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Research Article

Sustainable Development Through Solar Energy: A Bibliometric Analysis

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ABSTRACT

Objective: This study aims to delve into the intricate patterns and advancements characterizing the contribution of solar energy to the progress of sustainable development; by identifying evolving trends in publications and the intellectual foundations within the domain of sustainable development through the application of solar energy.

Methodology: This research relies on purely secondary data sourced from the Scopus database, covering the period from 1991 to September 2023. The study focused on English-language research articles within the subject areas of business, accounting, management, economics, and finance. A stringent search string was employed to ensure relevance and specificity. The bibliometric analysis was conducted using the Bibliometrix R package and Vosviewer.

Findings: The dataset comprised 257 documents originating from 86 separate publications, demonstrating a resilient annual growth rate of 13%. Collaborative patterns were evident, with 32.3% of the documents showcasing international co-authorship. The analysis revealed distinct clusters of keywords, offering a nuanced understanding of the multifaceted dimensions within the sustainable energy planning domain. Clusters encompassed economic and social aspects, environmental impacts, global perspectives, and economic considerations, shedding light on the comprehensive nature of research in this field.

Originality: This study contributes to the field by providing a comprehensive and up-to-date bibliometric analysis of the intersection between sustainable development and solar energy. The identified clusters of keywords and statistical insights offer a unique perspective on the evolving landscape of research in this critical area, facilitating a deeper understanding of the collaborative dynamics, thematic trends, and knowledge dissemination within the scholarly community.

1. Introduction

Fossil fuels constitute 80% of the total energy supply (TES) with oil taking the lead with an approximate share of 30%, closely trailed by coal at 27%, and natural gas at 24%. In the realm of global emissions stemming from fuel combustion, coal took the foremost position, contributing a substantial 44%, followed by oil at 32%, and natural gas at 22%. In 2021, global carbon dioxide (CO_2) emissions resulting from fuel combustion experienced a substantial rebound, registering an increase of nearly 6%, and returning to levels that closely resembled those observed prior to the onset of the Covid-19 pandemic (International Energy Agency, 2023). Projections indicate a foreseen surge in global energy demand, expected to surge by 60% by the year 2030, compared to the current landscape as of 2006 (International Energy Agency, 2006). Notably, two-thirds of this upsurge will be attributed to the escalating energy needs of nations such as China and India, alongside other swiftly

advancing economies. Collectively, these countries are poised to contribute nearly half of the world's energy consumption by the year 2030 (International Energy Agency, 2010). Numerous countries continue to grapple with a substantial deficit in their energy supply (Echegaray, 2014; Padmanathan et al., 2019; Poier, 2021). Sustainable energy development can be defined as the process of advancing the energy sector with a focus on energy generation, distribution, and utilization in alignment with sustainability principles (Sandu et al., 2021). Energy systems have substantial repercussions on the environment in both developed and developing nations. Thus, the worldwide sustainable energy system should prioritize efficiency enhancements and emissions reduction (Salvarli & Salvarli, 2020). The sustainable development scenario is constructed with a foundation in economic considerations. It also assesses the necessary actions to achieve common long-term objectives related to climate benefits, improved air quality, and expanded energy accessibility. The short-term strategies are derived from the International Energy Agency's (IEA) sustainable recovery plan, designed to bolster economies and job opportunities by enhancing the reliability and cleanliness of energy infrastructure (IEA, 2021). Furthermore, sustainable development encompasses the adoption of renewable energy solutions, the implementation of smart grid technologies, assurance of energy security, fair energy pricing, and the formulation of a robust energy policy (Sandu et al., 2021).

Renewable energies encompass the harnessing of energy from naturally replenishing resources to promote sustainability. Commonly referred to as clean energy, these sources include solar energy, wind energy, geothermal energy, and hydropower. Renewable energy represents a modern technological shift, replacing conventional fossil fuels, which are finite and non-renewable (Chel & Kaushik, 2018). Governments worldwide are increasingly recognizing the significance of sustainable development and giving greater attention to such renewable energy sources (Cousse, 2021; Kumar & Kaushik, 2022; Nicolau et al., 2022; Palit, 2013). Solar energy is a technologically eco-friendly and substantial energy source, standing as one of the most significant contributors to renewable and green energy. Its role is vital in the pursuit of sustainable development through energy solutions (Maka & Alabid, 2022). It is becoming increasingly essential in a country's energy portfolio. This is not only to combat climate change but also to diversify energy sources and mitigate the impacts of supply disruptions and fluctuating oil prices (Hatamifard et al., 2023; Solangi et al., 2015). As governments face the challenge of doing more with limited resources, solar energy will play a pivotal role in their calculations for economic sustainability (Djurisic et al., 2020; Zlaoui et al., 2023). To realize a sustainable future, there is a pressing need for increased investment in renewable energy resources (Kumar & Hundal, 2019). The global power sector will be required to develop approximately 4,800 GW of new capacity by the year 2030 (International Energy Agency, 2006). However, anticipated clean energy investment was projected to experience a 24% increase from 2021 to 2023, primarily propelled by investments in renewables and electric vehicles. In contrast, investments in fossil fuels are expected to grow by 15% during this timeframe (International Energy Agency, 2023).

