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Sustainable Finance: A Bibliometric Study of Real Options as a Financial Tool for Making Geothermal Renewable Energy Feasible

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***Keywords*— Investments, real option, geothermal, renewable energy, sustainable finance.**

***Abstract*—** *The finance, investment, and renewable energy (RE) sectors are fundamental to any climate change program and the relationship among them has been a topic of growing interest. Financial assessments have hampered geothermal energy development and a real options approach could contribute to making it more feasible. This article aims to expand the understanding of investments and real options in geothermal power plants, selecting relevant studies on the subject and performing their bibliometric analysis.*

The real options theory is known for increasing the value of projects under uncertainty by modelling their flexibility in response to changes in their environment. It could be used to address environmental issues in the context of geothermal energy, which is a source of continuous low-carbon energy and heat.

A structured process was used for the selection and analysis of the studies. The Pro Know-C literature was searched on the Scopus and WoS databases, with investment analysis and renewable energy as core topics. The articles found were systematically sorted, resulting in a bibliographic portfolio (BP) of 25 articles, which supported the bibliometric analyses. The highlights of the bibliometric analyses are: a) journals - Energy Policy, Energy Economics, and Renewable and Sustainable Energy Reviews; b) authors - Ferreira, P. participated in 3 studies in the selected BP and Fleten, S. E. participated in more than 10 studies listed in the BP references; and c) articles - (Boomsma et al., 2012) and (Fernandes et al., 2011) led the ranking of academic relevance.

I. INTRODUCTION

The recent changes in the global climate are unprecedented. Different regions of the world are already being affected by extreme events such as heat waves, heavy rains, droughts, and cyclones caused by global warming. These are the findings of the AR6 report, approved and released by the Intergovernmental Panel on Climate Change(IPCC), released in August, 2021. This report is the first to claim with 100 percent certainty that human activities have caused climate change. In 2019,the concentration of carbon dioxide (CO_2)in the atmosphere was higher than at any other time in the last 2 million years and the concentration of methane and nitrous oxide was the highest in 800,000 years. However, a significant reduction in the emission of greenhouse gases (GHG) can still limit climate change(Masson-Delmotte et al., 2021).

The finance/investment and renewable energy (RE) sectors are central to any climate change program. Although the finance/investment sector have been slowly responding to the new demands of sustainable

economy(Ryszawska, 2016),these are considered fundamental for the progress of the energy carbon-zero transition, acting as a facilitator and catalyst for the transformation of economic climate(Chenet et al., 2019). The renewable energy sector, in turn, is the main component of any climate change mitigation strategy(Arent et al., 2011) and its associated technologies have garnered increasing interest as it hasbecome a reality in recent years.(Dranka et al., 2020).

Despite the increased RE generation worldwide(Arent et al., 2011), geothermal renewable energy generation using thermal energy from the earth's interior, with low carbon production and continuous supply capacity, has not gained the required scale.It still fails to meet the targets established for this source, because of financing and the apparent limitation of the traditional calculations of net present value (NPV) (Lukawski et al., 2016).

Other obstacles, such as high and uncertain capital investment costs, contribute to geothermal remaining marginalised. However, valuations using real options could contribute to its progress. These valuations have proven to yield better results than limited traditional techniques, differing significantly from a standard NPV calculation and offering much deeper insights into the risks associated with the development of geothermal source(Compernolle et al., 2019; Fernandes et al., 2011).The real options method has proven to be effective in energy investments because of its more realistic estimation of the value of projects. It allows investors to add value, using flexibility to deal with unpredictable fluctuations and provides greater precision in the calculation of subsidies. Additionally, it allows the use of certificates, which are vital for the sustainable development and viability of RE(Liu & Ronn, 2020).

Long-term investments involve relevant uncertainties, which determine the behaviour of investors and the market. Therefore, it is difficult to determine the influence of sustainable elements in this long-term market (Ferreira et al., 2016). ER projects are often high-risk projects. Thus, investors require more sophisticated valuation techniques to assess their investments(Dranka et al., 2020).

This issue emphasizes the need to develop requisite knowledge in a systematic way, based on scientifically recognised sources, to address the question: How could the real options approach contribute to the analysis of investments in geothermal power plants?

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

i. Selecting references on investment analysis and real options in geothermal power plants; and
ii. Performing bibliometric analysis of articles, their references, prominent authors and journals on this topic.

The Knowledge Development Process–Constructivist (ProKnowC) tool was used to achieve these goals. It is a structured process with a constructivist perspective for the selection and analysis of scientific literature. It takes into consideration the researcher's purpose when studying a given topic, and allows the generation of the necessary framework for scientific research.(Lacerda, 2021; Lacerda et al., 2012).

The development of this knowledge by the researcher is represented here by the selection of relevant articles for the bibliographic portfolio and bibliometric analysis of investments and real options in geothermal power plants.

