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Trends and Impact of Sustainable Energy Technologies in Mechanical Engineering: A Bibliometric Study

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ABSTRACT

The urgent environmental issues of the twenty-first century, particularly climate change, have thrust mechanical engineering into a central position in the creation of novel technologies for a future centered on sustainable energy. From energy-efficient mechanical designs to renewable energy systems, sustainable energy technologies provide a wide range of solutions. This bibliometric analysis uses sophisticated tools, such as VOSviewer, to examine a large dataset of academic articles in mechanical engineering that deal with sustainable energy technology. Dominant research themes, significant writers, collaborative networks, and prominent journals are identified by the study. Important discoveries include the notable increase in research output during the previous 20 years, the rise to prominence of notable writers and research teams, the connection between research themes, and the critical importance of particular papers and journals. These revelations help to shape a more sustainable and ecologically conscious energy future by offering a road map for navigating the complex world of sustainable energy in mechanical engineering.

Keywords: *Sustainable Energy, Technologies, Mechanical, Engineering, Bibliometric Analys*

1. INTRODUCTION

The worldwide imperative to solve urgent environmental challenges—chief among them being climate change and the search for sustainable energy solutions—marks the twenty-first century. The engineering community, especially in the field of mechanical engineering, has taken a leading role in creating novel technologies targeted at reducing the environmental effects of energy production and consumption as the world struggles with the effects of anthropogenic climate change [1]–[5]. Sustainable energy technologies have become a ray of hope in this crucial undertaking, including a broad range of solutions from energy-efficient mechanical designs to renewable energy systems [6]–[9].

There is potential for lowering greenhouse gas emissions, improving energy efficiency, and advancing environmental sustainability through the incorporation of sustainable energy technology into mechanical engineering methods [10]–[12]. The job of engineers is to design, optimize, and execute energy systems that fulfill the world's increasing energy needs while simultaneously being environmentally friendly. This endeavor is supported by the realization that conventional energy sources, which are typified by their significant reliance on fossil fuels, are not only limited but also contribute to the concentrations of greenhouse gases in the atmosphere that are causing the worrisome increase in global temperatures [13]–[18].

The study that is being provided here aims to give a thorough analysis of the developments and effects of sustainable energy technologies in the discipline of mechanical engineering. Sustainable energy technologies, also known as "clean energy" or "green energy" solutions informally, are a broad category of technologies and approaches. These include utilizing biomass and biofuels, optimizing HVAC (heating, ventilation, and air conditioning) systems, developing cutting-edge energy storage solutions, utilizing energy-efficient mechanical systems, and harnessing

energy from renewable sources like solar, wind, and hydropower. In the field of sustainable energy technologies in mechanical engineering, bibliometrics—a quantitative analysis of scholarly publications—provides an invaluable lens through which to examine the development of research themes, the network of researchers who collaborate, and the impact of particular articles, journals, or authors.

2. LITERATURE REVIEW

2.1 Sustainable Energy Technologies in Mechanical Engineering

Mechanical engineering has played a significant role in the development of sustainable energy technologies in the 21st century. Engineers and researchers in this field have focused on creating renewable energy systems that are both economical and efficient. Some of the key renewable energy sources include hydropower, wind turbines, and solar photovoltaics, which have the potential to lower greenhouse gas emissions and reduce reliance on fossil fuels [17], [19]–[23].

A crucial aspect of sustainable energy technology is energy efficiency. Mechanical engineers have concentrated on improving mechanical systems and procedures to utilize less energy. This field of study encompasses the development of enhanced insulation materials, efficient transport methods, and energy-saving HVAC systems [19], [24], [25]. In recent years, there has been a growing awareness of the potential of renewable energy sources to contribute to the sustainable development of the economy and reduce greenhouse gas emissions. The implementation of renewable energy sources, such as solar and wind power, in combination with energy storage systems, has been shown to lead to a significant reduction in harmful CO2 and NOX emissions [26]–[28].