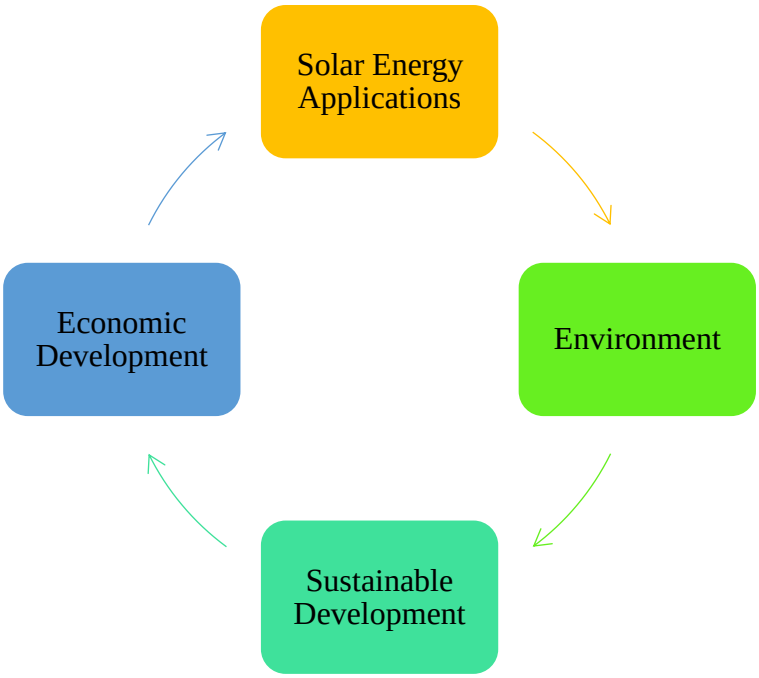

Fig 1. Blueprint for Integrating Solar Energy into Sustainable Energy
Source: Authors' own creation

The roots of solar energy reach as far back as the seventh century when mirrors utilizing solar power were employed. The breakthrough in solar technology came in 1893 with the discovery of the photovoltaic (PV)

effect, which, after several decades of research and development, was harnessed for electricity generation (Fraas & O'Neill, 2023). Following years of extensive research and development efforts by researchers across the globe, solar energy technology has been categorized into two primary applications: solar thermal and solar PV. PV systems harness solar energy and convert it into electricity using solar panels. These PV devices have rapidly become the most cost-effective option for new electricity generation in many parts of the world due to their widespread adoption. For instance, between 2010 and 2018, the cost of generating electricity from solar PV plants decreased by a significant 77%. Furthermore, the progress in solar PV installed capacity witnessed a remarkable 100-fold increase from 2005 to 2018. Consequently, solar PV has emerged as a crucial component of the low-carbon sustainable energy system, playing a vital role in providing access to affordable and reliable electricity. This technology contributes to fulfilling the goals set out in the Paris Climate Agreement and achieving the targets outlined in the 2030 Sustainable Development Goals (SDGs) (Gahrens et al., 2021).

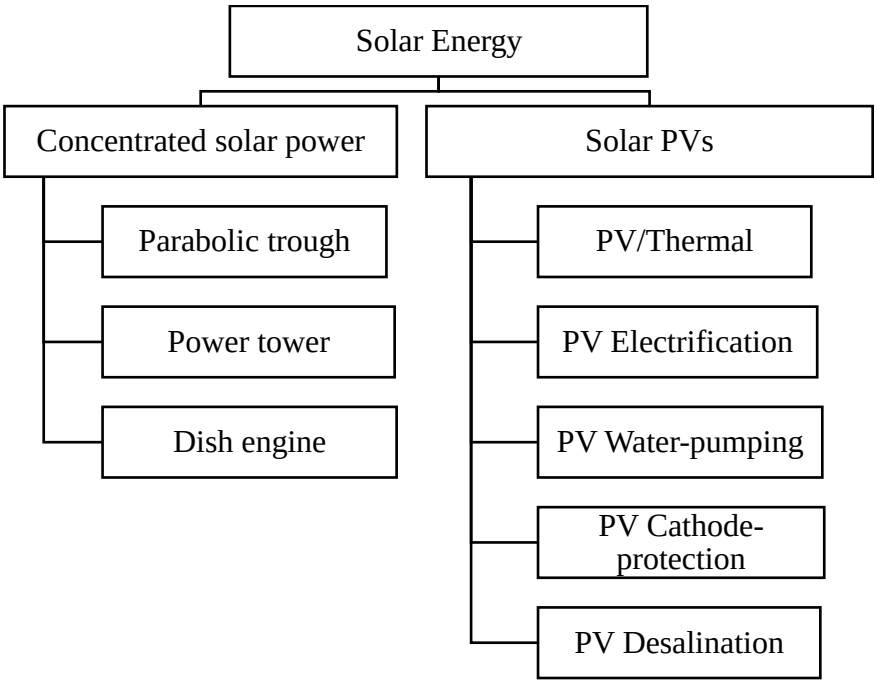

Fig 2. Solar Energy Application Taxonomy
Source: (Maka & Alabid, 2022)

Solar energy projects are anticipated to enhance the quality of life for residents in various ways, including creating employment opportunities (Elmustapha et al., 2018; Zlaoui et al., 2023), decreasing CO_2 emissions (Hatamifard et al., 2023; Sangroya & Nayak, 2017), and serving as the most cost-effective source of renewable energy (Rahmani & Bonyadi Naeini, 2023; Waris et al., 2023), which could contribute to a sustainable environment (Kumar & Kaushik, 2022). Hence, the study aims to explore the patterns and developments in the contribution of solar energy to advancing sustainable development. Employing bibliometric analysis, the authors seek to identify trends in publications and the intellectual underpinnings within the realm of sustainable development through the utilization of solar energy. Specifically, this study seeks to address the subsequent research questions (RQs):

Research Query 1: What is the present trajectory of publications concerning sustainable development through solar energy?

Research Query 2: Which journals and authors exhibit the highest levels of productivity within the selected domain?

Research Query 3: What are the publications exerting the greatest influence in the selected field?

