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ARTIFICIAL INTELLIGENCE, SUSTAINABILITY AND ENERGY SECTOR: A BIBLIOMETRIC ANALYSIS

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Abstract

The present paper aims to conduct a literature review using bibliometric analysis to understand the relationship between artificial intelligence, sustainability, and energy sector-related publications in journals indexed in the Scopus Database for the period 2004 to 2023. The study has conducted two bibliometric analysis, namely Network analysis and Science mapping to study what have been various important journals, authors, and countries producing significant publications as well as what have been influential collaborations between authors, co-citation between article sas well as thematic analysis of the study. Performance analyses reveal that China followed by the USA and India have been the leading countries in producing research work in this domain, authors like Quammi, and Saciler are the influential authors in this field and the Journal of Cleaner Production and Sustainability are the twoleading journals with a High H index. Co-citation analyses show research carried around clusters like 'sustainable development goals, agenda 2030, and transforming our world' as themes. The thematic analysis reveals motor themes like decision making while niche themes like energy efficiency and energy utilization are also revealed. Our study concludes by suggesting that further research in the domain of energy efficiency using AI while incorporating sustainable means is the need of the hour given the rising climate extremists. It is significant for academia, industry as well as policy makers to ensure cleaner and sustainable energy solutions are crafted for our society.

Keywords: Artificial Intelligence, Sustainability, Energy Sector, Bibliometric Analysis

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Introduction

Preserving the resources of energy is of utmost need today looking at scarcity of various resources of energy. The demand for energy is increasing worldwide and hence its posing challenges for optimum energy utilization and management (Makala *et al.,* 2020). Twentieth century has explored artificial intelligence and machine learning widely and the technology now prudently aids the human decision–making at the same time stimulating humans' learning (Entezari *et al.,* 2020). Energy system is a system which is integrated in nature hence it is not easy to conserve energy but given the new machine age, it is possible to evaluate optimum supply and demand (Entezari *et al.,* 2020). The developed nations are already making use of artificial intelligence and related technologies for optimum and efficient utilization of power sector. Sustainable Development Goal (SDG) 7 "*affordable, reliable, sustainable and modern energy for all*" has a primary object of providing affordable, reliable and sustainable modern energy for the development of agriculture, business, communications, education, healthcare and transportation worldwide. Today, the global average surface temperature is around 1.2^0C above pre-industrial levels, leading to heat waves and other extreme events. The energy sector has been found to be the primary cause of air pollution, more than 90% of the world's population is forced to breathe such polluted air leading to more than 6 million premature deaths a year (IEA, 2023). Investment in clean energy has risen by 40% since 2020 due to economic pressure to bring down emissions, drive towards energy security, inclination towards mature clean energy technologies like solar PV and electric vehicles which provide hope for the way forward (IEA, 2023). It can be seen from **Figure 1** that CO_2 emissions from different types of fossil fuels like oil, natural gas and coal have remained consistent largely till 2019 with a subsequent dip during Covid and then following the recovery from Covid-19, CO_2 emissions have definitely seen a major increase by all three fossil fuels. This is definitely an alarming situation, making both the policymakers as well as the industry ponder over how the increasing energy requirements need to be met with cleaner and greener alternative sources of energy. **Figure 2**, highlights that the largest CO_2 emitter in the world is China followed by USA, India and Japan, Except India, the other three countries are developed while India is a rapidly growing developing country. As the energy requirements in these countries soar higher and higher, so is the amount of pollution being released by industries in these countries. While the ongoing increase in energy demands and resultant increase in levels of CO_2 emissions is threatening the very existence of humankind, the sensitivity of human race towards developing

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alternative sources of energy is also heartening. **Figure 3** highlights the annual cleaner energy investments during the period 2015-23. The accelerated investments in cleaner and greener energy exhibit increasing awareness among industry and society for creating and nurturing alternative cleaner sources of energy.