As the world continues to face the challenges of climate change and limited fossil fuel resources, the importance of mechanical engineering in the development of sustainable energy technologies will only increase. By focusing on renewable energy sources and improving energy efficiency, mechanical engineers can help pave the way for a greener, more sustainable future.

3. METHODS

3.1 Data Collection

The first step in this bibliometric study involved systematically collecting scientific publications related to sustainable energy technologies in the field of mechanical engineering. To ensure the completeness of the dataset, we used leading academic databases, including Web of Science, Scopus, and Google Scholar. Keywords such as "renewable energy", "energy efficiency", "solar power", "wind energy", and "biofuels" were used as search terms to obtain relevant articles published between 1968 and 2023 through the help of Publish or Perish (PoP) software accessed on 08 August 2023. This dataset covers a wide range of publication types, including peer-reviewed journal articles, conference papers, and review articles. These diverse publication types were chosen to capture the breadth and depth of research in the field.

Table 1. Metrics Data

Publication years	: 1968-2023
Citation years	: 55 (1968-2023)
Paper	: 980
Citations	: 251847

Cites/year	: 4579.04
Cites/paper	: 256.99
Cites/author	: 114756.73
Papers/author	: 422.43
Author/paper	: 3.07
h-index	: 241
g-index	: 483
hI,norm	: 162
hI,annual	: 2.95
hA-index	: 89
Papers with ACC	: 1,2,5,10,20:882,836,754,622,417

Source: Publish or Publish 2023

3.2 Data Analysis with VOSviewer

VOSviewer, a widely known bibliometric analysis tool, is used for in-depth analysis and visualization of bibliographic data. The software offers advanced features for mapping author networks, co-cited references, keywords, and institutions, thus enabling the extraction of meaningful insights from large data sets [22]. The following components of the analysis were conducted using VOSviewer:

VOSviewer was used to analyze publication trends in the field of sustainable energy technologies in mechanical engineering over the past two decades. This analysis provided insights into periods of rapid growth or decline in research output, identifying key moments and shifts in research focus. Authorship patterns and collaboration networks were visualized using VOSviewer. By analyzing authorship networks, influential authors and research groups are identified based on their publication record and number of citations. Collaboration networks depict research collaborations among authors, institutions, and countries, highlighting the global nature of research in this area.

To identify dominant research themes, VOSviewer was used to extract and analyze keywords from the dataset. A co-occurrence network of keywords revealed prevalent research themes and their interconnections, providing a comprehensive overview of the research areas in sustainable energy technologies in mechanical engineering. The citation network was mapped using VOSviewer to identify important articles and their impact on the field. This analysis facilitates the identification of key works that significantly influence future research in sustainable energy technologies.

4. RESULTS AND DISCUSSION

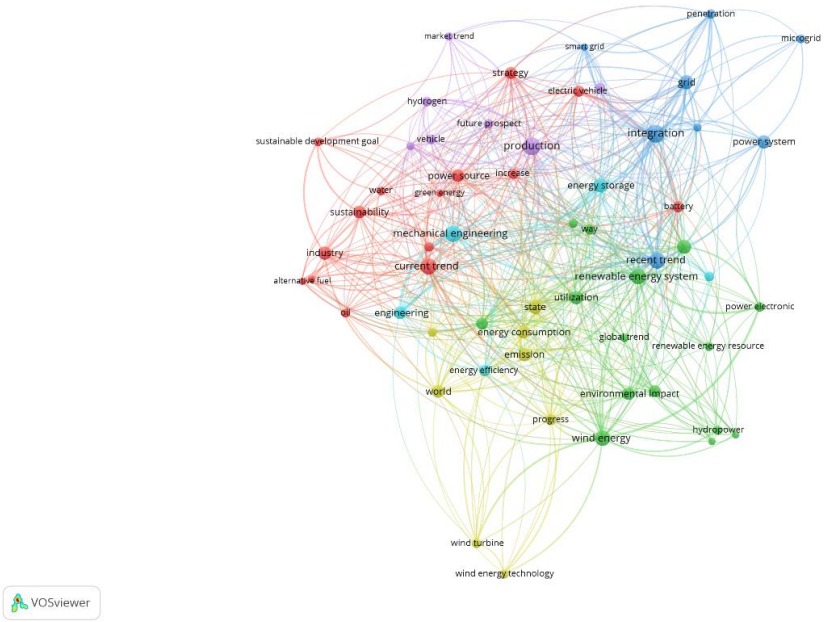

Figure 1. Mapping Results by Vosviewers (2023)