Research Query 4: What are the dominant research themes currently prevalent and the promising future areas of the selected study?

1.1 Rationale of the study

Table 1. Reviews of similar studies

Article	Focus	Duration	PC	Methodology	Keywords	Gaps
(Hou & Wang, 2021)	Energy, Environment and Climate Change	1990-2019	7982	Bibliometric analysis	"Energy" AND ("Environment OR Environmental OR Environments") AND ("Climate	No clear specification of solar energy. Limited to WOS- core

					Change OR Climatic Change OR Climate Changes")	collection database only. No discussion of sustainability or sustainable development.
(Calderón et al., 2021)	Solar power	2000-2019	6300	Bibliometric analysis	("solar tower" OR "solar field") AND ("concentrated" NOT "pv" OR "photovoltaic" OR "parabolic trough" OR "concentrated solar") AND ("power" OR "thermal" OR "fresnel reflect OR *" OR "dish stirling" OR "molten salt*") AND ("solar" OR "CSP" NOT "pv" OR "photovoltaic" OR "polymer" OR "barrier" OR "lithium" OR "solar-cells" OR "heat transfer fluid") AND ("concentrated" OR "heliostat*") AND ("tower" OR "CSP" OR "solar")	No thematic evolution discussed. Limited to solar power in WOS-core collection only.
(Reyes-Belmonte, 2020)	Integrated solar combined cycles	1990-July 2020	1277	Bibliometric analysis	"Integrated Solar Combined Cycle" OR "Solar Combined Cycle"	Limited to WOS- core collection only. No discussion about complete solar energy and sustainable development
(Tan et al., 2021)	Green energy and environment technologies	1998-2020	2905	Bibliometric analysis	("Green Energy") AND ("Environmental Technologies OR Environmental Technology")	Limited to WOS- core collection. No clear discussion about solar energy and sustainable development
(Sonawane et al., 2022)	Solar desalination systems	1961-July 2022	1932	Bibliometric analysis	("Desalination" OR "Solar Still") And ("CFD" OR "Computational Fluid Dynamic*") And ("Radiation")	Limited to Scopus database and solar desalination systems only.
Present study	Sustainable development and solar energy	1991 to Sept. 2023	257	Bibliometric analysis	("Sustainability" OR "Sustainable growth" OR "Sustainable development") AND ("Solar energy" OR "Solar Goods" OR "Solar Products")	Limited to Scopus database and also other renewable energy sources like hydro, wind, etc. can be further explored.

Researchers have delved into the selected research domain over recent decades. Nevertheless, the present study seeks to delve deeper into the gap discerned within the existing literature, as outlined in Table 1. The study conducted by (Hou & Wang, 2021) specifically focused on the interplay between energy, environment, and climate change, drawing from a pool of 7,982 articles retrieved from the "Web of Science – core collection" database spanning the years 1990 to 2019. It is important to note that the concept of energy is multifaceted, encompassing various forms such as renewable, non-renewable, solar, hydro, wind, among others, which may introduce some degree of ambiguity in the conducted study. (Calderón et al., 2021) conducted an extensive review of the solar power concept spanning the years from 2001 to 2019. It observed that solar power is a rapidly advancing field characterized by increasing technological innovation. However, it is worth noting that the study did not employ a thematic analysis technique, which could potentially provide additional insights into the subject matter. In the similar vein, (Reyes-Belmonte, 2020) publication trends related to "Integrated Solar Combined Cycles" (ISCC) were examined. The study spanned the period from 1990 to July 2020 and analyzed 1277 publications from the Web of Science (WOS) database. Indeed, the study notably recognized China as the most prolific nation within the specific domain of solar energy. (Tan et al., 2021) delved into the evolution of scholarly trends in the realm of green energy, spanning various environmental technologies, during the period from 1998 to 2020. They sourced their data from the "WOS-core collection." The study brought to light that while there was a substantial focus on catalytic production of clean energy, the generation of value-added chemicals, strategies aimed at mitigating greenhouse gas emissions, and addressing global energy challenges and environmental issues, the aspect of sustainability remained relatively unexplored in these contributions. (Sonawane et al., 2022) undertook a bibliometric investigation centred around "solar desalination systems" powered by solar energy and computational fluid dynamics (CFD). They found that research pertaining to desalination, especially when linked with CFD or solar radiation, was primarily conducted within the fields of Engineering and Environmental Science. However, the study did not delve into network analysis of keywords or assess collaboration among authors. It is worth noting that the previous studies lack focus on the overarching theme of sustainability, which is a prominent and relevant topic.

This study is presented as an innovative endeavor aimed at addressing the previously mentioned gaps. It conducts a bibliometric review focused on the intersection of sustainable development and solar energy. Through this comprehensive literature analysis, the authors illuminate various facets of sustainable development, the pivotal role played by solar energy within this domain, and recent advancements in this field. Unlike previous studies, this research leveraged the Scopus database, which encompasses a wider range of journals compared to the WOS, thus broadening the scope of the analysis (Block & Fisch, 2020). In contrast to prior researches, our study aspires to offer a comprehensive examination of sustainable development through solar energy, encompassing the period from 1991 to September 2023. The primary objectives of this research are to scrutinize the trajectory of research within the field of sustainable development through solar energy and to offer valuable insights for prospective scholars. The subsequent sections are structured as follows: Section 2 furnishes an in-depth account of the research methodology employed in the study, while Section 3 delves into the study findings. Furthermore, Section 4 delineates the potential avenues for future research, and the conclusions and implications are presented in Section 5.