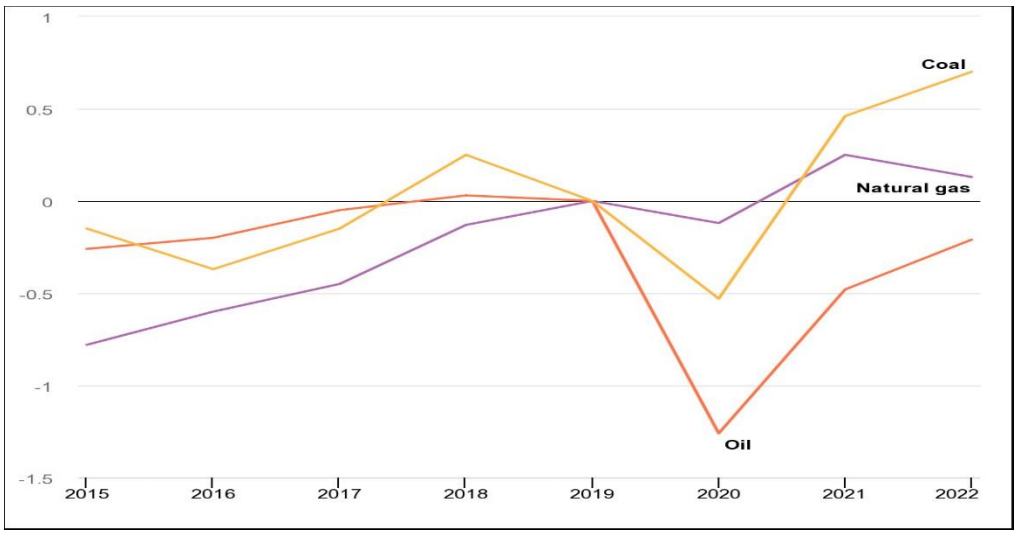

Figure 1: Change in global CO2 emissions by fuel, 2015-2022

Source: www.iea.org/data and statistics

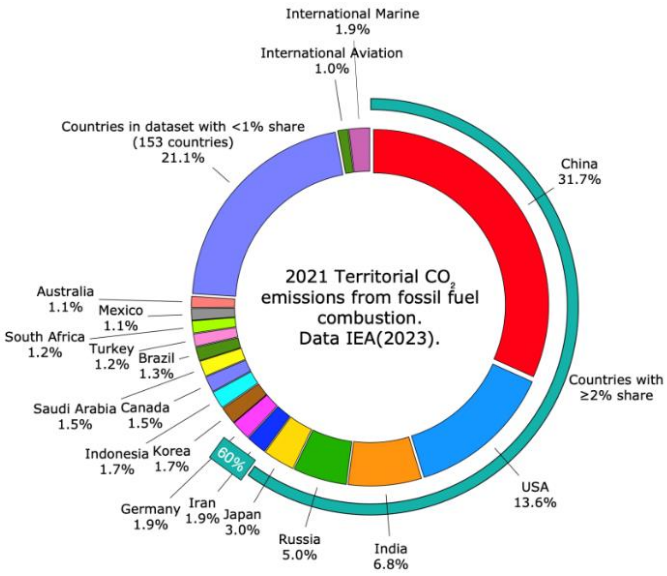

Figure 2: Territorial Fossil Fuel CO_2 Emission

Source: EA Greenhouse Gas Emissions from Energy Highlights, 2023

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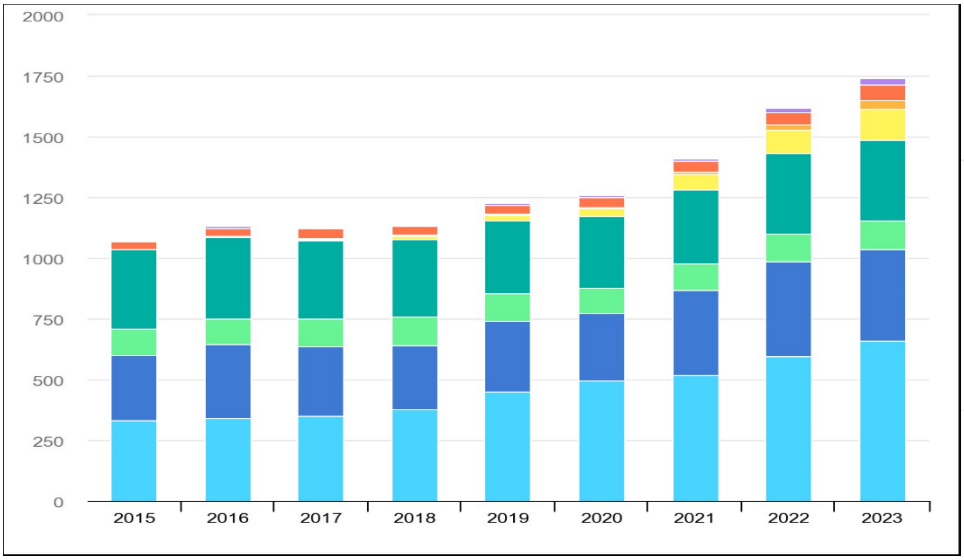

Figure 3: Annual Clean Energy Investments 2015-23

Source:www.iea.org/data and statistics

The world added 50% more renewable capacity in 2023 than in 2022 while solar PV makes for 3/4th of additions worldwide, according to Renewables 2023, the latest edition of the IEA's annual market report on the sector.

