# Analyzing Trends and Innovations in Solar Energy-Powered Water Pumping Systems: A Bibliometric Study on Renewable Energy Applications

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**KEYWORDS**

Solar Energy, Water pumping, Bibliometric Analysis, Photovoltaic.

**ABSTRACT**

Energy security has received significant attention in both industrialized and developing nations. During the energy transition, the use of renewable energy in electrical power networks has grown significantly. Solar photovoltaic is being acknowledged as an alternative to conventional generation sources, particularly for remote and rural locations that have isolated power infrastructures. National policies and government laws play a crucial role in promoting carbon-neutral solar photovoltaic. A bibliometric analysis was conducted on research related to solar power from 1961 to 2023 in journals covering all subject areas of the Science Citation Index to provide a deep insights the about research published in solar photovoltaic domain. The terms "solar," "solar energy," "water pump," and "water pumping system" were chosen to be searched in the title, abstract, or keywords section. The bibliometric analysis is conducted using pertinent authors, sources, words, fields, and conceptual analysis. These discoveries can help researchers and the scientific communities quickly grasp the foundational knowledge in the field of solar photovoltaic. The number of articles and citations is limited but growing, which indicates solar energy for agriculture or irrigation is a developing field and needs more contributions from researchers to enhance knowledge in this area..

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## 1. Introduction

The population of developing countries such as India, China, and Bangladesh is increasing rapidly. The increasing population intensifies the need for improved food production. The agricultural industry is continuously undergoing modernization to meet the growing demands for food (Rubio-Aliaga et al., 2016). According to Vohra & Franklin, (2021), the projected demand for food grains in India is expected to rise from 278 to 450 million metric tons by the year 2050. In developing countries such as India, agricultural activities rely heavily on

rainfall. To ensure a consistent water supply for agriculture throughout the year, the Indian government and regional authorities have implemented various measures, such as rainwater harvesting, Building river check dams and maintaining ponds and lakes in good condition are essential tasks. Most of the time, we use pumps to distribute water to fields located in various areas (M. Kumar et al., 2015). Water pumping plays a crucial role in irrigation and farming, as providing water at the appropriate time and in the correct amount enhances crop productivity. Most agriculturist depends on groundwater for their agricultural endeavors (M. N. I. Sarkar & Ghosh, 2017). In certain areas of India and Africa, the use of buckets for crop irrigation results in subpar crop output (M. Kumar et al., 2023; Roblin, 2016). Approximately 20.3% of India's electrical energy is used for farming purposes (A. Sarkar, 2020). Typically, diesel engines or grid power are used to pump water for agricultural activities on a large scale. Nevertheless, the progress of these techniques is impeded by increasing fossil fuel costs, CO2 emissions, and inadequate electric infrastructure in remote, rural, and arid areas.

An approach proposed for achieving sustainability and profitability in agriculture is adopting renewable energy sources for water pumping (Rubio-Aliaga et al., 2016). According to A. Kumar & Kandpal (2007), there are four viable options for utilizing renewable energy to power water pumping systems: solar energy, wind energy, producing gas, and biogas. Crops demand a substantial amount of water during sunny months or days. Therefore, solar energy is particularly well-suited for irrigation in agriculture, among other renewable energy sources, as its availability aligns with the time when water is most needed for crop irrigation. Furthermore, solar energy-powered irrigation is more dependable and appropriate for watering agricultural grounds in dry, isolated, and rural areas, as these locations lack access to electrical networks in many developing nations. According to Roblin (2016), implementing appropriate water pumping systems might increase crop output in arid zones by approximately 300.0%. Although solar energy-based water pumping systems may have a high initial cost, they offer significant long-term advantages such as zero fuel expenses, no ongoing costs, and lower pollution levels. Solar pump installations are prevalent in underdeveloped nations across Africa, Asia, and South America. The projected installation of solar PV pumps in Bangladesh by 2025 is approximately 15,872 (M. N. I. Sarkar & Ghosh, 2017). Solar water pumping viability depends on several factors, including weather, the kind of crop, the depth of groundwater and availability, accessible conventional electric grid power, government financial incentives, and the cost (Kelley et al., 2010).

Currently, the application of photovoltaic conversion of solar energy to operate water pumps is a developing technology that presents significant difficulties. Photovoltaic (PV) technology can be implemented on a larger scale and offers an environmentally beneficial alternative to conventional water pumps powered by fossil fuels such as diesel and electricity (A. Kumar et al., 2010)(Mittal et al., 2012). Furthermore, the significance of solar photovoltaic (PV) energy in powering water pumps is heightened by the ongoing depletion of oil supplies, unequal distribution, and escalating cost of electricity. This is particularly worrisome for emerging nations such as India (Abu-Aligah, 2011; Demirbaş, 2006) Small-scale water supply systems, which offer residential, animal, and irrigation water in isolated regions, have significantly increased in popularity, dependability, and effectiveness. The installation of SPVWPS offers numerous benefits to pumping sites that lack access to the national power grid yet have plentiful solar energy and inadequate transportation infrastructure. Furthermore, SPVWPS can endure harsh weather conditions such as snow and ice (Ghoneim, 2006; M. Kumar et al., 2023; Malhan

et al., 2021). Additionally, due to the inherent correlation between water needs and solar power availability, solar photovoltaic electricity can operate the water pumping system most efficiently (Dekam, 1986)(M. Kumar et al., 2023).

