

Nuclear energy: a bibliometric analysis of the last ten years (2012-2022)

The present work presents a study of bibliometric analysis of the use of nuclear energy and its importance on the socio-environmental, economic and safety aspects of this source of electricity, aiming to verify the impacts of its use in the scientific publications on the subject in the period of 10 years (2012 - 2022). Thus, this study has the general objective of carrying out a bibliometric analysis about the use of nuclear energy and the potential environmental and economic benefits of its implementation in the last 10 years, specifically, measuring the economic and environmental benefits and harms of the use of nuclear energy; historically contextualize nuclear energy and its implementation in Brazil; present the bibliometric analysis of the main authors who have addressed the theme of nuclear energy in the last 10 years, and of the main countries and organizations with scientific publications. Adopting, as a research method, a literature review of a focal approach, with reading of published material, books, articles, and others, in this sense, based on the survey and analysis of scientific articles. As a result, a growth trend in the numbers of published articles was obtained, which reveals a concern to deepen the reflection on this theme, especially in the 2020 to 2022 years.

Keywords: CO2 emissions; Bibliometrics; Sustainability.

Energia nuclear: uma análise bibliométrica dos últimos dez anos (2012-2022)

O presente trabalho apresenta um estudo de análise bibliométrica do uso da energia nuclear e sua importância nos aspectos socioambientais, econômicos e de segurança desta fonte de energia elétrica, visando verificar os impactos de seu uso nas publicações científicas sobre o assunto em o período de 10 anos (2012 - 2022). Assim, este estudo tem como objetivo geral realizar uma análise bibliométrica sobre o uso da energia nuclear e os potenciais benefícios ambientais e econômicos de sua implementação nos últimos 10 anos, especificamente, mensurar os benefícios e malefícios econômicos e ambientais do uso de energia nuclear; contextualizar historicamente a energia nuclear e sua implementação no Brasil; apresentar a análise bibliométrica dos principais autores que abordaram o tema energia nuclear nos últimos 10 anos, e dos principais países e organizações com publicações científicas. Adotando, como método de pesquisa, uma revisão de literatura de abordagem focal, com leitura de material publicado, livros, artigos e outros, neste sentido, a partir do levantamento e análise de artigos científicos. Como resultado, obteve-se uma tendência de crescimento nos números de artigos publicados, o que revela uma preocupação em aprofundar a reflexão sobre esta temática, especialmente nos anos de 2020 a 2022.


Palavras-chave: Emissões de CO₂; Bibliometria; Sustentabilidade.


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INTRODUCTION

The state of the world energy matrix is increasingly shaped by the expansion of the share of renewable energy resources. The high participation of these energy sources in the countries was only possible thanks to the institution of the Incentive to Alternative Sources of Electric Energy (PROINFA), through Law nº 10.438, of April 26, 2002, which was concerned with the reduction of scarcity and energy emissions.

Regarding the state of global electricity consumption, combined with the widespread use of renewable resources, the use of coal is the main source of energy. The share of renewable resources corresponds to only about 25% of the global electricity matrix, with hydropower as the main source (IEA, 2019).

Brazil is currently known worldwide for its vast wealth of natural resources and biodiversity. Concerning the electricity matrix, the Department of Mines and Energy (MME), Murayama et al. (2021), highlights that approximately 85% of the electricity generated in the country comes from renewable energy sources, which have low operating costs and emit small amount of greenhouse gases, 76.9% of which are produced by hydroelectric plants in the country (MURAYAMA et al., 2021).

However, Murayama et al. (2021) also point out, supported by the Brazilian Society of Energy Planning (SBPE), the existence of a strong dependence in the use of natural resources in large quantities on the hydroelectric part, facing the growing climate change currently, putting the country at risk in terms of energy distribution problems only in the use of hydroelectric plants.

In the mid-1960s, the government, together with the Union, began the development of the Brazilian Nuclear Program (PNB) with the ratification of the treaty. The Investment Partnership Program (PPI), which aims to start the production of nuclear energy in the country through the Almirante Álvaro Alberto Nuclear Power Plant (CNAAA), located in the Angra dos Reis city, province of Rio de Janeiro, and built in three nuclear power plants: Angra 1, Angra 2 and Angra 3 (ELETROBRÁS, 2020).

In addition to the emphasis on the use of renewable energies, according to Alves et al. (2021), the use of nuclear energy and the improvement of its use on a large scale has become effective in Brazil, as the country currently has full control on one of the largest mines in the nuclear fuel cycle and the production of elements, in addition to its use in thermonuclear plants, considered the ninth largest uranium mine in the world (INB, 2020).

In this study, therefore, attention is paid to the use of nuclear energy and its importance on the socio-environmental, economic and safety aspects of this source of electricity, aiming to verify the impacts of its use in the midst of publications of scientific studies on the subject.

THEORETICAL REVIEW

The nuclear program in Brazil

Ever since nuclear bombs were dropped on two Japanese cities in 1945, the world has been living in a nuclear war nightmare. During this time, science made nuclear energy available to the public as a source of

supply for humans (KURAMOTO et al., 2002).

