International Journal of Advanced Engineering Research and Science (IJAERS)
Peer-Reviewed Journal
ISSN: 2349-6495(P) | 2456-1908(O)
Vol-11, Issue-3; Mar, 2024
Journal Home Page Available: https://ijaers.com/
Article DOI: https://dx.doi.org/10.22161/ijaers.113.2

Nuclear law: Scientometric study of the scientific literature indexed by the Scopus database between 1970 and 2023 using VOSviewer

Almeida dos Santos. A[1], Souza Lima. R.[2], Araripe Marinho.C[3], Assumpção Silva. E[4]

Department of Administration and Logistics, Brazilian Nuclear Energy Commision
Email: alberto.santos@cnen.gov.br
[2]Department of Nuclear Law, Brazilian Nuclear Energy Commision
Email: romulo.lima@cnen.gov.br
[3]Department of Technology and Innovation, Institute of Nuclear Engineering
Email : cristovao.marinho@ien.gov.br
[4]Department of Administration and Logistics, Brazilian Nuclear Energy Commision
Email: eduardo.silva@cnen.gov.br

Received: 15 Jan 2024,

Receive in revised form: 01 Mar 2024,

Accepted: 08 Mar 2024,

Available online: 18 Mar 2024

Keywords *— **Nuclear law, Scientometric study, Scientific literature, Scopus***

Abstract *— Nuclear law refers to the legal framework that governs the development, regulation, and use of nuclear energy and technology. The gap that this study seeks to fill concerns the use of the scientometric method, based on an information structure found in indexed scientific studies on the evolution of the theme of nuclear law. The present study aimed to map out the themes of scientific production between 1970 and the first semester of 2023. Data were collected from research activities indexed by the SCOPUS database and analyzed with the aid of the scientometric VOSviewer software. Considering the limitations of this study, the main scientometric results related to the theme of nuclear law are the following: the United Kingdom and the United States of America present the greatest collaboration in co-authorship between countries; the subject has a broader scope in the field of social science and no significant impact or frequency of Brazilian publications or authors was identified. It was concluded that nuclear law, in line with legal and ethical principles, can contribute to the wellbeing of humanity and the preservation of the environment.*

I. INTRODUCTION

Nuclear law refers to the legal framework that governs the development, regulation, and use of nuclear energy and technology. It covers national and international laws, regulations, and treaties that aim to ensure the safe, secure, and peaceful use of nuclear energy, minimizing the risks associated with nuclear materials and facilities (TANTER, 2014; AMPOVSKA, 2013; SZIEBIG, 2021).

Nuclear law covers various aspects related to the nuclear industry, including the licensing and operation of nuclear power plants, nuclear safety and security measures, management and disposal of radioactive waste, nuclear non-proliferation, and liability for nuclear accidents. It also involves regulating the mining, enrichment, and transport of uranium, as well as the import and export of nuclear materials and technology (ARBOUSSET, 2021; SANDS, 1996; BOWDEN, 2021).

The legal framework for nuclear energy varies from country to country, but often includes specific legislation and regulatory bodies responsible for overseeing the nuclear industry. These bodies are typically tasked with enforcing safety standards, carrying out inspections, granting licenses, and ensuring compliance with

international obligations (BUGOS, 2022; VIKTORIYA, 2019).

At the international level, nuclear law is governed by various treaties and conventions, such as the Treaty on the Non-Proliferation of Nuclear Weapons (NPT), the Safeguards Agreements of the International Atomic Energy Agency (IAEA), the Convention on Nuclear Safety and the Convention for the Prevention of Marine Pollution by Discharge of Wastes and Other Materials, known as the "London Convention", 1972, which entered into force in 1975. In this Convention, at its seventh Consultative Meeting of the Contracting Parties in 1983, an amendment was made to ban the dumping of all radioactive waste at sea. These agreements establish international standards of nuclear safety, protection, non-proliferation, and cooperation between nations (BURNS, 2022; KOVUDHIKRULRUNGSRI, NAKSEEHARACH, 2011; CALMET, 1989).

Given the potentially catastrophic consequences of nuclear accidents and the dual-use nature of nuclear technology, nuclear law plays a crucial role in ensuring the responsible and peaceful use of nuclear energy, while also addressing issues of safety, security, the environment, and non-proliferation (HANDRLICA, 2018; KECSKÉS, 2008; EKARDT, VON BREDOW, 2011).

Considering the relevance of the theme, The present work aimed to conduct a scientometric study of the scientific production indexed by the Scopus database between 1970 and 2023, which answers the following questions regarding the theme of nuclear law: (1) Which countries collaborated with each other with the co-authorship of documents? (2) Which organizations have the most public documents? (3) Who are the most published authors? (4) Which journals concentrate publications? (5) What are the most used keywords in publications? (6) In which field of science is this subject the broadest? (7) What are the impacts and frequency of Brazilian publications or authors?

The scientometric study, as a research method, is a research field that applies quantitative methods to analyze scientific publications and their characteristics. It involves the systematic collection and analysis of data related to scientific literature, such as citation counts, authorship patterns, publication trends, and collaborations (VAN ECK; WALTMAN, 2010).

Based on the limitations of this study, the main scientometric results related to the theme of nuclear law are the following: (1) the United Kingdom and the United States of America have the greatest collaboration in co-authorship between countries; (2) Charles University in Prague is the organization with the largest number of published documents; (3) Jakub Handrlica is the most published author on the subject; (4) the Journal of World Energy Law and Business has concentrated a significant number of publications on the subject over the last 5 years; (5) nuclear energy and international law are the two most used keywords when the topic of the article is nuclear law; (6) the subject has a broader scope in the field of social sciences; and (7) no significant impact and frequency of Brazilian publications or authors was identified.

II. METHODOLOGY

2.1 Scientometric studies

The main objective of scientometric studies is to provide insights into the structure, dynamics, and impact of scientific research. These studies often examine various aspects of scientific output, including research productivity, citation patterns, co-authorship networks, and scientific collaboration at individual, institutional, and national levels. By analyzing such data, scientometricians can identify trends, patterns, and relationships within scientific communities and across disciplines.

Scientometric analyses can be conducted using a variety of methods, including citation, co-citation, analysis, and content analyses. These methods enable researchers to examine the impact and influence of scientific publications, identify key contributors and research fronts, and assess the development and evolution of scientific fields.

Scientometric studies are valuable for multiple purposes, including the evaluation of individual researchers' productivity and impact, assessing the performance of research institutions, tracking the progress of scientific fields over time, and identifying emerging research areas. They also provide insights into knowledge dissemination, the flow of information within scientific communities, and the interconnectedness of research (BONYADI NAEINI, MOGHISEH, 2023).