Bibliometric analysis, which was popularised by Pritchard in 1969, consists of a set of methods and techniques for visualising information and drawing up maps that can adequately represent the quantitative and cognitive aspects of science(Macedo dos Santos & Kobashi, 2009; Vanti, 2002). The parameters considered for this research are: the selected articles, their references, authors, number of citations, and most relevant journals.

The rest of this article is structured as follows. Section 2 discusses the theoretical framework, Section 3 presents the methodological framework and procedures used in this research, Section 4 describes the bibliometric analyses and results; Section 5 presents the conclusions and notes, and finally, the last section lists the references used in this article.

II. THEORETICAL FRAMEWORK

RE financing and sustainable finance: RE financing promotes the sustainable financial system by aligning with the long-term needs of a sustainable economy. It includes the following aspects: climate finance, aiming to reduce GHG; green finance, by seeking regenerative environmental outcomes; and sustainable finance, by improving environmental, social, and economic outcomes(Ryszawska, 2016).Sustainable finance uses more robust metrics to seek models in which all relevant costs and benefits are properly accounted for, including the explicit recognition of incremental cash flows attributable to sustainability, in addition to the usual set of cash flows(Popescu et al., 2021).

The economic evaluation of investments in energy: Investments in energy have specific characteristics that differentiate them from others, such as practically irreversible investment once the capital becomes immobilised, preventing it from being used for other areas or companies. There also exists a temporal flexibility which allows the investor to postpone the decision to select the best investment moment. Furthermore, several generation technologies associated with different levels of uncertainty can be chosen. Therefore, it is mandatory for investors to have adequate tools for investment analysis, which accounts for this matrix of risks and uncertainties(Santos et al., 2014).

Real options: The real options theory is known to increase the value of projects under uncertainty. This is achieved by modelling the flexibility of managers to adjust projects in response to changes in their environment. This theory could be used to address current energy and environmental issues, 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 that is derived from thermal energy generated and stored inside the earth. Its production has a low carbon footprint and can provide continuous energy and heat. However, despite its environmental and economic benefits and in contrast to most renewable energies, the development of geothermal energy has not achieved the expected growth. High initial investment and multiple sources of uncertainty result in high investment risk, making it difficult to raise the necessary capital(Compernolle et al., 2019).

III. METHODOLOGY

There is no one size fits all approach to conduct research. The methodological choices influence the findings, and the most appropriate approaches, strategies, and methods for research depend on the problem being addressed(Calvetti, 2019; SAUNDERS, 2009). Hence this section aims to provide the reader with sufficient information to understand the reliability and validity of the methods used in this research.

3.1 Methodological framework

The methods, techniques, and procedures selected for this research are show in Figure1.

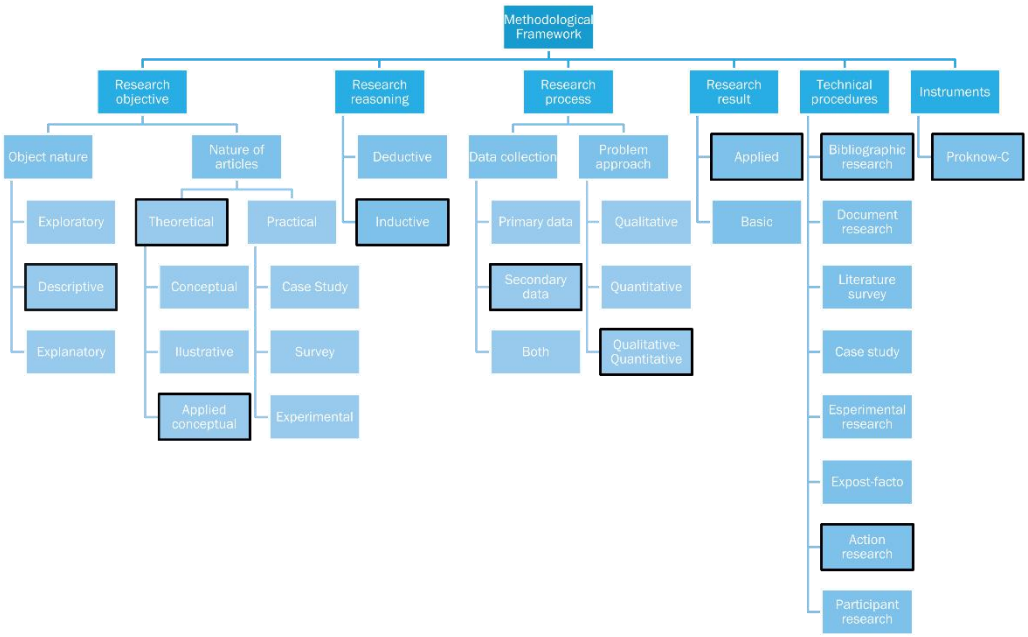

Fig.1 - Methodological framework

Source: Adapted from (Lacerda et al., 2012)

3.2 Intervention instrument

According to Saunders (2009), literature review is an initial step in providing the foundation upon which research is developed, with the main objectives of augmenting the understanding and gaining insight into past research and trends. It helps to review the most relevant and significant research on the topic of interest. An effective analysis allows to get familiar with the current state of knowledge on a given subject and the respective limitations of studies(SAUNDERS, 2009).