Water is the primary determinant of plant growth in agricultural production. Irrigation refers to the deliberate and regulated use of water for agricultural reasons. It utilizes artificial systems to meet water needs that are not satisfied by rainfall. Water sources include groundwater from wells or borings, surface water from streams, lakes, or reservoirs, floodwater, and non-conventional sources like treated effluent, desalinated water, or wastewater (M. Kumar et al., 2022)(GIZ, 2016). Solar-powered electrical pumps function similarly to conventional water pumps that are widely utilized. The fundamental differentiation lies in the fact that water supply pumps propelled by solar energy operate exclusively on solar energy and do not require external power sources, including utilities or conventional petroleum-based fuel (M. Kumar et al., 2015, 2023) A solar-powered system drives the volume of water during a given period based on the total amount of solar energy available. The dimensions of the photovoltaic (PV) array and the conversion of solar radiation to direct current (DC) power constrain the discharge rate of pumped water. The basic parts of a solar-powered water pump system include photovoltaic (PV) cells and the supporting structure that they are attached to. There is also a power electronic converter and controller to improve the electric pump's performance (USDA NCRS, 2010). A typical PV pumping system typically comprises a collection of PV panels installed in a designated area with a tracking mechanism that can be operated manually or automatically. Additionally, it includes a surface mount and either a submersible or floating pump systems (Chilundo et al., 2018; M. Kumar et al., 2024; Pankaj et al., 2023).

**Research Questions**

RQ1. What is the global trend of solar photovoltaic water pumping systems publications related in the incorporated domain?
RQ2. To identify the field's top ten prolific contributors (authors, countries and affiliations).
RQ3. To identify the collaboration network between countries and the authors.
RQ4. To identify core research gaps and propose potential routes for future study.
In order to investigate these topics, the current study utilized a thorough examination of existing literature and a quantitative analysis of bibliographic data.

This work aims to analyze the limits highlighted in past research on solar photovoltaic (SPV) water pumping systems to make a significant addition to the broader field. This study entailed a thorough review of pertinent scholarly sources to acquire knowledge, followed by critically examining the gathered data. A comprehensive scientific analysis was conducted to assess the progress made in reverse migration research from 1961 to 2023. Multiple relevant indicators were employed during the evaluation procedure. The indicators encompass the annual trend of publications and citation patterns, the countries with the highest productivity, the productivity of authors, and the most cited research articles, the prevailing most and emerging themes, and the inter-country collaboration for publication. This study employed the Scopus database to get bibliographic data on solar photovoltaic (SPV) water pumping systems. This study exhibits a higher degree of comprehensiveness than previous research, reducing the likelihood of disregarding any significant contributions to the topic area. The duration of prior research has exhibited significant variability, contingent upon the subject under investigation and the study's objectives.

## 2 Research Methodology

### 2.1 *Materials and Methods*

Bibliometric analysis is a widely employed approach for examining a specific research domain by utilizing bibliographic data (Bashar et al., 2024; M. Kumar et al., 2023; Rabbani, 2022) In the context of solar water pumping systems, this method involves analyzing a field's overall trajectory through explicit network analysis (Cobo, 2011; M. Kumar et al., 2023) and scientific mapping techniques (Noyons et al., 1999)(Raan, 2005). Additionally, it enables the analysis of the domain's expansion over time, scholarly cooperation, and collaboration between universities and countries through user-friendly graphical representation (Donthu et al., 2021; Herrera-Franco et al., 2020; M. Kumar et al., 2024). Researchers utilize this tool to examine citations, co-citations, emerging words, and pertinent topics within their specific areas of interest. The data was acquired from the Scopus database by utilizing carefully selected keywords drawn from the literature on solar water pumping systems. The Scopus database provides a comprehensive and easily accessible compilation of scientific literature for bibliometric analysis, consistent with prior studies (Gorraiz & Schloegl, 2008; M. Kumar et al., 2023, 2024).

The following string was used for a title search on the solar water pumping system: ( TITLE-ABS-KEY ( "solar" OR "solar energy" ) AND TITLE-ABS-KEY ( "water pump" OR " water pumping system" ) ) AND PUBYEAR > 1960 AND PUBYEAR < 2024 AND ( LIMIT-TO ( SUBJAREA , "ener" ) OR LIMITTO ( SUBJAREA , "soci" ) OR LIMITTO ( SUBJAREA , "busi" ) OR LIMITTO ( SUBJAREA"mult" ) OR LIMITTO ( SUBJAREA , "arts" ) ) AND ( LI MITTO ( DOCTYPE , "ar" ) ) AND ( LIMITTO ( LANGUAGE , "english" ) ). The data was retrieved from Scopus database on March 4, 2024. Total result from the first search was 1,850. In the second phase of inclusion and exclusion process according to different criteria, including (1) publication year, (2) subject area, (3) document type, (4) language, which removed a total number of 1,452 articles. Further, analysis performs on a total number of 398 documents.

## 3 Results and interpretations

### 3.1 Sample characteristics

This section provides an overview of the bibliometric data and authorship characteristics. According to Table 1, the Scopus query yielded a total of 398 articles from 120 journal and book sources published between 1961 and 2023. The yearly percentage growth rate of documents was found to be 5.8%. Additionally, the average number of years since the initial publication of papers relevant to solar water pumping systems across all 120 journals was determined to be 11.1. The mean citation count was 25.81, calculated by dividing the total number of citations by the total number of papers. In aggregate, the 398 articles listed a total of 10,045 references. Regarding the keywords, there were a total of 1063 keywords throughout all 398 articles, and 2333 distinct phrases were found to be often present in the titles of the articles' references. Regarding authorship, the 398 articles were authored by a combined total of 1071 people, with 40 of them being the sole authors of a single document. The number of books written by a single author was 43, but the number of co-authors per document was 3.28.

