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Bibliometric Analysis of Innovation and Economic Impact in Trends of Solar Energy Utilization in Agriculture

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ABSTRACT

This paper presents a comprehensive analysis of thematic clusters, research trends, potential research opportunities, and author collaborations within the field of renewable energy and its impact on economic growth, using bibliometric visualizations generated by VOSviewer. We identified distinct thematic areas including renewable technologies such as solar and wind energy, and broader themes like energy utilization and economic implications. Our trend analysis revealed a significant temporal shift from technology-centric studies to a broader examination of how renewable energy integrates with economic systems and impacts global economic policies. Further exploration of less explored areas suggested potential research opportunities in the direct economic impacts of renewable energy, its role in industrial processes, and sustainable tourism. The examination of author collaboration networks illuminated the collaborative structures within the academic community, highlighting the formation of research clusters based on shared interests and common research goals. These findings underscore the evolving nature of renewable energy research, revealing both current focuses and prospective areas for future investigation.

Keywords: *Renewable Energy, Economic Growth, Bibliometric Analysis, VOSviewer, Solar Energy*

1. INTRODUCTION

Solar energy, as a sustainable and renewable resource, has garnered significant attention for its potential to revolutionize various industries, including agriculture [1]. The integration of solar energy into agricultural practices is not only pivotal for reducing carbon footprints but also enhances energy efficiency in food production processes [2], [3]. Over the years, the evolution of solar technologies, such as photovoltaic (PV) systems and solar thermal energy, has opened new avenues for innovation in agricultural methodologies [4]. Consequently, there has been a growing body of literature that explores various aspects of solar energy applications in agriculture, ranging from small-scale installations to large agricultural operations [5].

The adoption of solar energy in agriculture has been driven by the need to address the dual challenges of energy scarcity and environmental sustainability [5]. As the agricultural sector is a substantial consumer of energy, primarily sourced from non-renewable resources, there is an increasing pressure to shift towards more sustainable energy solutions [6]. This transition not only supports the global sustainability goals but also ensures long-term economic benefits for farmers and agricultural enterprises [7], [8]. Furthermore, the variability in energy costs and the vulnerability of traditional energy sources to market fluctuations underscore the importance of integrating renewable energy sources like solar power into the agricultural framework [9].

Despite the apparent benefits, the utilization of solar energy in agriculture involves complex dynamics that are influenced by technological, economic, and policy-related factors [10]. These factors collectively impact the pace and extent of solar energy adoption in farming practices [11]. Therefore, a systematic exploration of the scholarly work surrounding solar energy in agriculture is essential to understand the current trends, identify gaps in knowledge, and forecast future directions [12]–[14]. This necessitates a bibliometric analysis to map the existing research landscape, revealing the most influential studies, prevalent themes, and key contributors in the field.

While there is an acknowledgment of the potential benefits of solar energy in agriculture, comprehensive insights into how innovations in solar technology are being integrated within agricultural practices remain fragmented. Additionally, the economic implications of adopting solar energy, which are crucial for stakeholders' decision-making, are not thoroughly understood. This gap in comprehensive analysis impedes the formulation of effective strategies that could facilitate broader adoption and optimal utilization of solar energy in agriculture.

The objective of this research is to conduct a bibliometric analysis to examine the trends, innovation, and economic impacts of solar energy utilization in agriculture. By mapping the research landscape, this study aims to identify the core themes, key publications, and influential researchers in the domain. This analysis will provide a structured overview of the academic discourse, highlighting the evolution of topics and the interconnections between different research areas.

2. LITERATURE REVIEW

2.1 Trends in Solar Energy Utilization in Agriculture

The application of solar energy in agriculture has been diverse, ranging from basic uses such as solar-powered water pumps and irrigation systems to more complex applications like solar-powered greenhouse climate control and photovoltaic systems for electric farm machinery. A pivotal study by [15] highlighted that solar irrigation systems not only reduce dependency on traditional electric and diesel pumps but also enhance water management efficiency. This sentiment is echoed by [16], who found that solar-powered greenhouses could extend growing seasons in colder climates while reducing energy costs. Moreover, recent advancements have introduced solar drones for crop monitoring and solar energy storage systems, which further optimize agricultural operations and resource use [17].