Thus, to establish a representative sample of references on the topic, we used the Knowledge Development Process-Constructivist Pro Know-C structured process as an intervention instrument for the

selection and analysis of scientific literature. It was developed in the Multicriteria Methodology Laboratory of Decision Support (LabMCDA) of the Federal University of Santa Catarina (UFSC)(Ensslin et al., 2017).

The steps of Pro Know-C addressed here include bibliographic portfolio selection and bibliometric analysis. The procedure carried out in each of the stages of the investigation is described below in detail.

3.3 Initial search for portfolio selection

The initial search consisted of the selection of articles that will form an initial, non-filtered database, which is later filtered to include articles considered to be of greater significance for the research topic.

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

Two scientific databases, Scopus and Web of Science, were selected for the study. These databases are considered relevant in the international scientific community and offer more search options and advanced filters using Boolean expressions. Therefore, the authors believe that the selected databases are suitable for the purpose of this research.

Two core topics were combined, investment analysis and renewable energy, and the keywords to be searched in the selected databases were defined. Different words were combined using search strings. The number of articles found in each database can be seen in Figure 2.

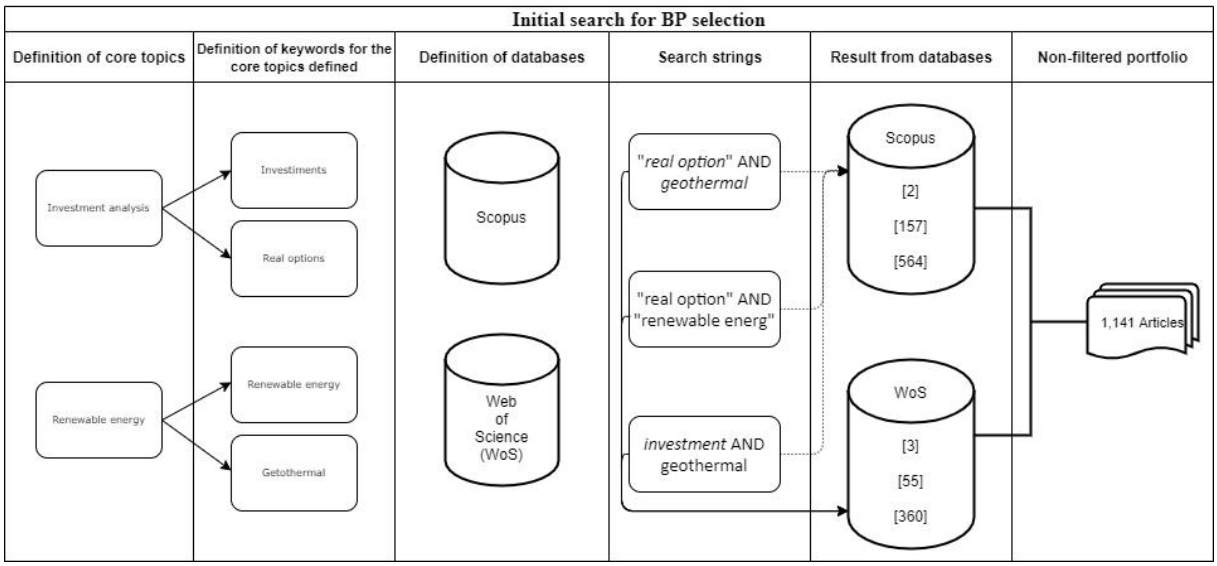

Fig.2 - Initial search for BP selection

Resultantly, 1,141 articles were obtained, which are now part of the Non-filtered Article Database.

3.4 Choice of articles to compose the bibliographic portfolio

The next step of the ProKnow-C process was taken using the EndNote20 software and consisted of identifying and excluding duplicate articles, resulting in the exclusion of 250 references. The remaining 891 articles were filtered using their titles and excluding those that were not aligned with the initially defined core topics, resulting in 119 articles.

The process of filtering articles from the non-filtered bibliographic portfolio is illustrated in Fig.3.