1. Literature Review

1.1 An overview of Artificial Intelligence and sustainability

Artificial Intelligence (AI) refers to how machines can be made intelligent through science and engineering. AI deals with designing intelligent computer programs and technology in conformity with environment to achieve efficiency in various sectors like energy, agriculture, industry, academia etc. (Makala, 2020). AI can assist human resources in lowering energy cost, cutting energy waste, facilitating and increasing the use of clean renewable energy resources and provide clean and cheap energy worldwide thus contributing to development. Energy industry, power system operators will have to integrate their traditional set ups with AI technologies, if they want to achieve efficiency and growth. Global economy is greatly dependent on energy production, distribution planning and financial stability (Ahmad *et al.*, 2018).

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AI techniques are today used in big data handling preventing cyber-attacks, smart grids, internet of things (IOT), robotics, energy efficiency optimization and computational efficiency (Kow *et al.*, 2016).

Predicting technologies are used in forecasting fossil fuels and renewable energy resources generation demand and price etc. (Ranaweera *et al.*, 1997). It is widely known and accepted how well AI can plan and forecast load demand (Kong *et al.*, 2018), Solar energy (Rodriquez *et al*., 2018), wind energy (Ren *et al*. 2015), Hydro and geothermal energy (Debnath and Mourshed, 2018). A bibliometric analysis is required to synchronize the literature in this field, to determine its scope, trends and unexplored themes to facilitate future research in this field.

1.2 An overview of bibliometric analysis

Bibliometrics is a commonly used statistical approach for organizing research fields (Van Eck and Waltman, 2010). The current state, scope of the field, latest developments and future research directions can be investigated using bibliometric analysis (Tunger and Eulerich, 2018; Castriotta et al., 2019). According to Xu et al. (2018), bibliometric analysis is a useful technique for organizing massive amounts of data quantitatively and spotting long-term trends in a certain sector. Performance analysis and science mapping methodologies are included in the bibliometric study (Donthu*et al.*, 2021). Performance analysis evaluates the contributions that various research components—such as journals, nations, authors, articles, and institutions—make to a certain topic. It ranks research components according to their effectiveness in the field and employs a number of criteria to evaluate the influence of each component (Cobo *et al.*, 2011; Zupic and Cater, 2015; Donthu *et al.*, 2021).The goal of science mapping is to depict the dynamic organization and structure of scientific domains (Zupic and Cater, 2015). Science mapping examines the links between research components as well as their structural and conceptual relationships (Cobo *et al.*, 2011). Bibliographic coupling, coauthorship, co-word, co-citation, and citation analyses are all included in science mapping. These methods can be used to describe the intellectual and bibliographic organization of an area in conjunction with network analysis. A publication's impact in citation analysis is determined by the number of citations it has (Donthu *et al.*, 2021). Coauthorship analysis can provide the social structure of the field and show cooperative efforts (Zupic and Cater, 2015). According to Kumar et al. (2021), keyword co-occurrence analysis makes the assumption that frequently occurring terms in a given article have a conceptual relationship, show temporal

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patterns, and organize into clusters connected to the same theme. Based on their common appearance in the bibliographies of other published works, co-citation analysis establishes a connection between two publications (Zupic and Cater, 2015; Donthu *et al*., 2021). According to Rossetto et al. (2018), co-citation analysis can provide insight into the conceptual framework of a certain topic of study. It helps academics locate the most scholarly foundations, original publications, and significant research papers. Articles with comparable citation patterns can be grouped using bibliographic coupling. This makes it easier to comprehend the recurring themes that the author addresses.

2. *Objective of the study*

The study aims to conduct literature review on the topic use of AI and Sustainable Energy Solutions through articles published in social science database Scopus from 2004-2023. This is primarily done to achieve the following objectives:

- Conduct Performance Analysis of the research topicto reveal influential authors, publications, countries and journals and
- Conduct Science Mapping of the research topic, to reveal collaboration network, relevant research trends and scope for future research of the topic.