Figure 1 presents a keyword co-occurrence network, showing the most common research themes and their interrelationships. Some of the dominant research themes in this field include renewable energy systems, energy-efficient mechanical systems, solar energy technologies, wind power generation, biomass and biofuel applications, energy storage technologies, sustainable HVAC systems, green building design, and carbon capture and utilization. The interconnectedness of these themes underscores the multidisciplinary nature of sustainable energy technologies in mechanical engineering.

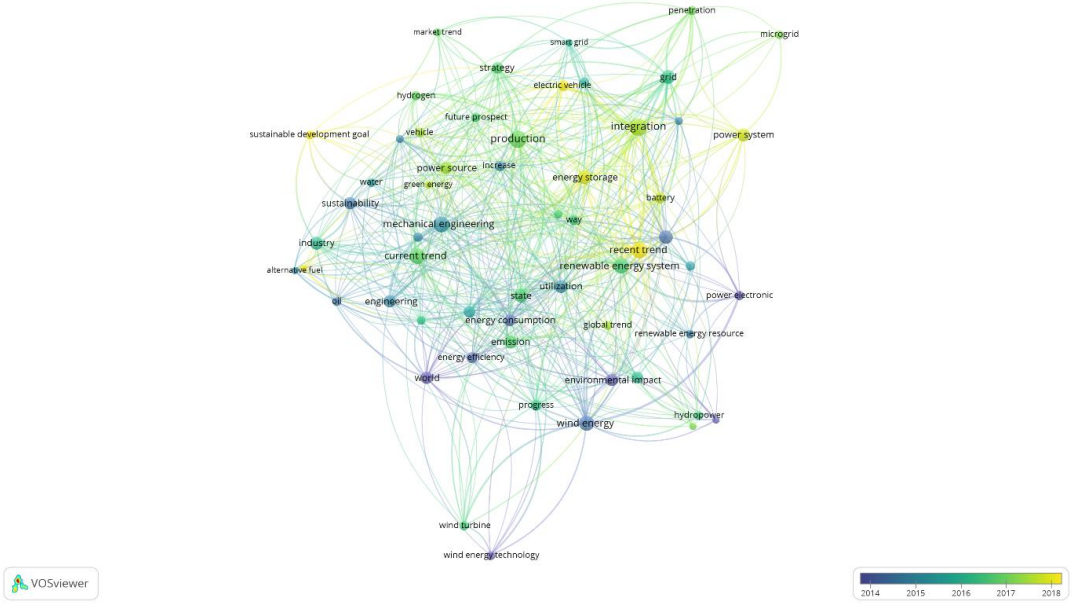

Figure 2. Research Trend by Vosviewers (2023)

Figure 2 illustrates the publication trend in sustainable energy technologies in mechanical engineering from 2014 to 2023. The graph showcases a significant increase in research output over time, indicating the growing importance and attention given to this field. Notably, a sharp increase in publications is observed in the last decade, highlighting the urgency of addressing environmental challenges through innovative mechanical engineering solutions.

