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Mapping of the Scientific Output on Nuclear Energy: A Scientometric Study

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ABSTRACT

The study analyzes the Mapping of Global Scientific Output in Nuclear Energy Research from 2002 to 2024. The study aims to evaluate the distribution of research patterns based on publications by scientists in the field of Nuclear Energy. The analysis is based on bibliographical records retrieved from the Web of Science (WoS) during the study period. Data was sourced from the Web of Science (WoS) database, covering the years 2002 to 2024. A total of 461,371 records were obtained using search queries that included the term "Nuclear Energy." The study finds that 2021 was the peak year for publications, with a total of 23,952 entries (5.18%). The annual growth rate (AGR) fluctuated between -0.0426 in 2004 and 21.9528 in 2008, with variations noted throughout the study period. The highest effective growth rate (EGR) recorded was 27.9055 in 2024, indicating a clear upward trend from 0.0741 in 2003 to 27.9055 by 2024. The findings provide insights into current activities and perspectives on research trends in the field. This study will be beneficial for policymakers, academics, and researchers aiming to stay informed about research developments. The study explores mapping techniques using field-specific data and applies innovative tools to conduct a quantitative analysis based on available bibliographical data at the global level from the Web of Science (WoS).

KEYWORDS: Nuclear Energy, Nuclear Power, Atomic Power, Atomic Energy, Web of Science, Doubling time, Exponential Growth Rate, Prolific Authors, Network Visualization.

INTRODUCTION

Nuclear energy is a form of energy released from the nucleus, the core of atoms, made up of protons and neutrons. This source of energy can be produced in two ways: fission, when nuclei of atoms split into several parts – or fusion – when nuclei fuse together. The Nuclear Energy harnessed around the world today to produce electricity is through nuclear fission, while technology to generate electricity from fusion is at the Research and Development phase. This article will explore nuclear fission, it demonstrates to learn more about nuclear fusion. Nuclear fission is a reaction where the nucleus of an atom splits into two or more smaller nuclei, while releasing energy. For instance, when hit by a neutron, the nucleus of an atom of uranium-235 splits into two smaller nuclei, for example a barium nucleus and a krypton nucleus and two or three neutrons.

These extra neutrons will hit other surrounding uranium-235 atoms, which will also split and generate additional neutrons in a multiplying effect, thus generating a chain reaction in a fraction of a second. Each time the reaction occurs, there is a release of energy in the form of heat and radiation. The heat can be converted into electricity in a nuclear power plant, similarly to how heat from fossil fuels such as coal, gas and oil is used to generate electricity (Andrea Galindo, 2022). Nuclear power plants have been around for over 60 years. During this time we have learned a lot about working in a nuclear power plant and what we need to know.

Nuclear power plants have become smarter and safer. 25 percent of all electricity in the EU is currently produced by nuclear power. To ensure that nuclear energy can contribute to climate neutral energy in the coming years, it is important that we continue research into the future. There is always something new to learn. Computer models are crucial to this research. The drastic increasingly powerful computers, we are better able to simulate what happens in and around the reactor. The results show what can still be improved and what innovations can really improve safety (NRG ,2020). For decades, NRG has conducted research in nuclear technology and nuclear power applications. Nuclear power can significantly contribute to a stable carbon-neutral energy supply.

NRG researches safe and reliable nuclear power generation in existing nuclear reactors and develops new and innovative concepts such as the thorium reactor. With these new concepts, we want to make nuclear energy more economical by increasing the use of resources and reducing the amount of radioactive waste. Important research areas include the recycling and storage of radioactive waste and improving the safety of people and the environment in nuclear technologies, for example through the development of new technologies in the field of radiation protection.

Atomic energy has played a vital role in the global energy landscape, despite the concerns raised by the 2011 Fukushima nuclear disaster regarding the future of nuclear power (IAEA,2014; Q. Wang, Chen, Yi-chong, 2013; Q. Wang, Li,2017). Currently, China, the world's largest energy consumer, is constructing approximately 24 reactors (Q. Wang, R. Li , 2016 ; IAEA , 2015). Meanwhile, the United States, the second-largest energy consumer, is either considering or building five new reactors (Y. Zhou , 2010). Additionally, Japan restarted its first nuclear reactor in August 2015 since the Fukushima incident. Given its status as the largest energy consumer, China has been focusing more on the expansion of non-fossil energy sources (X. Guo, X. Guo ,2016; A. Li, B. Lin ,2013).

Furthermore, the country favors the development of nuclear power due to its advantages over other clean energy alternatives (C. Medel-Vera, T. Ji , 2015). Existing literature reviews have primarily concentrated on specific technologies and the surrounding developmental environments. Carlos offers a comprehensive review of SPS in nuclear engineering (Uchida S, Otoha K, Ishigure K, 2006), while Shunsuke discusses water chemistry control technologies to ensure safe and stable operations in nuclear power plants. Our world runs on ‘energy’, and access to affordable sources of energy is essential not only for running modern industry but to meet our own basic necessities including electricity to our homes and operating our cars. As the world economy expands, energy demand is likely to increase, no matter what efforts are made to increase the efficient use of energy (Poole, Bain, Cavallo, Larson,., Macedo, Barnett, 1992).

RENEWABLE ENERGY

The expansion of distributed energy resource (DER) projects is notable in industrialized countries, particularly in Europe. This development has contributed to the reduction of CO2 emissions, a decrease in the use of primary energy sources (PES), and an increase in the adoption of renewable technologies (H.L. Ferreira, Costescu, L'Abbate, Minnebo, Fulli , 2011). In contrast, underdeveloped and developing nations often experience low economic growth and poor human development indices (HDI). Issues such as low income, unstable economies, inadequate governance, and historical challenges related to technology transfer, high costs associated with technical innovation (M. Bell, K. Pavitt ., 1997), and insufficient environmental and technological policies contribute to these conditions. Nonetheless, recent decades have witnessed industrial progress and advancements in education that have influenced various economic sectors, leading to the introduction of new regulations and policies in energy markets.

Such changes have promoted the adoption of technologies aimed at minimizing environmental impacts and fostering social and economic development within local communities (C. Newman, J. Rand, 2012). Consequently, the use of mathematical modeling tools, tailored to the specific characteristics of developing nations, has been enabled to identify trends, barriers, challenges, opportunities, and benefits associated with the implementation of distributed energy resources. The economic climate represents a significant challenge to increasing the role of renewable resources in energy generation within these nations.

Thus, the adoption of more efficient technology is seen as a way to support the transition to distributed energy systems instead of centralized ones (Z. Hussein, T. Hertel, 2013). There is a notable preference for renewable sources as the foundation of energy systems, particularly in off-grid configurations, due to specific criteria and comparatively lower dependence on fossil fuels and biofuels. The use of renewable energy has increased in developing countries; for instance, India has achieved a 20% growth in power generation from green sources (R. Pandey, 2002) .