2. Research Methodology

As the body of literature expands, researchers face a growing challenge in conducting thorough reviews of pertinent articles and understanding their complicated connections. Consequently, literature reviews serve as valuable sources of information for both academics and practitioners (Ohlan & Ohlan, 2023). Examining previous studies is a prevalent strategy for transforming abstract concepts into well-defined objectives and systematic frameworks for evaluating their content. There exist various types of literature reviews, including narrative reviews, systematic literature reviews, thematic-based reviews, among others. In addition, the bibliometric review, a relatively recent methodology Pritchard (1969) and further developed by (Lawani, 1981), involves a quantitative evaluation of content. This systematic process seeks to quantify published works in terms of their primary sources, countries of origin, affiliations, authors, and more. It provides a comprehensive examination of scholarly work. Within bibliometric analysis, two key tools are employed: performance analysis, which gauges productivity, and science mapping, which elucidates the structural aspects of the subject under study. The research utilizes bibliometric analysis and visualization techniques to thoroughly depict the knowledge domain within the field of sustainable development through solar energy (Poonam et al., 2022; Rathee et al., 2023).

Bibliometric analysis integrates mathematical and statistical methods to explore the technological trends and developments in science and technology with the aim of categorizing the existing works within a specific subject area and contributing to the creation of evidence-based guidelines for practitioners in that research field. Additionally, a bibliometric examination serves to assess the current state of knowledge in the field. Reference metrics have been widely employed to gauge the trends in research and development within a particular domain, playing a crucial role in helping researchers gain a comprehensive understanding of a specific research topic.

The researchers identified three significant bibliometric principles: Lotka's Law, Bradford Law (Bradford, 1934), and Zipf Law (Zipf, 1949) to examine the connection between scholars and their publications, the distribution of scientific documents among academic journals, and the concept of recurrence, respectively. The utilization of bibliometric methods in various domains of finance and its associated fields boasts a rich history, encompassing a vast array of publications spanning across the years. A multitude of insightful research has been authored by numerous scholars.

2.1 Data source and refinement procedure

The study is purely secondary data-based and followed the path discussed in Figure 3.

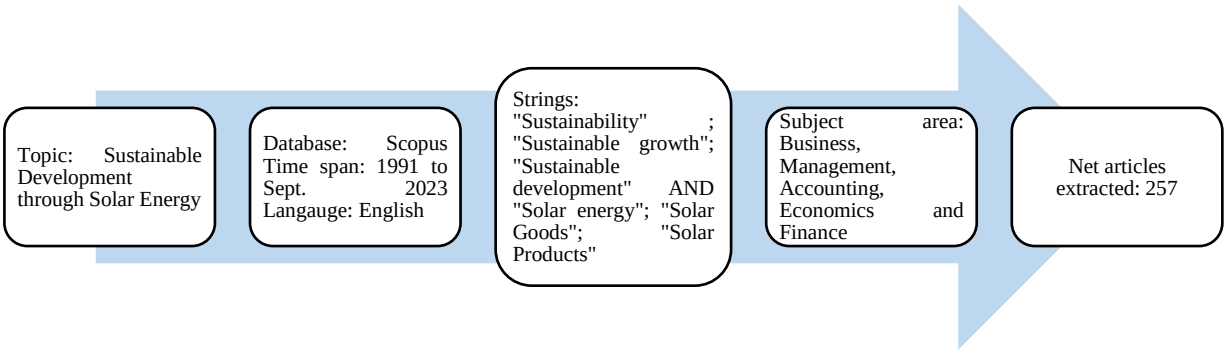

Figure 3: Data Filtration process
Source: Researchers' compilation

The research sourced its data from the Scopus database, covering the period from 1991 to September 2023. Only research articles in the English language, within the subject areas of business, accounting, management, economics, and finance, were included. The string employed were "(TITLE ("Sustainability") OR TITLE ("Sustainable growth") OR TITLE ("Sustainable development") AND TITLE ("Solar energy") OR TITLE ("Solar Goods") OR TITLE ("Solar Products")) AND (LIMIT-TO (SUBJAREA, "BUSI") OR LIMIT-TO (SUBJAREA, "ECON")) AND (LIMIT-TO (DOCTYPE, "ar")) AND (LIMIT-TO (LANGUAGE, "English"))." Following a thorough screening, a total of 257 articles were selected for analysis.

2.2 Software

In the present study, a comprehensive bibliometric analysis is conducted to thoroughly examine the selected domain. While various open-source tools are accessible for such analyses, including BibExcel, Citespace, R-Studio, Pajek, and HistCite, the study has drived conclusions by employing the Bibliometrix R package (Aria & Cuccurullo, 2017) and Vosviewer (Eck & Waltman, 2009). These tools have been selected due to their widespread utilization in bibliometric analysis and their capacity to offer enhanced visual representations of the data.