2.2 Innovation in Solar Technologies for Agriculture

Innovation in solar technology has been crucial in expanding its applicability in agriculture. Technological breakthroughs have focused on increasing the efficiency and reducing the costs of solar panels, which are essential for broader adoption. Research by [18] demonstrates how advancements in thin-film photovoltaic cells have made solar installations more affordable and feasible for small to medium-sized farms. Additionally, innovative solar tracking systems have improved the efficiency of solar panels by aligning them optimally with the sun's path, maximizing energy capture [19].

2.3 Economic Impact of Solar Energy on Agricultural Productivity

The economic impact of integrating solar energy into agricultural practices is a critical area of study. Numerous studies have quantified the cost savings associated with reduced energy expenditures and enhanced crop yields due to optimized solar solutions. For instance, [20] provided an economic analysis showing that farms utilizing solar energy experienced a 20-30% reduction in energy costs over five years. Furthermore, the economic analysis by [21] suggests that government subsidies for solar technology can significantly improve the return on investment for farmers, making solar technology a financially viable option.

2.4 Challenges and Barriers to Adoption

Despite the benefits, the adoption of solar energy in agriculture faces several challenges. The initial installation costs and the lack of technical expertise are significant barriers, as noted by [22]. There is also a need for better policy support and financial incentives to encourage farmers to transition to renewable energy sources. Moreover, [19] discuss the intermittency issues associated with solar energy, which can be mitigated through integrated energy storage solutions or hybrid systems that ensure a continuous energy supply.

3. METHODS

This study employs a bibliometric analysis approach to systematically review and synthesize existing literature on the trends, innovations, and economic impacts of solar energy utilization in agriculture. The data for this analysis is sourced from Google Scholar, covering publications from the years 1967 to 2024. Key search terms used include "solar energy in agriculture", "innovation in solar technology", and "economic impacts of solar energy in agriculture". This study utilizes VOSviewer for data visualization, which facilitates the identification of major research clusters, key authors, and foundational papers in the field. The inclusion criteria for the studies involve peer-reviewed articles, conference proceedings, and reviews published in English. The data extracted includes publication year, authors, and citations, which are analyzed to map the evolution of the field and identify prevalent themes and research gaps.

4. RESULTS AND DISCUSSION

4.1 Research Data Matriks

Table 1. Research Data Metrics

Publication years	: 1967-2024
Citation years	: 57 (1967-2024)
Paper	: 980
Citations	: 187893
Cites/year	: 3296.37
Cites/paper	: 191.73
Cites/author	: 92414.28
Papers/author	: 404.15
Author/paper	: 3.21
h-index	: 198
g-index	: 404
hI,norm	: 124
hI,annual	: 2.18
hA-index	: 79
Papers with ACC	: 1,2,5,10,20:941,914,798,602,379

Source: Publish or Perish Output, 2024

The table titled "Research Data Metrics" presents a comprehensive bibliometric analysis covering publications from the years 1967 to 2024. Over this 57-year period, a total of 980 papers have been published in the field, garnering an impressive total of 187,893 citations. This indicates a strong interest and significant impact within the academic community, as evidenced by an average of 3,296.37 citations per year and 191.73 citations per paper. The high citations per paper ratio underscores the quality and relevance of the research in this domain.

The analysis further details that the average number of citations received per author is 92,414.28, reflecting the collaborative nature of research in this field, where papers tend to have multiple contributors. On average, each author has contributed to approximately 404.15 papers, and each paper has about 3.21 authors, suggesting a robust network of collaboration among scholars. The h-index, a metric that measures both the productivity and citation impact of the publications, stands at 198, indicating that 198 papers have each received at least 198 citations. This high h-index is complemented by a g-index of 404, suggesting that the most cited papers have received a substantial number of citations, highlighting the influential nature of the top-tier research.

Additional indices like the hI,norm and hI,annual provide insights into the normalized impact of the author's work and the yearly impact, standing at 124 and 2.18, respectively. The hA-index at 79 further highlights the consistency in citation impact across the author's publications. The distribution of papers with a certain number of citations (ACC) is also noteworthy, with 941 papers receiving at least 1 citation, and progressively fewer papers reaching higher citation thresholds, down to 379 papers receiving at least 20 citations.