By applying scientometric approaches, researchers can gain a deeper understanding of scientific endeavors, identify areas of collaboration and potential interdisciplinary research, and inform policy decisions related to scientific funding, research evaluation, and resource allocation.

Scientometric studies are based on the analysis of published literature and may not capture the entire landscape of scientific research, including unpublished or non-indexed works. Nonetheless, they provide a quantitative foundation for understanding the

characteristics and dynamics of scientific knowledge and contribute to evidence-based decision-making in academia and research policy (VAN ECK; WALTMAN, 2010).

2.2 Confirmation of the research gap through bibliometrics

Considering that bibliometrics is a valid instrument for scientometric studies, within the scope of this qualitative study, the context and the preliminary gap of the investigation were established based on the preliminary research. The core question of the study was then defined, which seeks to understand scientific interest and concern through causal relationships with the context in order to justify and explain it (TREINTA ET AL., 2014).

The objective of the work was defined, and through this objective, the method allowed the researchers to define the thematic areas associated with the core question of the study, seeking to guide the application of operators using the Boolean architecture for extracting bibliometric data from the SCOPUS base.

From the systematic analysis of the returned documents, observing the framework of the study, the understanding that there is a research gap was corroborated, that is, the absence of works that sought to map the development of "research trends on nuclear law" in the scientific literature, considering the period from 1970 to the first half of 2023, using scientometric methodology, and based on research data published and indexed by the SCOPUS database.

To confirm the preliminary research gap, in the first round of filter application, and using Boolean architecture, it was possible to identify only one study collected in the databases indexed by SCOPUS, using keywords associated with the thematic areas: scientometrics, nuclear legislation, and nuclear law.

First, Boolean operators "OR"; "AND" and "AND"; "AND" were used with the code "ALL", which returned documents as long as the word researched appeared in one of the following variables: in the title of the paper, in the title of the source, language, author, editor, affiliation, abstract, key words, references, DOI, ISBN, ISSN, CODEN, subjects, volume fields, year of publication, sequence bank, number of sequence bank, number, chemical name, number of CAS registration, manufacturer, editor or conferences.

In the following rounds, the use of operators "OR"; "AND" and "AND"; "AND" was kept, combined with more specific search codes, namely, TITLE-ABS-KEY, which returned documents as long as the word searched appeared in variables: abstract, title of the paper, or key word.

During the search in the base, using Boolean architecture, it was observed that, as the uses of operators with codes form more specific search scripts, as is the case of the code TITLE-ABS-KEY, the number of returned documents decreased and reached zero, as demonstrated in Table 1, confirming the research gap.

Table 1: Boolean architeture to verify the reserarch gap

Round	Operators	Architecture with codes	Number of documents returned
1ª	OR, AND	(ALL ("nuclear law")) OR (ALL ("nuclear legislation")) AND (ALL (scientometric))	1
2ª	AND, AND	(ALL ("nuclear law")) AND (ALL ("nuclear legislation")) AND (ALL (scientometric))	0
3ª	OR, AND	(TITLE-ABS-KEY ("nuclear law")) OR (TITLE-ABS-KEY ("nuclear legislation")) AND (TITLE-ABS-KEY (scientometric))	0
4ª	AND, AND	(TITLE-ABS-KEY ("nuclear law")) AND (TITLE-ABS-KEY ("nuclear legislation")) AND (TITLE-ABS-KEY (scientometric))	0

Source: Developed by the Authors

2.3 Mapping of the development of studies indexed in the Scopus database

After the research gap had been confirmed, in the second phase of the application of filters using the Boolean architecture, 502 national and international studies were identified and collected from the databases indexed by SCOPUS. The details of the Boolean research application and the collection product are presented in Table 2.

Table 2: Boolean architecture linked to the study's core subject matter

Architecture with Boolean operators	Amount of documents
(ALL ("NUCLEAR LAW") AND (LIMIT-TO (PUBYEAR , 2023) OR LIMIT-TO (PUBYEAR , 2022) OR LIMIT-TO (PUBYEAR , 2021) OR LIMIT-TO (PUBYEAR , 2020) OR LIMIT-TO (PUBYEAR , 2019) OR LIMIT-TO (PUBYEAR , 2018) OR LIMIT-TO (PUBYEAR , 2017) OR LIMIT-TO (PUBYEAR , 2016) OR LIMIT-TO (PUBYEAR , 2015) OR LIMIT-TO (PUBYEAR , 2014) OR LIMIT-TO (PUBYEAR , 2013) OR LIMIT-TO (PUBYEAR , 2012) OR LIMIT-TO (PUBYEAR , 2011) OR LIMIT-TO (PUBYEAR , 2010) OR LIMIT-TO (PUBYEAR , 2009) OR LIMIT-TO (PUBYEAR , 2008) OR LIMIT-TO (PUBYEAR , 2007) OR LIMIT-TO (PUBYEAR , 2006) OR LIMIT-TO (PUBYEAR , 2005) OR LIMIT-TO (PUBYEAR , 2004) OR LIMIT-TO (PUBYEAR , 2003) OR LIMIT-TO (PUBYEAR , 2002) OR LIMIT-TO (PUBYEAR , 1999) OR LIMIT-TO (PUBYEAR , 1998) OR LIMIT-TO (PUBYEAR , 1997) OR LIMIT-TO (PUBYEAR , 1996) OR LIMIT-TO (PUBYEAR , 1995) OR LIMIT-TO (PUBYEAR , 1993) OR LIMIT-TO (PUBYEAR , 1991) OR LIMIT-TO (PUBYEAR , 1990) OR LIMIT-TO (PUBYEAR , 1988) OR LIMIT-TO (PUBYEAR , 1986) OR LIMIT-TO (PUBYEAR , 1985) OR LIMIT-TO (PUBYEAR , 1982) OR LIMIT-TO (PUBYEAR , 1981) OR LIMIT-TO (PUBYEAR , 1980) OR LIMIT-TO (PUBYEAR , 1979) OR LIMIT-TO (PUBYEAR , 1978) OR LIMIT-TO (PUBYEAR , 1977) OR LIMIT-TO (PUBYEAR , 1976) OR LIMIT-TO (PUBYEAR , 1975) OR LIMIT-TO (PUBYEAR , 1972) OR LIMIT-TO (PUBYEAR , 1971) OR LIMIT-TO (PUBYEAR , 1970))	502

Source: Developed by the Authors

Excel software was used to conduct data analysis and the presentation of results, as follows: (1) comparison among the research organizations with the highest number of documents published on nuclear law between 1970 and the first half of 2023; (2) comparison among authors with the highest number of documents published on nuclear law between 1970 and the first half of 2023; (3) frequency of documents published between 1970 and the first half of 2023; documents organized by country and area of knowledge; and (4) comparison among the types of areas indexed by the Scopus database on nuclear law. Data analysis and the presentation of clusters included: (1) countries co-authorship; (2) citation of documents by organizations; (3) citation of authors; (4) bibliographic cupping of documents by sources; (5) comparison among the three journals with the highest number of documents published on nuclear law between 1986 and the first half of 2023; and (6) keywords co-occurrences, the collected data were entered into the VOSviewer software database for scientometric data processing, available at www.vosviewer.com.