### 3.2 Annual scientific production

Figure 1 provides annual scientific production in solar photovoltaic water pumping systems, where it is recognized that the first few years were not focused on solar photovoltaic water pumping systems until the early 1990s, when the enquiry began and very few articles were reported. The current investigation's articles follow a yearly trend. The number of publications in

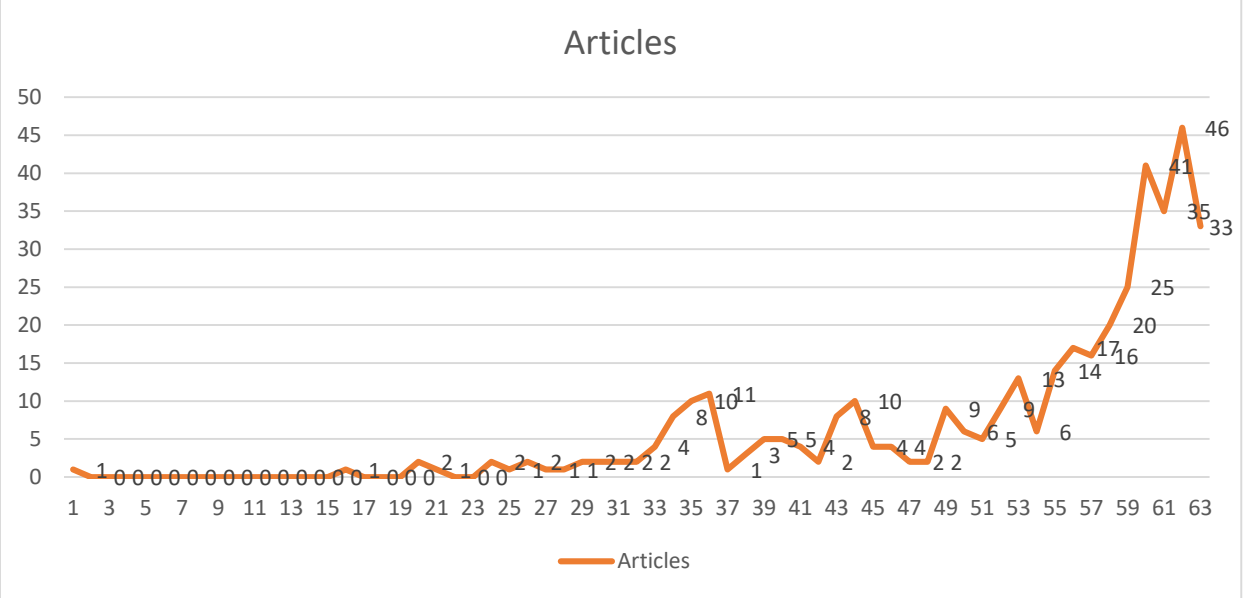
this discipline is increasing somewhat. Researchers became increasingly interested in solar photovoltaic water pumping systems in 2013, conducting 13 studies. In 2010, there were only six studies, but in 2011, there were five. Of the 398 scholarly works analyzed, 35 and 46 were attributed to the years 2021 and 2022, respectively. This is due to the fact that the energy industry at the time focused more on the characteristics, applications, and research of solar photovoltaic water pumping system advancements.

*Table 1: Overview of final dataset*

| Description | Results |
|---|---|
| **Main Information about Data** | |
| Time span | 1961:2023 |
| Sources (Journals, Books, etc) | 120 |
| Documents | 398 |
| Annual Growth Rate % | 5.8 |
| Document Average Age | 11.1 |
| Average citations per doc | 25.81 |
| References | 10045 |
| **Document Contents** | |
| Keywords Plus (ID) | 2333 |
| Author's Keywords (DE) | 1063 |
| **Authors** | |
| Authors | 1071 |
| Authors of single-authored docs | 40 |
| **Authors' Collaboration** | |
| Single-authored docs | 43 |
| Co-Authors per Doc | 3.28 |
| International co-authorships % | 22.36 |

Source: Authors' own development using R-Studio.