According to the retired regional attorney of the Republic, Rogério Tadeu Romano, the Brazilian nuclear program began in October 1956, when President Juscelino Kubitschek created the Cnen (National Nuclear Commission). And, in August 1962, João Goulart's government established a nuclear holocaust. According to the author

In 1967, President Costa e Silva created the Brazilian Nuclear Program. In March 1970, the Emílio Médici government announced that Angra dos Reis (RJ) had been selected to maintain a nuclear power plant and, in 1971, it approved the proposal by Westinghouse (USA). With a budget of US\$ 308 million, Angra 1 began construction in 1972. It began operations in 1982, after costing US\$ 2 billion. The agreement with Westinghouse did not transfer technology to the country. The move became a source of controversy, leading to a change in direction. In December 1974, under Ernesto Geisel, Nuclebrás was created and, in June 1975, the country signed a nuclear agreement with Germany, as reported by Folha on January 11, 2004.

Although it does not produce greenhouse gases, the danger of nuclear energy lies in the high levels of radioactivity and the potential for damage to plants, which can be very dangerous. Currently, there are several nuclear disasters recorded in history, such as: Chernobyl (1986), Three Mile Island (1979), Kyshtym (Ozyorsk - 1957), the Cesium tragedy in 1987 in Brazil, Tokaimura (1999), Seversk (1993), Yucca Flat (1970), Windscale (1957), Bohunice (1977), Fukushima (2011).

The Brazilian nuclear energy program began in October 1956, when President Juscelino Kubitschek created the Cnen (National Nuclear Commission). After the creation of the National Research Council (CNPq), in 1951, with Admiral Álvaro Alberto da Mota e Silva as its representative, aiming to promote and encourage the development of independent scientific and technological research in the sector (INB, 2020).

The program encouraged the creation of regulatory bodies, such as: the National Nuclear Energy Commission (CNEN), which directly negotiated agreements with the Eletrobrás, in 1968, for the construction of the first Brazilian nuclear power plant, in Angra 1 and Angra 2, the International Atomic Energy Agency (IAEA), in 1976, with the main objective of preventing the use of nuclear energy for military purposes (SATO, 2016; INB, 2020).

Only in March 1970, the Emílio Médici government officially announced that Angra dos Reis (RJ) had been selected to maintain a nuclear power plant, and the Westinghouse proposal was approved only in 1971. (USA). With a budget of US\$ 308 million, Angra 1 started construction in 1972, and Angra 2 started operation only in 1982, but slowed down its construction, after costing US\$ 2 billion (SATO et al., 2016; MURAYAMA et al., 2021).

The International Atomic Energy Agency (IAEA) was also created in 1976, with the main purpose of preventing the use of nuclear energy for war purposes (SATO et al., 2016; MURAYAMA et al., 2021). In addition, later on, other secondary projects were started, in addition to the use of energy for energy generation, as shown in Table 1.

Table 1: Secondary applications of nuclear energy.

FIELD	CHARACTERISTICS
Medicine	use of radioisotopes and manufacture of radiopharmaceuticals; diagnostics;

	sterilization of hospital equipment and supplies;
Industry	quality control; checking for defects and cracks in the body of civil construction parts; weld inspection; geological and aquifer surveys etc..
Naval Propulsion	improvement in the autonomy of nuclear powered submarines; new naval bases and shipyards for the production of nuclear submarines; international defense development program; strategic importance for Brazilian economic development .

Source: Murayama et al. (2021).

Angra 1

In 1971, through an agreement with the United States, Brazil acquired a nuclear plant from the American company Westinghouse, named Angra 1, which would be the first unit of the Central Nuclear Almirante Álvaro Alberto (CNAAA). The purchase contract, in the turnkey form, represents the simple acquisition of equipment, without technology transfer (ELETRONUCLEAR, 2019).

With the operation of the PWR reactor, considered the most common type of reactor, with 230 units worldwide, the Angra 1 plant became the first nuclear plant in operation in the country, in 1985. Currently, its generation capacity energy is 640 MW (megawatts) (ELETRONUCLEAR, 2020). Despite the problems faced during its first years of operation, its production level remained high, making its operation very important at the moment. Currently, the agreements signed between Eletrobrás and Westinghouse seek to extend the useful life of Angra 1, from 40 to 60 years (WNA, 2020).

Angra 2

Since it started operating in 2001, the second nuclear power plant in Brazil, Angra 2, has a PWR reactor of German technology, from the company Areva NP (Siemens), formerly known as Kraftwerk Union (KWU), which can meet the needs of a city with a million inhabitants (ELETRONUCLEAR, 2020).

Established by the nuclear agreement signed in 1975 between Brazil and Germany, the construction of Angra 2 provided the transfer of jet centrifuge technology, in addition to receiving the PWR nuclear reactor, which led the country to its technological development, achieving dominance in almost all stages of nuclear fuel production (WNA, 2020). Built in 1981, the operation of this plant has been exemplary since the beginning of its operation, which is one of the main plants that contribute to saving water in the reservoirs of Brazilian power plants, reducing the effects of the country's energy balance (INB, 2020).