Brazil has implemented substantial economic mechanisms to enhance the integration of renewable energy sources in the transformation of its energy sector (D.M. Kammen, C. Kirubi, 2008). However, reliance on environmental factors necessitates the use of conventional technologies as a fallback option, with new technologies being employed as storage solutions (B. Jairaj, Martin, Ryor, S. Dixit, A. Gambhir, Chunekar, Bharvirkar, Jannuzzi, Sukenaliev, 2016). This situation can lead to increased capital costs and a reliance on subsidies and external strategies. According to the World Bank, approximately 15% of the global population lacks access to energy facilities, primarily affecting rural, low-income areas in emerging nations (World development indicators, 2016).

REVIEW OF LITERATURE

Price (1963) first reported that the proportion of multi-authored research papers in research literature was increasing. Large industrial projects, improvements in communication facilities led by information technology, and the mobility of researchers created fertile ground for researchers to work in groups (Luukkonen, Persson, & Sivertsen, 1992 ; Beaver, 2001). Using co-authorship to measure scientific collaboration has been a subject of significant interest since the 1960s (de Price, & Beaver, 1966. ; Glänzel & Schubert, 2005 ; Melin, & Persson,1996. Newman, 2001). Co-authorship studies garnered renewed interest after (Barabasi, & Albert, 1999). Quantitative methods could be used to investigate the macro and micro characteristics of large co-authorship networks. Two network models commonly investigated are the 'scale-free' and 'small-world' models. In a scale-free network, popular nodes attract significantly more edges than others in the network (Watts, & Strogatz, 1998).

The scale-free character of the network is generally responsible for the short distance between nodes, a phenomenon also known as 'small-world' (Barabasi, Jeong, Neda, Ravasz, Schubert & Vicsek, 2002 ; Newman, 2001) followed up with Newman's 2001 work (Newman, 2004) which investigated the dynamics and evolution of co-authorship networks. Co-authorship networks have since been studied extensively in variety of ways and in several realms of both the natural and social sciences (Moody, 2004. ; Quatman, & Chelladurai, 2008 ; Yan, Ding, Zhu, 2010 ; Racherla & Hu, 2010). Studies examining co-authorship networks have found correlations between centrality measures and productivity (Lewison & Markusova, , 2010 ; Uddin, Hossain, Abbasi & Rasmussen, 2012 ; Yan, E. Ding & Zhu, 2010). Scholars work in certain communities based on their research interests, and this could be deciphered, at times, by network patterns (Kumar, Jan, 2013). The underlying cognitive structure created by the scholarship has also been analysed extensively (Girvan, Newman, 2002 ; Boyack, Klavans, Börner, 2005 ;Mane, Börner, 2004). The research was conducted based on Web of Science data for the 1993–2021 periods. The study found out that India's research effort in the energy storage and conversion field was significantly less than world production for all years in the study period from 1993 to 2021 (Chinnasamy, B., Yuvakkumar, R., Kumar, P.S. *et al.*, 2022).

Gupta, Ahmed and Gupta (2018) analysed the publications on Tinospora cordifolia research for the period of 2001-2016. It analysed 865 global and 747 Indian the publications on Tinosporacordifolia research. Gupta, B. M., Ahmed, K. M., Dhawan and Gupta evaluated the global publications on Aloe Vera research for the period of 2007-16. For this study a total of 1988 records were retrieved from Scopus database. The annual average growth rate and average citation impact were found to be 3.91% and 9.57 CPP respectively in Aloe Vera research. Jayabal and Balasubramanian (2018) evaluated the research papers published in the Indian Journal of Chemical Technology during the years from 2008 to 2017. The main aim of the study is to report the publication trends in the field of chemical engineering and technology. A total of 646 research papers were analysed for the purpose of this study.

Saravanan and Baskaran (2020) analysed the research output in Bioremediation literature during 1994 to 2018. The study covered number of publication, Relative growth rate and doubling time, scattering of publication over journals, and its impact, over journals, authorship pattern, Citation analysis, Baba atomic research centre and CSIR are the leading institutions in the area of bioremediation research output . Ahmed, Gupta, Bansal and Bansal (2019) examined the research output on the "Rhodiolarosea" plant during the period of 1993-2018. The data for this study were collected from Scopus database. The study reported the average annual growth, international collaborative papers, relative citation index, citations per paper, activity index, productive countries, Prolific organizations, Prolific authors, Prolific journals and highly cited papers.

Ameer and Afzal, M (2019) carried out a study to evaluate the indices belonging to two different factors in the field of neuroscience research. The two different factors assessed here are quantitative variants which include h-index, hg-index, e-index and m-quotient and qualitative variants which include R-index and f-index. Bid, Subhodip and Mandal, Sukumar (2020) discussed about India leads China in terms of average citation per paper. China shows tremendous growth after 2012. In terms of collaboration, Germany is at the top with India and USA is at the top with China. Bilson, Albert PaaKojoEbi (2019) analysed that the International Nuclear Information System (INIS) database and the search query language (country: Ghana AND record type: Thesis/Dissertation) were the main instruments used in retrieving the data before extracting them onto Microsoft excel spread sheet for analysis.

Madni Sohail et al. (2022) focussed that the resource assessment shows that for economical hybrid energy system the average annual wind speed and average annual solar radiation should be 5 m/s and 5 KWh/m^2 respectively.

The map of hybrid renewable energy system research in developing regions is not available. Our study gives energy scenario and clear map of hybrid energy in developing regions of the world. Baskaran (2020) analyzed by Web of Science (WoS) database from Clarivate analytics for purpose of study during period. It analyses the highest 441 (9.04%) of the publications appeared in the year 2018. The highest number of publications (679; 9%) and the most significant developments in nuclear fuel research is from USA, France, South Korea and Germany. Mondal (2018) reported the Saha Institute of Nuclear Physics (SINP) is one of the prestigious autonomous research institutes under the Department of Atomic Energy, Govt. of India. The present study is carried out to identify the research performance of the scientists of SINP during 2005-2016. Baskaran (2021) analyses the research paper on the publications of Web 2.0 during 2000-2019 and total no. 7123 publications recorded over the period of study. A maximum 825 (12.08%) of the publications appeared in 2016 .