3. *Data & Methodology*

The study is based on the articles being published in Scopus database over a period 2004-2023.The Scopus database is an online social science database, having 20% more citation analysis than web of sciences and having wider journal coverage(Mongeon and Paul-Hus, 2016; Mishra *et al*., 2021). Google scholar is not used for credibility issues (Falagas*et al*., 2008).The basis for the analysis is the bibliographical descriptions of articles and their references from academic journals listed in Scopus database. The Scopus database was searched using the keyword the “Artificial Intelligence”, “Sustainability” and “Energy” as a part of a title, abstract, or keyword to compile a bibliography of all manuscript related to this topic of research. Out of the initial search of 938 articles, final articles were limited to 412, after limiting them to English language and document type being “Article”. Using the data set, various Bibliometric graphs, tables and maps were drawn and analyzed in Biblioshiny (Aria and Cuccurullo, 2017).

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4. Results and Analysis of Data

Table 1 exhibits the bibliographical key information related to research on data extracted from Scopus database. The documents were published in 222 sources and had an average citation per document of 21.25, indicating significant research undertaken during the relevant period of study. Total of 412 articles represent the relevant articles covering the topic of research. Of the authors, percentage of international co-authorship is 36.89% while the single author documents in this area are 30. We also found out that the co-authors per documents are 4.3. The international collaboration on this topic has not been very encouraging and definitely shows greater need to collaborate among authors at the international level. Figure 4 shows the distribution of research documents subject wise, showcasing that major research documents have been contributed by engineering sector making 18% of all documents under the study, followed by document from fields of energy, computer science, environmental science, social science, management and business subjects. This shows growing interest for research among researchers hailing from diverse subjects.

Table 1: Description of extracted documents by Scopus

Main Information About Data	Figures
Timespan	2004:2023
Sources (Journals, Books, etc)	222
Documents	412
Document Average Age	2.55
Average citations per doc	21.25
References	27172
DOCUMENT CONTENTS	
Keywords Plus (ID)	3547
Author's Keywords (DE)	1588
AUTHORS	
Authors	1645
Authors of single-authored docs	29
AUTHORS COLLABORATION	
Single-authored docs	30
Co-Authors per Doc	4.3
International co-authorships %	36.89
DOCUMENT TYPES	
Article	412

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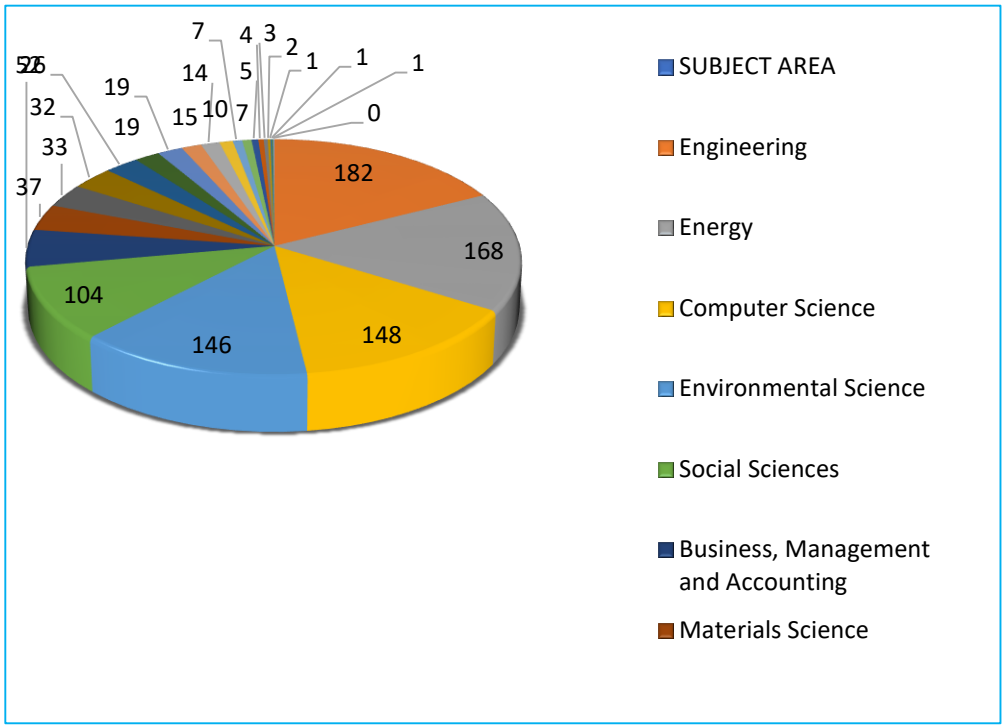