4.2 Network Visualization

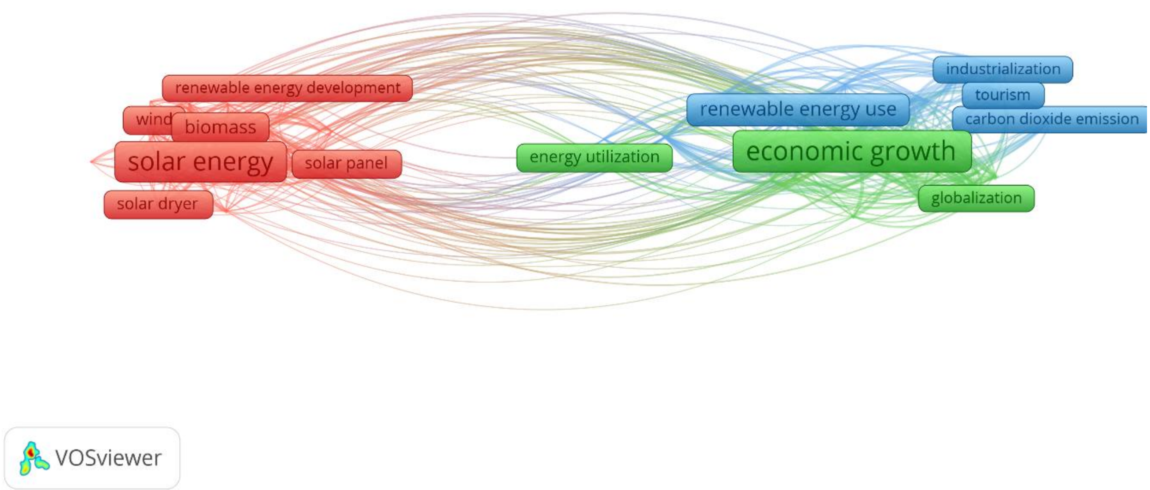

Figure 1. Network Visualization
Source: Data Analysis Result, 2024

The figure 1 above is a visualization from VOSviewer, a software tool commonly used for constructing and viewing bibliometric networks. This particular network appears to display thematic clusters based on keyword co-occurrence from a set of scholarly articles or data sources, focusing on energy and economic themes. Several themes and clusters can be identified as follow:

1. Red Cluster (Solar Energy and Biomass)

   Keywords like "solar energy," "solar panel," "wind," "biomass," and "solar dryer" are grouped here, indicating a focus on renewable energy development using solar and wind resources. This cluster suggests research themes revolving around the technological aspects and applications of solar and wind energy, including devices like solar dryers.

2. Green Cluster (Energy Utilization)

   Central to this cluster are "renewable energy development," "renewable energy use," and "energy utilization," bridging the technologies in the red cluster to broader applications in energy use. This may encompass studies on how renewable energy is incorporated into existing energy systems and its impact on overall energy efficiency and sustainability.

3. Blue Cluster (Economic Growth)

   This cluster focuses on broader economic and environmental implications of energy use, featuring keywords like "economic growth," "industrialization," "tourism," "carbon dioxide emission," and "globalization." It likely explores how economic activities, including tourism and industrialization, interact with energy use and environmental impacts, especially related to carbon emissions and global economic trends.

Each cluster suggests a thematic concentration: technology and device-specific research in the red, application and systems integration in the green, and economic and environmental impact in the blue. The lines connecting the clusters indicate that there is substantial overlap and interrelation in research topics, such as how advancements in renewable energy technologies (red cluster) are applied within energy systems (green cluster) and affect economic outcomes and sustainability (blue cluster).