Currently, with a 1,350 MW generation capacity, this unit was the 33rd in energy production among the 436 plants in operation in the world. In 2009, it occupied the 21st position in relation to the 50 largest American plants in the analysis of performance indicators of the Association Worldwide of Nuclear Operators (WNA, 2020; ELETRONUCLEAR, 2020).

According to the Annual Report of the Ministry of Mines and Energy (MME), the daily operation at maximum capacity of the Angra 2 plant, which reached 99.43% of capacity and lasted 13 consecutive months, created a new kind of world for Brazil.

METHODOLOGY

Bibliometric Analysis

The bibliographic survey was carried out through an approximation of the focal theme. This method consists of reading published material (books, articles and others), increasing the initial knowledge about the subject, as well as the determination of indicators for the development of the bibliometric study. Bibliometric analysis allows bringing the researcher closer to the object of study, as well as enabling the statistical analysis of academic literature, from different perspectives (ELLEGAARD et al., 2015). This method employs a quantitative approach, which gives quality to the description, evaluation and monitoring of scientific production (ELLEGAARD et al., 2015).

The main laws that govern bibliometrics are focused on the scientific productivity of authors, journals and on the productivity of journals and word frequency. The bibliometric study is applicable to several areas of Science, commonly used to obtain indicators of scientific production, demonstrating the behavior, development and trend of a certain area of knowledge.

Data collection was carried out between July and August 2022, using the scopus database for the selection of articles and dissertations in the period from 2012 to 2022, using the Capes Periodicals Portal platform. The query was applied to the title, abstract and keywords, using the indicators "Nuclear energy" and "CO2 emissions". For the deepening of bibliometrics, 288 documents found on the scopus search site were used, a scientific database that gathers information about scientific studies, using the Boolean operators 'OR' and 'AND', in the last 10 years.

For the bibliometric analysis of the documents related to the indicators researched found, the VosViewer software, developed by Van Eck et al. (2010), was used, a free program used to build maps (clusters) based on networks, using data cluster mapping techniques.

The Vosviewer software was used as a tool to build bibliometric networks for citation of documents, journals, co-authorship of authors and co-occurrence of keywords and summarizing the main authors in the last 10 years, totaling 813 authors.

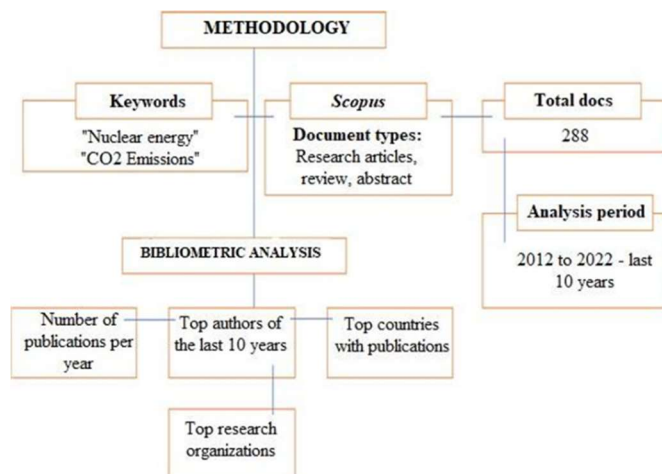


Figure 1: Flowchart of the bibliometric analysis methodology.

RESULTS AND DISCUSSION

Bibliometric analysis

For bibliographic analysis, aspects of Vosviewer were approached, such as: Citation, Co-authors, authors, documents published in prominence and related to each other, as well as mentioning the organizations and countries that stood out in the publication on the subject, always presenting the numbering between, which are connected and related to each other.

For the bibliometric analysis, we chose to analyze works with at least 1 author, and at least 5 citations. For the selection of organizations and countries, we chose to follow the same line, choosing at least 1 organization or country, always with at least 5 citations. Only for the selection of the main authors highlighted in the last 10 years, which used at least 20 citations, to delimit in a specific way the works of the authors, who were most references until the present day.

Analysis of publications per year

After searching for scopus data, accessed through Periódicos Capes, a total of 288 documents corresponding to the theme of CO2 emission through nuclear energy published in the last 10 years were obtained, in which it presents the total publication of each year from 2012 to 2022.

Scientific production related to nuclear energy demonstrates a constant evolution until the years 2016 and 2017, showing a significant drop in the year 2019, and reaching the peak of publications again, in the year 2021 and 2022, summarized in Figure 4.

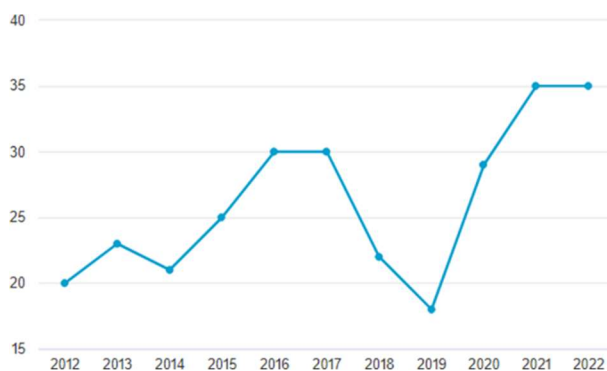


Figure 2: Documents per year.