Figure 4: Documents - Subject wise Distribution

4.1 Performance Analysis

In performance analysis, annual publication and citation counts are frequently used. According to Donthu et al. (2021), the former signifies output, whereas the latter shows influence and impact. In **Figure 5**, production of articles by leading authors is depicted. Quammi and Saciler have produced articles in AI and sustainability domain largely during the period from 2010 to 2012, while authors like Tayebi and Huang have produced their research work from the year 2018 onwards. The figure reflects citations as well, where in for authors like Tayebi, Kumar, Huang and Zhang significant citation have taken place especially towards the last 4-5 years depicting the rising interest among academia to research in this field. **Figure 6**, shows the most influential authors with number of articles being 5 each for Quammi and Saciler and authors like Tayebi, Zhang, Huang and Kumar having 4 articles each. **Figure 7** reflects the sources' local impact factor by H Index. It shows top 10 journals ranked by the H-index based on the effect and productivity of their citations (Ingale and Paluri, 2022). It shows the journal of "Cleaner Production" has H index of 15 showing that each of its 15 published articles has received at least15 citations. The next leading journal is "Sustainability" (Switzerland) having an H index of 13. The other relevant journal include 'Energies', 'Sustainable cities and towns', 'Sustainable energy technologies and Assessment' and applied sciences among others,

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displaying the authors' productivity over the period. Quammi has an H-index of 18, indicating that each of their 18 published articles have received at least 18 citations.

4.2 Science Mapping

Techniques like Co- citation analysis and co-authorship analysis are used in science mapping. Co- citation analysis reveals network maps containing nodes that show acited reference. The size of the nodes inform about the number of documents that have been co-cited.In **Figure 9,**Co-citation analysis reveal clusters like sustainable development goal, Agenda 2030 and transforming our world, indicating that various research articles are written around these themes. Co-authorship analysis depict the collaborative efforts between various authors. **In figure 10**, the international collaboration between scholars is shown. The co-authorship ties emphasizes important authors and their groupings. Through the collaboration network, the significant authors like Quammi, Saciler, Kumar, Huangetc are revealed. The amount of collaborations between academics from different countries is shown by the thickness of the lines, while the blackness of a country's colour denotes the frequency of collaborations. In Figure 10, international collaboration between authors like Quammi and Saciler, between authors like Kumar, Agarwal and Gehlot and between authors like Chen, Guo and Chang are shown. A number of clusters show cooperative organizations, where most of the writers are from the same or nearby nations. The authors' limited geographic concentration limits their ability to share information with one another.

4.3 Thematic Analysis

The Thematic map is made up of X and Y axis. In the thematic map, the X- and Y-axes, respectively, represent centrality and density. While centrality refers to the degree of a network's engagement with another network and the significance of a specific domain in the research area, density indicates the degree to which a subject has grown in literature and the internal dependability of a given network (Wilczewski and Alon, 2023). Higher density and centrality motor themes, which denote well-developed and pertinent subjects, are displayed in the upper right quadrant.

In **Figure 11**, in the right quadrant, mature and well developed themes like decision support systems are revealed depicting extensive work in this domain. The research on topics like artificial intelligence, sustainable development and sustainability have been growing at

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steadfast pace rendering these topics in the domain of basic themes. As the world battles, extreme climate turmoil at an increasing rate, the need to leverage technology for resolving energy problems becomes pertinent, giving rise to niche themes like

energy efficiency and energy utilization. The different quadrants in the thematic map reflect evolution of advanced research topics in this area highlighting the need to integrate technology spill overs to solve real life problems.