3. Bibliometric Analysis and Discussion

3.1 Publication Statistics

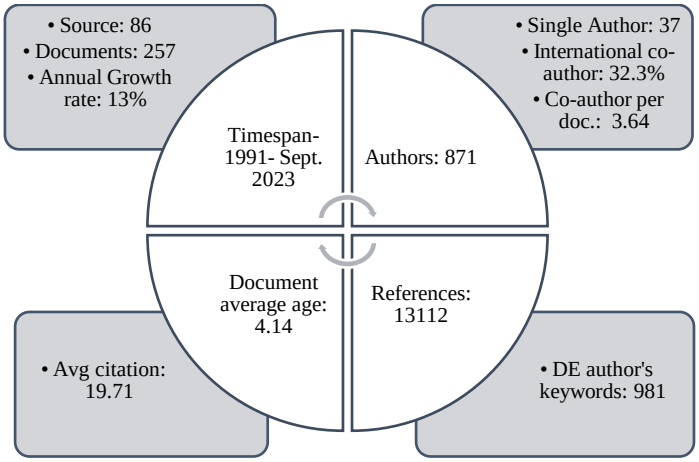

Figure 4: Statistics Summary
Source: Authors' own calculations

Figure 4 provides comprehensive bibliometric statistics for the dataset covering the timespan from 1991 to September 2023. In the considered dataset, there were 257 documents sourced from 86 distinct publications, showcasing a robust annual growth rate of 13%. The scholarly contributions were attributed to 871 authors, among whom 37 were single authors, while approximately 32.3% engaged in international co-authorship, highlighting the collaborative nature of research in the field. On average, each document in the dataset had 3.64 co-authors, indicating a propensity for collaborative research. The collective body of work referenced a substantial 13,112 sources, reflecting a rich knowledge base. Notably, the dataset featured 981 distinct author's keywords, illustrating the diversity of research themes within the domain. The average age of the documents in the dataset was 4.14 years, and each document garnered an average of 19.71 citations, signifying their impact and relevance in the scholarly community. These statistics offer valuable insights into the scope, collaborative dynamics, and knowledge dissemination in the sustainable development and solar energy domain.

3.2 Trend Analysis

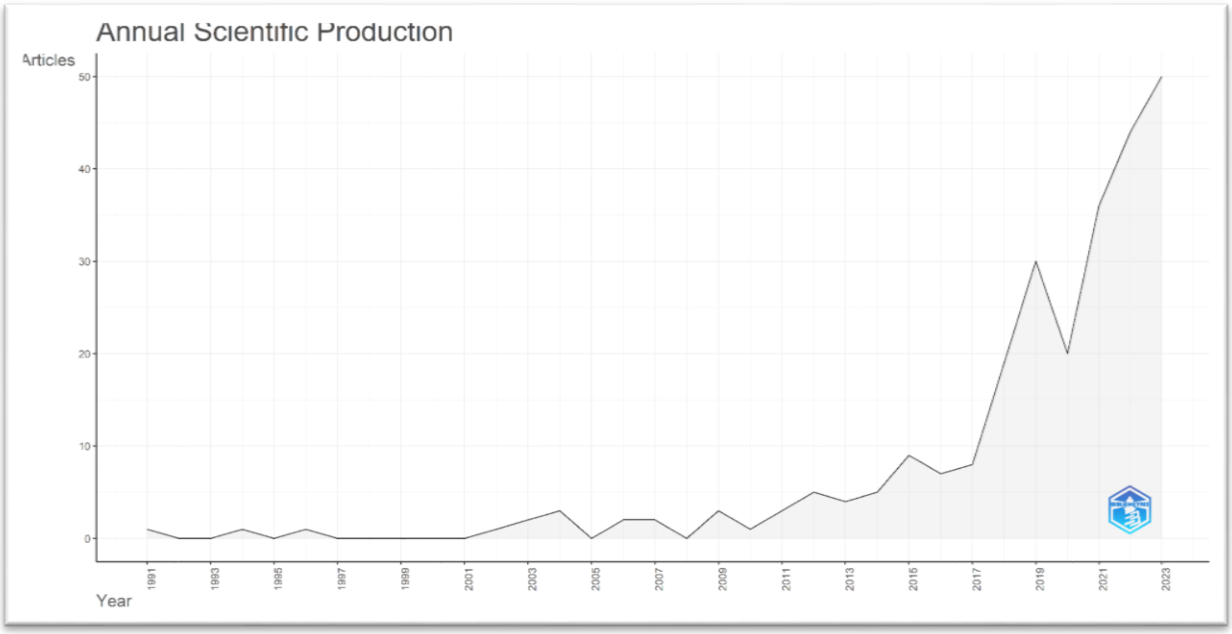

Figure 5: Trend analysis of the documents
Source: Authors' own calculations using RStudio

The trend analysis of the documents reveals the evolution of scholarly contributions over the years, providing valuable insights into the growth and prominence of the field (see Figure 5). In the early 1990s, there were sporadic articles, with 1991, 1994, and 1996 each witnessing one publication while no publication in the year 1992, 1993, 1995, 1997 to 2001, 2005, 2008. The subsequent years up to 2002 showed limited activity. However, from 2003 onwards, there was a noticeable uptick, with a gradual increase in the number of articles. The year 2015 marked a turning point, with 9 articles, signaling a substantial growth in scholarly activity. The following years witnessed a steady rise, with particularly notable increases in 2018 (19 articles), 2019 (30 articles), and 2021 (36 articles), although decreased in 2020 due to pandemic which resulted in countrywide lockdowns and worldwide fiscal declines (Gebreslassie, 2022). The most recent years, 2022 and 2023, demonstrated a remarkable surge in research output, with 44 and 50 articles, respectively. This trend suggests that solar energy is increasingly being seen as a viable and important solution to the challenges of sustainable development. Solar energy is a renewable resource that does not produce greenhouse gases or other pollutants. It is also a clean and reliable source of energy that can be used to generate electricity for homes, businesses, and communities of all sizes (Calderón et al., 2021; Elmustapha et al., 2018; Gebreslassie, 2022; Mah et al., 2012; Ongeri & Mbataru, 2023). Indeed, the escalating trend in research output on solar energy reflects a heightened recognition of its importance among policymakers and academics alike indicating a growing commitment to understanding, harnessing, and advancing solar energy solutions.