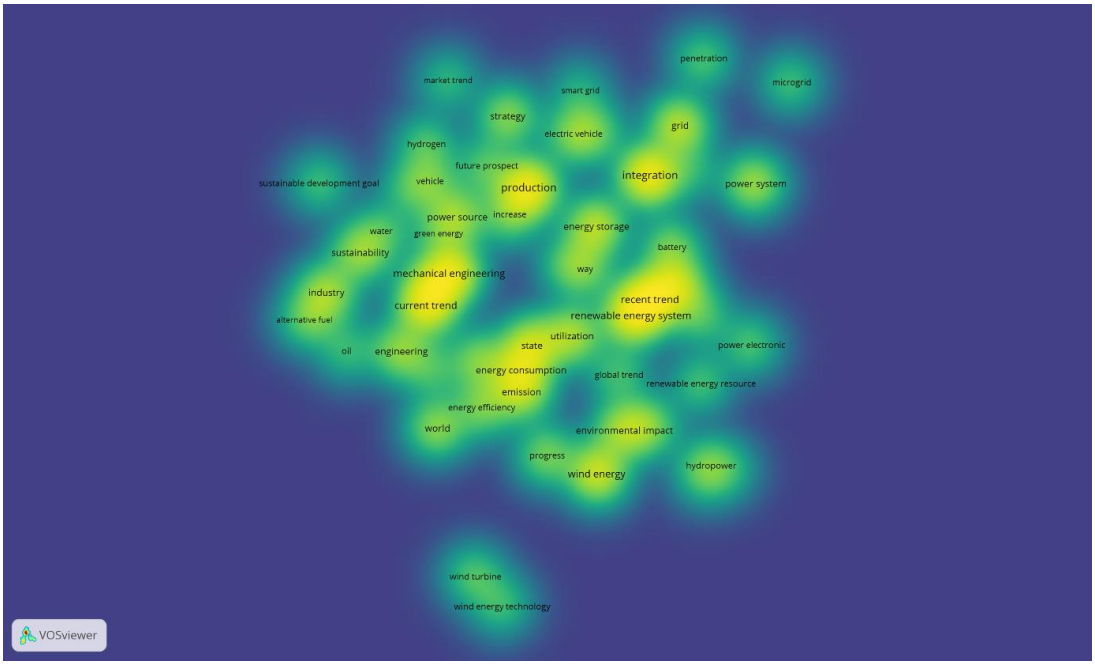

Figure 3. Cluster Identity by Vosviewers (2023)

These clusters offer an organized perspective of the various study topics in mechanical engineering's field of sustainable energy technology. Alternative fuels, renewable energy sources, grid modernization, emissions reduction, hydrogen use, and overall sustainable energy technology are just a few of the topics that each cluster focuses on. In addition to highlighting the current trends and directions that academics are investigating to address the global challenge of sustainable energy and environmental conservation, the keywords within each cluster emphasize the multidisciplinary nature of study in this topic.

Table 2. Cluster Identity

Cluster	Total Items	Most frequent keywords (occurrences)	Keyword
1	15	Biogas (25), electric vehicle (20), sustainability (20), water (15)	Alternative fuel, battery, biogas, clean energy, current trend, electric vehicle, green energy, increase, industry, oil, power source, strategy, sustainability, sustainable development, water.
2	15	clean energy technology (25), power electronic (30),	Biomass, clean energy source, clean energy technology, energy production, environmental energy, global trend,

		renewable energy resource (20)	hydropower, power electronic, power generation, renewable energy resource, renewable energy system, utilization, way, wind energy
3	8	Microgrid (20), power system (25), smart grid (15)	Grid, integration, microgrid, new trend, penetration, power system, recent trend, smart grid
4	8	Emission (20), non renewablne energy system (15), wind turbine (20)	Emission, energy consumption, non renewablne energy system, progress, state, wind energy technology, wind turbine, world
5	7	Hydroge (20), sustainable energy source (30)	Biofuel, future prospect, hydrogen, market trend, production, sustainable energy source, vehicle
6	5	sustainable energy technology (20)	Energy efficiency, energy storage, engineering, mechanical engineering, sustainable energy technology

Source: Results of The Author's Data Analysis 2023

Electric cars and alternative fuels are the main subjects of Cluster 1, as they are essential to the development of sustainable energy and transportation systems. The term "biogas," which is a renewable substitute for conventional fuels, is used frequently to highlight the significance of sustainable fuel sources. An alternative to more environmentally friendly transportation is represented by electric cars. Water and sustainability are also important buzzwords that draw attention to the environmental aspects of this cluster. Renewable energy sources and clean energy technology are the focus of Cluster 2. An essential component of the effective management and conversion of renewable energy is power electronics. The focus on clean energy technologies highlights the necessity of creative solutions for the switch to greener energy sources. Terms such as wind energy and hydropower denote the variety of renewable resources taken into consideration in this cluster. Cluster 3 focuses on smart grids and microgrids, which are developments in power management and distribution. Microgrids provide resilient and localized energy solutions; they are particularly pertinent when considering sustainability and energy dependability. Smart grids make it easier to integrate renewable energy sources and distribute electricity efficiently. Grid modernisation trends are examined in this cluster.