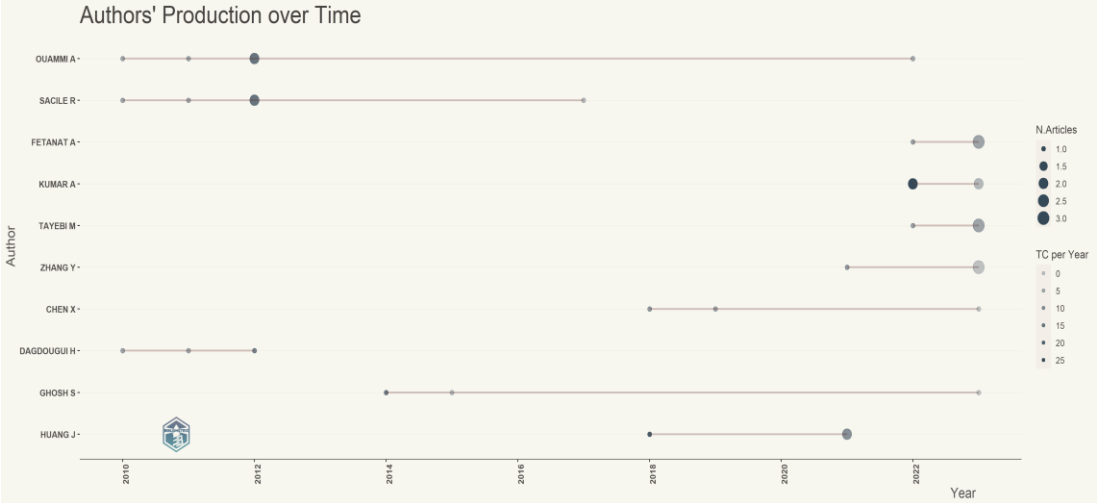

Figure 5: Author's productivity

Sources: Authors' Compilation using Biblioshiny

Figure 6 : Most influential Authors

Sources: Authors' Compilation using Biblioshiny

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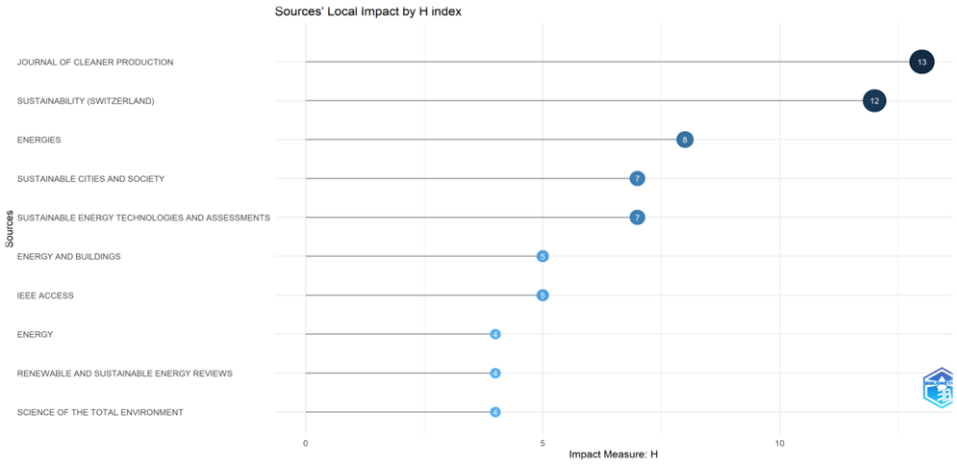