The program identifies the core subject matter in documents in a low dimension space so that the space between any two elements mirrors the equivalence or affinity of items with the best possible precision. For each pair of items, i and j, the VOSviewer requires a similar ij (Sij ≥0) as entry. It treats Sij similarities as measurements in a ratio scale. Thus, the device minimizes a weighted sum of square distances among all pairs of items.

The square of the distance between a pair of studies is calculated by the similarity among items. To avoid trivial solutions where all elements have the same position, the restriction imposed is that the average distance between two items must be equal to 1.

Considering the core objective of this study, for each of the 502 documents exported from the SCOPUS base, in CSV (Excel) format, were considered for the VOSviewer to analyze the database, fields, types of data, and counting methods, as presented in Tables 3 and 4 (VAN ECK; WALTMAN, 2010).

Table 3: Types of fields for scientometric analysis

Data and fields from the Scopus database for migration to the VOSviewer software		
Data	**Types of fields**	**Number of fields**
Citation information	Authors, document title, year, source title, volume, pages, citation count, source, and types of	9

	documents, doi	
Bibliographic information	Affiliations, editor, idiom of the original document, corresponding address, abbreviated source title	5
Abstract and key words	Abstract, author key words, key words index	3
Other information	Information and conference, references	2

Source: Developed by the Authors

Table 4: Types of counting methods for scientometric analysis

Counting methods used in the VOSviewer software.		
Type	**Consolidated description**	**Number of consolidated descriptions**
Full	Only the presence or absence of a term in a document is considered.	1
Fragmented	The weight of a connection is fragmented, so that each reference, citation, or document makes the same global contribution.	1

Source: Developed by the Authors

Tables 5 and 6 present a consolidated description of the types of analysis used in this phase of research and the criteria used in the software parameterization, including the counting of terms, the bibliographic coupling and co-citation, the respective analysis units present in the database, and the number of analysis units selected to calculate the total strength of the links for the preparation of cluster maps.

Table 5: Types of analysis used in the VOSviewer software.

Types of analysis used in the VOSviewer software.		
Type	**Consolidated description**	**Number of Consolidated descriptions**
Counting of terms	Frequency of term appearing in the main body of the document (title and abstract)	1
Bibliographic coupling	The list of items is determined based on the number of references that they share.	1
Co-citation	The list of items is determined based on the number of times they are cited together.	1

Source: Developed by the Authors

Table 6: Types of parameterization used in the VOSviewer software.

Criteria used in software the VOSviewer parameterization.			
Type of analysis	**Unit of analysis**	**Minimum number of analysis units in the database**	**Number of analysis units selected for calculation**
Co-authorship	Countries	01	49
Co-occurrences	Keywords	02	459
Citation	Authors	01	235
(Citation) Documents	Organizations	01	395
Citation	Countries	01	49
Bibliographic Coupling	Sources	01	194

Source: Developed by the Authors

Specifically to create the maps, based on the main body of both the title and the abstract of the documents, the punctuation of the terms was created based on the year of publication in the field, using the binary counting method, where the number of occurrences of the term was at least equal to 10. The number of analyzed units selected to calculate the total form of links was 37,302 terms. After processing the data in Microsoft Excel and VOSviewer software, the results analysis phase began.

Figure 1 illustrates the macro view of the methodological process used in this scientometric study.

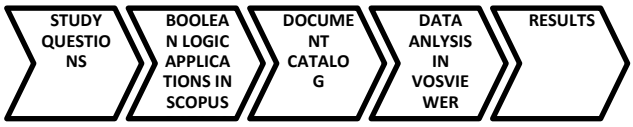

Figure 1: macro view of the methodological process.

Source: Developed by the Authors

III. RESULTS AND DISCUSSIONS

3.1 Co-authorship of countries

Co-authorship of countries refers to the collaboration between researchers from different countries in publishing scientific papers. When researchers from multiple countries collaborate on a research project and publish a paper together, it is considered a co-authored publication between those countries.

Analyzing the co-authorship patterns of countries can provide insights into the extent and nature of international scientific collaboration. This helps to identify trends, patterns, and networks in scientific research, and can provide valuable information for policymakers, funding agencies, and researchers themselves.

Co-authoring networks view the connections between countries based on their collaborative relationships. Figure 1 shows that the United Kingdom and the United States of America have the greatest collaborative connection of co-authorship between countries on the subject of nuclear law.

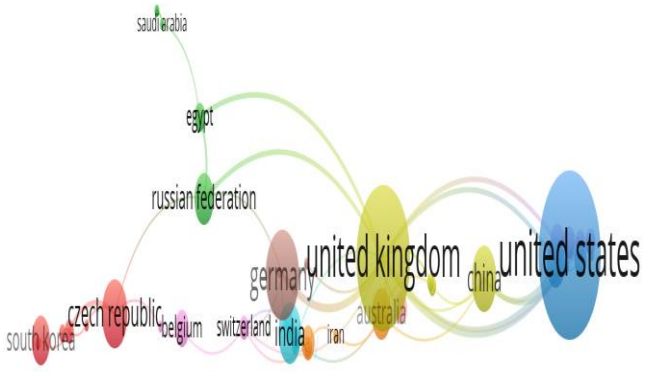

Figure 2: Countries co-authorship

Source: Developed by the Authors

The field of nuclear law encompasses regulations and legal frameworks related to the peaceful use of nuclear energy, nuclear safety, nuclear liability, non-proliferation and other legal aspects related to nuclear activities. Collaboration between US and UK authors in this field can contribute to the exchange of knowledge, the sharing of expertise, and the development of international legal frameworks in the nuclear sector. The results presented in Figure 2 demonstrate that US and UK researchers frequently collaborate on research papers and publications related to nuclear law, reflecting a shared interest in specific topics or legal issues within the field. In collaborating, US and UK authors bring diverse perspectives, legal frameworks, and experiences to tackle complex challenges in nuclear law.

3.2 Citation and documents published by organizations

Figures 3 and 4 below show the results related to the citation of documents by organizations and the comparison between the research organizations with the highest number of documents published on nuclear law between 1970 and the first half of 2023.

