

REVIEW ARTICLE

A systematic review on renewable energy and international trade: Current trends and future implications

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ABSTRACT

Renewable energy is critical to the achievement of sustainable development goals. Transitioning from fossil fuels to renewable energy alternatives enhances environmental sustainability, decreases dependence on energy imports, and fosters economic growth. The capacity of major countries in the global energy market to dedicate increased resources to renewable energy projects, as well as the impact of trade uncertainty on renewable energy investments by raising project expenses, exemplifies a vital connection between international trade and renewable energy. Within this framework, it is essential to examine research concerning renewable energy and international trade to identify trends in this field. The research aims to evaluate current trends in the literature, identify research gaps, and suggest directions for future investigation by examining the relationship between renewable energy and international trade through bibliometric analysis. In this context, 375 scientific studies published between 1992 and 2024, with a notable surge in research activity observed since 2010, were analyzed using data from the Web of Science database with the R program. As a result of the analysis, key findings were identified: a consistent increase in scientific production and citations during 2010–2020, the predominance of keywords such as "CO₂ emissions," "economic growth," and "consumption," and China emerging as the most productive country. Based on these outcomes, prominent authors, countries, topics, concepts, and research gaps in this field were identified, and suggestions for future research were made.

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INTRODUCTION

In order to realize sustainable development goals, climate change stands out as one of the most discussed issues by both climate scientists and scientists working in different disciplines [1, p. 628]. Given the volatility of fuel prices, the significant environmental externalities associated with fossil fuels, and their incompatibility with global carbon budgets and climate targets, there is an urgent need to transition toward renewable energy alternatives [2, p. 2]. However, the relatively low adoption of renewable energy sources compared to fossil fuels raises significant concerns regarding both environmental sustainability and energy security, thereby underscoring the importance of expanding clean energy sources, including bioenergy, hydro, wind, and solar energy worldwide [3, pp. 502–503]. Renewable energy plays a pivotal role in addressing the energy trilemma—encompassing energy security, economic competitiveness, and environmental sustainability—while simultaneously

fostering economic growth and reducing inequalities in international trade [4, 5, 6]. Moreover, trade openness has been linked to renewable energy investments through mechanisms such as technology transfer, which facilitate the adoption of innovative renewable technologies [7]. Countries with high trade openness are often observed to allocate greater investments towards renewable energy initiatives [8, 9]. Therefore, international trade is important in the international flow of renewable energy technologies [7].

A variety of studies examine the connection between international trade and renewable energy within the existing literature [7 - 15]. These studies emphasize the importance of technological innovation, economic freedom, and governance quality as mediating factors [7, 8, 9]. Trade in critical resources, such as minerals, is also found to support the expansion of renewable energy capacities [11], while trade-related risks—such as policy uncertainty—may hinder progress toward sustainability goals [14, 15]. Moreover, regional studies show that these dynamics vary across

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different economic and environmental contexts, particularly in Asia and Africa [8, 10, 12]. Prior analyses [7 - 15] indicate that a significant portion of these studies are based on econometric analysis.

Existing bibliometric studies predominantly address topics such as economic growth [16, 17], the circular economy [18, 19], and sustainable development [20]. A search in the Web of Science database reveals that bibliometric studies covering both international trade and renewable energy constitute approximately 10% of all studies [21]. In contrast, relatively few studies have examined the nexus between international trade and renewable energy [22, 23]. This study seeks to assess contemporary trends and research gaps in the literature, analyze studies investigating the correlation between renewable energy and international trade through bibliometric analysis, and provide recommendations for future research based on the conclusions derived. Using bibliometric analysis, this study aims to quantify citation metrics, keyword trends, and publication counts, map emerging research trends, identify collaboration networks among authors and institutions, and detect underexplored themes in the field. This study addresses underexamined intersections in existing literature, investigates the relationship between renewable energy and international trade, and provides direction for future studies in the field. Thus, utilizing the publications acquired from the search conducted in the Web of Science database, findings such as the number of citations these studies have received by year, keywords used, word trends, authors with the most publications in this field, the most productive institutions, and scientific cooperation between countries were evaluated; prominent topics and concepts in the field of renewable energy and international trade were identified. Accordingly, the analysis of publications acquired from the Web of Science database search encompasses metrics such as citation counts by year, prevalent keywords, word trends, and the contributions of the most productive authors and institutions, along with the exploration of international scientific cooperation.

CONCEPTUAL FRAMEWORK AND LITERATURE REVIEW

Renewable energy is widely acknowledged as pivotal for achieving global sustainable development goals [2, 24, 25, 26]. Consequently, the transition from fossil fuels—primarily responsible for elevated carbon emissions—to clean energy emerges as a key solution. The United Nations emphasizes that although countries have made notable progress in accessing sustainable energy, these advancements remain insufficient. For instance, The 2023 Sustainable Development Goals Report projects that by 2030, approximately 660 million individuals will lack access to electricity, remaining dependent on polluting fuels and technologies [27]. This underscores the need for sustainable policies to expand renewable energy adoption and improve energy efficiency, particularly in developing countries and across multiple sectors.

Diversifying energy sources mitigates environmental pollution and enhances energy security, enabling countries to build resilience against energy market fluctuations and supply disruptions [4, 5]. By increasing the utilization of renewable energy, countries can achieve greater control over their energy supply and reduce their dependence on energy imports. Consequently, the resulting savings can be

reinvested in various sectors, thus boosting production and facilitating a more active role in global trade.

The literature encompasses numerous studies that have examined the interplay between international trade and renewable energy using diverse methodologies. For example, [7] conducted a comprehensive quantitative analysis to show that nations with advanced technological innovation and high trade openness are more likely to invest in renewable energy initiatives. Nevertheless, energy-deficient countries often become dependent on imports of clean energy equipment, making them vulnerable to disruptions in international trade and exacerbating their energy security risks. In contrast, several studies demonstrate that trade openness fosters green technology transfer and enhances energy efficiency, thereby supporting the expansion of renewable energy sources and contributing to environmental sustainability [12, 13, 14].