The crucial topic of emissions is covered in Cluster 4, along with the contribution of wind energy to lessening environmental effects. When it comes to sustainability and mitigating climate change, emissions are a big concern. A vital part of renewable energy systems, wind turbines symbolize the significance of lowering dependency on non-renewable energy sources. The potential of hydrogen as a sustainable energy source, particularly its use in fuel cells and transportation, is examined in Cluster 5. Reducing greenhouse gas emissions requires the use of sustainable energy sources, and hydrogen has potential as a clean energy source. The cluster focuses on market trends and potential applications for hydrogen-based technology in the future. A thorough examination of sustainable energy technology is included in Cluster 6. Despite having fewer elements, it functions

as a basic cluster covering a range of sustainable energy-related topics, such as mechanical engineering, energy storage, energy efficiency, and the interdisciplinary nature of sustainable energy technology research.

Table 3. Citations Analysis

Citations	Authors and year	Title
8884	S Chu, A Majumdar (2012)	Opportunities and challenges for a sustainable energy future
5732	B Scrosati, J Garche (2010)	Lithium batteries: Status prospects and future
4984	JM Carrasco, LG Franquelo (2006)	Power-electronic systems for the grid integration of renewable energy sources: A survey
3808	NL Panwar, SC Kaushik, S Kothari (2011)	Role of renewable energy sources in environmental protection: A review
3158	DE Olivares, A Mehrizi-Sani (2014)	Trends in microgrid control
2950	O Ellabban, H Abu-Rub, F Blaabjerg (2014)	Renewable energy resources: Current status, future prospects and their enabling technology
2836	MR Patel, O Beik (2021)	Wind and solar power systems: design, analysis, and operation
2630	W Kempton, J Tomic (2005)	Vehicle-to-grid power implementation: From stabilizing the grid to supporting large-scale renewable energy
2595	JD Sachs (2015)	The age of sustainable development
2537	I Dincer, MA Rosen (2021)	Thermal energy storage: systems and applications

Source: Results of The Author's Data Analysis 2023

These highly cited articles collectively represent a diverse range of topics within the field of sustainable energy technologies in mechanical engineering. They serve as foundational references, offering insights into critical aspects such as environmental impact, energy storage, grid integration, and the future of sustainable energy. Researchers and policymakers continue to draw upon these works to inform their efforts to advance sustainable energy solutions.

Table 4. Keywords Analys

Most occurrences		Fewer occurrences	
Occurrences	**Term**	**Occurrences**	**Term**
57	Production	15	Wind energy technology
57	integration	15	Oil
51	Recent trend	15	Non renewable energy source
50	Mechanical engineering	15	Water
49	Current trend	14	Clean energy technology
44	Wind energy	14	Hydropower
39	Power generation	13	Market trend

38	Energy storage	13	Biofuel
37	State	12	New trend
37	Grid	11	Geothermak energy
34	Utilization	11	Biogas
33	Renewable energy system	11	Alternative fuel
33	Emission	11	Green energy
31	Industry	11	Smart grid
31	Power system	11	Clean energy source

Source: Results of The Author's Data Analysis 2023

Most Occurrences:

The term "Production" holds the highest occurrence in the dataset, indicating its significance in sustainable energy research. This term likely encompasses various aspects of energy production, including methods, technologies, and efficiency. "Integration" is another prevalent term, suggesting a focus on the seamless incorporation of sustainable energy technologies into existing systems. This may include grid integration, technology integration, and interdisciplinary approaches to sustainability. The frequent appearance of "Recent Trend" underscores the dynamic nature of sustainable energy technologies. Researchers are keen on identifying and analyzing the latest developments and shifts in the field, which is crucial for staying updated.