Figure 1: Annual Scientific Production

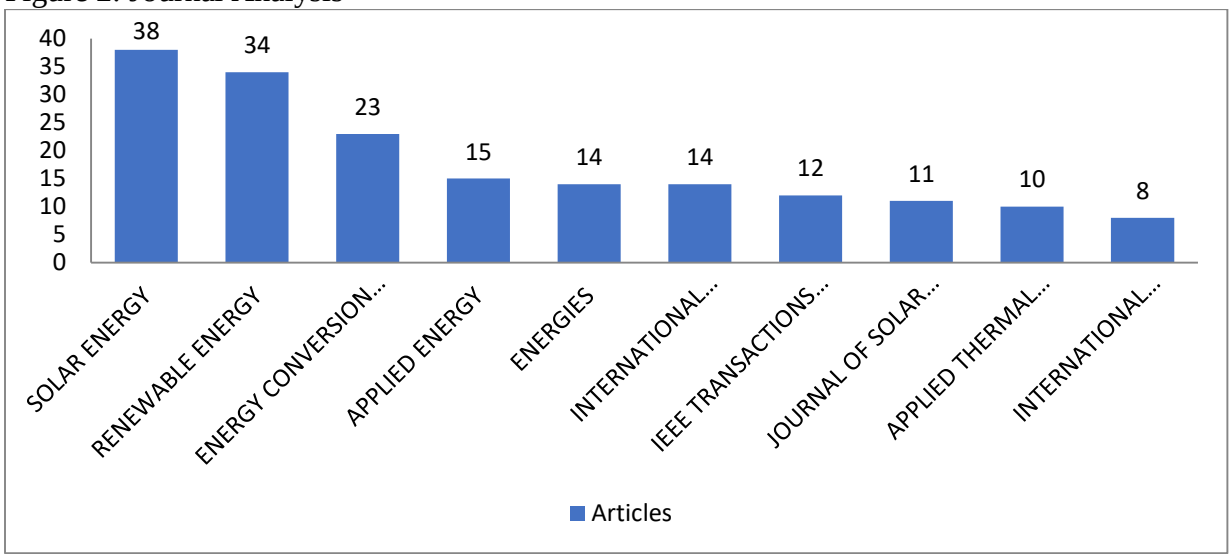


Source: Authors' own development using R-Studio

### 3.3 Journal Analysis

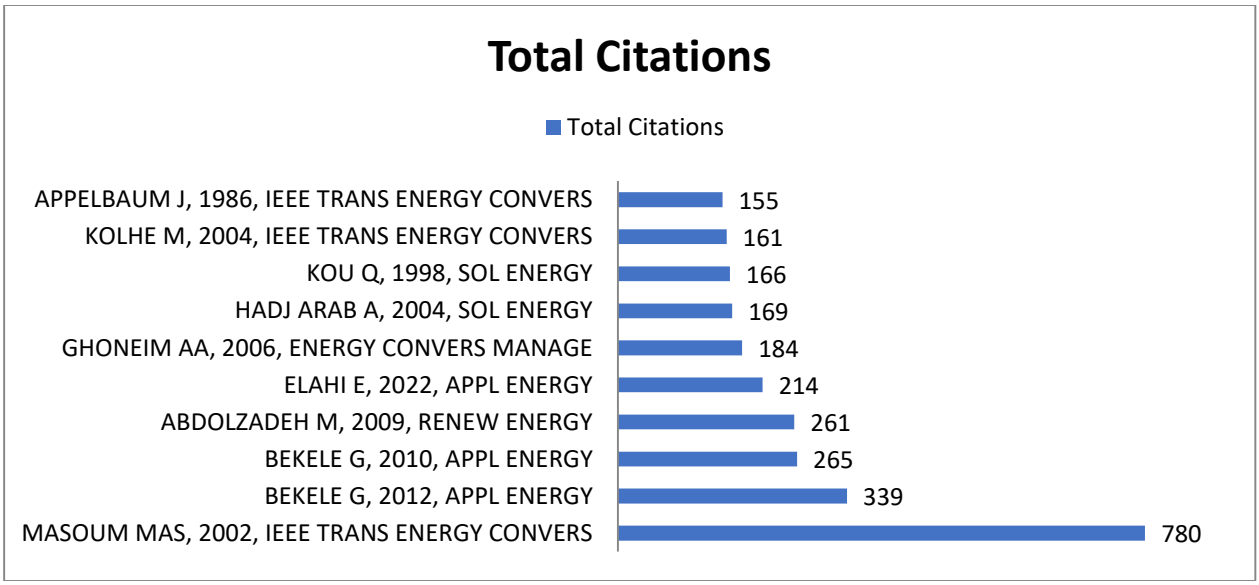
After conducting a thorough analysis of various sources, the author discovered that there are only three journals that have published 20 or more articles. The journal Solar Energy holds the top position with 38 articles published, followed by "Renewable Energy" and "Energy Conversion and Management" with 34 and 23 publications, respectively. The numbers are insufficient, suggesting that journals should prioritize and encourage publishing in the field of solar photovoltaic water pumps. Additional details regarding the top 10 journals, as indicated in the provided figure 2, are available. In figure 3, According to the author's citation analysis, just four journals have received more than 250 citations. The Journal of IEEE Transactions on Energy Conversion has the greatest citation count, with 780 citations. It is followed by the Applied Energy Journal, which has 339 citations, and the Renewable Energy Journal, which has 265 citations. Additional details regarding the top ten journals, ranked according to the number of citations, are provided in the accompanying figure. Furthermore, it has been discovered that prior to 1986, publications were only published in the Journal of IEEE Transactions on Energy Conversion. Subsequently, in 1998, the Journal of Solar Energy began publishing articles specifically focused on solar energy. More specific information can be found in the figure labeled "Source Analysis.".