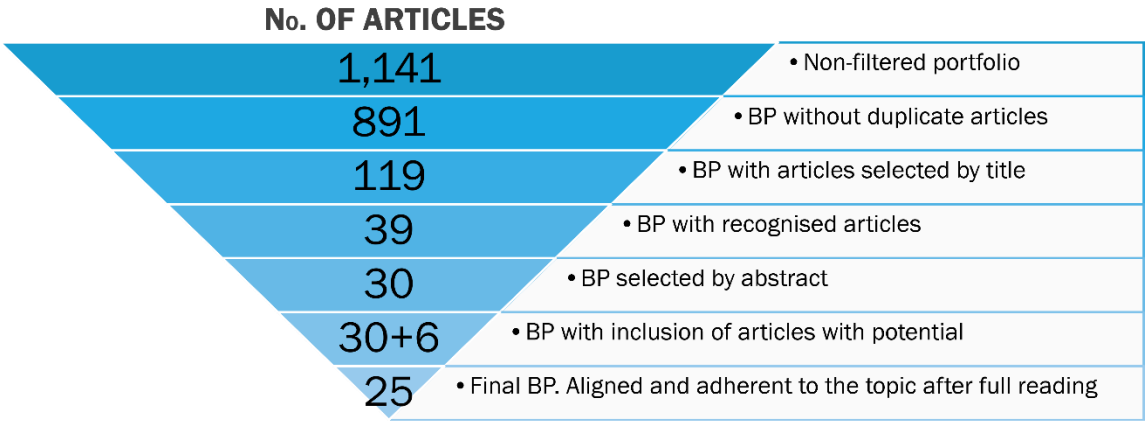

Fig.3 - Filtering Steps

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

The authors of the present study used a cut-off value of 82% articles with more citations, which correspond to 39 articles, totalling 2,909 citations, as can be seen in Fig.3. The 80 unselected articles, with scientific recognition not yet confirmed, in line with Pro Know-C, will undergo further analysis and evaluation.

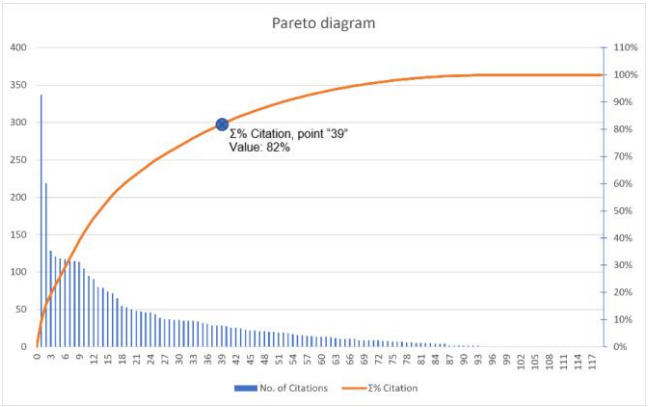

Fig.4 - Selection of Articles by Scientific Recognition

The 39 selected articles were analysed in respect of their alignment with the current research objective. After reading the respective abstracts, 9 articles were excluded at this stage, leading to 30 articles.

In the next step, 80 articles with potential for scientific recognition and pending confirmation were retrieved, representing 18% of citations. Of these, the abstracts of articles published in the last two years (after 2019) were read to check alignment with the research topic as they had little chance of having even a low number of citations. Authors of articles published before 2019 were searched in the database of authors who wrote the articles selected in the preceding step.If they were not in the list, they were excluded. Otherwise, the abstract was read to confirm adherence. At this stage, 6 articles were selected.

All 36 selected articles were fully read to identify the alignment to research and adherence to the proposed theme. A total of 11 documents were eliminated at this stage, resulting in a bibliographic portfolio consisting of 25 articles, which formed the BP of this research. From this BP, bibliometric analyses were carried out to support the results and description of this report.

IV. RESULTS

A BP was formed consisting of 25 articles, which are arranged in descending order as per number of citations as shown in Fig.7.

Sequence	Authors	Title	Year	No. of 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. Ritzenhofen 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. Haščič, 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. Compernolle, K. Welkenhuysen, E. Petitclerc, D. Maes and K. Piessens	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

Fig.5 -BP Table of Articles

5.1 Bibliometric analysis of BP

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

i. Articles

We analysed the scientific recognition of articles within the BP, identified by the highest number of citations in Google Scholar as on June 2020 shown in column 'Number of citations'in Fig.7.We observed that the articles by (Boomsma et al., 2012) and(Fernandes et al., 2011) are the most predominant, with 337 and 219 citations, respectively, corresponding to 28% of the total citations.

ii. Authors

The authors of the articles composing the selected theoretical framework, who participated in more than one article in the sample, are shown in Fig.7