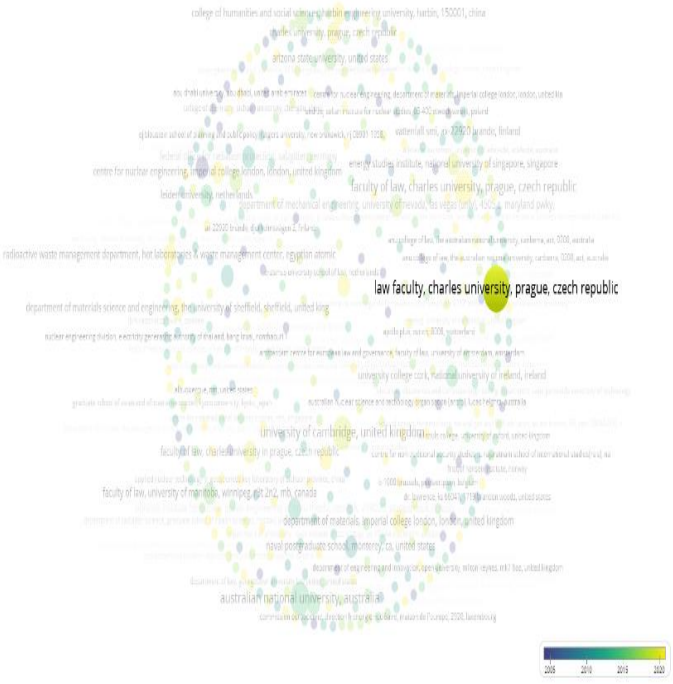

Fig.3: Citation of documents by organizations

Source: Developed by the Authors

Although the Czech Republic is not ranked number one among the most cited countries in nuclear law, the organization that has the highest frequency of citations is the School of Law at Charles University in Prague, which is an organization that plays a prominent role in nuclear law studies. The university offers academic programs and

conducts cutting-edge research in this particular area. The Charles University School of Law is known internationally for its academic tradition.

The college houses the Center for Nuclear and Environmental Law (CENEA), which is one of the leading research and teaching centers in nuclear law. CENEA collaborates with other national and international institutions and contributes to the development of nuclear and environmental law through research, seminars and conferences (HANDRLICA, 2019).

Nuclear law studies at Charles University cover a wide range of resources related to regulatiosn, governance, and legal issues of nuclear energy. Courses offered may include International Nuclear Law: Study of international treaties, conventions, and regulations related to nuclear energy, including the Czech Republic's participation in international bodies, such as the IAEA.

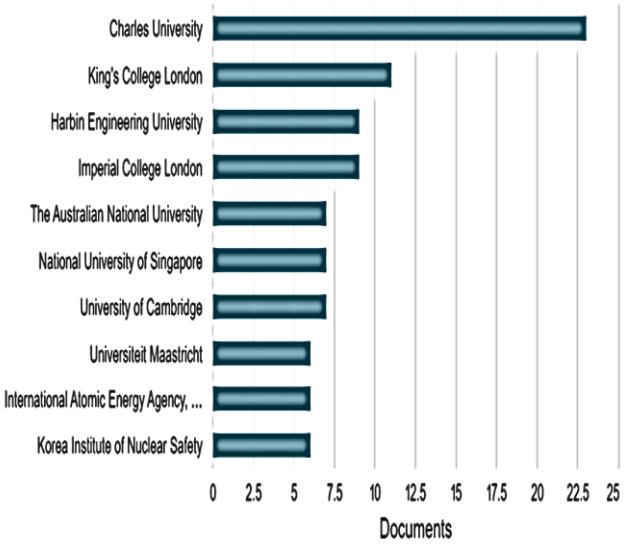

Fig.4: Comparison between the research organizations with the highest number of documents published on nuclear law between 1970 and the first half of 2023

Source: Developed by the Authors

3.3 Citation of authors and number of documents published

Figures 5 and 6 below show the results referring to the comparison among the authors with the highest number of documents published on nuclear law between 1970 and the first half of 2023, and the authors with the highest frequency of citations in indexed scientific works.

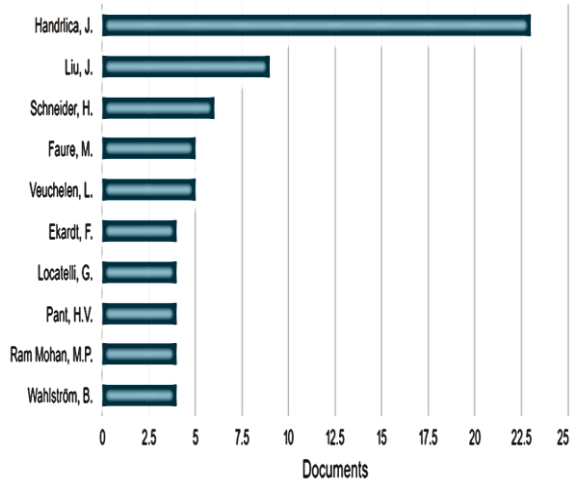

Fig.5: Comparison among the authors with the highest number of documents published on nuclear law between 1970 and the first half of 2023

Source: Developed by the Authors

In the area of scientometrics, the comparison of authors by the number of published documents is a common analysis to assess the scientific productivity of researchers. This metric is useful for identifying authors who have a significant contribution in terms of the number of publications.

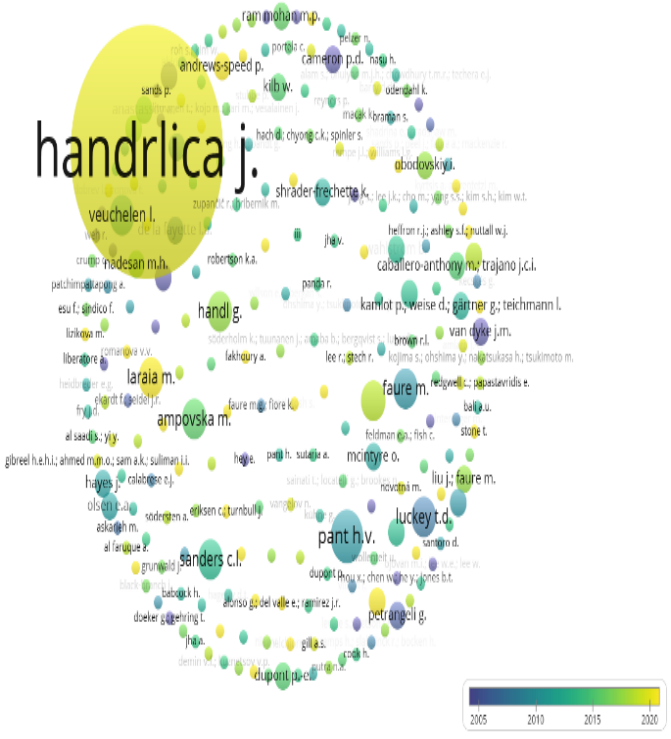

Figure.6: Citation of authors

Source: Developed by the Auth

In scientometrics, one citation per author refers to counting the number of times a given author is cited in academic or scientific works. This metric is often used to assess an author's influence and impact upon the academic community.

