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

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Research Article

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ABSTRACT

The 21st century's pressing environmental problems, especially climate change, have made mechanical engineering a key player in developing cutting-edge solutions for a sustainable energy-focused future. Sustainable energy technologies provide a variety of alternatives, from renewable energy sources to energy-efficient mechanical designs. This bibliometric research looks at a large dataset of scholarly mechanical engineering papers that discuss sustainable energy technologies using advanced tools like VOSviewer. The analysis identifies influential journals, important authors, collaborative networks, and dominant research issues. The significant surge in research output over the last 20 years, the rise to prominence of prominent authors and research teams, the relationship between research topics, and the crucial significance of specific publications and journals are all significant findings. By providing a road map for negotiating the challenging field of sustainable energy in mechanical engineering, these discoveries contribute to the development of a more environmentally responsible and sustainable energy future.

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

INTRODUCTION

The twenty-first century is characterized by the global need to address pressing environmental issues, primary among them being climate change and the pursuit of sustainable energy solutions. As the globe battles with the repercussions of human climate change, the engineering community, particularly in the discipline of mechanical engineering, has taken the lead in developing innovative solutions aimed at decreasing the environmental effects of energy production and consumption [1]–[5]. In this important endeavor, sustainable energy technologies—which include a wide spectrum of solutions from energy-efficient mechanical designs to renewable energy systems—have emerged as a ray of hope [6]–[9].

By integrating sustainable energy technology into mechanical engineering techniques, it is possible to reduce greenhouse gas emissions, increase energy efficiency, and promote environmental sustainability [10]–[12]. Designing, optimizing, and implementing energy systems that meet the world's growing energy demands while still being ecologically sustainable is the responsibility of engineers. The understanding that conventional energy sources, which are characterized by their heavy reliance on fossil fuels, are not only limited but also contribute to the atmospheric concentrations of greenhouse gases that are causing the alarming rise in global temperatures [13]–[18] lends support to this endeavor.

The paper presented here attempts to offer a comprehensive review of the advancements and consequences of sustainable energy technologies in the field of mechanical engineering. Informally referred to as "clean energy" or "green energy" solutions, sustainable energy technologies include a wide range of methods and technology. Utilizing biomass and biofuels, improving HVAC (heating, ventilation, and air conditioning) systems, creating innovative energy storage solutions, employing energy-efficient mechanical systems, and utilizing energy from renewable sources like solar, wind, and hydropower are some of these.

Bibliometrics, a quantitative analysis of academic publications, offers a crucial lens through which to look at the evolution of research themes, the network of collaborating researchers, and the influence of specific articles, journals, or authors in the field of sustainable energy technologies in mechanical engineering.

LITERATURE REVIEW

Sustainable Energy Technologies in Mechanical Engineering

The development of sustainable energy technologies in the twenty-first century has been greatly aided by mechanical engineering. This field's engineers and researchers have concentrated on developing cost-effective and efficient renewable energy solutions. Hydropower, wind turbines, and solar photovoltaics are some of the major renewable energy sources that have the ability to cut greenhouse gas emissions and lessen dependency on fossil fuels [17], [19]–[23].

Energy efficiency is a key component of sustainable energy technologies. Improving mechanical systems and processes to use less energy has been the focus of mechanical engineers. This area of research includes the creation of improved insulating materials, effective transportation strategies, and energy-efficient HVAC systems [19], [24], and [25]. The potential of renewable energy sources to lower greenhouse gas emissions and support sustainable economic growth has gained more attention in recent years. It has been shown that the use of energy storage devices in conjunction with renewable energy sources, such solar and wind power, may significantly lower harmful CO2 and NOX emissions [26]–[28].

The significance of mechanical engineering in the development of sustainable energy technology will only grow as the world continues to confront the problems of climate change and finite fossil fuel supplies. Mechanical engineers may contribute to the development of a more sustainable and environmentally friendly future by concentrating on renewable energy sources and increasing energy efficiency.

METHODS

Data Collection

This bibliometric study's first phase entailed methodically gathering scholarly articles on mechanical engineering's use of sustainable energy technology. We utilized top academic databases, such as Web of Science, Scopus, and Google Scholar, to guarantee the dataset's completeness. Using Publish or Perish (PoP) software, which was accessed on August 8, 2023, keywords including "renewable energy," "energy efficiency," "solar power," "wind energy," and "biofuels" were used as search phrases to find relevant publications published between 1968 and 2023. Peer-reviewed journal articles, conference papers, and review articles are only a few of the many publishing formats included by this dataset. These many publishing formats were selected to reflect the depth and scope of the field's study.

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

Data Analysis with VOSviewer

A popular tool for bibliometric study, VOSviewer is used to analyze and visualize bibliographic data in great detail. In order to extract valuable insights from massive data sets, the program provides sophisticated tools for mapping author networks, co-cited references, keywords, and institutions [22]. VOSviewer was used to perform the following analysis components:

Over the last 20 years, publishing patterns in the subject of sustainable energy technologies in mechanical engineering were examined using VOSviewer. This study identified pivotal occasions and changes in research emphasis, offering insights into times of fast increase or fall in research output. VOSviewer was used to visualize authorship trends and collaborative networks. Based on their publication history and quantity of citations, prominent writers and research teams are found by examining authorship networks. The worldwide aspect of study in this field is shown by cooperation networks, which show research partnerships across authors, institutions, and nations.