RESEARCH QUESTIONS

1. Is there a clear trend of growth in research publications related to Nuclear Energy from 2002 to 2024, as indicated by the year-wise distribution of publications?
2. Does the research reveal a growth pattern that supports the Relative Growth Rate and Doubling Time in the Nuclear Energy sector?
3. Was the validated data examined using the Annual Growth Rate (AGR), Exponential Growth Rate, and Time Series Analysis in the field of Nuclear Energy during the years 2002 to 2024?
4. Can we identify a greater number of publications categorized by document type and language distribution in the area of Nuclear Energy?
5. Have the rankings of publications been established concerning prolific authors, countries, subjects, institutions, funding agencies, and publications indexed in the Web of Science Database?

SIGNIFICANT OF THE STUDY

The demand for bibliometric indicators has risen sharply due to the significant increase in scientific output in this century. The abundance of literature publications allows these indicators to effectively characterize research activities. This study examines the characteristics and utilization of literature related to nuclear power, focusing on the development and organization within this field. The bibliometric method offers a valuable quantitative perspective for assessing the growth and direction of research in nuclear energy. The increasing recognition of the importance and advantages of nuclear power technologies has attracted more attention in research.

Therefore, it is crucial to evaluate the rapidly expanding literature on nuclear energy. The research aims to identify growth trends and map the scientific output in the field of Nuclear Energy, analysing aspects such as year-wise distribution, document types, language distribution, prolific authors, countries, subjects, institutions, funding agencies, and publications indexed in the Web of Science Database from 2002 to 2024.

LIMITATION OF THE STUDY

This study employs bibliometric methods to analyse trends in nuclear power literature, aiming to characterize the landscape and features of nuclear power research while forecasting emerging directions. It examines publications related to nuclear energy from 2002 to 2024 and their implications. A total of 461,371 records were identified from the Web of Science for the years 2002 to 2026. However, data from the years 2025 and 2026 has been excluded, as those publications have not yet been released in the relevant journals within the field of nuclear energy.

METHODOLOGY

The study aim to evaluate the distribution of research patterns based on publications by scientists in the field of Nuclear Energy. Data was sourced from the Web of Science (WoS) database, covering the years 2002 to 2024. A total of 461,371 records were obtained through search queries including terms such as “Nuclear Energy.” The data was analyzed using MS-Excel in alignment with the study's objectives and presented in both tabular and graphical formats. This research examines the annual distribution of publications, growth rates, citation trends, and performs time series analysis and exponential growth rate assessments.

The analysis process involved exporting data into a CSV file and conducting a comprehensive review. The study focuses on relative growth rates, doubling times, prolific authors, and institutions within the context of Nuclear Energy literature from 2002 to 2024. The search utilized the following terms: “nuclear power,” “atomic power,” “nuclear energy,” “atomic energy,” “nuclear reactor*,” “nuclear accident*,” and “nuclear plant*.”

Moreover, an article may feature co-authors from various institutions and countries. Collaboration is determined by the affiliations provided for each author; papers with authors hailing from the same institution or country are classified as "independent," whereas those with authors from at least two different institutions or countries are regarded as examples of "international collaboration." As a result, the total number of papers for the three categories (Country productivity distribution and Institution Analysis) published by each institution or country exceeds the overall count of publications (B. Dong, Xu, X. Luo, Cai, W. Gao, 2012).

Year wise Distribution of in the scientific productivity of Nuclear Energy

The analysis of publication distribution by year aimed to evaluate growth trends within the Nuclear Energy area. Data from Table 1 shows that a total of 461,371 publications related to Nuclear Energy were sourced from the Web of Science (WoS) for the years 2002 to 2024. The findings indicate that the peak year for publications was 2021, which recorded 23,952 entries (5.18%). This was followed closely by 22,913 publications (9.57%) in 2022, 21,721 (4.70%) in 2020, 20,312 (4.39%) in 2019, 19,674 (4.26%) in 2018, and 19,117 (4.14%) in 2017. Conversely, publication activity was notably lower in 2002, which saw only 8,194 publications, accounting for just 1.74% of the total.

The study underscores a steady increase in the number of publications over the years, with the exceptions of 2002, 2012, 2015, 2022, and 2023, and productivity figures of 9,375 (2.03%), 14,692 (3.18%), 17,903 (3.87%), 22,913 (4.96%), and 22,119 (4.79%), respectively. Overall, this suggests that researchers in Nuclear Energy have consistently contributed to the field over period of study. This analysis specifically focused on the period from 2008 to 2024, as it was observed that significant research contributions began around the year 2000.

Table 1: Year wise Distribution of Scientific productivity of Nuclear Energy

Year	No. of Productivity	%
2002	8194	1.776
2003	8555	1.854
2004	9380	2.033
2005	9376	2.032

2006	9515	2.062
2007	9683	2.099
2008	10354	2.244
2009	12627	2.737
2010	12719	2.757
2011	15059	3.264
2012	14693	3.185
2013	16695	3.619
2014	17339	3.758
2015	17903	3.88
2016	18127	3.929
2017	19116	4.143
2018	19675	4.264
2019	20312	4.403
2020	21720	4.708
2021	23952	5.191
2022	22913	4.966
2023	22120	4.794
2024	24338	5.275
Total	461371	

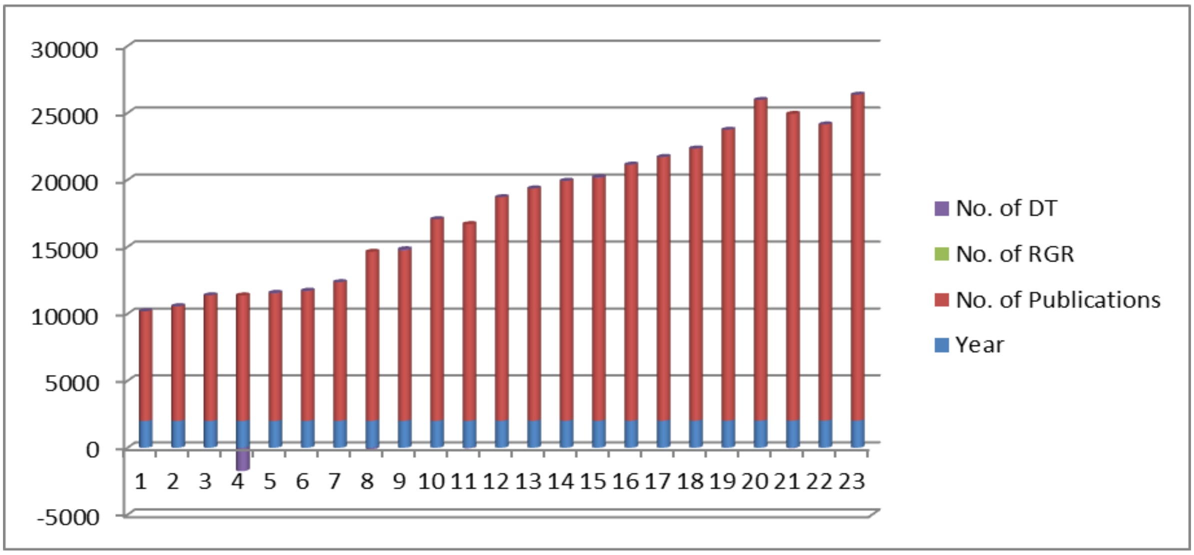

Figure 1 : Relative Growth Rate and Doubling Time in the Scientific productivity of Nuclear Energy