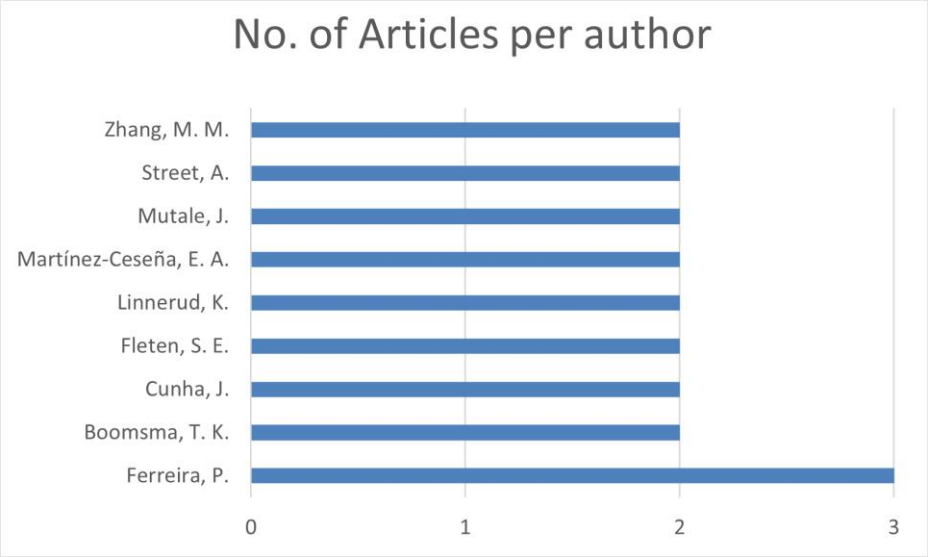

Fig.6 - Main Authors of BP

iii. Journals

Six journals had more than one publication in BP and are presented in Fig.7. The journal Renewable and Sustainable Energy Reviews is the most prominent, with seven published articles (28%), more than double the number of other publications.

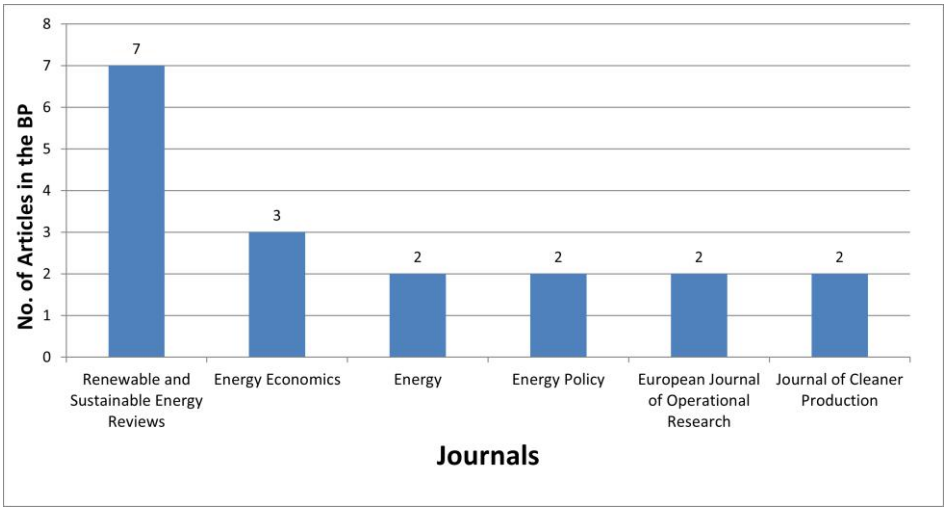

Fig.7–Most prominent Journals of the BP

iv. Keywords

The most prominent keywords were analysed using a network of co-occurrences of the articles of the BP. VOS viewer software was used for analysing the sections of the title, abstract, and the list of keywords of the documents. Fig.8 demonstrates the frequency of occurrences of the keywords by the size of the circle. The strength of association is represented by the proximity between them.