"Mechanical Engineering" is a key term, emphasizing the core discipline from which many sustainable energy technologies originate. Mechanical engineers play a central role in designing and developing innovative energy solutions. Similar to "Recent Trend," "Current Trend" highlights the focus on tracking ongoing developments and emerging themes in sustainable energy research. "Wind Energy" is a prominent term, reflecting the continued growth of wind power generation as a renewable energy source. Wind energy technology and innovation remain a significant area of study.

"Power Generation" underscores the importance of efficient energy generation methods. Researchers are likely exploring various approaches to generating clean and sustainable power. "Energy Storage" is crucial for managing intermittent renewable energy sources. The emphasis on this term reflects the need for reliable energy storage solutions. "State" may refer to the condition or status of energy systems or technologies. Researchers may be assessing the current state of renewable energy adoption and performance. "Grid" suggests a focus on grid-related aspects, including grid integration, microgrids, and smart grid technologies. Effective grid management is essential for incorporating renewable energy sources.

Fewer Occurrences:

While "Wind Energy" is a prevalent term, "Wind Energy Technology" appears less frequently. This distinction indicates that the dataset may include discussions on wind energy in a broader context, encompassing various aspects beyond technology specifics. "Oil" appears fewer times, highlighting the transition away from conventional fossil fuels like oil towards sustainable energy sources. The term "Non-Renewable Energy Source" signifies a focus on contrasting renewable and non-renewable energy sources within the dataset. "Water" suggests potential discussions related to hydropower, water usage in energy production, or water-related environmental considerations.

"Clean Energy Technology" emphasizes the importance of technology solutions that promote environmental sustainability. "Hydropower" represents a subset of renewable energy sources, focusing on energy generation from flowing water. "Market Trend" may signify an interest in the economic aspects and market dynamics of sustainable energy technologies. "Biofuel" points to research involving renewable fuels derived from biological sources. "New Trend" suggests a focus on emerging topics and innovations within sustainable energy research. "Geothermal Energy" highlights the study of energy derived from the Earth's heat, which is a subset of renewable energy technologies.

Discussion

This research paper's discussion section explores the importance and ramifications of the bibliometric analysis results. The investigation showed that over the previous 20 years, there has been a notable increase in mechanical engineering research output in sustainable energy technology. This pattern emphasizes how important it is becoming for people all over the world to switch to greener, more sustainable energy sources. The field has advanced significantly as a result of joint efforts, as evidenced by the notable writers and research organizations involved. The network of authors shows that the development of sustainable energy solutions is an interdisciplinary undertaking involving scholars from different backgrounds.

The network of keywords that co-occur highlighted prominent research themes and highlighted the transdisciplinary character of sustainable energy technology. The need for integrated strategies to meet the energy and environmental concerns is highlighted by the interconnectedness of themes including renewable energy systems, energy storage, power generation, and environmental effect. The key publications featured in the citation network have had a substantial impact on later research. These papers influence the direction of sustainable energy research by acting as fundamental sources for both scholars and decision-makers. Publishing journals devoted to sustainable energy technology has been essential to the dissemination of research results. Highly cited journals have a crucial role in developing a community of researchers and promoting the sharing of knowledge, raising the field's profile and gaining recognition.

5. CONCLUSION

To sum up, this bibliometric analysis presents a thorough examination of mechanical engineering's sustainable energy technologies and delivers insightful information on research trends and implications. The area has expanded and changed significantly, with an increasing focus on innovation, interdisciplinary cooperation, and sustainability. The study's conclusions are a useful tool for practitioners, politicians, and scholars alike. They underline the significance of continuing to invest in sustainable energy solutions, offer direction for future research, and inform strategic alliances. Sustainable energy innovations in mechanical engineering emerge as a ray of hope as the globe struggles with environmental degradation and climate change. The foundation for furthering the shift to greener, more efficient, and ecologically conscious energy systems is provided by this research. A sustainable and successful energy future can be paved by stakeholders working together to leverage the lessons gained from this study.

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