3.3 Most productive journals

Table 2: Top 10 productive journals

Journal Name	Publisher	PY start	Impact Factor (as of 2023)	Articles

Journal Of Cleaner Production	Elsevier	1993	11.072	96
Resources, Conservation and Recycling	Elsevier	1988	13.176	14
Frontiers In Energy Research	Frontiers Media S.A.	2007	3.858	10
Environment, Development and Sustainability	Springer	1999	4.08	9
International Journal of Energy Economics and Policy	EconJournals	2001	0.38	9
International Journal of Energy Sector Management	Emerald	2007	0.468	8
Ecological Economics	Elsevier	1989	6.536	7
Emerging Markets Case Studies	Emerald	2011	0.213	4
Energy Economics	Elsevier	1979	9.252	4
Resources Policy	Elsevier	1999	8.222	4
Total				165
Percentage share out of total (165/257) * 100				64.20%

Source: Researchers' own calculations

In order to gain insights into the present state and potential future directions of research in any domain, it is crucial to acquaint oneself with the journals that consistently publish a substantial number of top-tier scholarly articles in the same field (Eck & Waltman, 2009). Table 2 presents a comprehensive overview of the top 10 productive journals in the field under consideration. These journals span various publishers and have been contributing significantly to the scholarly discourse in this domain over the years. Notably, the "Journal of Cleaner Production," published by Elsevier, holds a prominent position as the top journal, with a substantial impact factor of 11.072 as of 2023 and an impressive total of 96 articles. Elsevier maintains a strong presence in this list, with "Resources, Conservation and Recycling" being another notable journal, boasting an impact factor of 13.176 and 14 articles. Additionally, journals such as "Frontiers in Energy Research," "Environment, Development and Sustainability," and "International Journal of Energy Economics and Policy" have also made noteworthy contributions, with impact factors ranging from 3.858 to 4.08. The list extends to include journals from various publishers like Springer, EconJournals, and Emerald, covering a wide spectrum of topics within the field. These journals collectively account for 64.20% of the total articles considered in the analysis, reflecting their significant role in shaping the scholarly landscape of the sustainable development using solar energy.

3.4 Most productive authors

Table 3: Top 10 impactful authors

Authors	Articles	Total citations	Average citations	H_index	G_index	PY_START
Sovacool Bk	4	132	33	57	4	2016
Hook A	3	86	28.67	126	3	2020
Irfan M	3	206	68.67	31	3	2021
Li J	4	76	19	145	4	2009
Martiskainen M	3	86	28.67	14	3	2020
Antonanzas J	2	28	14	58	2	2019
Arena S	2	12	6	8	2	2022
Bertheau P	2	80	40	30	2	2018
Cavallaro F	3	136	45.33	12	3	2018
D'adamo I	2	114	57	1	2	2015
Total	27	956	35.41			

Source: Authors' own calculations

Table 3 shows the top 10 most impactful authors in the domain of promoting sustainable development through solar energy, based on the number of articles they have published, the total number of citations their work has received, the average number of citations per article, the H-index, the G-index, and the year they first published on this topic. The top 10 authors have published a combined total of 27 articles, which have received a total of 956 citations. This gives an average citation rate of 35.41 citations per article. The H-index, which measures the breadth and impact of an author's work, that ranges from 1 to 57 for the authors, with an average H-index of 26. The G-index, which measures the productivity and impact of an author's work, that ranges from 4 to 31 for the authors, with an average G-index of 15.5. The year in which the top authors first published on the considered topic ranges from 2009 to 2022. However, Sovacool K was the most prominent among them with 4 articles having 132 citations and H_index of 57 followed by Hook A and Irfan M respectively. The most impactful authors in the field are from a variety of countries, including the United Kingdom, the United States,

Canada, Finland, Spain, Italy, France, and Australia. This suggests that research on this topic is being conducted all over the world. This information can be used to identify leading experts in the field and to track the latest trends in research.

3.5 Citation analysis

Table 4: Top 10 influential documents

Article	DOI	Total Citations	TC per Year	Normalized TC
(Meek et al., 2010)	10.1016/j.jbusvent.2009.09.007	322	23.00	1.00
(Brown & Buranakarn, 2003)	10.1016/S0921-3449(02)00093-9	271	12.90	1.94
(Yang et al., 2012)	10.1177/0276146713481605	244	22.18	3.34
(Irfan et al., 2021)	10.1016/j.jclepro.2021.126008	158	52.67	7.46
(Prinsen et al., 2016)	10.1016/j.worlddev.2006.10.001	157	9.24	1.86
(Bórawski et al., 2019)	10.1016/j.jclepro.2019.04.242	156	31.20	6.27
(Yang et al., 2012)	10.1007/s10668-020-01038-9	103	34.33	4.87
(Ekren et al., 2021)	10.1016/j.jclepro.2020.123615	102	34.00	4.82
(Barbara Kitchenham, 2014)	10.1016/j.jclepro.2013.10.043	99	11.00	2.49
(Cavallaro et al., 2019)	10.1016/j.techfore.2018.12.009	93	18.60	3.74

Source: Authors' own compilations

Table 4 presents the top 10 most impactful documents in the realm of sustainable development through solar energy. Their impact is assessed by considering three factors: total number of citations (TC), average annual citations (TC per year), and normalized total citation (NTC), which considers the document's age and the field it belongs to (Cavalcante et al., 2021; Jia & Mustafa, 2023). These top 10 documents collectively boast 2,170 citations, averaging 217 citations per document. NTC values for these documents range from 1.00 to 7.46, with an average NTC of 3.70. This signifies that these documents are highly cited, both in absolute terms and relative to the age of the field. It is noteworthy that these influential documents are dispersed across various journals, such as "Journal of Business Venturing" (32 TC, 23 TC/year, 1 NTC), "Energy Policy" (271 TC, 12.90 TC/year, 1.94 NTC), "Journal of Cleaner Production" (244 TC, 22.18 TC/year, 3.34 NTC), and "World Development" (158 TC, 52.67 TC/year, 7.46 NTC), and so on indicating the widespread dissemination of research in sustainable solar energy development to a diverse readership.