Figure 2: Journal Analysis




Source: Authors' own development using R-Studio

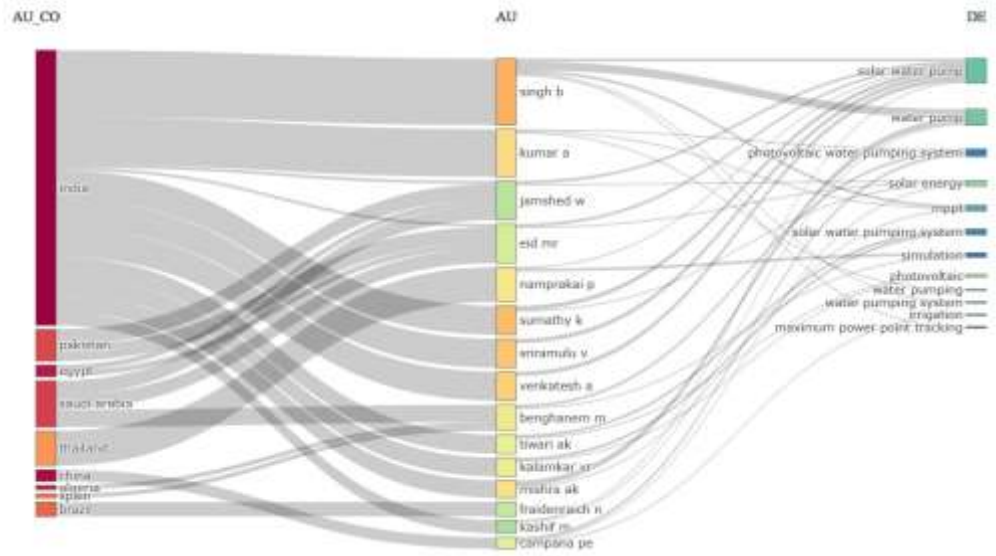
Figure: Total Citations



Source: Authors' own development using R-Studio

### 3.4 Three Field Plot

The figure 4 illustrates three elements authors' countries and keywords in a three-field depiction. Grey connections are used to depict the relationships between the elements of a three-field plot. Following the author's country of origin, the author's name is appended, and finally, the author is linked to the keywords. The count of documents associated with the specified element is denoted by the rectangle size in the list. The author's country sits on the left side of this narrative. India is the leading country in terms of the number of articles published on the subject of solar photovoltaic water pumping systems, according to a plot of three fields. Several authors, including Singh B., Kumar A., Jamshed W., Eid M., Sumathy K., Sriramulu V., Venkatesh A., and others, have contributed to this field. The second component of this three-field diagram is the author's name and position in the plot's center. The majority of the most prolific authors include Singh b, Kumar a, Jamshed w, Eid m, Namprakai p, and Sumathy K. A three-field plot displays the frequent keywords that connect each author. The plot displays these keywords on the right-hand side. The third component comprises the keywords that occur most frequently in the sample articles. The plot displays a list of twelve keywords. The most frequently occurring ones are "solar water pump," "water pump," "photovoltaic water pumping system," "solar energy," "mppt," "solar water pumping system," "simulation," "photovoltaic," "water pumping," and "irrigation," as indicated by the larger rectangles representing these terms. Most authors address "solar pumps" as their subject matter.
Figure: Three field plot

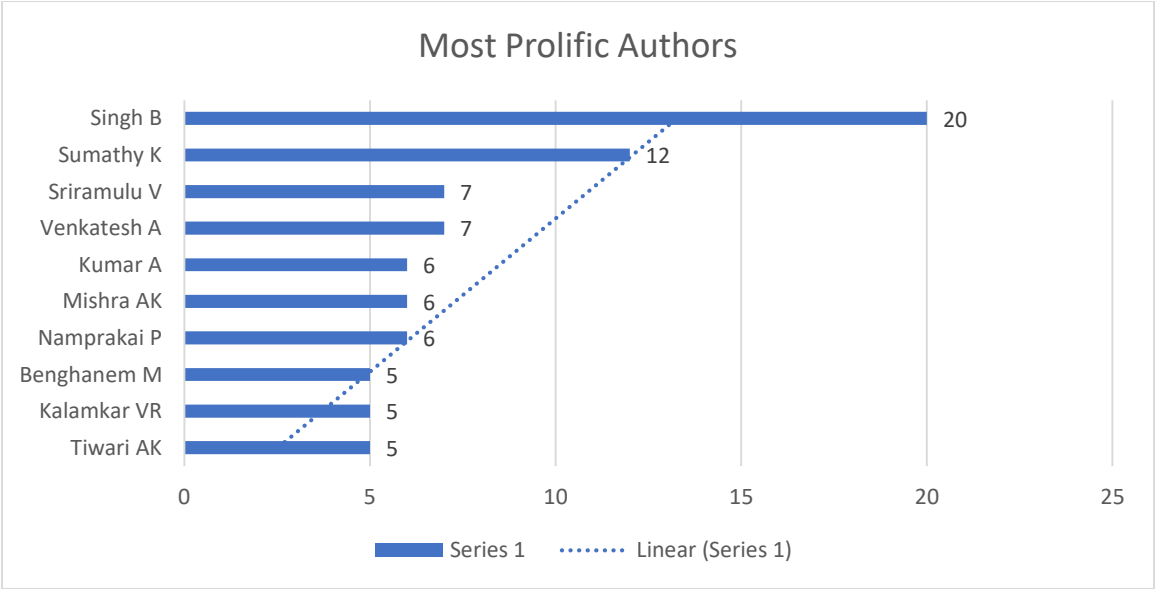



Source: Authors' own development using R-Studio

### 3.5 Most prolific author

Prominent authors play a crucial role in the field of research, making significant contributions. This analysis provides valuable insights into the authors' total effort, as evidenced by their publication output, co-authorship, and citations (S. Kumar et al., 2021)(Singh & Bashar, 2023). The present analysis is predicated on the aggregate quantity of articles authored by a given individual. According to Figure 5, Singh B. demonstrates the highest level of research activity in the field of solar water pumping, having produced a total of 20 documents. Sumathy K follows closely behind with 12 academic contributions, while Sriramulu V and Venkatesh A occupy the third position with 7 articles.