Rede bibliométrica de citação de documentos

Of the 288 scientific publications on the subject identified in the scopus database after bibliometric analysis in the VosViewer software, 151 publications were identified, connected and unconnected, presented by their respective author and year of publication, being summarized according to the weight of their work, identified with a varied color to differentiate from authors who are not connected, referenced in gray, as shown in figure 5.

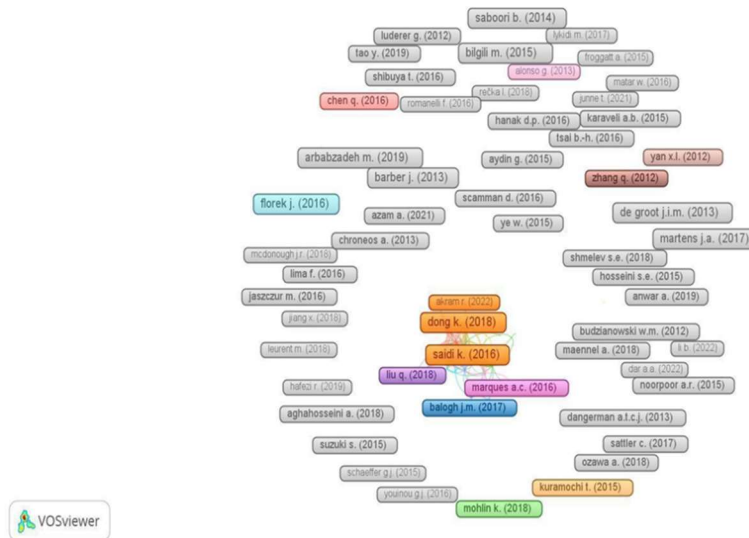


Figure 3: Standing out publications per author in the last 10 years (2012-2022).

It is important to mention that 41 documents are connected to each other, as shown in Figure 6. Using the filter of 1 author per document, with at least 5 citations.

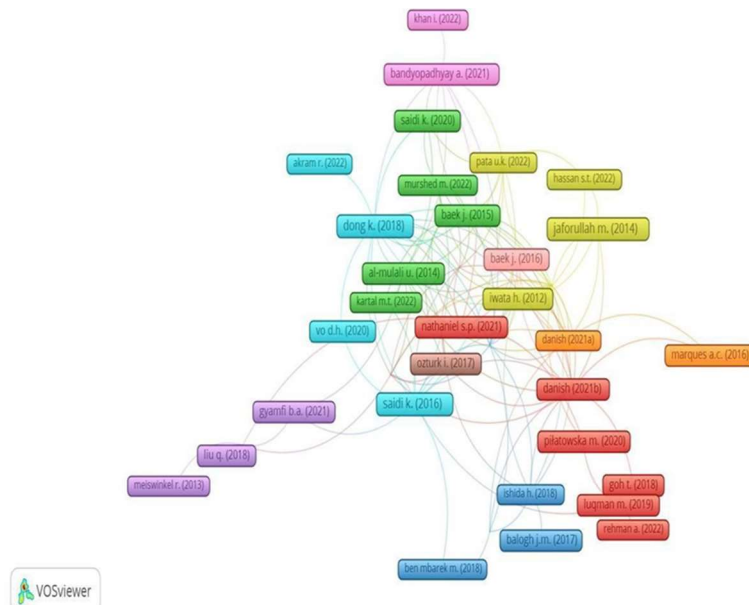


Figure 4: Publications connected by author, in the last 10 years (2012-2022).

Thus, the 10 most cited documents according to the author, in the last 10 years, between 2012 and 2022, regardless of being related or not, are summarized in table 2, showing the number of citations and the year of prominence of their works.

Table 2: The 10 more cited authors.

AUTHOR	CITATIONS	FEATURE YEAR
1°	Lhan Ozturk	2015, 2016, 2021 e 2022
2°	Benjamin C. Mclellan	2012, 2015 a 2021.
3°	Yuan J.	2021
4°	Danish	2020, 2021 e 2022.
5°	Jungho Baek	2021
6°	Muhammad Majeed Tariq	2020, 2021 e 2022
7°	Syed Taussef Hassan	2019 e 2022
8°	Azan A.	2021
9°	Nils Haneklaus	2016 e 2022
10°	Binlin Li	2016 e 2022

Of the 10 most cited documents in the last 10 years among all organized in table 2, as most cited between the period from 2012 to 2022, the studies of Lhan Ozturk stands out in first place, with 19631 citations in general. The award-winning study entitled “*A literature survey on energy-growth nexus*”, published by *Energy Policy* in 2010, stands out with 1,089 citations featuring highlights of his studies in the years 2015, 2016, 2021 and 2022.

The article addresses that most empirical studies focus on testing the role of energy (electricity) in stimulating economic growth or examining the direction of causality between these two variables. Although the positive role of energy in growth has become a stylized fact, there are some methodological reservations about the results of these empirical studies, demonstrating the causalities of these energy consumptions for the environment and society.