Document type distribution in the scientific productivity of Nuclear Energy

Table 2 outlines the types of documents published in the global literature on Nuclear Energy, highlighting research conducted worldwide from 2002 to 2022. The analysis shows that out of a total of 461,371 publications, journal articles dominate, comprising 437,995 (94.93%) of the total. This indicates that the majority of significant research in the field of Nuclear Energy has been disseminated through journal articles. The results further categorize the document types, revealing that proceeding papers accounted for 62,726 (13.59%), followed by review articles at

14,109 (3.05%), editorial materials at 2,613 (0.56%), meeting abstracts at 2,093 (0.56%), and early access documents at 1,867 (0.40%). Letters, notes, and corrections represent smaller portions of the publications, with 1,384 (0.30%), 1,095 (0.23%), and 1,028 (0.22%), respectively.

Further, the study identifies that sixteen document types each have fewer than a thousand contributions to Nuclear Energy research. Generally, journal articles are the predominant publication format across research disciplines, as researchers in this specific field prefer to publish their work in peer-reviewed and indexed journals relevant to their areas of expertise.

Table 2: Document type distribution of the scientific productivity of Nuclear Energy

S. NO	Document type	No. of Records	%
1	Article	437995	94.933
2	Bibliography	83	0.018
3	Biographical-Item	55	0.012
4	Book Chapters	421	0.091
5	Book Review	185	0.04
6	Correction	1028	0.223
7	Correction, Addition	60	0.013
8	Data Paper	38	0.008
9	Discussion	13	0.003
10	Early Access	1867	0.405
11	Editorial Material	2613	0.566
12	Expression Of Concern	1	0
13	Item About an Individual	13	0.003
14	Letter	1384	0.3
15	Meeting Abstract	2093	0.454
16	News Item	575	0.125
17	Note	1095	0.237
18	Proceeding Paper	62723	13.595
19	Publication With Expression Of Concern	5	0.001
20	Reprint	34	0.007
21	Retracted Publication	161	0.035
22	Retraction	26	0.006
23	Review Article	14109	3.058
24	Software Review	7	0.002

Language wise distribution in the Scientific productivity of Nuclear Energy

Table 3 examines the research publications produced in various languages, highlighting six significant contributions to research productivity in the field of Nuclear Energy from 2002 to 2024. The analysis reveals that a substantial majority of the research evidence 454,783 publications (98.57%) was published in English, making it the leading language for Nuclear Energy research. Globally, journal publications from various publishers and citations are primarily measured based on English-language research productivity.

The study identified other than English language, there were five languages that contributed to research in this field, with notable counts: Chinese with 3,657 publications (0.79%), German with 952 (0.20%), Russian with 733 (0.15%), Japanese with 663 (0.14%), and French with 209 (0.04%). In conclusion, the study notes that other languages contributed only a small number of publications, with most regional languages registering single-digit counts in the core field of Nuclear Energy.

Table 3: Language wise distribution of the scientific productivity of Nuclear Energy

S. No.	Languages	No. of Records	%
1	Afrikaans	2	0
2	Chinese	3657	0.793
3	Czech	13	0.003
4	English	454783	98.572
5	Finnish	5	0.001
6	French	209	0.045
7	German	952	0.206
8	Greek	3	0.001
9	Hungarian	13	0.003
10	Italian	19	0.004
11	Japanese	663	0.144
12	Korean	76	0.016
13	Lithuanian	3	0.001
14	Malay	3	0.001
15	Norwegian	4	0.001
16	Polish	32	0.007
17	Portuguese	59	0.013
18	Russian	733	0.159
19	Serbian	3	0.001
20	Serbo Croatian	3	0.001
21	Spanish	95	0.021
22	Turkish	6	0.001
23	Ukrainian	19	0.004
24	Unspecified	5	0.001
25	Welsh	3	0.001

Annual Growth Rate (AGR)

Growth rates refer to the percentage change of a specific variable within a specific time period, given a certain context. The annual growth rate of publications was calculated from the following formula

$$AGR = \frac{\text{End value} - \text{First value}}{\text{First value}} \times 100$$

Table 4 presents an analysis of the Annual Growth Rate (AGR) of publications in the field of Nuclear Energy from 2002 to 2024. The AGR varied between -0.0426 in 2004 and 21.9528 in 2008. Throughout the study period, fluctuations in the annual growth rate were observed. The highest annual growth rate occurred in 2008, reaching 300, followed by rates of 18.2976 in 2010, 13.6255 in 2012, and 10.2762 in 2020. The average AGR for the entire study period from 2002 to 2024 is calculated to be 4.4584 .

Table 4: Annual Growth Rate (AGR) in the scientific productivity of Nuclear Energy

Year	No. of Papers	%	Annual Growth Rate (AGR)
2002	8194	1.776	0
2003	8555	1.854	9.6666
2004	9380	2.033	-0.0426
2005	9376	2.032	1.4825
2006	9515	2.062	1.7656
2007	9683	2.099	6.8965
2008	10354	2.244	21.9528
2009	12627	2.737	0.7285
2010	12719	2.757	18.3976
2011	15059	3.264	-2.4304
2012	14693	3.185	13.6255
2013	16695	3.619	3.8574
2014	17339	3.758	3.2527
2015	17903	3.88	1.2511
2016	18127	3.929	5.4559
2017	19116	4.143	2.9242
2018	19675	4.264	3.2376
2019	20312	4.403	6.9318
2020	21720	4.708	10.2762
2021	23952	5.191	-4.3378
2022	22913	4.966	-3.4609
2023	22120	4.794	10.0271
2024	24338	5.275	0.0040
		Mean	4.4584

Exponential Growth Rate (EGR)

Exponential growth rate can be used to predict future population of any species of animals. It is used globally to predict human population. With the knowledge of the periodic rate i.e., the number of years through which the growth rate is to be calculated for the original population, calculation of the exponential growth rate can be done with ease. The formula for calculating the exponential growth is given below:

$$N_{(t)} = N_{(0)}(1 + r)^t$$

Where,

$N_{(t)}$ = the population when the time elapsed is “t” years

$N_{(0)}$ = the initial publications

r= the growth rate

t=the number of years

Exponential Growth Rate in the Scientific productivity of Nuclear Energy

Table 5 presents an analysis of the average exponential growth rate (EGR) for publications in the field of Nuclear Energy from 2002 to 2024. The analysis shows that the highest EGR, recorded at 27.9055, occurred in 2024. It illustrates a clear upward trend in EGR, starting at 0.0741 in 2003 and rising to 27.9055 by 2024.