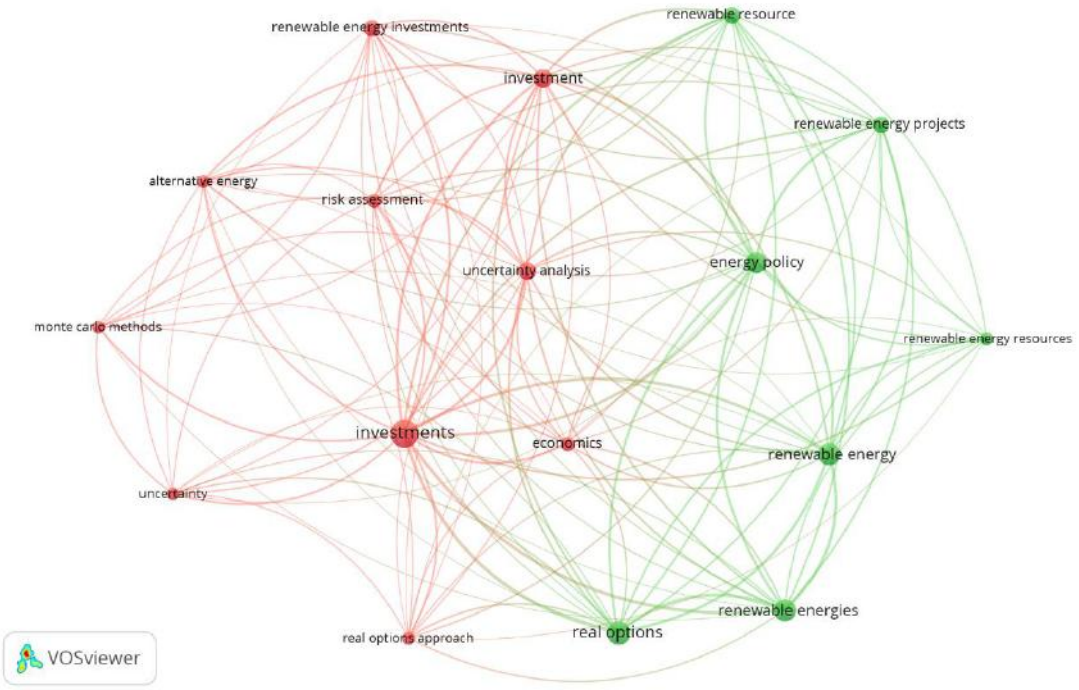

Fig.8– Keywords of the BP

5.2 Bibliometric analysis of the references of the BP

To further identify prominent authors, articles, and journals in the research context, the 703 articles listed in the references of the BP were analysed. The results are described below.

i. Most prominent authors

The most prominent author in the BP is Fleten S.E., who has published ten articles. Figure 9 shows the relative position of this author compared to other authors with more than five publications in the references of the BP.

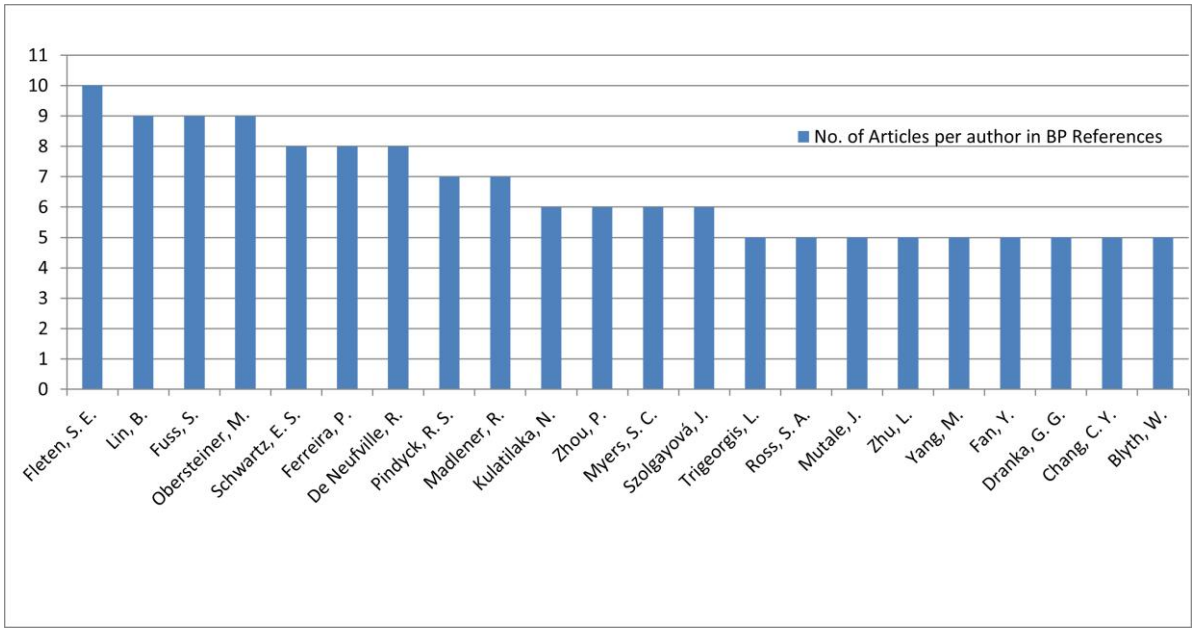

Fig.9 – Main Authors in BP References

ii. Journals

The journals that published more than 10 articles listed in the references of the BP are presented in Fig.10. The most prominent are Energy Policy, with the publication of 71 articles, representing more than double the mean publication among the most prominent journals.