Second is author Benjamin C. Mcllan, with 3956 citations overall. Highlighting the work entitled “*Costs and carbon emissions for geopolymers pastes in comparison to ordinary portland cement*”, with 900 citations, published by the *Journal of Cleaner Production* in 2012. Highlighting his studies from 2012, 2015 to 2021. This article presents an analysis of the life cycle cost and carbon impacts of ordinary Portland cement (OPC) and geopolymers in an Australian context, with the identification of some of the main challenges for the development of geopolymers to reduce CO₂ emission in the greenhouse effect.

Third, Yuan J.'s article, with 3940 citations overall. With the featured work entitled “*Energy consumption and economic growth: evidence from China at aggregate and disaggregated levels*”, cited 413 times, published by *Technological Change and the Environment* in the year 2008. Featuring a prominent number of citations from his studies, especially in 2021.

This study presents a neoclassical model of aggregate production in which capital, labor and energy, in the country of China, are treated as separate inputs, testing the existence and direction of causality between the growth of production and use of energy in China, both at aggregate total energy and at disaggregated levels such as coal, oil and electricity consumption. Using the Johansen cointegration technique. Empirical results indicate that there is a long-term co-integration between production, labor, capital and energy use in China, both at the aggregate level and at the three disaggregated levels.

In fourth place, the work by the Danes (Danish), with 1327 citations in all, is highlighted by the study entitled “*Determinants of the ecological footprint: Role of renewable energy, natural resources, and urbanization*”, with 289 citations, published in March 2020, in the *Sustainable Cities and Society* journal. Featuring a featured number of citations from his studies, in the years 2020, 2021 and 2022.

The present study explores the relationship between real income, renewable energy, urbanization, natural resource income and ecological footprint in BRICS economies. Panel data estimators such as fully modified ordinary least squares (FMOLS) and long-term dynamic ordinary least squares (DOLS) estimators are employed for the period 1992 to 2016 to produce reliable estimates. Empirical findings document that natural resource rent, renewable energy and urbanization decrease the ecological footprint, implying that they make a positive contribution to environmental quality.

In fifth place is author Jungho Baek, with 1761 citations. Highlighting the study entitled

“*Environmental Kuznets curve for CO₂ emissions: The case of Arctic countries*”, with 199 citations, published in *Energy Economics* in 2015. Featuring highlights of their studies, in the year 2021. This study seeks to examine the curve hypothesis of Environmental Kuznets (EKC), using time series data at individual country levels. The empirical focus is on the assessment of income per capita from CO₂ emissions in Arctic countries, taking into account the role of energy consumption. An autoregressive distributed lag (ARDL) modeling approach to cointegration is applied to annual data for the period 1960–2010.

In sixth place is the author Muhammad Tariq Majeed, with 1429 citations in general, with emphasis on the study entitled “*Heterogeneous effects of energy efficiency and renewable energy on carbon emissions: Evidence from developing countries*”, with 115 citations, published in the *Journal of Cleaner Production* in 2020. Highlighting his studies in the years 2020, 2021 and 2022.

This study analyzes the heterogeneous effects of energy efficiency (EE), renewable energy (RE) and other variables on carbon emissions in the context of the environmental Kuznets curve (EKC) hypothesis in 66 developing countries from 1990 to 2014, incorporating the role of EE in the construction of the EKC hypothesis, which was neglected in the previous literature. Using the panel's ordinary least squares and fixed-effect panel (PQR) quantile regression, finding that the impact of emission deciding factors is heterogeneous in different amounts.

In seventh place, there is the work of Syed Taussef Hassan, with 771 citations in general, highlighting the work entitled “*Role of alternative and nuclear energy in stimulating environmental sustainability: impact of government expenditures*”, published by *Environmental Science and Pollution Research* in March 2022. Featuring highlights of their studies, in the year 2019 and 2022.

This study examined the role of alternative and nuclear energy in sustaining the environment in a sustainable way, while measuring the role of government spending and economic growth in the top three CO₂-emitting countries. We applied advanced econometric methodologies for empirical analysis from 1981 to 2016 and found long-term relationships between variables that suggest that general government final consumption expenditures and economic growth are positively related to CO₂ emissions.

In eighth place is the author Azan A., with 338 citations in general, highlighting the study entitled “*Analyzing the effect of natural gas, nuclear energy and renewable energy on GDP and carbon emissions: A multi-variate panel data analysis*”, with 68 citations. Presenting highlights of studies, cited in the year 2021. Study sought to determine the effect of consumption of natural gas, renewable energy and nuclear energy on economic growth and carbon dioxide emissions in the ten highest levels of CO₂ in the emitting countries, within a multivariate context for the period 1990–2014.

In ninth place is the author Nils Haneklaus, with 331 citations in general, highlighting the study entitled “*To extract, or not to extract uranium from phosphate rock, that is the question*”, published in *Environmental Science and Technology* in 2017, with 34 citations. Featuring highlights of his studies, in the years 2016 and 2022. Study addresses conscious uranium extraction as an alternative to technological improvements in its extraction, for the protection of water and later human health, since its use helps to reduce the total radiological doses received by workers.