Furthermore, the study notes that the EGR was below 1 during the period from 2003 to 2007, increased to more than 1 but less than 5 from 2008 to 2013, then surpassed 6 and reached over 20 between 2014 and 2021, and finally exceeded 20 from 2021 to 2024.

Table 5: Exponential Growth Rate in the scientific productivity of Nuclear Energy

S. No	Year	No. of Publications	%	Exponential Growth Rate (EGR)
1	2002	8194	1.776	0
2	2003	8555	1.854	0.0741
3	2004	9380	2.033	0.1829
4	2005	9376	2.032	0.3251
5	2006	9515	2.062	0.5155
6	2007	9683	2.099	0.7557
7	2008	10354	2.244	1.0996
8	2009	12627	2.737	1.7515
9	2010	12719	2.757	2.2329
10	2011	15059	3.264	3.2639
11	2012	14693	3.185	3.8534
12	2013	16695	3.619	5.2107
13	2014	17339	3.758	6.3512
14	2015	17903	3.88	7.6055
15	2016	18127	3.929	8.8401
16	2017	19116	4.143	10.6068
17	2018	19675	4.264	12.3243
18	2019	20312	4.403	14.2641
19	2020	21720	4.708	16.9948
20	2021	23952	5.191	20.7659

21	2022	22913	4.966	21.9013
22	2023	22120	4.794	23.2049
23	2024	24338	5.275	27.9055

Relative Growth Rate (RGR)

The Relative Growth Rate (RGR) expresses growth in terms of a rate of increase in size of publications per unit of time. The growth of publications was analysed by using two parameters RGR and DT (Mahapatra ,1994). The mean Relative Growth rate (R) over the specific period of interval can be calculated from the following formula.

$$R\ (1 - 2) = \frac{W_2 - W_1}{T_2 - T_1}$$

Whereas,

R = Mean relative growth rate over the specific period of interval

W_1 = Log of initial number of publications

W_2 = Log of final number of publications after a specific period of interval

$T_2 - T_1$ = the unit difference between the initial time and final time.

Doubling Time (DT)

The Doubling time is directly related to RGR. If the numbers of publications or pages of subject double during a given period, then the difference in the logarithms of numbers at the beginning and end of this period must be logarithms of number 2. If natural logarithm is used, this difference has a value of 0.693. Thus the corresponding doubling time for each specific period of interval and for both publications and pages can be calculated by the formula.

$$\text{Doubling Time (DT)} = \frac{0.693}{R}$$

Where,

R = Relative Growth Rate

Relative Growth Rate and Doubling Time in the scientific productivity of Nuclear Energy

Table 6 presents an analysis of the relative growth rate (RGR) and doubling time (Dt) of publications by prominent scientists in the field of Nuclear Energy from 2002 to 2024. Throughout the study period, RGR exhibited an increasing trend, while Dt showed a decreasing trend. The RGR for publications in Nuclear Energy varied from -0.0004 in 2005 to 0.1689 in 2011. Doubling time began at -15.608 and increased to 55.887 by 2022 and 2016, respectively.

The lowest values recorded for RGR and Dt were -0.0004 in 2005 and -15.608 in 2022. The study concludes that the average mean values for RGR and Dt over the entire period were 0.0399 and -63.7617, respectively, in the field of Nuclear Energy research (Figure 1).

Table 6: Relative Growth Rate and Doubling Time in the scientific productivity of Nuclear Energy

Year	No. of Publications	%	W1	W2	RGR (W_2-W_1)	DT (0.693/R)
2002	8194	1.776	0	9.0111	0	0.000
2003	8555	1.854	9.0111	9.0542	0.0431	16.079
2004	9380	2.033	9.0542	9.1463	0.0921	7.524
2005	9376	2.032	9.1463	9.1459	-0.0004	-1732.500
2006	9515	2.062	9.1459	9.1606	0.0147	47.143
2007	9683	2.099	9.1606	9.178	0.0174	39.828
2008	10354	2.244	9.178	9.2451	0.0671	10.328
2009	12627	2.737	9.4508	9.4435	-0.0073	-94.932
2010	12719	2.757	9.4435	9.4508	0.0073	94.932
2011	15059	3.264	9.4508	9.6197	0.1689	4.103
2012	14693	3.185	9.6197	9.5951	-0.0246	-28.171
2013	16695	3.619	9.5951	9.7228	0.1277	5.427
2014	17339	3.758	9.7228	9.7607	0.0379	18.285
2015	17903	3.88	9.7607	9.7927	0.032	21.656
2016	18127	3.929	9.7927	9.8051	0.0124	55.887
2017	19116	4.143	9.8051	9.8582	0.0531	13.051
2018	19675	4.264	9.8582	9.8871	0.0289	23.979
2019	20312	4.403	9.8871	9.9189	0.0318	21.792
2020	21720	4.708	9.9189	9.9859	0.067	10.343
2021	23952	5.191	9.9859	10.0838	0.0979	7.079
2022	22913	4.966	10.0838	10.0394	-0.0444	-15.608
2023	22120	4.794	10.0042	10.0042	0	0.000
2024	24338	5.275	10.0042	10.0997	0.0955	7.257
				Mean	0.0399	-63.7617

Prolific Authors on Nuclear Energy in the scientific productivity of Nuclear Energy

Table 7 displays the prolific authors who have published research in the field of Nuclear Energy. This analysis identifies unique authors who contributed to publications during the study period from 2002 to 2024. The top fifty authors, ranked by their publication counts, are listed below. The highest-ranked author is Zhang Jing, with 5,630 publications (1.22%), followed by ten more authors who have demonstrated significant research output: Zhang Y with 5,341 (1.158%), Wang J with 5,137 (1.113%), Zhang L with 5,117 (1.113%), Liu Y with 4,984 (1.08%), Wang Y with 4,523 (0.98%), Wang Z with 4,161 (0.902%), Yang Y with 4,129 (0.895%), Banerjee S with 4,102 (0.889%), and Wang H with 3,885 (0.842%).

The study reveals that among the fifty authors listed, twenty-five have achieved notable publication counts. Out of these, four authors have surpassed five thousand publications, five authors have surpassed four thousand, and sixteen authors have recorded over three thousand publications within the field of Nuclear Energy. The study indicates that a majority of these scientists are from China, showcasing their initiative in exploring innovative research ideas and contributing to the literature in this domain.