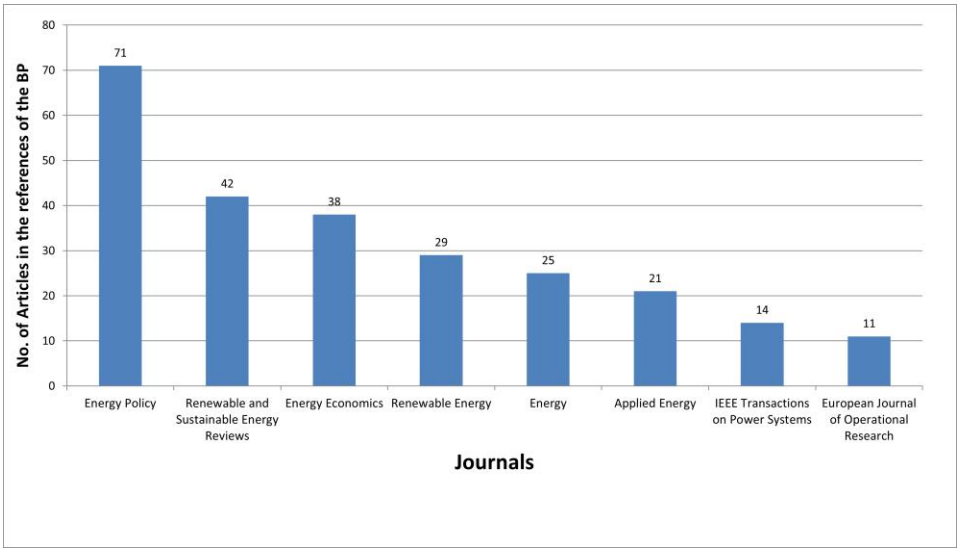

Fig.10 – Main Journals in the BP References

5.3 Bibliometric analysis, BP versus references of the BP

i. Journals

Journals that published more than six articles which are listed in the references of the BP were compared with journals of the BP, as illustrated in Fig.11. The most prominent journals such as Energy Policy, Energy Economics, and Renewable and Sustainable Energy Reviews, were positioned in quadrant A, standing out both in BP and their references.

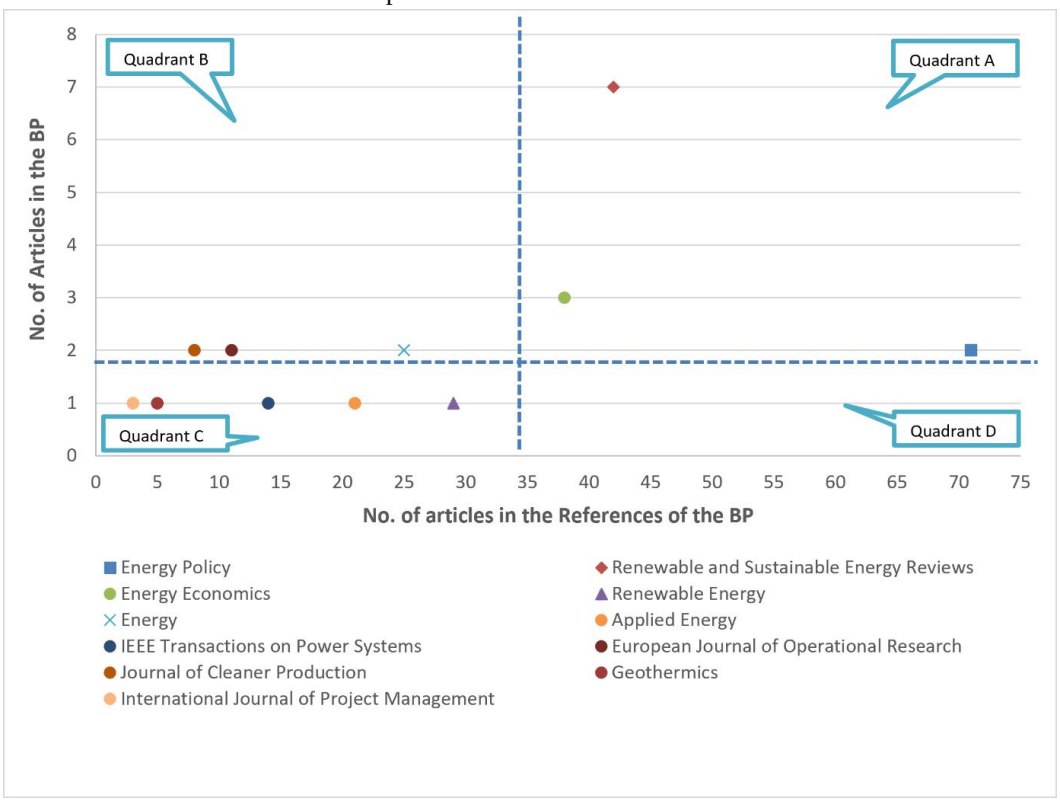

Fig.11 – Prominent Journals of the BP and References of the BP

ii. Classification of articles according to academic relevance in the sample

Two criteria were considered when classifying the articles of the BP by their academic relevance: 1) number of citations in Google Scholar (2021) since the publication of the article; 2) number of citations of the author with greater citations in the references of the articles in the portfolio, according to Fig.12.