And, in tenth place, is author Binlin Li, with 62 citations in general, highlighting the study entitled *“The role of clean energy, fossil fuel consumption and trade openness for carbon neutrality in China”*, published by *Energy Reports* in July, 2022. Featuring highlights of their studies in the year 2021 and 2022. This work explores the long and short-term relationships between CO2 emissions, real GDP, clean energy, fossil fuel consumption and trade opening in China, covering the period of 1992-2020. 1992 is suggested as the starting year, as China's economy shifted to a market-oriented open economy from that year.

Bibliometric network of the main publications by countries

When searching the keywords: “Nuclear energy” and “CO2 emission” in the scopus database, without delimiting the year period from 2012 to 2022, 539 documents were obtained on the subject, in which, reducing to the 10 main countries, with publications on the subject, the United States stands out with 72 publications, China with 70 publications, and Japan with 63 published documents, organized in figure 5.

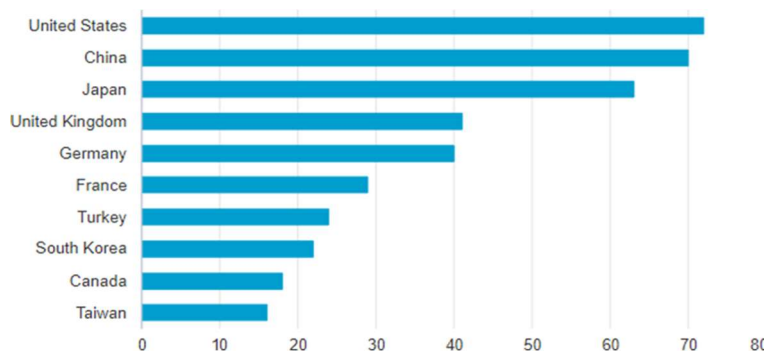


Figure 5: Main publications per country. **Source:** Scopus (2022).

After delimiting the period from 2012 to 2022 - totaling 10 years, using the same keywords: "Nuclear Energy" and "CO2 emission", 288 publications on the subject were obtained, in which, after selecting the 10 main countries in which published scientific documents on the subject, China was highlighted in the first place, as seen in figure 8.

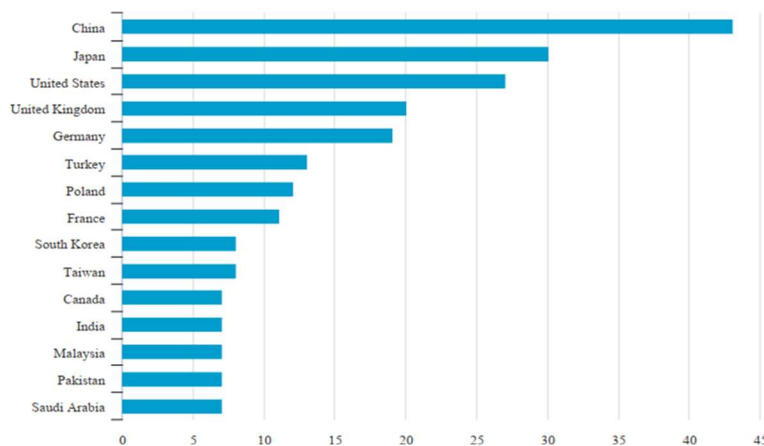


Figure 6: Main publications per country in the last 10 years (2012 -2022). **Source:** Scopus (2022).

Unlike Figure 6, in which the United States is at the top, with 72 publications, after delimiting the 10-year period, there is an inversion of places, in which China has 43 publications occupying the first place, the Japan in second place, with 30 published documents, and the United States in third place, with 27

publications.

After analyzing the VosViewer software, selecting 1 country with at least 5 citations, among the 288 documents, as selection criteria, a total of 64 countries was obtained, in which 50 met the established criteria, as shown in Figure 6.

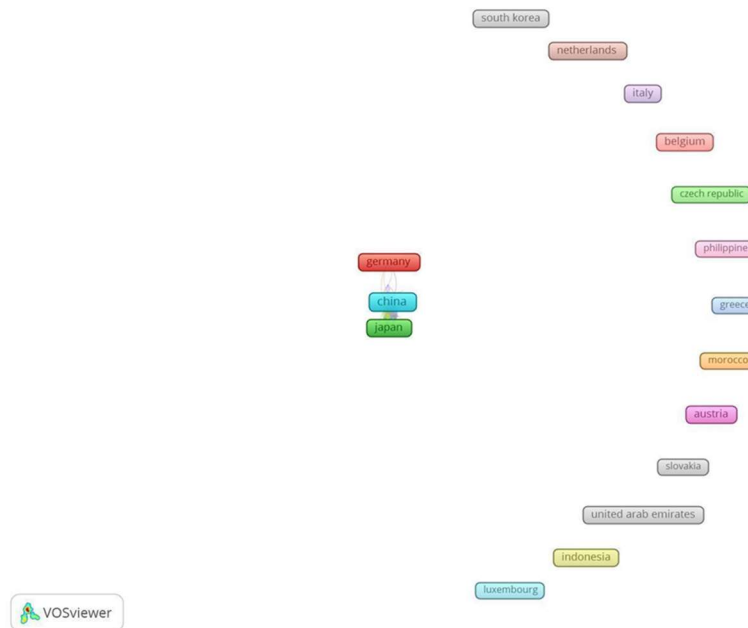


Figure 7: Main publications by country in the last 10 years (2012 -2022).