Several empirical and conceptual studies have emphasized the significant influence of trade-related factors on renewable energy development. While trade uncertainties may escalate project costs and financing challenges for renewable energy investments [15], in contrast, the synergistic effects of trade openness and foreign direct investments [8], coupled with the strategic advantages of engaging in mineral trade [11], and holding central positions within the global energy trade network [9], can collectively foster enhanced renewable energy capacities and overall sector performance.

The literature suggests that countries with high levels of trade openness and prominent roles in the global energy trade network are more inclined to allocate substantial resources to renewable energy initiatives. However, trade-related uncertainties increase project costs, negatively affecting renewable energy investments. This highlights that international trade offers significant opportunities while presenting certain risks to the renewable energy industry. Therefore, examining studies in renewable energy and international trade is essential for identifying trends and guiding future developments.

Bibliometric analysis serves as a valuable method for identifying influential studies and mapping the intellectual structure of this interdisciplinary field. In this regard, Table 1 presents studies conducted using bibliometric analysis in areas including renewable energy, international trade, carbon trading, circular economy, and sustainable development. These studies primarily employ systematic literature review and bibliometric techniques, drawing data predominantly from the Scopus database. Some studies also utilize data from the WOS database, offering a complementary perspective. Acknowledging the limitations inherent in the selected databases and tools is important. For example, while the Scopus database generally offers broader coverage in terms of journals and subject areas, the WoS database is known for its rigorous indexing standards, which may lead to variations in article representation across fields. The analyses have predominantly been conducted using the VOSviewer software; however, other tools, such as R software, have also been utilized, albeit less frequently. Although VOSviewer provides several visualization capabilities, it has certain limitations in detecting emerging trends over time compared to tools like R. These methodological nuances have been carefully considered to contextualize our choices and ensure a comprehensive analysis.

Table 1. Bibliometric studies in the related field

| Author | Purpose and Methods | Key Findings |
|--------|--|---|
| [19] | This study aims to analyze the trends, challenges, and future research directions in the literature to elucidate the use of renewable energy within the circular economy. 294 articles retrieved from the Scopus database were analyzed using the R software. | The analysis revealed that, with the increasing environmental awareness on the subject, the emphasis in scientific studies has shifted from renewable energy to effective waste and resource management and green technologies. The findings indicate that the principal obstacles to incorporating renewable energy into the circular economy are high initial investment costs, insufficient regulatory frameworks, governmental support, and a shortage of resources and components for renewable energy production technologies. |
| [23] | This study aims to investigate the development and transformation processes in energy trade and electricity markets through bibliometric analysis. The research seeks to identify the impacts of technological advancements, policies, and market dynamics on energy trade. A total of 642 articles published from 1996 to 2023 were included in the analysis, utilizing data sourced from the WoS database. The analyses were conducted using the CiteSpace software. | The analysis revealed a notable rise in publications concerning energy trade from 2021 to 2023. The studies in this field have been found to focus on various topics, including energy management and optimization, renewable energy systems, and carbon trading. The results demonstrate that China is pivotal in scientific research on energy trade. Additionally, the U.S., Australia, and the U.K. are identified as among the most active countries contributing to this area. Future research is recommended to focus on developing artificial intelligence and blockchain-based energy trading mechanisms, integrating renewable energy, and improving carbon trading policies. |
| [17] | This study aims to evaluate the relationship between renewable energy, economic growth, and economic development through bibliometric analysis, identifying research trends and possible areas for future studies. Accordingly, the analyses were conducted using data from the WoS and Scopus databases between 2008 and 2021, utilizing the VOSviewer software. | The analysis revealed a continuous increase in studies on renewable energy since 2008, with a significant portion of publications produced after 2015 reflecting the impacts of the Kyoto Protocol. The study revealed that research focusing on less-developed economies remains limited. China has established itself as the nation with the highest number of publications. Furthermore, most scientific studies concentrated on the relationship between renewable energy consumption and economic growth. |
| [16] | This study aims to assess the impact of renewable energy on sustainable economic growth through bibliometric analysis, offering a comprehensive overview of the existing literature, identifying research gaps, and suggesting potential directions for future studies. In this context, 6,794 academic articles published between 1990 and 2023 were selected from the WOS database. The analyses were conducted utilizing the VOSviewer software. | The results of the analysis indicate a substantial rise in publications concerning renewable energy and economic growth since 2017. China, Türkiye, and Pakistan were identified as the foremost nations in terms of publication output in this field. Most studies focus on the correlation between environmental sustainability, renewable energy policies, and economic growth. Furthermore, technological limitations and insufficient infrastructure were found to be major obstacles to the incorporation of renewable energy. The findings also suggest that future studies should prioritize multidisciplinary research that fosters greater collaboration. |
| [29] | This study aims to examine renewable energy investments in the countries participating in the Belt and Road Initiative, analyzing investment trends, key topics addressed in the field, and international collaboration networks. Accordingly, 268 articles published between 2017 and 2024 were analyzed using the WoS database and VOSviewer software data. | The analyses reveal a notable rise in articles regarding renewable energy investments from 2019 to 2022. However, a decline in research output was observed after 2022, attributed to the impacts of COVID-19, geopolitical risks, and economic uncertainties. The study indicates that the Russia-Ukraine war has adversely affected the progress of projects and investments in this field. |
| [22] | This study aims to systematically examine the applicability of blockchain technology in sustainable solar energy trade, evaluate existing research, identify knowledge gaps, and provide recommendations for future studies. Accordingly, 87 articles were included in the analysis, using data obtained from the Scopus and WoS databases. The analyses were conducted utilizing VOSviewer software. | The analyses indicate a growing interest in blockchain-based energy trading, highlighting the technology's ability to enhance transparency and ensure secure data exchange in energy transactions. It is noted that integrating blockchain with smart contracts can automate trading processes, thereby reducing costs. The study identifies gaps in regulatory frameworks related to energy trading and emphasizes the need for further research on solar energy trading as a key recommendation for future studies. |
| [18] | This study examines the literature's contextual relationship between renewable energy and the circular economy. It identifies the main research trends in these areas through a systematic literature review and content analysis. In this context, 751 articles retrieved from the Scopus database were analyzed using Latent Semantic Analysis. | The analysis results of the study indicate a substantial rise in research on the circular economy and renewable energy between 2011 and 2023. Topics such as biogas, biomass, and end-of-life product management are highlighted as being increasingly significant in the forthcoming years. The findings also reveal that sustainable consumption has emerged as a central research theme. |
| [28] | The study aims to evaluate the relationship between green energy and investment through bibliometric analysis. Accordingly, 2,949 articles obtained from the Scopus database were included in the analysis. The VOSviewer software was utilized for data analysis and visualization. | The study's findings indicate a rise in publications regarding green energy and investment since 2007. China, the U.S., and the U.K. were identified as the leading countries in terms of scientific output in this domain. The findings also underscore the necessity for increased subsidies to facilitate the widespread adoption of green technologies. |
| [20] | This study aims to assess scientific research in renewable energy and sustainable development through bibliometric analysis, identifying key trends and international collaborations in this domain. In this context, 8,349 articles retrieved from the WoS database were analyzed using Bibliometrix and VOSviewer software. | The analysis results indicate that scientific publications on renewable energy and sustainable development have increased rapidly since 2017. China has established itself as the foremost nation in this domain, excelling in publication output and citation impact, and it is recognized for its openness to international collaboration. The studies predominantly focus on key research topics such as economic growth, energy efficiency, and energy policies. The findings suggest that future research should prioritize areas related to energy transition, carbon emission reduction, and environmental sustainability. |
| [30] | This study analyzes the relationship between green finance and carbon trading while identifying research trends and future directions in this field. Accordingly, 506 articles about sustainable finance and carbon trading, published between 2014 and 2022, were included in the analysis using data from the Scopus database. The analyses were conducted utilizing VOSviewer software. | The findings from the analysis reveal a consistent increase in scientific publications on green finance and carbon trading since 2014, with the Paris Agreement playing a significant role in driving the growth of research in these areas. These studies primarily examine the economic impacts of carbon pricing and trading mechanisms implemented to reduce CO ₂ emissions. It is emphasized that future research should focus more on the relationship between carbon trading and renewable energy investments. |