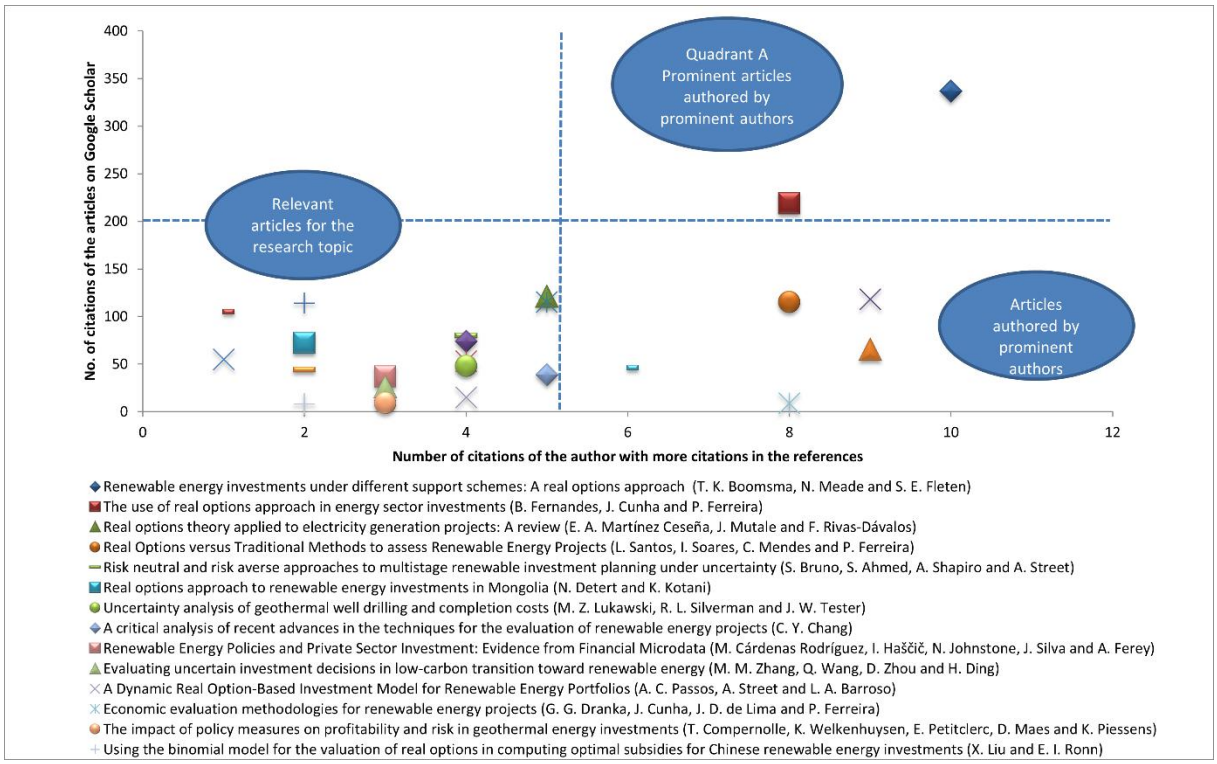

Fig.12 - Classification of Articles According to their Academic Relevance.

A horizontal and a vertical line were drawn dividing the image in four quadrants, which accommodates the combinations between the number of citations of the article and the number of citations of the author with higher citations in the references. Quadrant A accommodates articles with a great potential to contribute to the research topic, consisting of prominent articles written by prominent authors, namely,(Boomsma et al., 2012) and (Fernandes et al., 2011).

V. CONCLUSION

Given the imminent need to create mechanisms to mitigate global warming, it becomes crucial to conduct academic research for improving financial tools and the viability of renewable energy projects.

Therefore, this study proposed a relevant theoretical BP, detailing the systematic process used (Proknow-c), which started with the evaluation of 1,141 articles and resulted in a portfolio of 25 articles, as can be seen in Fig.7

The bibliometric analyses performed based on the BP and the references in the BP revealed that: a) the most prominent journals are Energy Policy, Energy Economics, and Renewable and Sustainable Energy Reviews; b) the author, Ferreira, P.,is the only one who participated in three studies in the selected BP while Fleten S. E. has more than ten studies in the BP; and c) the articles(Boomsma et al., 2012) and(Fernandes et al., 2011)are the most academically relevant articles in terms of number of citations and authors with greater citations in the references of the articles selected in the final portfolio.

Our analysis of the scientific production on investments and real options in geothermal plants provides insights for the better understanding of the topic by the scientific, business, and social communities. It can contribute towards the planning and optimisation of future research. Future studies could perform a systemic content analysis of the selected portfolio for identifying research opportunities.

A limitation of this study is that it only considered articles indexed in the Scopus and Web of Science databases between 2011 and 2021.

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