4.3 Overlay Visualization

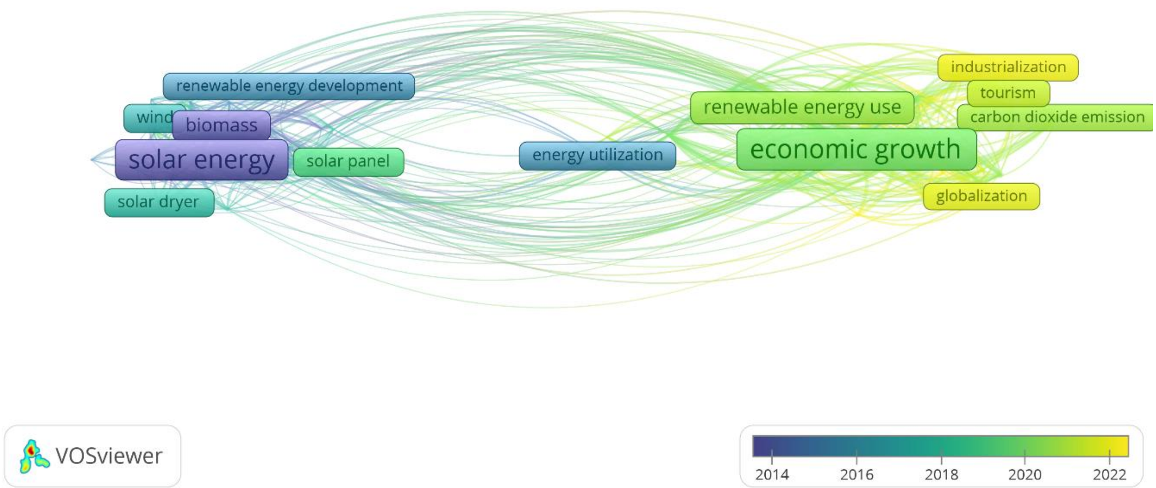

Figure 2. Overlay Visualization

Source: Data Analysis Result, 2024

The second figure, another VOSviewer visualization, includes a temporal element indicated by the color gradient from purple (2014) to yellow (2022), which helps in understanding the evolution and trends in research focus over time. Early in the timeline, the focus is heavily on technologies such as "solar energy," "solar panel," "wind," "biomass," and "solar dryer." As time progresses from purple to blue, these topics show a shift toward integration and broader energy development applications. The transition from "renewable energy development" to "energy utilization" suggests a maturing focus on not just developing renewable technologies but increasingly on how they are integrated and utilized in energy systems. The color transition from blue to green shows the growing emphasis on practical applications and system efficiency improvements.

Over time, there's a noticeable shift towards understanding the economic impacts of renewable energy, as seen in the emphasis on "economic growth," "industrialization," "tourism," "carbon dioxide emission," and "globalization." The shift from green to yellow illustrates the evolving discussion towards economic sustainability and global environmental impacts. The connections across the clusters grow denser over time, signifying an increase in interdisciplinary research that ties renewable energy technologies and utilization to broader economic and environmental outcomes. The intensification of yellow tones towards the most recent years around terms related to "economic growth" and "globalization" implies a significant research interest in how renewable energies affect global economic policies and practices, alongside concerns with environmental sustainability (notably, carbon emissions).

This visualization effectively captures the dynamic evolution of research focus areas within the fields of renewable energy and economic growth, showing how initially technology-focused research has increasingly considered broader economic and systemic implications. The recent emphasis on globalization and economic growth in the context of renewable energy underscores a shift towards understanding and addressing global challenges through sustainable development.

4.4 Citation Analysis

Table 2. The Most Impactful Literatures

Citations	Authors and year	Title
9455	[23]	Powering the planet: Chemical challenges in solar energy utilization
4338	[24]	Role of renewable energy sources in environmental protection: A review
4002	[25]	Environmental, economic, and energetic costs and benefits of biodiesel and ethanol biofuels
3393	[26]	Renewable energy resources: Current status, future prospects and their enabling technology
3036	[27]	Biomass as feedstock for a bioenergy and bioproducts industry: the technical feasibility of a billion-ton annual supply
2994	[28]	Renewable energy-power for a sustainable future.
2951	[29]	Renewable energy and sustainable development: a crucial review
2714	[30]	Renewable energy resources
2704	[31]	Renewable Power-to-Gas: A technological and economic review
2567	[32]	A review of renewable energy sources, sustainability issues and climate change mitigation

Source: Publish or Perish Output, 2024

Table 2, titled "The Most Impactful Literatures," showcases a list of significant scholarly works within the realm of renewable energy, highlighting their impact through citation counts and indicating the breadth and depth of research conducted in this field up to 2024. The most cited paper, "Powering the Planet: Chemical Challenges in Solar Energy Utilization" by NS Lewis and DG Nocera (2006), stands out with 9,455 citations, reflecting its pivotal role in advancing the discussion on chemical aspects of solar energy. This paper likely set a foundational perspective for subsequent research in renewable energy technologies.

Following this, the work by NL Panwar, SC Kaushik, and S Kothari (2011) titled "Role of Renewable Energy Sources in Environmental Protection: A Review" garnered 4,338 citations, emphasizing the critical link between renewable energy applications and environmental conservation. This piece serves as a key literature base, suggesting that it provided comprehensive insights into how renewable energy can mitigate environmental issues. Another notable entry, "Environmental, Economic, and Energetic Costs and Benefits of Biodiesel and Ethanol Biofuels" by J Hill et al. (2006), received 4,002 citations, indicating significant interest in the trade-offs associated with biofuel use, a crucial topic for policy and economic discussions surrounding alternative energies.