The literature review reveals a notable increase in scientific output in this domain, particularly since 2010, with China emerging as a leading contributor in terms of scientific production. Notably, multiple bibliometric studies [16, 17, 20, 28] provide evidence that China leads in scientific production, demonstrating the highest publication outputs and citation impacts in this field.

The studies discussed in the literature review focus on various topics, including the integration of the circular economy with renewable energy [19], the role of technological innovations in energy trade [22], investment trends in the energy sector [29], and the relationship between green finance and carbon trading [30]. These topics further emphasize the multifaceted nature of international trade in renewable energy, as they demonstrate how financial mechanisms and sustainable practices are pivotal in shaping global energy markets. Only 20% of the bibliometric analyses summarized in Table 1 explicitly address international trade, highlighting a significant research gap. There are relatively few bibliometric analyses that focus on studies in international trade and renewable energy when the literature is examined. Most existing studies primarily concentrate on topics such as economic growth, the circular economy, and sustainable development concerning renewable energy.

METHODOLOGY

Synthesizing research findings and data in the literature is crucial for the progressive enhancement of scientific knowledge. In this context, bibliometric analysis is described as a method that objectively evaluates the scientific literature in a specific field through a quantitative approach [31, p. 166]. This analysis can assess the volume and growth trends of the literature in a field, thereby evaluating potential future scientific contributions to that area [32, p. 1004]. Bibliometric analysis typically utilizes large-scale, objective data such as citation counts, publication numbers, and keywords. As a result, bibliometric analysis systematically interprets these large-scale, unstructured datasets. Therefore, such analyses

are valuable for deciphering and mapping the evolutionary development within the examined field [33]. Various software tools are available for conducting bibliometric analysis. Among these, BibExcel can construct citation networks but cannot generate graphs or maps. Tools such as Gephi, VOSviewer, and CiteSpace are commonly used to facilitate visualization. However, in conjunction with the Bibliometrix package, the R programming language was selected for this study due to its integrated environment that supports advanced statistical analyses and versatile data visualization. Specifically, Bibliometrix addresses key research needs by enabling detailed analyses such as keyword co-occurrence, source impact, source dynamics, and document analysis [34, pp. 156–158]. This comprehensive toolkit enhances the ability to identify thematic clusters and map evolving research trends, which are essential for the robust interpretation of bibliometric data. Therefore, the data obtained in this study were analyzed using the R programming language.

ANALYSIS AND FINDINGS

This study commenced with an initial search in the WoS database utilizing the terms "international trade," "global trade," "foreign trade," "export," "import," or "trade" in conjunction with "renewable energy," "renewable energy consumption," "green energy," or "clean energy" (Table 2). This initial search yielded a total of 378 publications. Subsequently, a language restriction was applied, and only publications written in English were included in the analysis, resulting in a total of 375 publications. Thereafter, all publications indexed in the WoS Index categories, including SSCI, SCI-Expanded, ESCI, Conference Proceedings Citation Index, Book Citation Index (Social Sciences & Humanities—BKCI-SSH), Book Citation Index-Science (BKCI-S), and Conference Proceedings Citation Index-Science (CPCI-S), were selected, and only those within these indices were included in the analysis.