Figure 7 : Sources Local Impact by H Index

Sources: Authors' Compilation using Biblioshiny

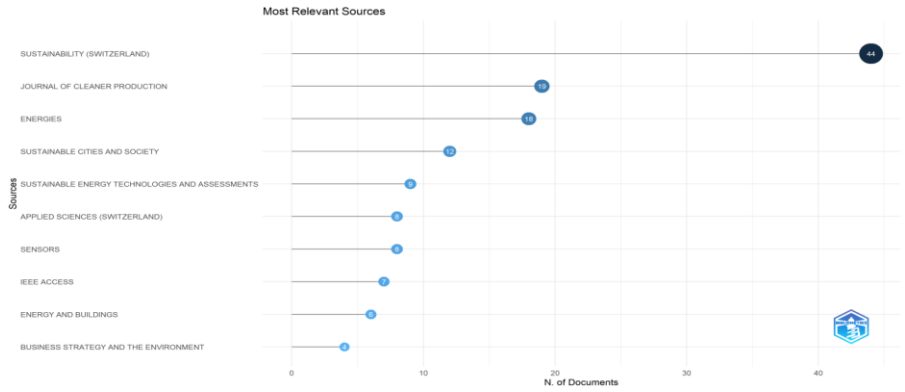

Figure 8: Most relevant Sources

Sources: Authors' Compilation using Biblioshiny

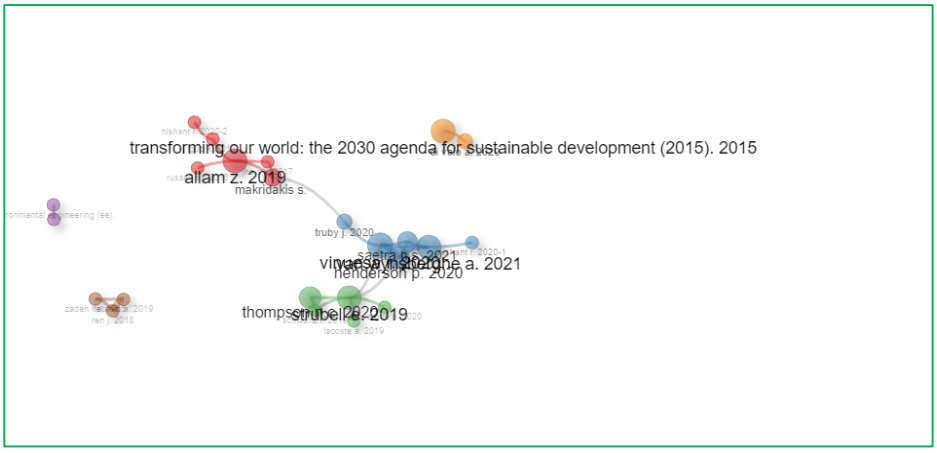

Figure 9: Co-citation Network Map

Sources: Authors' Compilation using Biblioshiny

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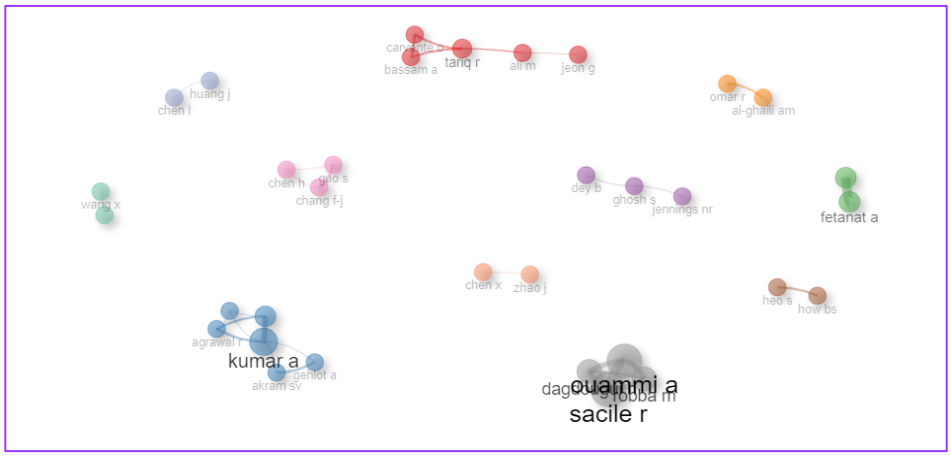