The list also includes more recent and technologically focused works like "Renewable Energy Resources: Current Status, Future Prospects and Their Enabling Technology" by O Ellabban et al. (2014), which has 3,393 citations and provides a contemporary look at the advancements and future potential of renewable energy technologies. This underscores ongoing innovation and shifts in renewable energy research focus over time. Other works, such as RD Perlack's (2005) exploration of biomass as a potential energy source and the economic and technological reviews by S Peake (2018) and M Götz et al. (2016), further enrich the discourse by examining specific aspects of renewable energy's role in sustainable development. Each of these papers, by crossing the 2,500 citation mark, has evidently influenced research, policy, and practice, guiding much of the contemporary understanding and strategic planning in renewable energy deployment.

4.5 Author Visualization

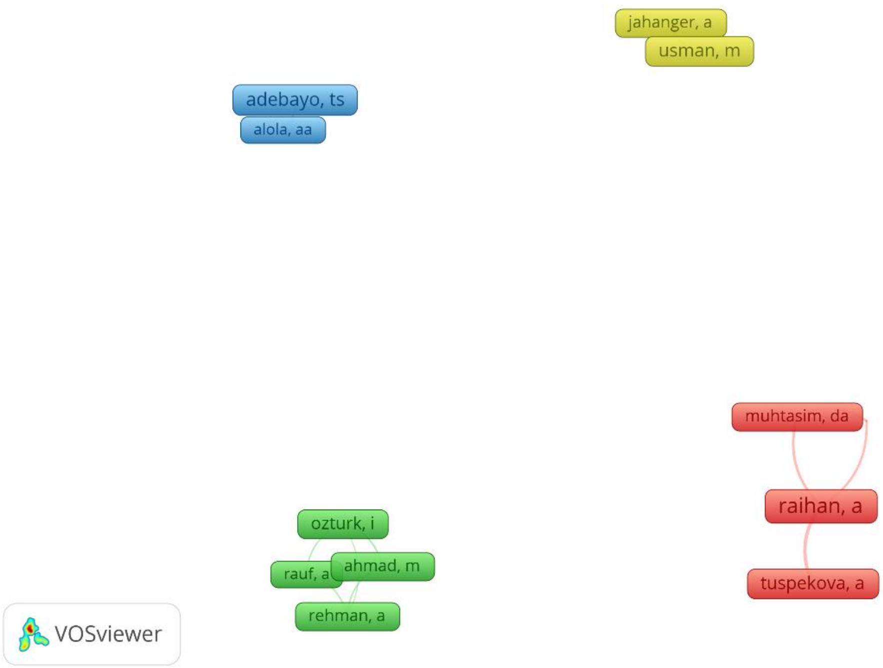

Figure 3. Author Visualization

Source: Data Analysis Result, 2024

The image displays a VOSviewer visualization of co-authorship networks where each node symbolizes an author and the connecting lines indicate co-authorship relations. The various colors likely demarcate different research clusters or teams. In the blue cluster, we see authors "adebayo, ts" and "alola, aa," suggesting a partnership possibly focused on a specific research area. The green cluster, containing "ozturk, i," "rauf, a," "ahmad, m," and "rehman, a," shows a larger, tightly knit group, indicative of substantial collaborative efforts. The red cluster comprises "muhtasim, da," "raihan, a," and "tuspekova, a," with notable strong connections especially between "raihan, a" and the others, pointing to intense joint research endeavors. Lastly, the yellow cluster with "jahanger, a" and "usman, m" represents another collaborative duo, potentially exploring different themes compared to the other groups. These clusters reflect the collaborative dynamics and thematic focus within this academic network, illustrating how researchers cluster around common interests or projects.