From the content analysis of the articles, 4 authors and 9 articles stand out, where the object and thematic centrality of the scientific study is nuclear law in a more specific and defined perspective, as shown in Table 7.

Table 7: Authors of articles, where the core object and thematic of the study is nuclear law – defined perspective

Document Title	Authors	Source	Year
Nemesis of New Technologies in Nuclear Law	Handrlica, J.	Pravnik	2022
The Feast of Insignificance of Small Modular Reactors in International Nuclear Law	Handrlica, J.; Novotná, M	Czech Yearbook of Public and Private International Law	2021
Whither the Future of International Nuclear Law? A Survey in Legal Futurism	Handrlica, J.	Czech Yearbook of Public and Private International Law	2020
From the Front Lines of International Nuclear Law: Looking Back at the 'Nuclear Inter Jura' Congress, Held in Abu Dhabi, United Arab Emirates	Handrlica, J.	Journal of World Energy Law and Business	2019
Nuclear Law Revisited as an Academic Discipline	Handrlica, J.	Journal of World Energy Law and Business	2019
"Atomic Law" or "Nuclear Law"? An Academic Discussion Revisited	Handrlica, J.	Brics Law Journal	2018
"Exclusivism" in International Nuclear Law: The Concept Revisited	Handrlica, J.	Lawyer Quarterly	2018
International Cooperation and Guarantee of Nuclear Safety in the Implementation of National Nuclear Law	Schneider, H.	Atw – Internationale Zeitschrift Fur Kernenergie	2011
The Justification and Optimisation Principle in International Nuclear Law: Theory and Practice	Veuchelen, L.	Atoms For Peace	2005

Source: Developed by the Authors

Figures 5 and 6, and Table 7, show that the articles on nuclear law presented by Jakub Handrlica, from Charles University, in the Czech Republic, are those that produced the greatest impact on the Scopus database, mainly from 2019 onwards. The author's main areas of interest include energy and nuclear law and international administrative law (HANDRLICA, 2021).

3.4 Frequency of documents published, bibliographic coupling, and journals

The Figure 7 below shows the frequency of documents published on the subject of nuclear law, and indexed by the Spocus database, between 1970 and the first half of 2023.

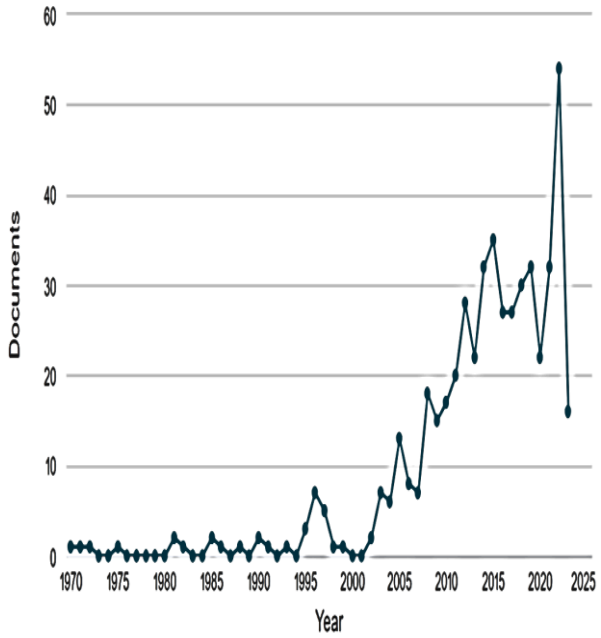

Fig.7: Frequency of documents published between 1970 and the first half of 2023

Source: Developed by the Authors

The growth of scientific publications on nuclear law is related to the growing importance of the subject and the development of nuclear energy and energy technologies worldwide. In recent years, there has been a significant increase in interest in and awareness of the legal aspects of nuclear power and energy activities. This is due to several factors, such as the growing demand for nuclear energy in some countries, the development of technologies, the need for effective regulation and governance, and concerns about safety at nuclear facilities. As a result of this increased interest, it is expected that the number of scientific publications on nuclear law has also increased. This includes articles in peer-reviewed journals, books, book chapters, and other types of scholarly publications.

Figure 8 presents the bibliographic coupling of documents by sources, which refers to the practice of identifying and analyzing the connections between scientific documents through the cited bibliographic sources. It is a technique used in scientometric analysis to examine the interconnectivity and mutual influence between scientific articles.

When carrying out the bibliographic coupling, the bibliographic references cited in a given article were identified, and these references were tracked to find the documents that contain them.

This allows one to map reference networks and discover which studies are closely related to or have influenced the original work.

Bibliographic coupling by sources is a valuable tool to understand the dynamics of scientific research and the interaction between academic journals. It also helps to identify key contributions to a field of study, track the spread of ideas, and identify gaps in scientific knowledge.

Figure 8 presents the main cluster formed from the bibliographic coupling of documents by source, identifying the Journal of World Energy Law and Business (JWELB) as that with the greatest connectivity and interaction with other journals.

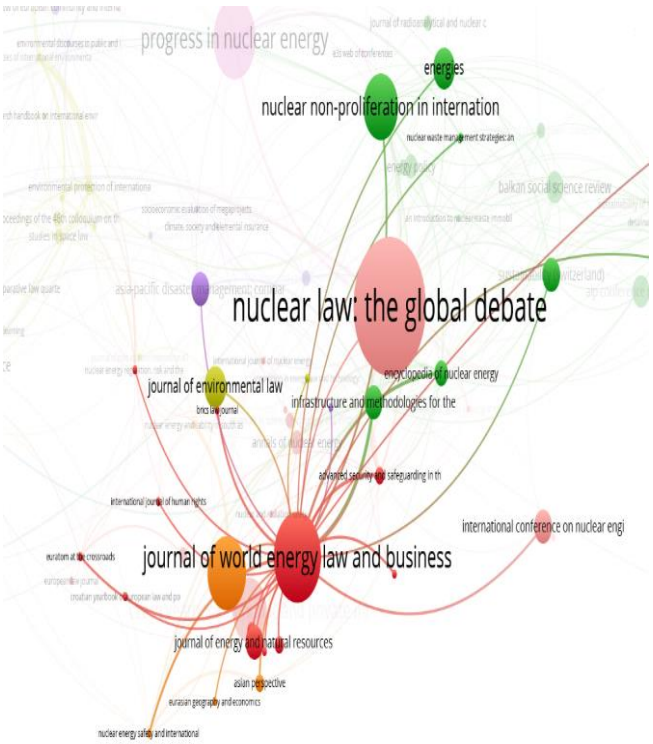

Fig.8: Bibliographic Coupling of Documents by Sources

Source: Developed by the Authors

The JWELB is a specialist academic publication that focuses on energy law and business at a global level. It covers a wide range of energy-related subjects, including nuclear law, regulation, public policy, energy investment, environmental issues, and sustainability.