Table 2. Search criteria in the Web of Science database

| Category | Search Criteria |
|--------------------|--|
| Specific Fields | Title |
| Keywords | "International trade," or "global trade," or "foreign trade," or "export," or "import," or "trade" |
| Search string | "Renewable energy," or "renewable energy consumption," or "green energy," or "clean energy" |
| Types of documents | Article, Proceeding Paper, Book Chapter, Review |
| Time range | 1992-2024 |
| Language | English |

This study involved an analysis of the citation counts for 375 articles over time, as well as the distribution of publications. Factor analysis was performed to investigate trends in the keywords used in the publications. Accordingly, the frequency of keyword usage across the 375 publications was analyzed over the years, along with increases or decreases in their usage trends. The fluctuation in publication counts and the citations they received over time were also identified. Additionally, categorical clustering analyses provided insights into authors, research areas, publication sources, and countries. The findings were visualized using graphs, maps, and tables generated with the R software. This analysis focuses on renewable energy and international trade,

examining 375 publications indexed in the WoS database, published from 1992 to 2024. An examination of the Web of Science database indicates that the earliest studies addressing the relationship between renewable energy and international trade date back to 1992. In this regard, it is considered that foundational theoretical approaches and early policy frameworks began to emerge during the 1990s. Accordingly, including data from this period is intended to capture the field's historical evolution and provide a comprehensive overview of its conceptual and policy-related development over time. These publications were distributed across 148 different journals. The mean citation count per publication was 50.41, with an average of 3.45 co-authors for

each publication. The year with the highest average annual citation count was 2020, with 26.4 citations per year (see Figure 1 and Table 3). A significant increase in publications in this field has been observed, particularly after 2020 (see Figure 2). This surge in citation dynamics post-2020 can be contextualized by several global developments, including policy shifts spurred by the Paris Agreement in 2015. The Agreement has facilitated measures such as establishing nationally determined contributions, promoting renewable energy and energy efficiency initiatives, supporting the transition to low-carbon economies through carbon pricing, and reducing fossil fuel subsidies for climate change mitigation and adaptation [35]. Coupled with increased investments in sustainable initiatives during the COVID-19 recovery period, these policies have contributed to heightened scholarly interest in renewable energy and international trade, as reflected in the observed citation trends [36]. An analysis of annual scientific output revealed that 2022 was the most productive year, with 77 publications, and scientific productivity in this area remained high in 2023. Upon evaluating Figures 1 and 2 in conjunction, it becomes clear that the scientific output concerning renewable energy and international trade was notably restricted until the early 2000s, as evidenced by the relatively low citation counts for publications in this domain. Between 2010 and 2020, however, both the level of scientific production and the number of citations increased steadily. This trend correlates with an expanding emphasis in scholarly works on climate change, the progress of renewable energy technologies, and the rising acknowledgment of the importance of these technologies in international trade.

Keywords summarize the content of a publication, making it more comprehensible. This enhances the accessibility of publications and enables more targeted and effective literature searches. As a data mining technique, word clouds visually represent the most frequently utilized words in a text or paragraph [37, p. 59]. The frequency table and word cloud generated from the analysis reflect key concepts and research trends frequently discussed in the field. The frequency table

(Table 4) and word cloud (Figure 3), produced using the R software, highlight the prominent keywords in research on renewable energy and international trade.

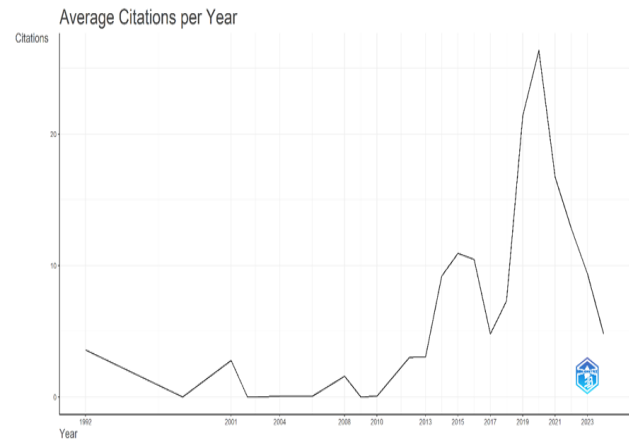


Figure 1. Average citations per year

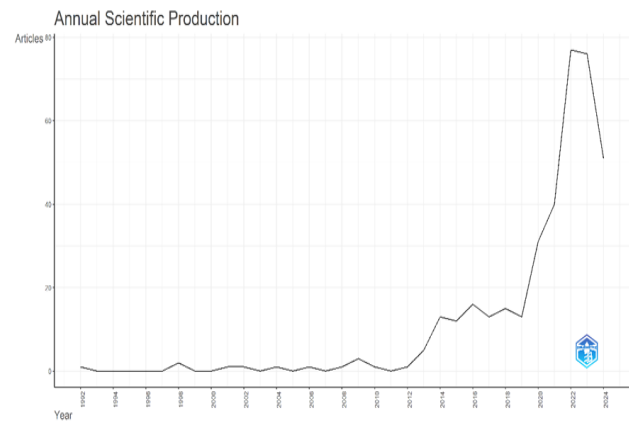


Figure 2. Annual scientific production

Table 3. Search criteria in the Web of Science database

| General Characteristics of the Analyzed Publications | | |
|--|--------------------|-------------------|
| Timespan | 1992-2024 | |
| Publication | 375 | |
| Journals | 148 | |
| Keywords | 618 | |
| Average Citations per Publication | 50.41 | |
| Number of Single-Authored Publications | 50 | |
| Average Number of Co-Authors per Publication | 3.45 | |
| International co-authorships % | 45.07 | |
| Year | Number of Articles | Mean TC Per Year* |
| 2017 | 13 | 4.80 |
| 2018 | 15 | 7.30 |
| 2019 | 13 | 21.40 |
| 2020 | 31 | 26.37 |
| 2021 | 40 | 16.73 |
| 2022 | 77 | 12.84 |
| 2023 | 76 | 9.36 |
| 2024 | 51 | 4.80 |