4.6 Density Visualization

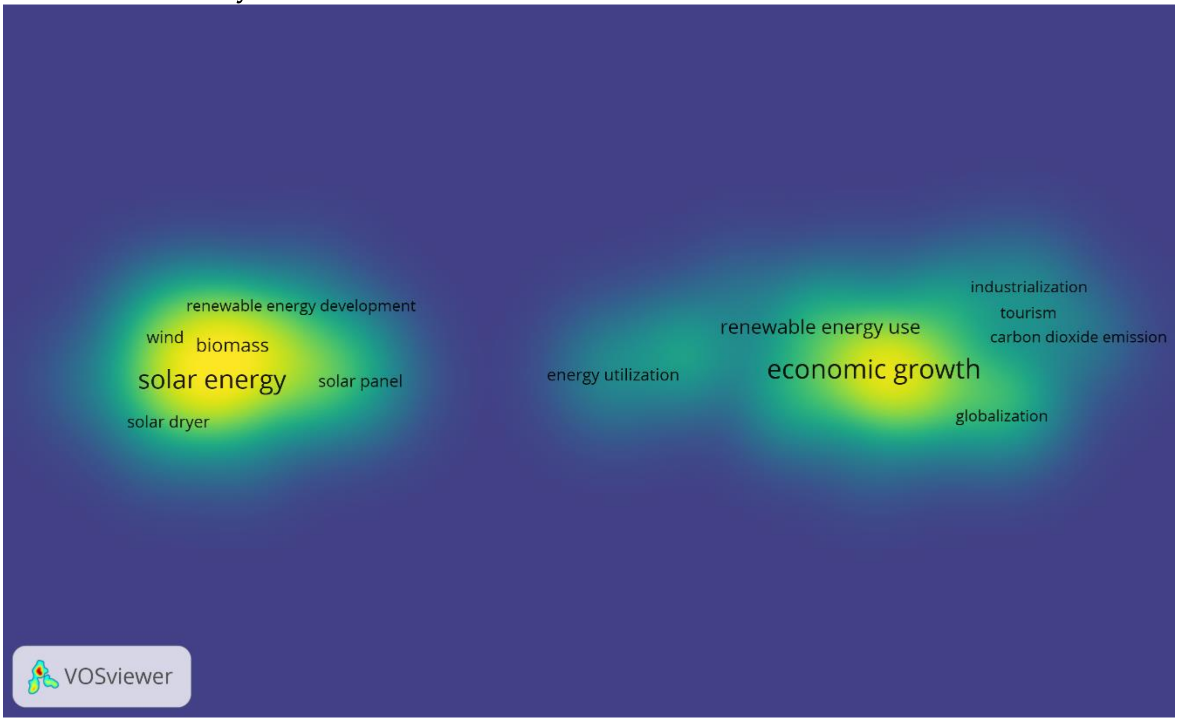

Figure 4. Density Visualization
Source: Data Analysis Result, 2024

The last figure showcases a VOSviewer keyword visualization with a focus on renewable energy and its relationship to economic growth. The visualization uses a color gradient, possibly indicating keyword density or the strength of research focus, with brighter areas showing higher concentration or more commonly researched topics. Several less bright areas can be identified:

1. Between "Solar Energy" and "Economic Growth"
   The space between these clusters might suggest a need for more exploration on how solar energy directly impacts economic growth. Potential research topics could include studies on the economic benefits of large-scale solar energy adoption or the role of solar energy in job creation and GDP growth in various regions.
2. Adjacent to "Industrialization" and "Renewable Energy Use"
   The dimmer area near these keywords indicates potential for further investigation into the integration of renewable energy systems within industrial processes. Research could focus on the barriers to renewable energy adoption in industrial sectors or the impact of renewable energy on traditional manufacturing and industrial output.

3. Near "Tourism" and "Globalization"

    This less highlighted area suggests room for more research on the intersection of tourism, globalization, and renewable energy. Possible topics might include the effects of global tourism trends on renewable energy investments or the role of renewable energy in sustainable tourism development.

These potential research topics highlight gaps or less-explored areas in the broader context of renewable energy and economic growth, providing opportunities for further scholarly inquiry into how these elements interact and influence each other in the modern world.

CONCLUSION

The series of VOSviewer visualizations provided insightful perspectives into thematic clustering, research trends, potential research opportunities, and author collaboration within the academic landscape of renewable energy and economic growth. Firstly, the thematic clusters highlighted distinct areas of focus, ranging from specific renewable technologies like solar and wind energy to broader themes such as energy utilization and economic impact. This was further elaborated through the analysis of research trends, which revealed a temporal shift from technology-focused research towards integrating renewable energy into broader economic and systemic implications. Additionally, the identification of less bright areas in the keyword visualization suggested potential research gaps, particularly in the direct impacts of renewable energy on economic growth, its integration within industrial processes, and its role in sustainable tourism. Finally, the exploration of author collaboration networks illustrated the structure of academic partnerships, showing how researchers form groups around shared interests, leading to robust collaborative outputs. Collectively, these analyses provide a comprehensive overview of the dynamic and evolving field of renewable energy research, indicating both its current state and future directions.

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