Figure 5: Most Prolific Authors in the incorporated domain



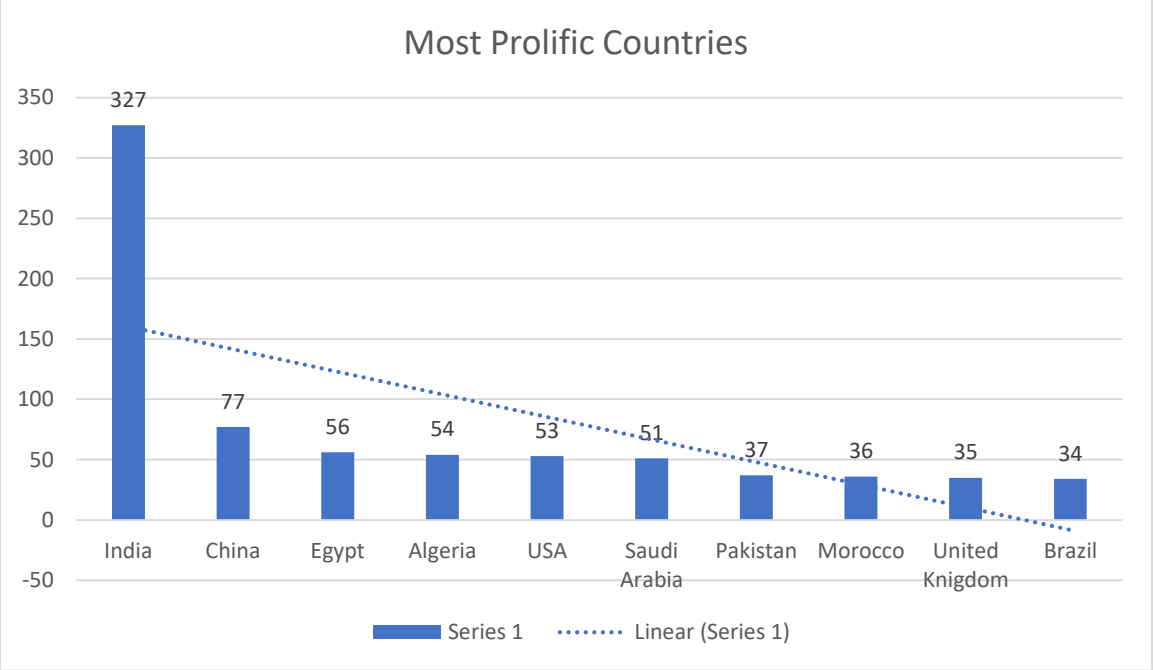

Source: Authors' own development using R-Studio.

Figure 6, which displays the number of publications, depicts the authors with the highest level of activity in the field of solar water pumping. Only a small number of early participants have made significant progress in solar water pumping and have been consistently involved since the late 1990s. Singh B., the author, has written the majority of the articles and maintained an active presence throughout the entire period. Namprakai P. is a renowned author who has consistently made significant contributions to the advancement of the scientific field of solar water pumping. Since 1993, this region has received significant attention from numerous scholars who have consistently investigated various aspects of solar water pumping.

### 3.6 Most Relevant affiliations

Figure 7 represent the "Most Relevant Affiliations" feature presents a comprehensive compilation of institutions that have made significant contributions and have high levels of activity. The Indian Institute of Technology Delhi (30) and Sohar University (13) are at the forefront of the list, with the China Institute of Water Resources and Hydropower Research (IWHR), Indian Institute of Technology, and National Institute of Technology following suit with 10 published publications each.

Figure 6: Most prolific Countries



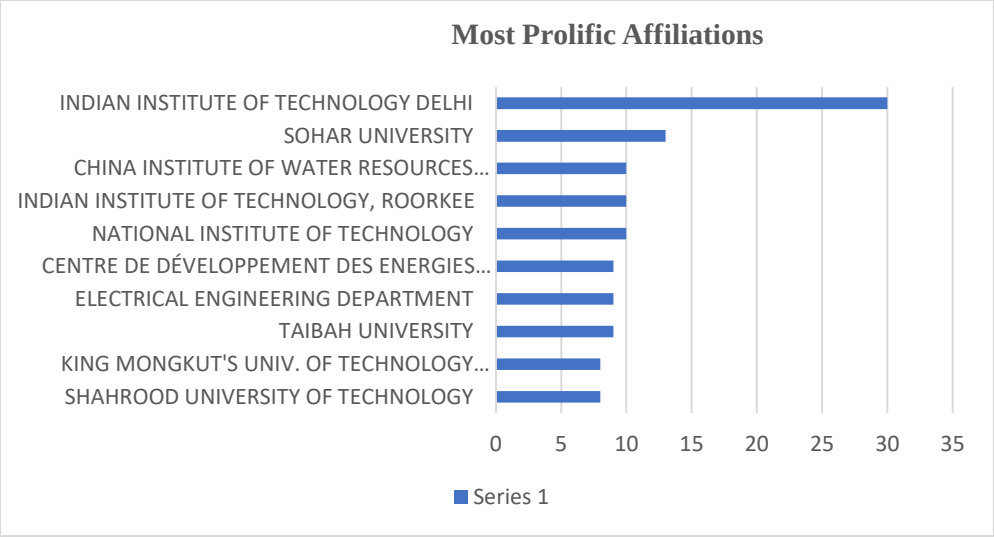

Source: Authors' own development using R-Studio.

These five institutions, which rank among the top 10, account for more than 18% of all reported and published articles on solar water pumping systems. Furthermore, the Centre de développement des energies renouvelables, the Electrical Engineering Department, and Taibah University individually rank sixth, seventh, and eighth on the list, respectively, with a total of nine publications. Two prominent institutions, namely King Mongkut University of Technology Thonburi and Shahrood University of Technology, have each produced a total of eight publications.