Author name disambiguation is a difficult and unresolved issue in bibliometrics (Garfield, 1969; Tang, & Walsh, 2010). Thomson Scientific has made internal disambiguation efforts on a massive scale (Smalheiser & Torvik, 2009). to reduce errors resulting from name variations of the same author and different authors that have the same name. Records were further checked manually for issues with author names. Recent bibliometric records also have more accurate author–institutional identification and a separate field for the author's full name. These qualities made it easier to disambiguate the names to the best extent possible. Still, given the complex nature of author name disambiguation, it remains a limitation of this study.

Table 7: Prolific Authors in the scientific productivity of Nuclear Energy

S. No	Authors	No. of Publications	%
1	Zhang J	5630	1.22
2	Zhang Y	5341	1.158
3	Wang J	5137	1.113
4	Zhang L	5117	1.109
5	Liu Y	4984	1.08
6	Wang Y	4523	0.98
7	Wang Z	4161	0.902
8	Yang Y	4129	0.895
9	Banerjee S	4102	0.889
10	Wang H	3885	0.842
11	Li H	3790	0.821
12	Chen Y	3759	0.815
13	Li L	3730	0.808
14	Li J	3704	0.803
15	Liu H	3704	0.803
16	Gao Y	3687	0.799
17	Zhang Z	3665	0.794
18	Kim H	3614	0.783
19	Zhang H	3599	0.78
20	Li X	3530	0.765
21	Wang C	3523	0.764
22	Li Y	3498	0.758
23	Chen X	3423	0.742
24	Kumar A	3370	0.73
25	Lee S	3284	0.712

Time Series Analysis in the scientific productivity of Nuclear Energy

Time series analysis is a forecasting technique that examines patterns in data over time for a specific variable, focusing on trends and cycles. A time series consists of observations gathered at designated time intervals, typically at consistent intervals. In this research, time series analysis is employed to predict future publication trends in Nuclear Energy Literature.

Table 8 offers a clear analysis of the projected trends in Nuclear Energy Literature output. The findings indicate that the output is expected to rise significantly, increasing from -90,134 publications in 2002 to an anticipated 267,718 publications by 2024. Consequently, it can be inferred that the output of Nuclear Energy literature is likely to show a positive growth trend in the coming years. The analysis also reveals a negative growth trend between 2002 and 2012, with rates fluctuating from -90,134 to -14,693. In contrast, a positive growth trend is observed in the time series, with output increasing from 17,339 publications in 2014 to the projected figure of 267,718 in 2024.

Table 8: Time Series Analysis in the scientific productivity of Nuclear Energy

Year	No. of Publications (Y)	%	X	X2	XY
2002	8194	1.776	-11	-121	-90134
2003	8555	1.854	-10	100	-85550
2004	9380	2.033	-9	81	-84420
2005	9376	2.032	-8	64	-75008
2006	9515	2.062	-7	49	-66605
2007	9683	2.099	-6	36	-58116
2008	10354	2.244	-5	25	-51770
2009	12627	2.737	-4	16	-50508
2010	12719	2.757	-3	9	-38157
2011	15059	3.264	-2	4	-30118
2012	14693	3.185	-1	-1	-14693
2013	16695	3.619	0	0	0
2014	17339	3.758	1	1	17339
2015	17903	3.88	2	4	35806
2016	18127	3.929	3	9	54381
2017	19116	4.143	4	16	76464
2018	19675	4.264	5	25	98375
2019	20312	4.403	6	36	121872
2020	21720	4.708	7	49	152040
2021	23952	5.191	8	64	191616
2022	22913	4.966	9	81	206217
2023	22120	4.794	10	100	221200
2024	24338	5.275	11	121	267718

Institutions-wise Distribution in the Scientific productivity of Nuclear Energy

Table 9 and Figure 2 illustrate the distribution of publications in the field of Nuclear Energy across various institutions. Among the top fifty institutions, the United States Department of Energy (DOE) made the largest contribution with 67,513 publications (14.63%). This is followed by INFN with 35,779 publications (7.75%), the Chinese Academy of Sciences with 30,117 publications (6.53%), the Helmholtz Association with 26,082 publications (5.65%), and CNRS with 25,900 publications (5.61%). Other significant contributors include the University of California System with 24,434 (5.30%), the Russian Academy of Sciences with 19,177 (4.16%), CEA with 18,161 (3.94%), the National Research Centre Kurchatov Institute with 18,052 (3.91%), and Université Paris Saclay with 18,003 (3.90%) of the Publications.

Further, the analysis revealed through figure 2, among twenty-five ranked institutions, only one has contributed more than ten percent of the publications, while seven institutions have surpassed five percent. Notably, researchers from China displayed the highest productivity in the Nuclear Energy sector, a result attributed to significant investments in research facilities and infrastructure, providing researchers with valuable experience and fostering a robust research culture in the field.

Table 9: Institutions-wise Distribution in the scientific productivity of Nuclear Energy

S. No.	Affiliations	No. of Publications	%
1	United states Department of Energy DOE	67513	14.632
2	Istituto Nazionale di Fisica Nucleare INFN	35779	7.754
3	Chinese Academy of Sciences	30117	6.527
4	Helmholtz association	26082	5.653
5	Centre National de la Recherche Scientifique CNRS	25900	5.613
6	University of California system	24434	5.295
7	Russian Academy of Sciences	19177	4.156
8	CEA	18161	3.936
9	National research Centre kurchatov institute	18052	3.912
10	Universite Paris Saclay	18003	3.902
11	Joint institute for Nuclear research Russia	15545	3.369
12	CNRS National Institute of nuclear and particle physics in2p3	15277	3.311
13	Max Planck society	13683	2.965
14	Japan Atomic Energy Agency	13398	2.904
15	Tsinghua University	12636	2.739
16	European organization for Nuclear Research CERN	12441	2.696
17	Los Alamos National Laboratory	12355	2.678
18	University system of OHIO	12020	2.605
19	Lawrence Berkeley National laboratory	11763	2.549
20	Consejo superior de investigaciones cientificas csic	11501	2.493

21	Institute of high Energy physics CAS	11361	2.462
22	Massachusetts institute of technology MIT	11360	2.462
23	University of CaliforniaB berkeley	11091	2.404
24	University of Tokyo	11045	2.394
25	Sandia National Laboratories	10774	2.335