* Mean TC Per Year: Average Citations per Year

The insights derived from the graph indicate that renewable energy and international trade literature embody a multidimensional structure encompassing diverse concepts. Table 5 evaluates the influence of sources within renewable energy and international trade domains based on h-index, total citations (TC), and total number of publications (NP). The h-index, as presented in the table, is an indicator that measures both the productivity and citation impact of publications in a journal. According to the information in the

table, the journals "Renewable Energy" and "Environmental Science and Pollution Research" significantly influence this domain based on their h-index, total citation values, and number of publications. Although "Renewable & Sustainable Energy Reviews" is less productive regarding publication count, it stands out as a highly impactful journal in the literature, with a total citation count of 2,188. This finding indicates that studies published in this journal are frequently referenced in academic publications focusing on renewable energy and international trade.

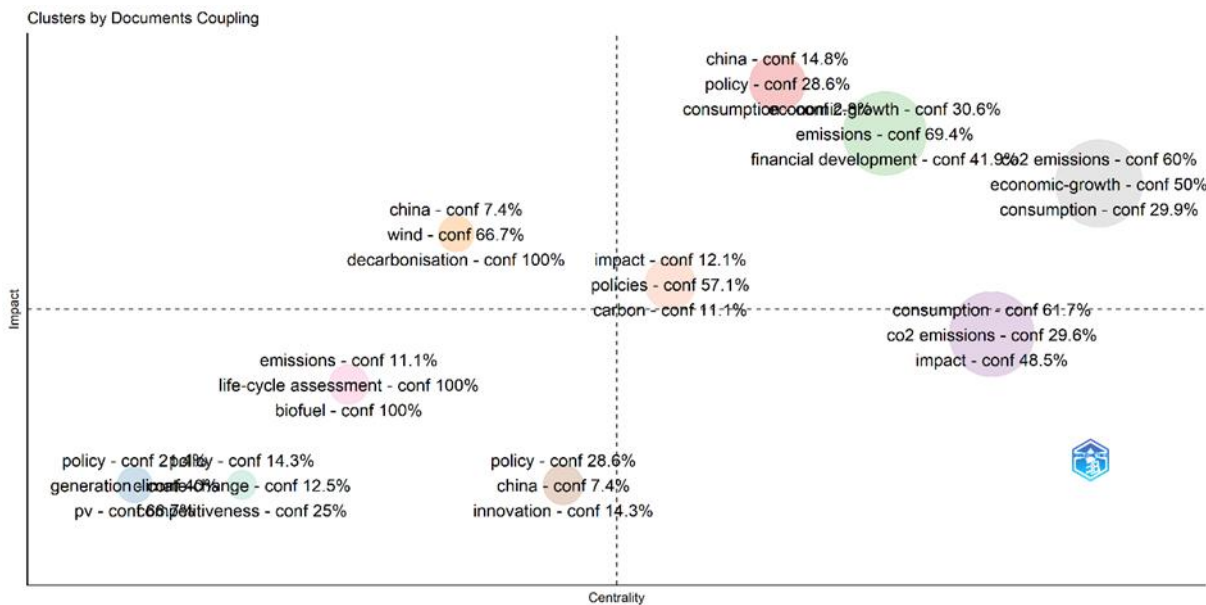


Figure 5. Conceptual structure map

Table 5. Sources impact

| Source | h_index | TC | NP | PY_start |
|--|---------|------|----|----------|
| RENEWABLE ENERGY | 27 | 3052 | 39 | 2015 |
| ENVIRONMENTAL SCIENCE AND POLLUTION RESEARCH | 23 | 1992 | 39 | 2018 |
| ENERGY POLICY | 10 | 698 | 12 | 2001 |
| RENEWABLE & SUSTAINABLE ENERGY REVIEWS | 10 | 2188 | 11 | 2012 |
| ENERGIES | 8 | 247 | 14 | 2018 |
| ENERGY | 8 | 651 | 11 | 2014 |
| JOURNAL OF CLEANER PRODUCTION | 8 | 1482 | 9 | 2018 |
| RESOURCES POLICY | 8 | 244 | 10 | 2020 |
| ENERGY ECONOMICS | 7 | 373 | 10 | 2019 |
| ENERGY REPORTS | 6 | 489 | 8 | 2021 |

*TC: Total number of citations, NP: Total number of publications

Figure 6 illustrates the productivity of the top 10 authors contributing to the field of renewable energy and international trade throughout the years. The productivity level of each author is represented by circles depicted in the figure. The size of the circles represents the volume of publications produced by the author during the corresponding period, with larger circles signifying higher publication output. The concentration of circles, particularly after 2020, and the increase in international trade and renewable energy studies can be associated with the growing emphasis on climate change and global pressures related to achieving sustainable development goals. Authors such as

Muntasir Murshed, T.S. Adebayo, Mukhtar Ahmad, and Umair Shahzad have emerged as prominent contributors to this field, consistently producing research since 2020.

Figure 7 depicts the collaboration networks among authors conducting research in renewable energy and international trade. In the figure, nodes represent authors, while the connections between nodes indicate co-authored publications. The size of the nodes represents the degree of influence of the authors within the network. Muntasir Murshed is positioned at the center of the network and stands out as the most collaborative author in this domain. T.S. Adebayo and Ilhan Ozturk also stand out as authors who

contribute to literature through collaborations with various other researchers. Additionally, the network contains less connected clusters, which may indicate that some authors in

this field have more limited collaboration networks or focus on more specialized topics in their research.