JWELB is a peer-reviewed journal that publishes high-quality articles accredited by academics, practitioners, and industry experts. The journal is published in collaboration with the Association of International Petroleum Negotiators (AIPN) and is widely recognized as a leading publication in the field of nuclear law and energy business.

JWELB's mission is to promote understanding and advance knowledge in the operational interdisciplinary areas of nuclear law and energy business on a global scale. It also provides a forum for debate and dissemination of original and innovative research, as well as an in-depth analysis of legal and business issues relevant to the energy sector.

Articles published on JWELB cover a wide variety of topics such as energy contracts, arbitration and dispute resolution, oil contract negotiation, regulatory issues in different jurisdictions, the development of renewable energy resources, sustainability policies, among many other aspects related to energy and its legal and business context.

The journal is an important reference for academics, industry professionals, and policymakers interested in issues related to nuclear law and energy business around the world. Through the publication of high-quality research, JWELB contributes to the advancement of knowledge and promotes discussion on the challenges and opportunities facing the energy sector on a global scale.

Figure 9 shows the comparison among the three journals with the highest number of documents published on nuclear law between 1986 and the first half of 2023. It was observed that the Journal of World Energy Law and Business, from 2018 onwards, has concentrated a significant number of publications on the theme (HANDRLICA, 2021; HANDRLICA, 2019).

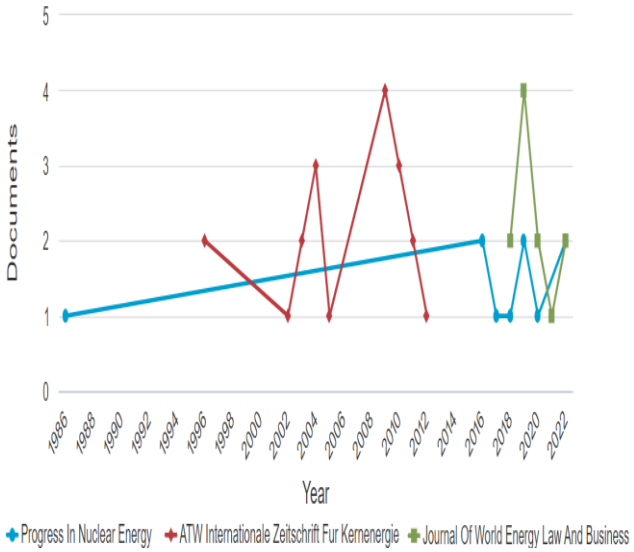

Fig.9: Comparison among the three journals with the highest number of documents published on nuclear law between 1986 and the first half of 2023

Source: Developed by the Authors

It was found that the Atw – Internationale Zeitschrift Fur Kernenergie, between 1996 and 2012, contained the largest number of publications on the subject of nuclear law. Progress in Nuclear Energy, on the other hand, has shown stability in a number of publications on nuclear law over the last 27 years.

Internationale Zeitschrift Fur Kernenergie is a scientific journal specialized in nuclear energy, covering a wide range of topics related to this specific field. The journal aims to provide a platform for the publication and dissemination of high-quality research on science, technology, applications, and regulatory aspects related to nuclear energy.

The journal is published in German and is one of the leading specialist magazines on nuclear energy in Germany and other German-speaking countries. It also has a long history, spanning over a 70-year period, and is known for its relevance and contributions to the nuclear community.

The journal publishes original scientific articles, reviews, short articles, and technical reports covering a wide range of topics related to nuclear energy, including regulations, safety standards, nuclear licensing, radiation protection, nuclear legislation, and safety management.

Progress in Nuclear Energy is an international scientific journal covering a wide range of resources related to nuclear energy. It publishes original research, reviews, case studies, and short papers on many aspects of nuclear power, including reactor technology, nuclear safety, toxic waste management, energy policy, lifecycle analysis, modeling and simulation, among others.

The journal aims to provide a platform to share knowledge and advance the field of nuclear energy. It promotes collaboration among researchers, academics, engineers, and professionals in the nuclear industry, and is well-known in the development of innovative solutions and improvement of nuclear technology.

Articles published in Progress in Nuclear Energy cover a variety of areas, such as energy policy and regulation. In this field, articles can explore government policies and regulations related to nuclear energy, including issues of non-perspectives, international agreements, nuclear law, and safety policies.

3.5 Keywords co-occurrences

Figure 10 shows the co-occurrence of keywords in the documents that were examined in this study. The co-occurrence of keywords in scientometric studies is a technique used to analyze the frequency and relationship between keywords in scientific documents. This analysis

makes it possible to identify patterns, trends, and research themes in a given field of study.

By performing a keyword co-occurrence analysis, researchers identify the keywords assigned to a set of documents and calculate how often those keywords appear together. This helps to understand the interconnectivity between keywords, and reveals the structure and thematic relationships of the scientific literature.

There are several ways to perform keyword co-occurrence analysis. A common approach is to use network analysis methods, as in this study, of keyword co-occurrence networks, which represent keywords as nodes and co-occurrence relations as edges. These networks can be viewed through graphs or network diagrams, which highlight the most frequent keywords and their interconnections.

