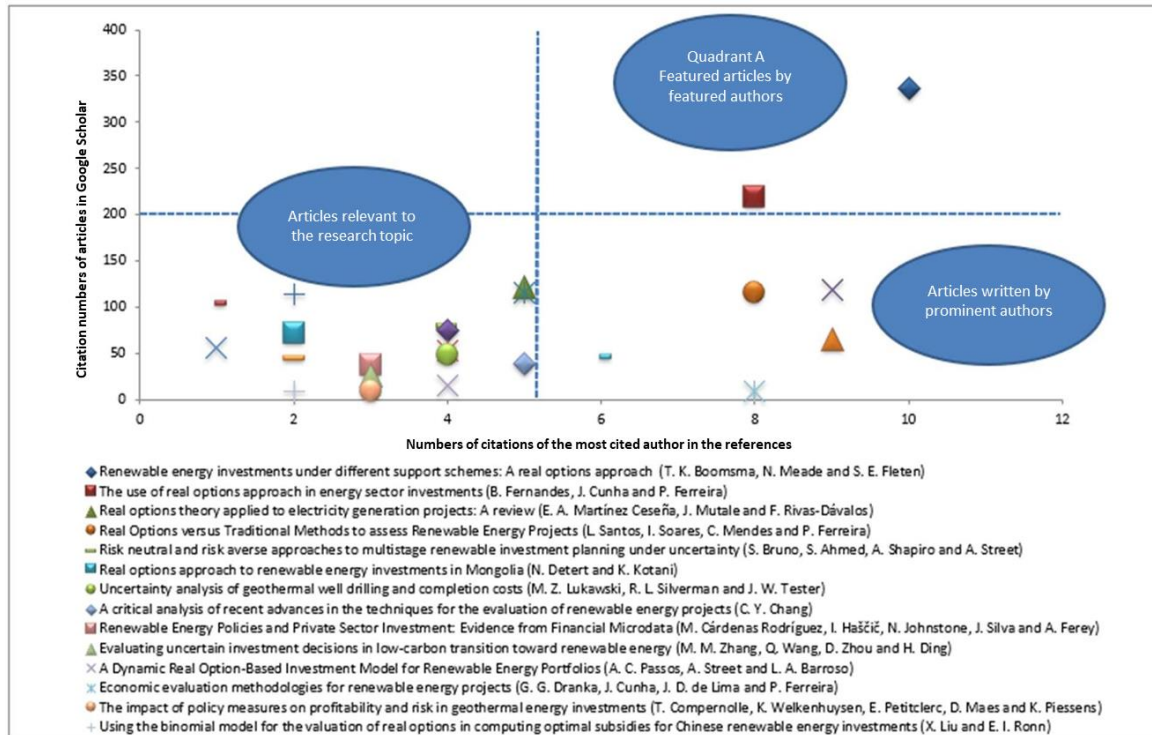


#### 4.3.2 Classification of articles according to academic relevance in the sample

To classify PB articles by their academic relevance, two evaluation axes were adopted: 1) number of citations in Google Scholar (2021) that the article has obtained since its publication; 2) number of citations of the most cited author in the analysis of the bibliographic references of the articles in the portfolio, as shown in Figure 12.



Figure 12 - Classification of Articles According to their Academic Relevance.



For analysis, a horizontal and a vertical line were drawn, delimiting four quadrants, which accommodate the combinations between the number of citations of the article as a function of the citation of the author most cited in the references. Quadrant A is the one that identifies the articles that have a greater contributory potential to the theme of this research, containing articles that were highlighted, elaborated by outstanding authors, being represented by (Boomsma et al., 2012; Fernandes et al., 2011).

## 5 CONCLUSION

Faced with the imminent need to create mechanisms to mitigate global warming, the development of academic research that improves financial tools and contributes to the viability of renewable energy projects becomes elementary.

Based on this context, the present research proposed to present a relevant theoretical bibliographic portfolio, detailing the systematic process used (Proknow-c), which started from the evaluation of 1,141 articles, which made up a portfolio of 25 articles shown in Figure 5.

Bibliometric analyses were also performed from the PB and the PB references, evidencing: a) that the highlighted journals were Energy Policy, Energy Economics and Renewable and Sustainable Energy Reviews; b) as authors the researcher Ferreira, P. was the only one who participated with three papers in the selected PB and Fleten S. E. had more than ten works composing the references of the PB; and c) the articles (Boomsma et al., 2012) and (Fernandes et al., 2011) stood out in the



classification of academic relevance carried out from the perspective of number of citations and as the most cited authors in the bibliographic references of the articles selected in the final portfolio.

This evidence of the most relevant articles, authors and journals in the area will contribute to the theoretical support of future academic and scientific works. Among the possible ones, there is the systemic analysis of the selected portfolio, with a view to identifying research opportunities through content analysis.

This study limited its analyses only to publications of articles, indexed to the Scopus and Web of Science databases, between 2011 and 2021.

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