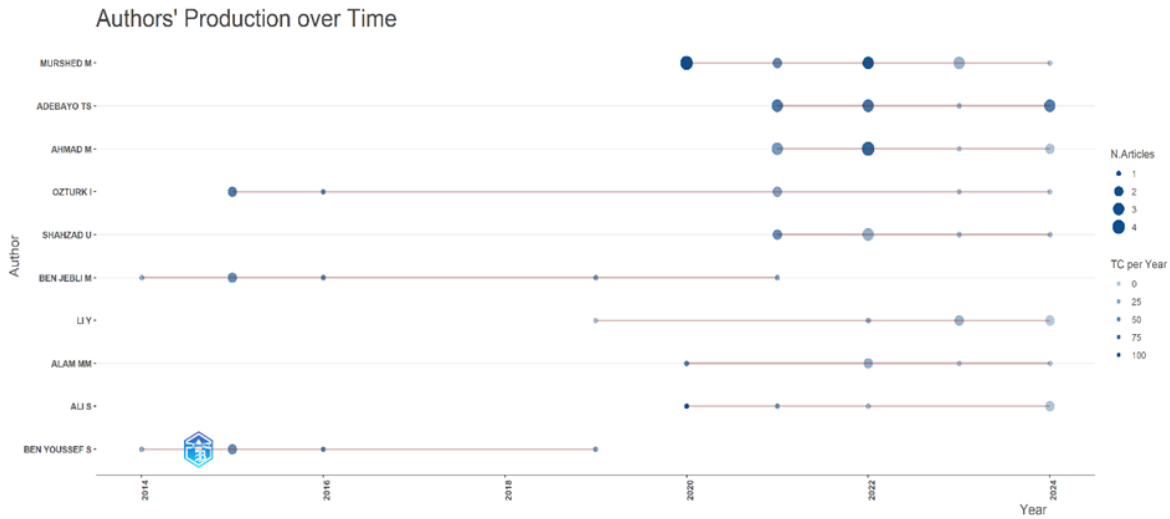


Figure 6. Authors’ production over time

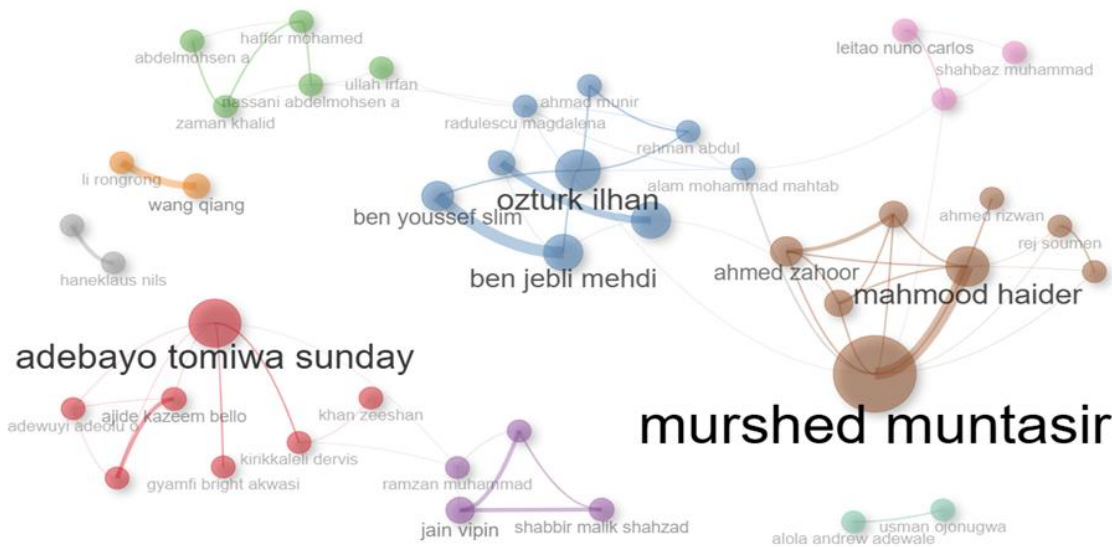


Figure 7. Academic collaboration among authors

Table 6 displays the countries that have produced the most publications on renewable energy and international trade. Between 1992 and 2024, the top five most active countries were identified as China (430 publications), Pakistan (102 publications), Türkiye (101 publications), the U.K. (74 publications), and the U.S. (70 publications), respectively. China's position as a leading global producer of renewable energy equipment, including solar panels and wind turbines, alongside its investments in renewable energy projects in regions like Sub-Saharan Africa [41, p. 40], has made the country prominent in scientific research in this field. Since 2013, nearly all investments by Chinese energy companies have been directed toward Belt and Road Initiative countries [42]. In 2017, China accounted for 45% of the global investment in renewable energy production and fuel sectors [43, p. 1]. Consequently, China has positioned itself as a key player in the global energy transition and the international trade of these energy sources. One of the six major economic

regions under the Belt and Road Initiative is the China-Pakistan Economic Corridor, making Pakistan a significant recipient of China's overseas renewable energy investments [44, p. 2]. In Pakistan, electricity supply is predominantly generated through thermal energy production based on petroleum and natural gas. Limited access to electricity negatively impacts the country's economic development. Rising electricity production costs adversely affect the industrial and agricultural sectors, leading to a slowdown in economic growth.

Additionally, the Pakistani government considers this dependence on thermal energy as a potential threat to energy security and actively supports renewable energy investments [45, p. 2]. Türkiye, with its growing population, is a country with an increasing energy demand. Electricity generation in Türkiye largely relies on thermal power plants using coal, lignite, natural gas, fuel oil, geothermal energy, and

hydroelectric power plants [46, p. 1]. Consequently, expanding energy production capacity and investing in new energy sources has become essential to meet the rising energy demand. Türkiye, situated in the Mediterranean Basin, is particularly vulnerable to the effects of climate change. The country is a party to various global agreements, such as the United Nations Framework Convention on Climate Change (UNFCCC), the Kyoto Protocol, and the Paris Agreement. Following the ratification of the Paris Agreement, Türkiye's President emphasized the goal of achieving net-zero emissions by 2053 [47, p. 4]. These commitments, along with the country's participation in global agreements aimed at reducing carbon emissions, have heightened interest in this issue within Türkiye, significantly contributing to the nation's scientific productivity in this area.