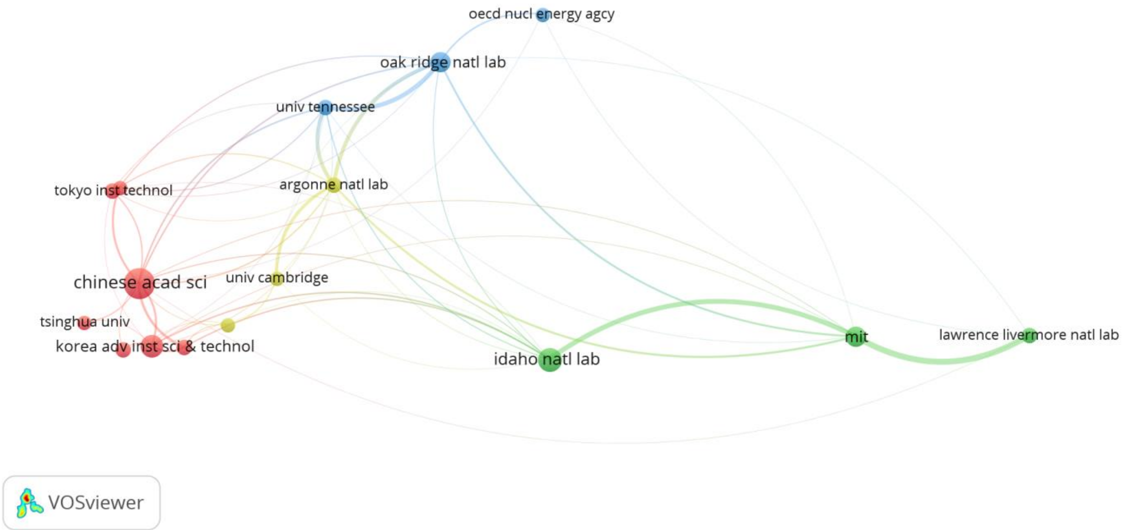

Figure 2: Institutions-wise Distribution in the Scientific productivity of Nuclear Energy (Network Visualization).

Subject wise Distribution of in the Scientific productivity of Nuclear Energy

Table 10 and Figure 3 illustrate the subject-wise distribution of publications on Nuclear Energy from 2002 to 2024. According to this distribution, the top twenty-five subject areas are identified among the forty-six most productive subjects in this field. Physics is the most productive subject, with 217,781 publications (47.198%). Following this, Nuclear Science and Technology ranks second with 121,463 publications (26.324%), followed by Chemistry with 64,782 (14.04%), Material Science with 54,501 (11.81%), and Engineering with 35,745 (7.747%).

Other notable areas include Astronomy and Astrophysics with 32,050 (6.94%), Science Technology Other Topics with 20,484 (4.43%), Energy Fuels with 16,162 (3.50%), Environmental Sciences and Ecology with 13,482 (2.922%), Radiology, Nuclear Medicine, and Medical Imaging with 12,741 (2.76%), and Biochemistry and Molecular Biology with 10,287 (2.22%).

The study reported that the remaining thirteen subjects had fewer than ten thousand records, and nine subjects had fewer than five thousand records in the field of Nuclear Energy. Furthermore, the study explored the most productive subjects based on publications observed in the field of Nuclear Energy during this period, providing evidence of the research potential within this core area.

Table 10: Subject wise Distribution in the scientific productivity of Nuclear Energy

S. No.	Research Area	No. of Publications	%
1	Physics	217781	47.198
2	Nuclear Science Technology	121463	26.324
3	Chemistry	64782	14.04
4	Materials Science	54501	11.812
5	Instruments Instrumentation	45854	9.938
6	Engineering	35745	7.747
7	Astronomy Astrophysics	32050	6.946
8	Science Technology Other Topics	20484	4.439
9	Energy Fuels	16162	3.503
10	Environmental Sciences Ecology	13482	2.922
11	Radiology Nuclear Medicine Medical Imaging	12741	2.761
12	Biochemistry Molecular Biology	10287	2.229
13	Metallurgy Metallurgical Engineering	8618	1.868
14	Optics	8266	1.791
15	Thermodynamics	5884	1.275
16	Mechanics	5549	1.203
17	Electrochemistry	4502	0.976
18	Polymer Science	4119	0.893
19	Computer Science	3960	0.858
20	Public Environmental Occupational Health	3516	0.762
21	Spectroscopy	3329	0.721
22	Geology	3188	0.691
23	Cell Biology	3036	0.658
24	Pharmacology Pharmacy	2998	0.65
25	Mathematics	2870	0.622

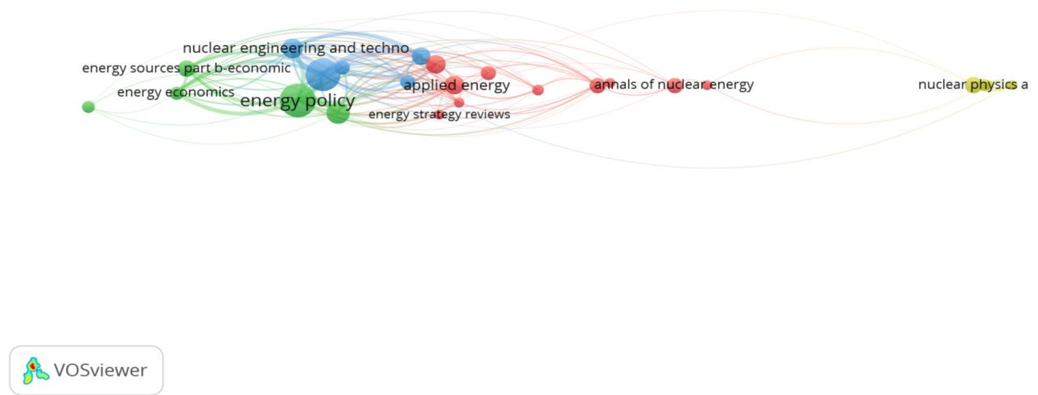

Figure 3: Subject wise Distribution in the Scientific productivity of Nuclear Energy (Network Visualization)

Research topics analysis in the scientific productivity of Nuclear Energy

VOS viewer is used to create a correlation network of research topics based on the co-occurrence of frequently used keywords (N.J. Van Eck L, 2011; N.J. van Eck & L. Waltman, 2014; N.J. van Eck, L. Waltman ,2013). The study illustrates and analyzes the correlation network and the pattern of research topics. It displays five clusters. The first cluster, represented on the left side of the figure in blue, focuses on the risks associated with nuclear power plants. The second cluster, located at the bottom of the figure and shown in red, is centered on nuclear power design research. The third cluster, positioned in the middle of the figure and denoted in green, is dedicated to simulation research.