### 3.7 Countries MCP/SCP Ratio:

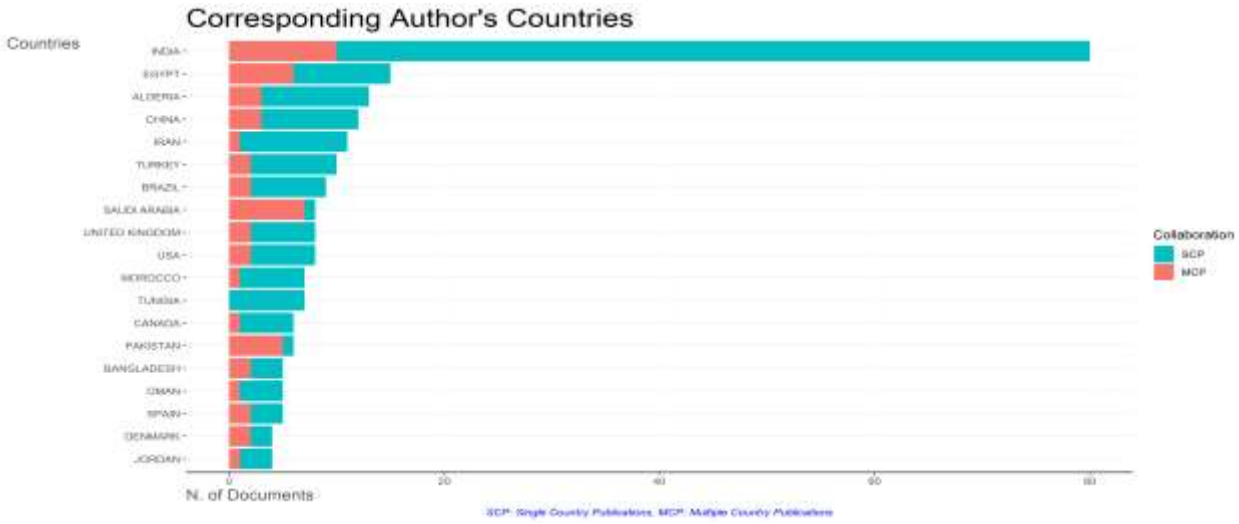
The research ascertained the output originating from the various nations comprising the dataset. The analysis focused on identifying the most productive countries. The findings indicate that India ranks first in terms of publishing output, with a total of 80 publications. This includes 70 publications solely from India (SCP) and 10 publications involving multiple countries (MCP). Based on this analysis, publications on "solar water pumping system" mainly produced by India (80), followed by Egypt (15), Algeria (13), China (12), Iran (11), Turkey (10), Brazil (9), Saudi Arabia (8), United Kingdom (8) USA (8). India seems the most linked country (10 MCP), followed by Egypt and Algeria. According to the data, the most productive nations are also the most cooperative as reveals in Figure 8.

Figure 7: Most relevant affiliations




Source: Authors' own development using R-Studio.

Figure 8: Countries MCP/SCP

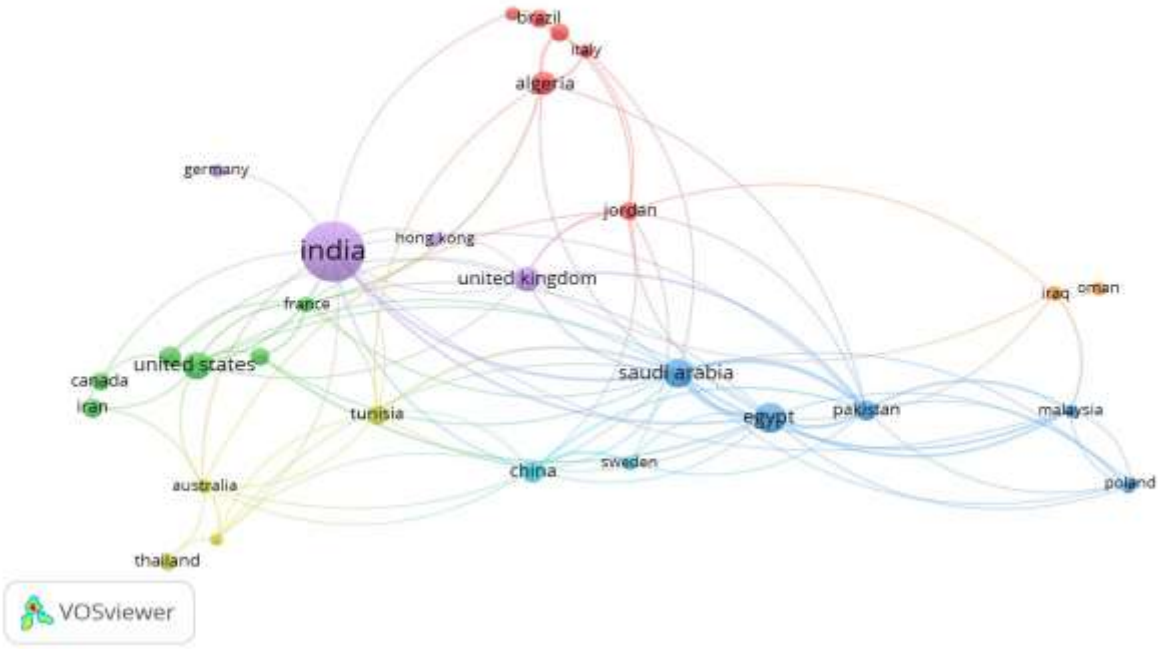


Source: Authors' own development using R-Studio.