Table 6. Top 10 countries by number of publications

| Countries | Number of Articles |
|----------------|--------------------|
| CHINA | 430 |
| PAKISTAN | 102 |
| TÜRKIYE | 101 |
| UNITED KINGDOM | 74 |
| UNITED STATES | 70 |
| INDIA | 69 |
| TUNISIA | 55 |
| BANGLADESH | 55 |
| SAUDI ARABIA | 45 |
| NIGERIA | 41 |

Table 7 compares scientific publications in renewable energy and international trade from 1992 to 2024 based on countries' total citation count (TC) and average article citations. The data indicates that China boasts the highest total citation count (5234) and is leading globally in studies on renewable energy and international trade. Türkiye is the second country with the most publications (4044) in this field and stands out for its high average citation count. Tunisia ranks third in terms of total citations (1773), demonstrating its significant impact on the literature. Belgium, with its high average citation count, also appears to produce influential studies frequently referenced in research on renewable energy and international trade.

Table 7. Most cited countries

| Country | TC* | Average Article Citations |
|----------------|------|---------------------------|
| CHINA | 5234 | 44,40 |
| TURKIYE | 4044 | 183,80 |
| TUNISIA | 1773 | 177,30 |
| NORWAY | 951 | 317,00 |
| BANGLADESH | 875 | 72,90 |
| NIGERIA | 795 | 72,30 |
| AUSTRALIA | 547 | 54,70 |
| UNITED KINGDOM | 448 | 28,00 |
| BELGIUM | 423 | 211,50 |
| CYPRUS | 381 | 42,30 |

*TC: Total number of citations

Table 8 and Figure 8 illustrate the academic collaboration network among countries in renewable energy and international trade. The data in the table represent the frequency of collaboration between countries conducting research in this area. The global collaboration map in Figure 8 visually depicts the geographical distribution of these collaborations, highlighting the interconnectedness of nations in this domain.

According to Table 8, the countries with the highest joint institutional affiliations in this field are China and Pakistan. China also demonstrates strong scientific collaboration with Saudi Arabia and Türkiye. Other notable partnerships include Pakistan-Saudi Arabia and China-United Kingdom, which are significant scientific collaborations in this domain. Notably, the pronounced collaboration between China and Pakistan may not be driven solely by academic interests but could also reflect underlying geopolitical alliances. Specifically, within the Belt and Road Initiative framework, China's credit provisions and infrastructure support to participating countries increase its control over strategic resources and transportation hubs [48]. Consequently, this geopolitical proximity and China's strategic approach may foster enhanced academic cooperation among these nations [49]. In this context, it can be concluded that China has established a broad scientific collaboration network with countries from various regions and plays a leading role in publications within this field.

Table 8. Countries with the highest joint institutional affiliations' frequency

| From | To | Frequency |
|------------|----------------------|-----------|
| CHINA | PAKISTAN | 38 |
| CHINA | SAUDI ARABIA | 17 |
| CHINA | TÜRKIYE | 16 |
| PAKISTAN | SAUDI ARABIA | 14 |
| CHINA | UNITED KINGDOM | 11 |
| BANGLADESH | SAUDI ARABIA | 9 |
| CHINA | BANGLADESH | 9 |
| CHINA | INDIA | 8 |
| CHINA | UNITED ARAB EMIRATES | 7 |
| PAKISTAN | TURKIYE | 7 |

Figure 8 geographically visualizes the collaboration network among countries conducting research in renewable energy and international trade. The lines on the map represent collaboration between countries, while the color intensity of each country indicates the frequency of these collaborations. Countries depicted in darker shades serve as central hubs in scientific collaboration. Notably, China, shown in the darkest shade on the map, has established a multidimensional network by collaborating with countries from various regions. A notable observation is the intense collaboration between Asian and European countries. Additionally, it can be stated that China is at the center of the collaboration network in scientific studies related to renewable energy and international trade. The significant collaborations conducted by Türkiye, Pakistan, and Saudi Arabia also make substantial contributions to the literature in this domain.

Country Collaboration Map

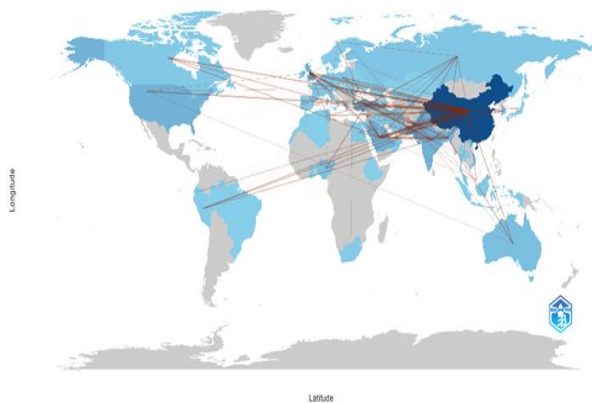
**Figure 8.** Countries' collaboration map

Table 9 lists the universities that produced the most renewable energy and international trade publications from 1992 to 2024. According to the table, the university with the most publications is the Cyprus International University in the Turkish Republic of Northern Cyprus, with 24 publications. The second position is held by North South University in Bangladesh, with 20 publications. These universities are followed by Jiangsu University in China, with 17 publications, and Ilma University in Pakistan, with 15 publications. The findings underscore the roles played by diverse institutions across various geographical areas in fostering scientific output in renewable energy and international trade through their dedicated research initiatives.