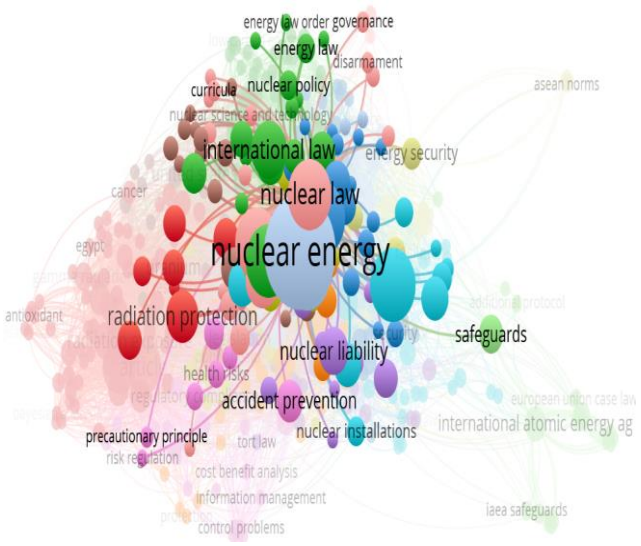

Fig.10: Keywords co-occurrences

Source: Developed by the Authors

Figure 10 shows that the keyword "nuclear law" nearly as frequently as the terms nuclear energy and international law. The strength of this relationship is natural, considering that international law seeks to regulate and govern activities related to the use of nuclear energy, nuclear weapons and nuclear non-proliferation, offering a set of norms and principles that aim to prevent the undue and uncontrolled use of nuclear energy, as well as promoting peaceful cooperation in this field.

Since the development of the first nuclear weapons during World War II, international law has played a key role in trying to control and regulate the use of these devastating weapons. The central landmark in this regard is the Treaty on the Non-Proliferation of Nuclear Weapons (NPT), which entered into force in 1970 and has been a pillar of international nuclear law. The NPT seeks to prevent the spread of nuclear weapons by promoting nuclear disarmament and facilitating access to nuclear energy for peaceful purposes (HANDRLICA, 2018).

In short, the relationship between international law and nuclear law is essential for regulating the peaceful use of nuclear energy and controlling the proliferation of nuclear weapons. While challenges remain, international law plays a key role in the quest for a safer, nuclear-weapon-free world.

3.6 Comparison among the types of areas indexed by the Scopus database on nuclear law

Figure 11 shows the comparison among the types of areas indexed by the Scopus database on nuclear law. It is interesting to note that more than half of the documents published on the subject were in the field of engineering, energy, and social sciences.

The highest concentration of indexed documents associated with the field of social sciences can be explained through four aspects: (1) social and political impacts; (2) public participation and decision-making; (3) global regulation and governance; and (4) historical perspective and normative evolution.

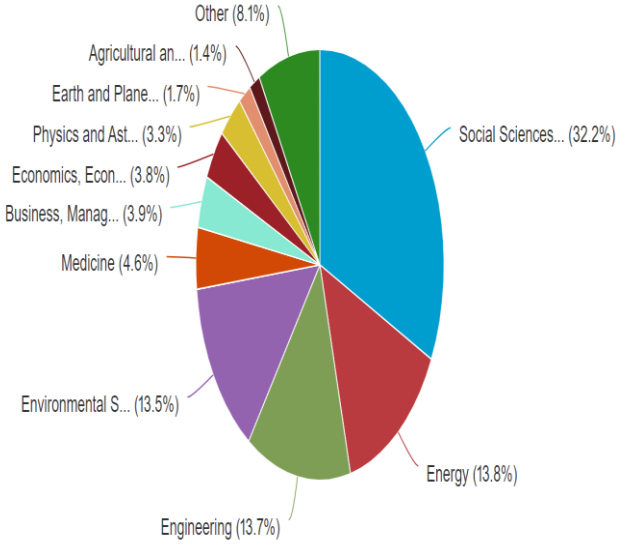

Fig.11: Comparison among the types of areas indexed by the Scopus database on nuclear law

Source: Developed by the Authors

In short, nuclear law is a multidisciplinary field that involves social, political, ethical, and legal issues. Social science researchers can explore nuclear law to understand the social and political implications of nuclear energy, analyze decision-making processes, examine global

governance, and investigate the field's normative evolution.

IV. CONCLUSIONS

Considering the limitations of this study, the main scientometric results related to the theme of nuclear law are the following: (1) the United Kingdom and the United States of America have the greatest collaboration in co-authorship between countries; (2) Charles University in Prague is the organization with the largest number of published documents; (3) Jakub Handrlica is the most published author on the subject; (4) the Journal of World Energy Law and Business has published a significant number of articles on the subject over the last 5 years; (5) nuclear energy and international law are the two most used keywords when the topic of the article is nuclear law; (6) the subject has a broader scope in the field of social sciences; and (7) no significant impact and frequency of Brazilian publications or authors was identified.

From the results, it is possible to conclude that the present scientometric study, based on the analysis of the scientific production on Nuclear Law, indexed by the Scopus database, between the years 1970 and 2023, using the VOSviewer tool, provided a comprehensive and detailed view of the evolution and trends of this area of knowledge over time.

The results revealed a notable growth in interest and scientific production in relation to Nuclear Law, especially in recent decades, following the accelerated development of the nuclear sector and the legal challenges that arose with this technological advance. This increase demonstrates the growing importance that the subject has acquired in the academic community and in society as a whole, highlighting its critical role in the formulation of policies, regulations and legal approaches to deal with complex and multifaceted core issues (FIALKOFF, MAN, 2022).

In addition, the analysis of citation networks and collaborations between researchers has enabled the identification of the main actors and institutions involved in the study of Nuclear Law, as well as the most relevant and interconnected themes that have been addressed in the scientific literature.

However, this study also highlighted the continuing need to invest in research in this area and encourage cooperation between researchers and institutions from different countries. Looking specifically at the discipline of Brazilian Nuclear Law, the scenario is worse than one can imagine. In fact, the literature in this field is quote sparse. There is no regular training in Nuclear Law in Brazil. Law academies do not offer knowledge of Nuclear Law, except for general classes in Regulatory Law, Administrative Law, and Constitutional Law, primarily because the core framework on nuclear activities is inserted in the Federal Constitution, which establishes the precept of monopoly, as well as the rules and principles related to nuclear activities. On the other hand, training in such areas as physics, chemistry, and nuclear engineering does not offer any type of approach to Nuclear Law.

Considering that Nuclear Law regulates nuclear activities in a broad sense, specifically from a legal point of view, this scenario reveals an inadequate and undesirable general internal framework, in view of the legal aspects of civil liability for nuclear damage, safeguards, the licensing process of nuclear energy, administrative sanctions, and legal proceedings in general (BARROS, 2011).

However, in 2022, during the 1st International Conference on Nuclear Law, held in Vienna, Austria, the International Atomic Energy Agency (IAEA) signed practical agreements with some countries, including Brazil, to support training in Nuclear Law. Due to this initiative, the IAEA and the National Nuclear Energy Commission of Brazil (CNEN) successfully produced the first training on Nuclear Law in May/June 2023. Today, CNEN, through its Institute of Nuclear Engineering, is preparing a postgraduate course in Nuclear Law, which is expected to begin in early 2024.

It is an important issue to understand whether this type of training will improve the scientific scenario of Nuclear Law in Brazil. Thus, it is recommended that future studies investigate the evolution of the impact and frequency of publications by Brazilian authors and the international cooperation of national institutions on the subject.