### 3.8 The Worldwide Author-Country-Resource Network:

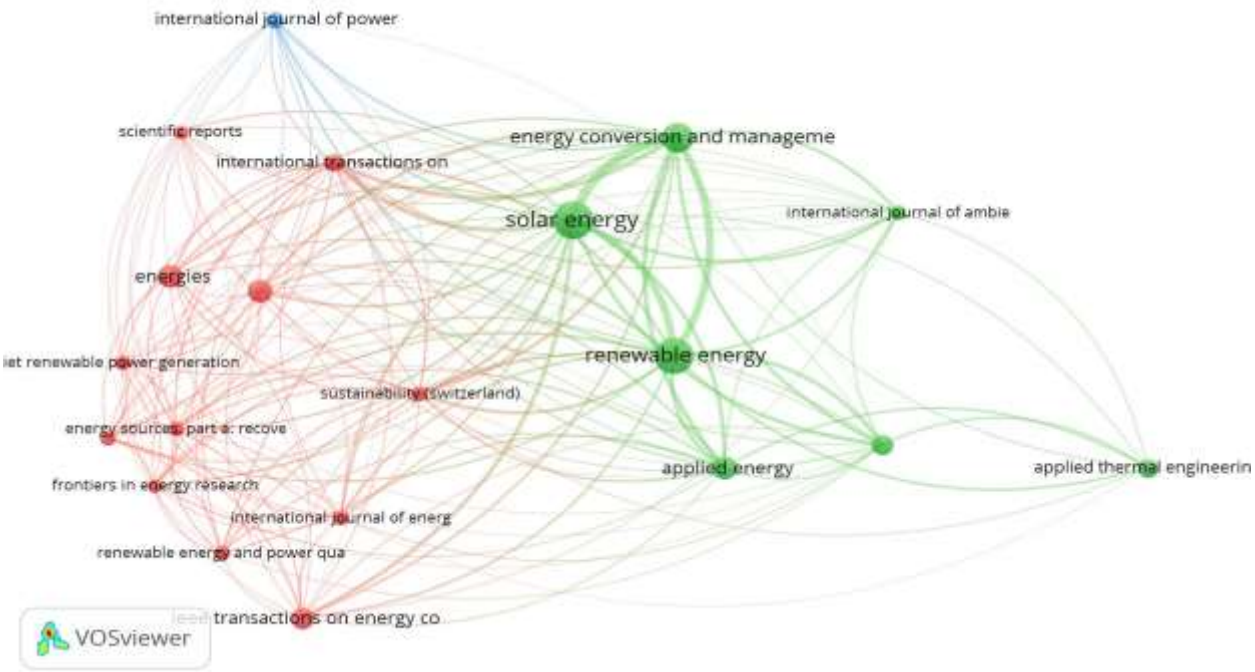
It suggests that researchers in the same publication cite a pair of these authors. Figure 9 depicts the bibliometric coupling among countries. India, Germany, Hong Kong, and the United Kingdom were the top countries in terms of research article production on the topic of "Solar power photovoltaic Water pumping system". The link between Algeria, Brazil, Denmark, Italy, Jordan, and Spain is characterized by proximity, indicating a strong connection among these countries. Furthermore, it is noteworthy that Egypt, Malaysia, Pakistan, Poland, Portugal, and Saudi Arabia have established a substantial partnership in the dissemination of research articles.
The size of the node increases proportionally with the number of publications published. Likewise, the distance between the nodes of the two journals shows the frequency at which these journals cite one other. Our research revealed that a greater distance between two nodes indicates a lower frequency of citations, and conversely, a smaller distance indicates a higher frequency of citations (Liao et al., 2018). As indicated in Figure 10, the publication titled "Solar Energy" is highly referenced and has a wide-reaching association with the journals "Renewable Energy", "Energy Conversion and Management", and "Applied Energy".

Figure 9: Countries collaboration network of authors




Source: Authors' own development using R-Studio.

Figure 10: Inter-connection between Sources




Source: Authors' own development using R-Studio.

## 4. Conclusion and future research directions

This study aimed to analyze the patterns in solar water pumping systems or their utilization in scientific production from 1961 to 2023. This work performed a bibliometric analysis of scientific metadata extracted from Scopus, a well-used academic abstract citation database. The Bibliometrix-R tool was utilized for this objective. The analysis was conducted using five main bibliometric indicators: scientific production, authors, sources or journals, affiliation, and nation-level. We have conducted a comprehensive analysis of the articles being reviewed, with a specific focus on important factors such as publication years, article type, source, and document content. This research paper provides comprehensive information regarding annual publication trends, authors who receive the highest number of citations annually, and other pertinent information extensively detailed in this study. Solar water pumping devices have revolutionized the utilization of energy technology in diverse sectors, such as irrigation and agriculture, practiced by farmers. A grand total of 398 documents were extracted from the SCOPUS database, encompassing 120 sources such as journals and books. These articles were authored by 1071 individuals and hail from 55 different countries. Annual publications have demonstrated various patterns over a period of six decades. During the initial three decades, spanning from 1961 to 1981, there was a notable scarcity of publications, with just a few exceptions observed in the years 1976, 1981, and 1984 to 1991. During this period, only a limited amount of research was published. The initiation of the proliferation of publications commenced in 1994, commencing with the release of four documents. The highest number of publications happened in 2022, totaling 46 documents. The findings illustrate the significant interest in the domain of solar water pumping systems across diverse academic fields and

geographical locations worldwide. The nations with the greatest prevalence of MCP were India, Egypt, Algeria, China, and Iran.

Source clustering offers scholars a comprehensive perspective on how to identify a corresponding source for a document or submit their article to the appropriate journal. Nevertheless, there is still a requirement for research that utilizes variables such as solar rooftops and solar AI. In developing nations, there is a scarcity of research opportunities. Therefore, the government must encourage research in this burgeoning field, as it can be beneficial for multiple stakeholders like farmers, industries, households, policymakers, and aspiring researchers. The study has exclusively utilized data from a single source, namely "Scopus," which implies that there may be some publications or studies overlooked by the author. Analysis conducted by alternative sources such as the Web of Science, Google Scholar, Research Gate, and others may yield contrasting outcomes. Further investigation can be conducted by employing a blend of alternative terms for "solar energy" or by scrutinizing data through alternative databases to verify the patterns.

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