Table 9. Universities ranked by number of publications

| Affiliation | Year | Articles |
|-----------------------------|------|----------|
| CYPRUS INT UNIV | 2024 | 24 |
| NORTH SOUTH UNIV | 2024 | 20 |
| JIANGSU UNIV | 2024 | 17 |
| ILMA UNIV | 2024 | 15 |
| CHINA UNIV PETR EAST CHINA | 2023 | 13 |
| UNIV HELSINKI | 2024 | 12 |
| ANHUI UNIV FINANCE AND ECON | 2024 | 12 |
| UNIV LAGOS | 2024 | 11 |
| LEBANESE AMER UNIV | 2024 | 11 |
| WUHAN UNIV | 2024 | 10 |
| ISTANBUL GELISIM UNIV | 2024 | 10 |
| ANHUI UNIV FINANCE AND ECON | 2024 | 12 |
| UNIV LAGOS | 2024 | 12 |

CONCLUSION AND RECOMMENDATIONS

Climate change and concerns regarding environmental sustainability continue to shape global energy policies and significantly influence the structure and direction of international trade. In this context, renewable energy sources are critical in limiting dependence on fossil fuels and reducing carbon emissions. Diversifying energy sources contributes to achieving the United Nations Sustainable Development Goals. It enhances national resilience by minimizing vulnerability to

global energy market fluctuations and reducing their reliance on energy imports.

Empirical studies analyzing the relationship between international trade and renewable energy demonstrate that countries characterized by high trade openness and active participation in global energy markets are more likely to facilitate the transfer of green technologies. Conversely, trade uncertainties negatively affect renewable energy investment, frequently elevating financing risks and discouraging long-term commitments. In this context, analyzing scientific studies in renewable energy and international trade is crucial for identifying current trends and research gaps in the literature and drawing insights for future directions.

The primary aim of this study is to evaluate the relationship between renewable energy and international trade through bibliometric analysis and to identify research gaps in this field. In this context, searches were conducted based on predefined criteria, and 375 publications retrieved from the Web of Science database were analyzed using the R program. The subsequent paragraphs provide a detailed discussion of the key findings derived from this analysis.

There was a consistent increase in scientific production and citations in studies addressing renewable energy and international trade during 2010–2020. Between 2010 and 2015, it can be stated that the extension of the Kyoto Protocol [50] and the enhancement of national renewable energy targets played an effective role in the observed growth. Furthermore, scientific productivity continued to increase after 2015. This result indicates that scientific publications have emphasized the promotion of universal access to sustainable energy, as outlined in the Paris Agreement [51], and have addressed the importance of ensuring accessible and clean energy, which is the focus of Goal 7 of the United Nations Sustainable Development Goals [52].

The most frequently used keyword in this field was identified as "CO2 emissions," followed by "economic growth" and "consumption." This indicates a strong emphasis on environmental and macroeconomic dimensions, particularly in relation to how renewable energy deployment intersects with economic performance and carbon mitigation efforts. These findings suggest a gap in the literature concerning studies that focus on renewable energy subtypes—such as solar energy, wind energy, hydroelectric, geothermal, and biomass energy [38]—with existing research predominantly concentrating on macroeconomic linkages.

It has been determined that China was the most scientifically productive country in the field of renewable energy and international trade between 1992 and 2024. This finding demonstrates that through scientific publications, China, a major player in global trade and supply chains, also supports its emphasis on the role of renewable energy and energy transition in international trade. The country's dominance in scientific output further suggests an institutional commitment to advancing energy transition narratives through international academic collaboration [16], [17], [20], [23], [28]. Based on the findings, it can be stated that the overrepresentation of Chinese publications, coupled with the country's active funding of its researchers to encourage more publications in this field, may serve as a factor that enhances China's visibility in this domain.

Recommendations for Future Research

Based on the findings, the following recommendations can be made for future studies on the relationship between renewable energy and international trade:

- ✓ The relationship between international trade and renewable energy has been predominantly explored through econometric analyses in the literature. Consequently, case studies, qualitative assessments, and policy-focused analyses have been relatively underexamined. Therefore, it is recommended that future research focus on these methodologies.
- ✓ Existing research mainly focuses on the macroeconomic linkages between international trade and renewable energy. Therefore, future research could focus on renewable energy sub-types such as solar, wind, hydropower, geothermal, and biomass.
- ✓ It is noteworthy that EU countries are not prominent in this field. In particular, it is recommended that researchers from EU countries, which have set a zero-carbon target by 2050 within the scope of the Green Deal, develop academic cooperation with countries such as China, Turkey, Tunisia, Pakistan, and Bangladesh, which stand out in terms of scientific productivity and high number of citations in this field.
- ✓ In addition to using Scopus, future studies might be encouraged to incorporate data from the Web of Science and other relevant databases such as IEEE Xplore, Proquest, and Google Scholar to ensure a more comprehensive bibliometric analysis.
- ✓ Although many bibliometric studies have employed VOSviewer for analysis, future research could benefit from utilizing alternative visualization tools such as CitNetExplorer, Sci2 Tool, SciMAT, CiteSpace, BiblioMaps, and R biblioshiny, to explore different network structures and validate the robustness of the findings.
- ✓ In research on renewable energy and international trade, researchers from diverse disciplines such as environmental science, economics, and engineering, as well as from different institutions, can collaborate to elevate international cooperation in this field to higher levels.

Based on these findings, future research can address the theoretical and methodological gaps in the literature, thereby increasing the effectiveness of scientific production in this field and providing more comprehensive insights into the impact of renewable energy policies on international trade.

DATA AVAILABILITY STATEMENT

The authors confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The author declares that there is no conflict of interest with any individual, institution, or organization in the preparation, evaluation, or publication of this study.

USE OF AI FOR WRITING ASSISTANCE

Not declared

ETHICS

There are no ethical issues with the publication of this manuscript.

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