3.6 Countries analysis

Table 5: Top 10 prolific countries

Country	**Articles**	**Percentage (%) Share**
China	177	33.34
USA	72	13.56
UK	49	9.23
Italy	45	8.47
Spain	44	8.29
India	41	7.72
Malaysia	29	5.46
Canada	26	4.90
Mexico	26	4.90
Colombia	22	4.14
Total	531	100

Source: Calculated by Authors'

Table 5 provides an overview of the top 10 countries in terms of their contributions to the selected research field, along with the respective percentage shares of their published articles. Remarkably, China emerges as the dominant force in this domain, responsible for 177 published articles, translating to a substantial 33.34% of the total output. In second place is the United States, with 72 articles (13.56% share), followed closely by the United Kingdom with 49 articles (9.23% share), Italy with 45 articles (8.47% share), and Spain with 44 articles (8.29% share). The remaining five nations in the top 10 include India, Malaysia, Canada, Mexico, and Colombia. Notably, all the countries in this ranking are either well-developed or rapidly emerging economies. This underscores the global consensus on the significance of solar energy as a sustainable and renewable energy source that can mitigate greenhouse gas emissions and enhance air quality. The preeminent position of China in solar energy research aligns with its status as both the largest emitter of greenhouse gases and the foremost investor in renewable energy globally (Zhang et al., 2020). China's unwavering commitment to ambitious solar energy targets signifies its dedication to leading the global transition towards a cleaner energy economy (Guo et al., 2019). Concurrently, other nations in the top 10 are equally committed to substantial investments in solar energy (Abban & Hasan, 2021). The United States, for instance, aims to achieve 100% carbon-free electricity generation by 2035 (Siegler et al., 2022), while the United Kingdom has set a net-zero greenhouse gas emissions target by 2050 (Sithole et al., 2016). These concerted efforts and investments by nations worldwide bode well for the future of sustainable development, as solar energy emerges as a clean, renewable, and promising energy source capable of satisfying the world's growing energy demands in an environmentally responsible manner.

3.7 Thematic Analysis

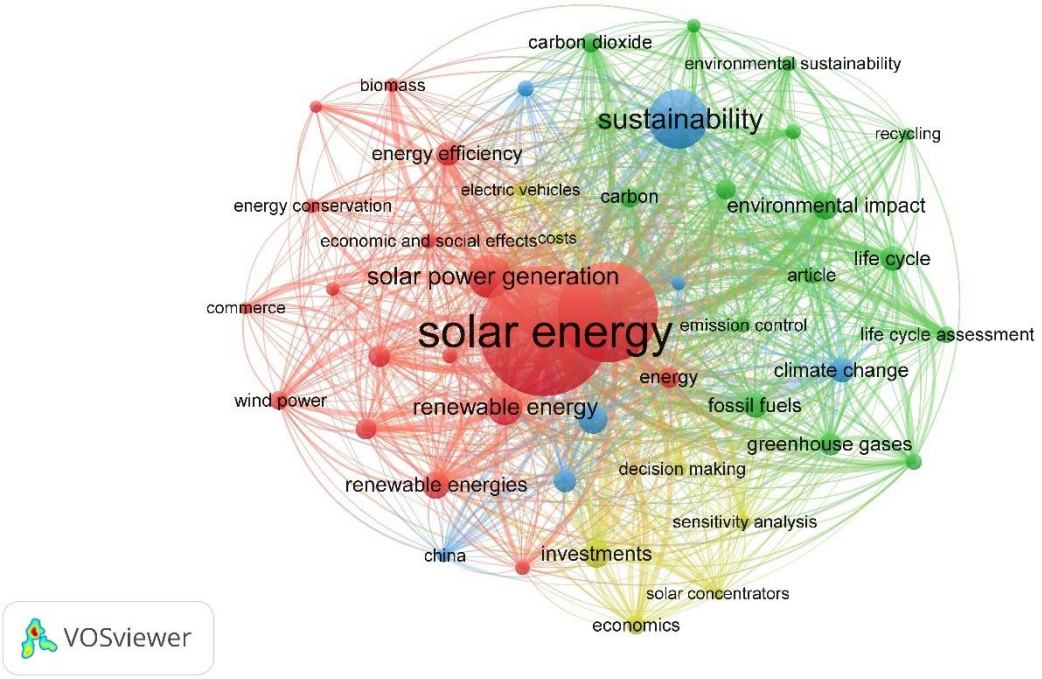

Figure 6. Network Map of Keyword occurrences
Source: Authors' own creation

Keyword co-occurrence analysis, a well-established bibliometric approach (Callon et al., 1983), is employed in this study to delve into the relationships between keywords within publications, offering valuable insights into the interconnected concepts within the field (Whittaker, 1989). Unlike other methods, co-word analysis establishes a similarity estimate based on the actual content of the texts, allowing for a nuanced understanding of the thematic landscape (Zupic and Cater, 2015). In this investigation focusing on sustainable development through solar energy, a comprehensive keyword co-occurrence analysis was conducted on 2569 keywords, with a minimum occurrence threshold set at 10, resulting in 48 keywords meeting the criteria. The top five keywords, "solar energy (184,866)," "sustainable development (133,715)," "sustainability (70,306)," "solar power generation (47,291)," and "environmental impact (27,221)," emerged as pivotal, (x,y) reflecting both their frequency and total link strengths respectively. Utilizing the VOS viewer, a network map (see Figure 6) was generated, visually presenting four distinct clusters that encapsulate specific facets of sustainable development through solar energy.