Figure 10: Collaboration network among Authors

Sources: Authors' Compilation using Biblioshiny

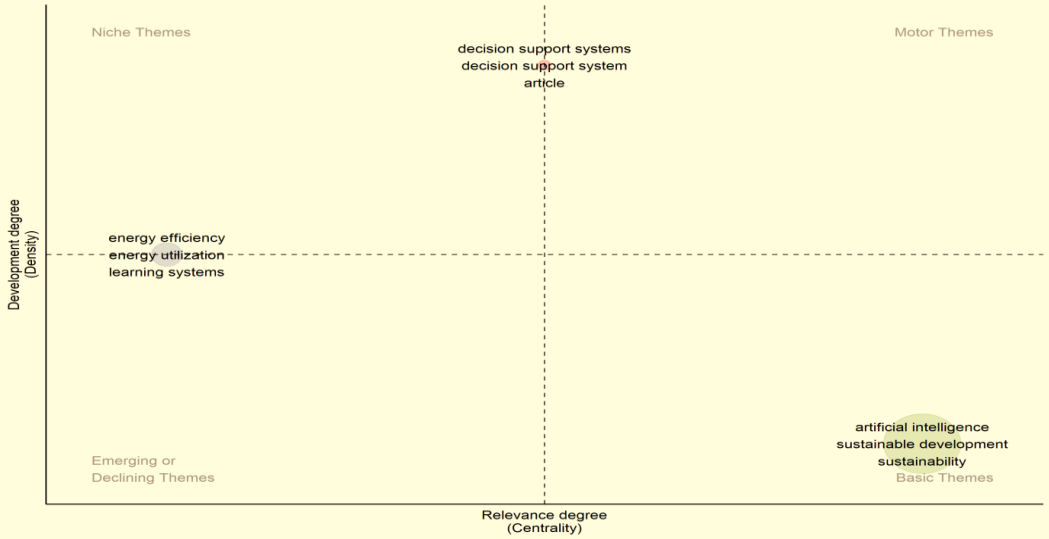

Figure 11: Thematic Map

Sources: Authors' Compilation using Biblioshiny

5 Limitations of the study

The study is consisting of primarily Scopus data base, other sources like Web of Science and SCSCI can also be considered for more engaging view. The paper is also subject to authors' personal experience and proficiency in application of software and its references. Apart from energy sector, the ever increasing role of AI can also be studied in sectors like agriculture, health care, education.

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6 Policy Implication and Suggestions

The sources of energy which are conventional have a massive side-effect on the global climate and climate change. Hence its most desirable to use clean energy which is environment friendly as it has minimum CO_2 contamination and is used to make the world safer and energy proficient (Jha *et al.*,2017).

It is the need of the hour to switch from fossil fuel based energy sources to new carbon free energy sources (Engels *et al*., 2020). Due to momentum behind clean energy transitions, global demand for coal, oil and natural gas has started to edge downwards to 73% by 2030 as against present trend of 80%. Policies and technologies are available to align energy security and sustainability goals, thereby keeping the door to 1.5^0C open (IEA, 2023). In addition innovative large-scale financing mechanisms are required to support clean energy investments in emerging and developing economies as are measures to ensure an orderly decline in the use of fossil fuels, including coal fired power plants. Actions such as the National Smart and Grid Mission or the smart cities and infrastructure or India Energy Dash Boards should be commenced (Chawla, 2022) The challenges with regard to data collection and communication with energy customers should be suitably resolved with used of AI enabling them to become smart energy users. India should focus on developing AI so that energy is used in an intelligent manner preferring renewable sources of energy (Chawla, 2022). To improve the use of energy resources, interrupted transmission of innovative solutions, poor affordability and climatic concerns, use of innovative solutions and modern technology should be enhanced.

Conclusion

The present paper undertakes a literature review by employing bibliometric analysis to identify significant contributions, themes, concepts and future research from the publications published in the area of AI, sustainability and energy sector. The study is based on the articles being published in Scopus database over a period 2004-2023, i.e for 19 years. The Scopus database was searched using the keyword the "*Artificial Intelligence, Sustainability and Energy*" as a part of a title, abstract, or keyword to compile a bibliography of all manuscript related to this topic of research. Out of the initial search of 938 articles, final articles were limited to 412, after limiting them to English language and document type being article. Our study has used two bibliometric analysis techniques, namely, performance analysis and science mapping (Donthu *et al*., 2021).Through the performance analysis we found that, 'Quammi', 'Sciale' and 'Kumar' as some of the most influential authors, 'Journal of Cleaner production' and

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'Sustainability' as the leading journals in this area. Our study also found out that China is the leading country in this field, followed by USA and India respectively as the most productive countries in producing sustainable, Artificial Intelligence and Energy Sector related literature. The co-citation analysis reveal themes like 'Sustainable development goal', 'Agenda 2030' and 'transforming our world', indicating that various research articles are written around these themes. Co-authorship analysis identifies the most influential author in collaborative efforts, and the most common pattern of collaboration is between researchers from different institutions in the same country, such as China and India followed by collaborations between authors from other countries. Our study revealed that limited collaboration between authors across the different regions also limit the extent of enrichment in this field.

The thematic analysis reveal more centralized and dense themes like decisions support systems reflecting substantial research work in this area. The niche themes generated from the thematic analysis include areas such as efficient energy utilization, decision making systems as the forth coming fields where further research can be undertaken to realize the true applicability of AI technologies in real life scenarios with reference towards sustainability. Our paper has identified that the research in the area of applicability of AI in solving problems of energy sector with sustainable solution is on the rise. As the developed nations, have already severely polluted the world through rapid industrialization, causing increase in emission of greenhouse gases, the development path for developing nations like India cannot be on the same path unless crafted with sustainable means. It is imperative that both developing and developed nations join hands to create more sustainable technology driven solutions.

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