It is noteworthy to observe that even after the analysis in the Vosviewer software, China, Japan and the United States appear as prominent countries with scientific publications on the subject. China with a total of 62, Japan with 30 publications, and the United States with a total of 29, summarized more specifically, for better understanding, in Figure 8.

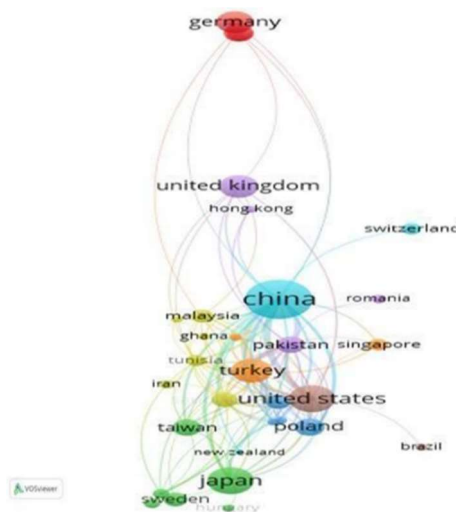


Figure 8: Main publications by country in the last 10 years (2012 -2022), on Vosviewer – Enlarged image.

It is worth mentioning that Figure 8 presents a total of connected and non-connected countries, in which China, Japan and the United States seem connected.

After analyzing the main countries, and putting them on Vosviewer, the results of the analysis of the 288 selected documents were obtained from the 50 main countries, always using the criterion of 1 country with at least 5 citations, a total of 37 countries connected and related to each other, out of the top 50 in

terms of results, one of them being Brazil, linked to the United States.

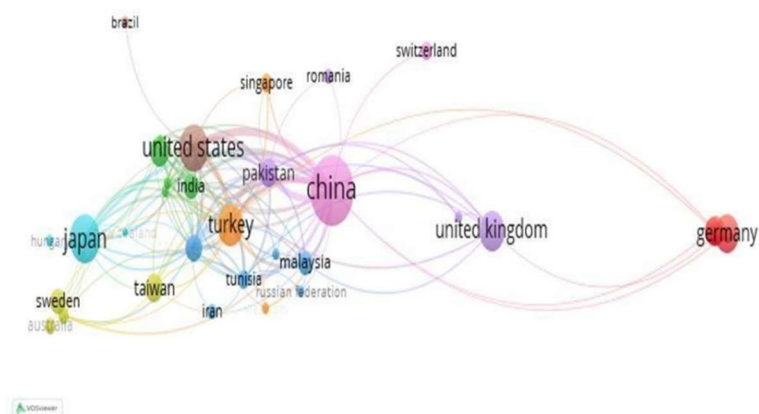


Figure 9: Main countries connected to each other, in the period of 10 years(2012 – 2022).

Thus, in Figure 9, the results of the main connected and related countries are summarized, among the 50 highlighted countries, analyzed in the 288 documents in the period of 10 years, in Vosviewer, totaling 37 countries. The intense color corresponds to the countries with the most weight and the most published works. Therefore, China, Japan, Germany, Turkey, the United States and the United Kingdom are the main countries with published scientific documents on the nuclear energy theme, as can be seen in figures 7, 8 and 9.

It is important to mention that the countries mentioned in the highlights have significant military power, in addition to presenting several studies and research on nuclear energy and uranium enrichment. Of which the United States, China, United Kingdom and China are parties to the Nuclear Non-Proliferation Treaty. Created through the results of the war power of the Second War, aiming to inhibit the expansion of these armaments. It was signed in 1968, effective only in 1970 and currently has the participation of 189 countries.

Bibliometric network of main organizations

For the selection of the main organizations cited in Vosviewer, the criterion of at least one organization with at least 5 citations was used, following the criterion previously established. Of the 288 documents, 582 organizations were cited as a result, and only 354 fit the established criteria, as shown in figure 10.

The color identified by some names corresponds to the organizations that are linked together, thus totaling 98 interconnected organizations, as organized in Figure 10. The other names are weighted, but they are not connected.

It can be observed in a more specific way in figure 11 the organizations that do scientific research about the CO₂ emission caused by nuclear energy, in which it stands out through the 98 organizations, 19 institutions with greater prominence.



Figure 10: Main organizations in the last 10 years (2012-2022).