Cluster 1 (Economic and Social Dimensions of Sustainable Energy): The first cluster, encompassing keywords such as "biomass," "commerce," "desalination," "economic analysis," and "renewable energy," highlights the economic and social implications of sustainable energy planning and utilization. This cluster suggests that sustainable energy development is not just about environmental concerns; it also has significant economic and social impacts. For instance, the development of renewable energy technologies can create new jobs and businesses, while also improving energy security and reducing reliance on imported fossil fuels. Additionally, sustainable energy can contribute to economic growth by reducing energy costs and improving energy efficiency.

Cluster 2 (Environmental Impacts and Emission Control): The second cluster, involving keywords such as "carbon," "carbon dioxide," and "global warming," underscores the environmental impacts of energy production and the need for emission control strategies. This cluster suggests that sustainable energy is crucial for mitigating climate change and reducing our carbon footprint. Renewable energy sources produce minimal greenhouse gas emissions compared to fossil fuels, making them a more environmentally friendly alternative. Additionally, carbon capture and storage technologies can play a role in reducing emissions from fossil fuel power plants.

Cluster 3 (Global Context and Climate Considerations): Cluster three, integrating keywords like "alternative energy," "China," and "climate change," highlights the broader global context of sustainable energy development. This cluster suggests that sustainable energy is a global challenge that requires international cooperation and collaboration. China, as one of the world's largest energy consumers, plays a crucial role in global efforts to transition to a low-carbon economy. Additionally, climate change is a borderless issue that requires a coordinated global response.

Cluster 4 (Economic Considerations and Decision-Making): The fourth cluster, comprising keywords like "costs," "decision making," and "economics," sheds light on the economic considerations and decision-making processes involved in sustainable energy initiatives. This cluster suggests that the economics of sustainable energy is a complex issue that needs to be carefully considered when making investment decisions. While renewable energy technologies are becoming increasingly cost-competitive, there are still upfront costs associated with their deployment. Additionally, decision-makers need to weigh the long-term economic benefits of sustainable energy against the short-term costs.

The interconnections between these clusters, represented by 878 links, unveil a rich tapestry of relationships among the analyzed keywords. The cumulative link strength of 3480 underscores the robustness and depth of these connections, emphasizing that the research landscape in solar energy and sustainable development is vibrant and dynamic. There is a wide range of topics being investigated, and new areas of interest are emerging. This is a positive sign for the future of sustainable development, as it indicates that researchers are committed to finding solutions to the challenges we face. Solar energy is not just a technology for generating clean electricity. It also has the potential to address a wide range of other sustainability challenges, such as climate change and water scarcity. This co-word analysis not only reveals the thematic structure of the field but also provides a nuanced understanding of the intricate relationships between key concepts, paving the way for informed research directions and comprehensive explorations in the realm of solar energy and sustainability.

5. Conclusion and Suggestions

This study presents a thorough bibliometric analysis of scholarly literature concerning sustainable development through solar energy. The findings emphasize the escalating importance of solar energy as a pivotal catalyst for sustainable development, reflecting a global commitment to shift towards cleaner and environmentally friendly energy sources. The identified trends in research themes, influential authors, and publication outlets unveil the dynamic and evolving nature of the field, indicating a substantial increase in interest and contributions over the years. The consistent upward trajectory in publications since the early 21st century indicates a promising trend, affirming ongoing exploration and advancements in solar energy solutions aimed at achieving sustainable development goals.

The study emphasizes that solar energy research is inherently interdisciplinary, requiring collaboration among researchers, policymakers, and industry stakeholders from various fields. This is because the implementation of solar energy solutions on a global scale is complex and involves technological advancements, policy frameworks, economic considerations, social impacts, and international cooperation. Engineers and scientists play a crucial role in developing new and more efficient solar energy technologies. This includes improving the efficiency of solar cells, developing new storage solutions, and designing cost-effective solar power systems (Kuleshov et al., 2018; Strebkov, 2015). Policymakers are responsible for creating and implementing policies that promote the adoption of solar energy. This includes providing incentives for solar energy investment, setting renewable energy targets, and streamlining the permitting process for solar installations (Cucchiella et

al., 2015). Economists play a role in analyzing the costs and benefits of solar energy. This includes assessing the economic viability of solar energy projects, calculating the return on investment, and evaluating the impact of solar energy on the economy (Bandyopadhyay, 2020). Sociologists and other social scientists study the social impacts of solar energy. This includes the impact of solar energy on jobs, communities, and the environment (Becker, 2001). International cooperation is essential for addressing the global challenges and reaping the benefits of solar energy (Walter et al., 2010). This includes sharing research and development, developing international standards, and providing financial assistance to developing countries. The factors mentioned above are all interconnected. For example, technological advancements can lead to lower costs, which can make solar energy more attractive to policymakers and investors. Additionally, social acceptance of solar energy can lead to more favorable policies and increased investment.

6. Limitations

While this research makes noteworthy contributions, it also presents certain constraints that create opportunities for subsequent investigations. The study exclusively relied on Scopus as the sole database, and future researchers might explore alternative databases such as Web of Science or Google Scholar, or employ a combination of multiple databases for a more exhaustive bibliometric analysis. While the current study utilized bibliometric performance analysis and keyword co-occurrence analysis, future researchers could opt for a mixed-method approach and integrate additional bibliometric techniques and tools, such as thematic analysis, correspondence analysis, etc., to unveil novel trends in the field. Lastly, although the bibliometric method is systematic, future researches could derive additional benefit by amalgamating it with qualitative approaches like systematic literature reviews, thereby offering a more comprehensive understanding of the phenomena in this domain. Addressing these limitations in subsequent studies would undoubtedly augment the research conducted in the domain.

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