The fourth cluster, found at the top of the figure in yellow, pertains to the impacts of nuclear power on human health. The fifth cluster, on the right side of the figure and indicated in purple, concentrates on the influence of nuclear power on atomic energy studies in the context of galaxy evolution. There is a strong connection between the third cluster and the other clusters; in contrast, the fifth cluster is primarily associated with the third cluster.

Country wise Distribution in the scientific productivity of Nuclear Energy

Table 11 and Figure 4 illustrate the country-wise distribution of publications in nuclear energy from 2002 to 2024. The analysis indicates that the most prolific countries in this field are the United States and the People's Republic of China, with publications contributing to productivity levels of 144,154 (31.241%) and 80,619 (17.472%), respectively, securing the first and second positions.

Furthermore, more than 25,000 records have been achieved by Germany (60,692), Japan (52,471), Italy (52,471), Russia (46,550), France (42,454), England (34,476), India (34,249), and South Korea (28,330). The study suggests that scientists have shown relatively strong engagement in this research area, which is reflected in the gradual increase in publication trends among researchers in nuclear energy. The analysis shows that the remaining 44.78% of publications are below 25,000 from the total of 461,371 for the period of 2002-2024.

Table 11: Country wise Distribution in the scientific productivity of Nuclear Energy

S. No	Countries/Regions	Publications	%
1	USA	144154	31.241
2	Peoples R china	80619	17.472
3	Germany	60692	13.153
4	Japan	52471	11.372
5	Italy	49358	10.697
6	Russia	46550	10.088
7	France	42454	9.201
8	England	34476	7.472
9	India	34249	7.423
10	South Korea	28330	6.14
11	Spain	24464	5.302
12	Switzerland	24108	5.225

13	Poland	21898	4.746
14	Canada	18525	4.015
15	Brazil	17491	3.791
16	Netherlands	15703	3.403
17	Sweden	14187	3.075
18	Australia	13278	2.878
19	Czech Republic	12693	2.751
20	Belgium	11528	2.498
21	Taiwan	11266	2.442
22	Austria	11034	2.391
23	Hungary	10430	2.26
24	Greece	9274	2.01
25	Finland	9177	1.989

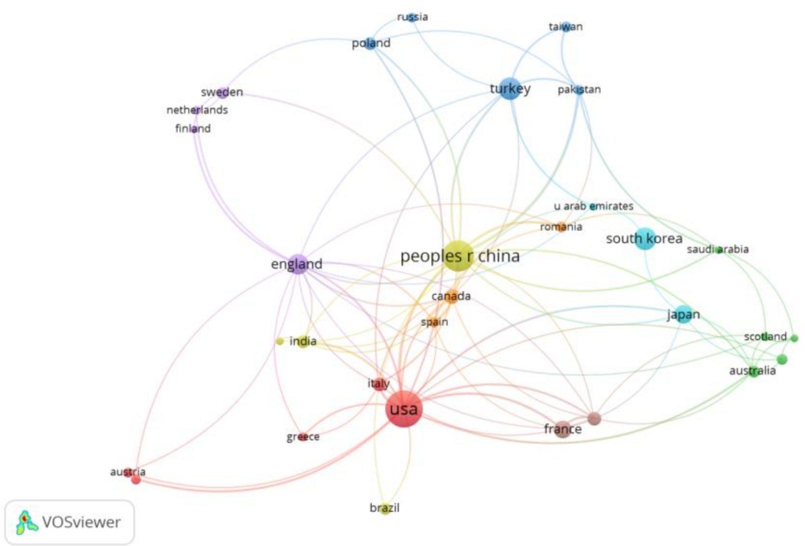

Figure 4: Country wise Distribution in the scientific productivity of Nuclear Energy (Network visualization)

DISCUSSION AND CONCLUSION

The study analysis made on the global publication trend being taken for the field of Nuclear Energy during 2002-2024. The study indicates that researchers in Nuclear Energy have made consistent contributions over the examined period. This analysis targeted the years 2008 to 2024, noting that significant contributions to research began around the year 2000. It identifies that sixteen document types each account for fewer than a thousand contributions to Nuclear Energy research. Generally, journal articles represent the main publication format across research disciplines, with researchers in this field favoring the publication of their work in peer-reviewed and indexed journals pertinent to their specialties.

Globally, journal publications from different publishers and citations are primarily assessed based on English-language research productivity. The peak annual growth rate was observed in 2008, reaching 300, followed by rates of 18.2976 in 2010, 13.6255 in 2012, and 10.2762 in 2020. The average annual growth rate for the entire study period from 2002 to 2024 is computed to be 4.4584. The results suggest a significant increase in output, projecting growth from 90,134 publications in 2002 to an estimated 267,718 publications by 2024. The United States Department of Energy (DOE) contributed the most, with 67,513 publications (14.63%).

The USA is recognized as a leading country in the field of nuclear energy. Scientists in the nuclear energy sector have dedicated significant efforts to research in the USA. Following the USA, China is noted for its strong research collaboration in this field, which can be attributed to the investments made by the governments of both countries to build laboratories focused on nuclear energy. Indian scientists rank fourth in terms of publication contributions from research institutions and universities. The Department of Science and Technology and the Department of Nuclear Energy in the Government of India have encouraged researchers to conduct valuable research and publish quality findings in peer-reviewed journals in this core area.

The study has been analyzed based on the distribution of the publications and researchers have collaboration between Universities and Institutions in the field of Nuclear Energy during 2002-2024. The research growth trend was witnessed steadily an increased trend, it proves numerous new researchers taken more attentions on their contribution during period of study. On the part of Publications distribution upon major share from English was predominantly appeared the Publications at globally contributed by the scientists in specific filed concerned. The Journals articles have been witnessed as major portion of the publications during 2002-2024. The research growth trend normally compared by analysis on Relative Growth Rate (RGR) and Doubling time (Dt), RGR shall be a fluctuate trend on contrary Dt was found an increasing trend. Similarly, the study could be noticed same trend being observed in the field of Nuclear Energy. The study was analyzed that majority of the Scientists have been contributed more publications from China as the first position, USA was the second position by witnessing their publications in the field of Nuclear Energy during study period.

Based on the “solar cells”, “solar energy”, “solar power plants”, and “solar radiation measurement”, indicated that the growth of the literature had been vigorous after the energy crisis [66]. Despite of the importance and high growth rate in the last 20 years, there have been few attempts to gather data about the worldwide scientific production of solar power-related research recently. Biometric studies in recent years provide an accurate and presumably objective method to measure the contribution of a paper to the advancement of knowledge (Garg & Sharma, 1991). Besides, the Science Citation Index (SCI) from Web of Science databases is the most widely accepted and frequently used course database choice for an analysis of scientific publications.

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