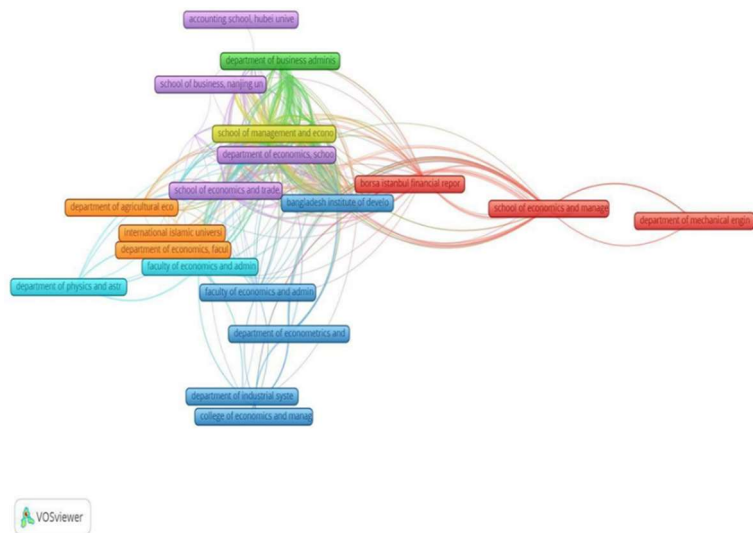


Figure 11: Main organizations in the last 10 years (2012-2022) – Connected.

Therefore, the 10 main connected organizations stand out as a weight reference: School of Economics and Trade, School of management and economics, School of economics and Manage, Banking and Finance Department, Facul of economics and admin., Department of industrial system, University of coastal interior a., International Islamic University., Accounting School Hubei University, Department of Econometrics and., among the top 98 related to each other.

CONCLUSIONS

The work in question aimed to address the production of nuclear energy in Brazil, demonstrating the environmental benefits in the consumption of this energy. Although nuclear energy is an excellent source of energy and does not produce greenhouse gases, the danger lies in the high levels of radioactivity and the potential for damage to plants, which can be very dangerous. As a result, the most recent hazard event is the Fukushima disaster (2011).

For the bibliometric analysis of the documents related to the indicators researched found, the

VosViewer software was used, in which, of the 288 documents resulting from the search in the database of Periódico Capes - *scopus*, it shows a constant evolution until the years 2016 and 2017, displaying a significant drop in the year 2019, but having a growth trend in the number of publications of articles and dissertations on the subject, especially in the years 2020, 2021 and 2022. A total of 64 countries connected and not connected, in which 50 met the established criteria (1 country with at least 5 citations), with only 37 connected countries delimited. Highlighting: China, Japan, United States, Germany and Turkey.

Among the organizations, the result was 582 mentioned organizations, which fit the established criteria of 1 org. with at least 5 citations, only 354, in which 98 organizations are interconnected. And, among the 98, only 19 stand out with the weight of their publications. Thus, the top 10 organizations that researched on the subject are: *School of Economics and Trade, School of management and economics., School of economics and Manage., Banking and Finance Department., Facul of economics and admin., Department of industrial system., University of beira interior a., International Islamic University., Accounting School Hubei University, Department of Econometrics and.*

REFERENCES

ALVES, V. E. A.; MESQUITA, A. Z.; RIBEIRO, P. A. M.; OLIVEIRA, A. M.; PECONICK, D. G. O.; MORCHI, Y.; SILVA, E. P.; RODRIGUES, R. R.; RODRIGUES, R. R.. Desenvolvimento de Metodologias e Aplicação de Técnicas de Análise e Gerenciamento de Riscos para Melhorias no Controle, Segurança e Licenciamento de Centrais Nucleares e Instalações Radioativas. **Brazilian Applied Science Review**, v.5, n.1, p.417- 428, 2021. DOI: <http://doi.org/10.34115/basrv5n1-027>

ELETROBRAS. **Relatório anual 2019**. Rio de Janeiro: ELETROBRAS, 2020.

ELETRONUCLEAR. **Unidade de armazenamento complementar a seco (UAS) de combustível irradiado da Central Nuclear Almirante Álvaro Alberto (CNAAA)**. Rio de Janeiro: ELETROBRAS, 2020..

ELLEGAARD, O.; WALLIN, J. A.. The bibliometric analysis of scholarly production: How great is the impact?. **Scientometrics**, v.105, n.3, p.1809-1831, 2015.

INB. **O Que é o Enriquecimento de Urânio? Como Ele é Feito**

na INB? Brasília: INB, 2020.

KURAMOTO, R. Y. R.; APPOLONI, C. R.. Uma breve história da política nuclear brasileira. **Caderno Brasileiro de Ensino de Física**, v.19, n.3, p.379-392, 2002.

MURAYAMA, C. C. S.; SCHMID, F. P.. **Perspectivas para a energia nuclear no Brasil**. Monografia (Bacharelado em Engenharia Mecânica) - Marckenzie, Higienópolis, 2021.

SATO, K.; FU, B. X.; CAVOSIE, A. J.; CLECHENKO, C. C.; FOURNELLE, J.; KITA, N. T.; LACKEY, J.; PAGE, Z.; WILDE, S.; VALLEY, J. W.. Ti in zircon: crystallization thermometer for zircon. In: SOUTH AMERICAN SYMPOSIUM ON ISOTOPE GEOLOGY, 10. **Anais**. Puerto Vallarta: Universidad Nacional Autónoma de México, 2016.

VAN ECK, N. J.; WALTMAN, L.. Text mining and visualization using VOSviewer. **Digital Libraries**, v.1, 2011. DOI: <http://doi.org/10.48550/arXiv.1109.2058>

WNA. **Nuclear Power in Brazil**. WNA, 2022.

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