The expansion of knowledge in this field will require the involvement of experts from different disciplines, promoting a multidisciplinary approach that covers not only legal aspects, but also technical, ethical, and social issues related to nuclear energy that can be explored in future research: international responsibility in the case of nuclear accidents, cybersecurity, and the protection of nuclear infrastructure, safe transport of nuclear materials, ethical and social aspects of nuclear energy, comparative legislation on nuclear energy, protection of human rights in nuclear areas, and legal aspects of nuclear energy in contexts of conflict and international cooperation (GROSSI, 2022; JADALHAQ, ALQODSI, 2021).

In conclusion, the scientometric study of the scientific production on Nuclear Law, conducted using the

VOSviewer tool, brought a valuable contribution to the understanding of the evolution, geographic distribution, and collaboration of researchers in the area. The findings of this work are essential in supporting informed decision-making by legislators, government officials, and other actors involved in the regulation and governance of the nuclear sector. Technological progress will continue to generate complex challenges, and the science of Nuclear Law will play a vital role so that nuclear energy can be used in a safe and responsible manner, in line with legal and ethical principles, contributing to the wellbeing of humanity and the preservation of the environment.

REFERENCES

[1] Ampovska, M. (2013). Nuclear Energy and Nuclear Law in Macedonia and Neighbor Countries-Bulgaria, Serbia and Albania. *Balkan Social Science Review*, (1), 3-23.Ampovska, Marija et al. Nuclear Insurance Pools Worldwide: The Role In The Nuclear Law. Balkan Social Science Review, v. 9, n. 9, p. 7-21, 2017

[2] Ampovska, M. (2017). Nuclear insurance pools worldwide: the role in the nuclear law. *Balkan Social Science Review*, *9*(9), 7-21.

[3] Arbousset, H., Rambour, M., Schellenberger, T., Lahorgue, M. B., Leger, M., & Rubercy, G. D. (2021). Nuclear law January-December 2020. Synthesis. *Droit de l'Environnement*, 42-48.

[4] Barros, A. C. R. (2011). Ensaio jurídico sobre o dano nuclear no direito brasileiro.

[5] Bonyadi Naeini, A., & Moghiseh, Z. (2023). Open Access Scientific Outputs Published by Iranian Researchers: Scientometrics and Altmetrics Study. *Scientometrics Research Journal*, *9*(1), 125-150.

[6] Bowden, P. (2021). Principles and Practice of International Nuclear Law. *Nuclear L. Bull.*, *107*, 83.

[7] Giacomo, C., & Bugos, S. (2022). Putin Calls Up Reservists, Renews Nuclear Threat. *Arms Control Today*, *52*(8), 28-29.

[8] Burns, S. (2022). Milestones in Nuclear Law: A Journey in Nuclear Regulation. *Nuclear Law*, 55.

[9] Calmet, D. P. (1989). Ocean disposal of radioactive waste. Status report. *IAEA bulletin*, *31*(4), 47-50.

[10] Ekardt, F., & von Bredow, H. (2011). *Managing the ecological and social ambivalences of bioenergy: sustainability criteria versus extended carbon markets* (pp. 455-480). Springer Berlin Heidelberg.

[11] Herbach, J. (2021). *International Arms Control Law and the Prevention of Nuclear Terrorism*. Edward Elgar Publishing.

[12] Grossi, R. M. (2022). Nuclear Law: The Global Debate. *Nuclear Law*, 1.

[13] Handrlica, J. (2018). "atomic law" or "nuclear law"? An academic discussion Revisited. *BRICS Law Journal*, *5*(3), 135-151.

[14] Handrlica, J. (2021). Black swans, dragon kings and the uncertainty in international nuclear law. *The Journal of World Energy Law & Business*, *14*(1), 25-37.

[15] Handrlica, J. (2021). Book review: Handbook on European Nuclear Law: Competences of the Euratom Community under the Euratom Treaty, by Rasa Engstedt.(Alphen aan den Rijn: Kluwer Law International, 2021). *Common Market Law Review*, *58*(3).

[16] Handrlica, J. (2018). "EXCLUSIVISM" IN INTERNATIONAL NUCLEAR LAW: THE CONCEPT REVISITED. *The Lawyer Quarterly*, *8*(3).

[17] Handrlica, J. (2019). From the front lines of international nuclear law: looking back at the 'Nuclear Inter Jura'Congress, held in Abu Dhabi, United Arab Emirates. *The Journal of World Energy Law & Business*, *12*(3), 271-274.

[18] Handrlica, J. (2019). Nuclear law revisited as an academic discipline. *The Journal of World Energy Law & Business*, *12*(1), 52-68.

[19] Handrlica, J. (2021). The mirage of universalism in international nuclear liability law: A critical assessment 10 years after Fukushima. *Review of European, Comparative & International Environmental Law*, *30*(3), 375-386.

[20] Jadalhaq, I. M., & Alqodsi, E. M. (2021). Tort law makes a quantum leap: a review of the civil liability regime for nuclear operators in UAE law. *Journal of Property, Planning and Environmental Law*, *13*(1), 17-30.

[21] Kecskés, G. (2008). The concepts of state responsibility and liability in nuclear law. *Acta Juridica Hungarica*, *49*(2), 221-252.

[22] Kovudhikrulrungsri, L., & Nakseeharach, D. (2011). Liability Regime of International Space Law: Some Lessons from International Nuclear Law. *JE Asia & Int'l L.*, *4*, 291.

[23] Romanova, V., & Handrlica, J. (2019). Problems and Tendencies of Nuclear Law. *Russ. LJ*, *7*, 194.

[24] Sands, P. (1996). Observations on International Nuclear Law Ten Years after Chernobyl. *Rev. Eur. Comp. & Int'l Envtl. L.*, *5*, 199.

[25] Sziebig, O. J. (2021). The Challenges Of Nuclear Waste Disposal–International Environmental Law Perspective. *Curentul Juridic*, *86*(3), 88-100.

[26] Tanter, R. (2021). Hope Becomes Law: The Treaty on the Prohibition of Nuclear Weapons in the Asia-Pacific Region. *Journal for Peace and Nuclear Disarmament*, *4*(sup1), 234-275.

[27] Treinta, F. T., Farias Filho, J. R., Sant'Anna, A. P., & Rabelo, L. M. (2014). Methodology of bibliographical research using multicriteria decision-making methods. *Production*, *24*, 508-520.

[28] Van Eck, N., & Waltman, L. (2010). Software survey: VOSviewer, a computer program for bibliometric mapping. *scientometrics*, *84*(2), 523-538.