VOSviewer was used to extract and examine keywords from the dataset in order to determine prevailing study topics. A thorough summary of the study fields in sustainable energy technologies in mechanical engineering was provided by a co-occurrence network of keywords that identified common research themes and their linkages. VOSviewer was used to map the citation network in order to pinpoint significant papers and their influence on the field. This methodology makes it easier to identify important publications that have a big impact on next sustainable energy technology research.

RESULTS AND DISCUSSION

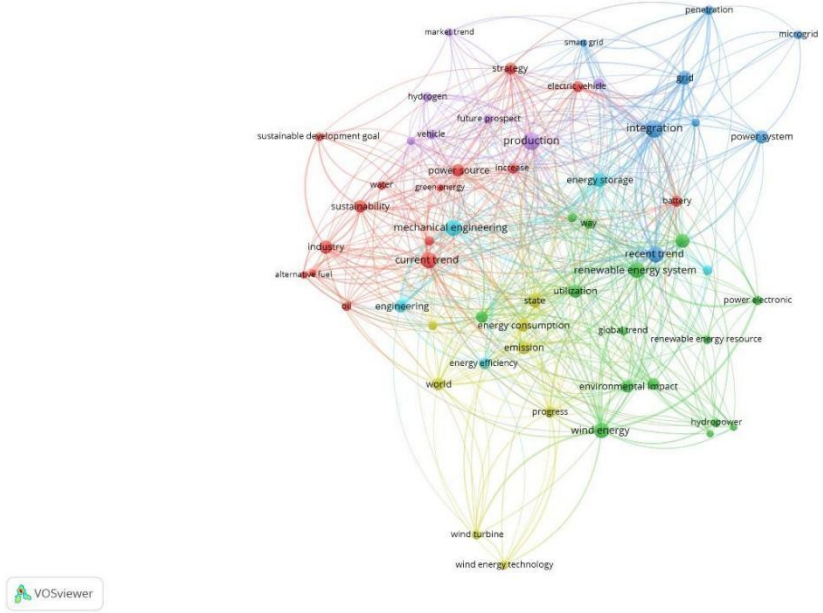


Figure 1. Mapping Results by Vosviewers (2023)

A keyword co-occurrence network illustrating the most prevalent study subjects and their connections is shown in Figure 1. 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 are some of the most popular research topics in this field. The interdependence of these topics emphasizes how interdisciplinary sustainable energy technologies are in mechanical engineering.

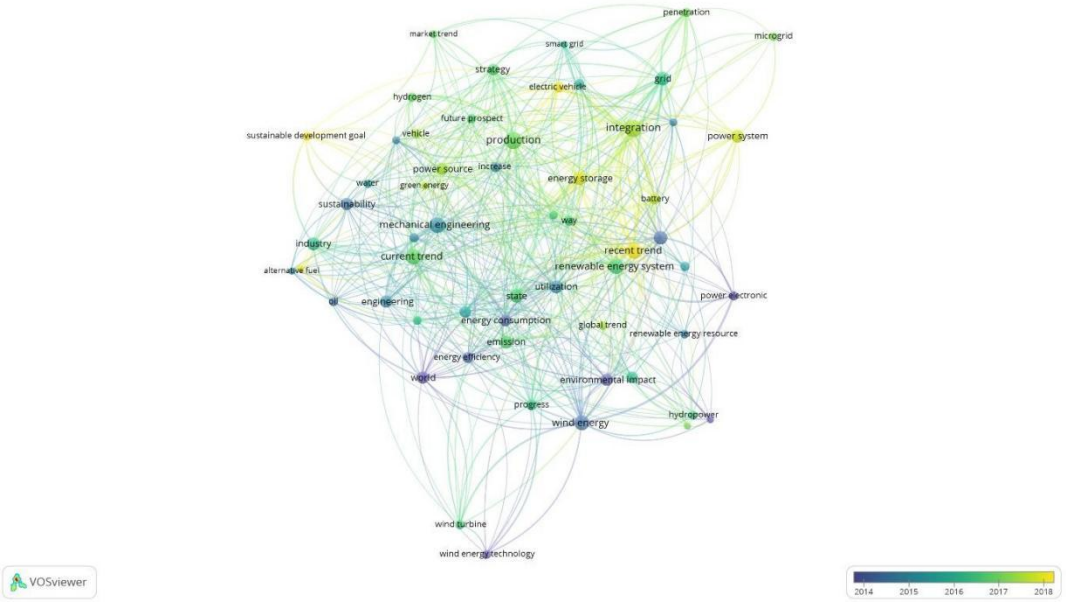


Figure 2. Research Trend by Vosviewers (2023)

The publishing trend in mechanical engineering for sustainable energy technologies between 2014 and 2023 is shown in Figure 2. The graph shows a notable rise in research output over time, demonstrating the field's increasing significance and attention. The past ten years have seen a notable rise in publications, underscoring the need of finding creative mechanical engineering solutions to environmental problems.

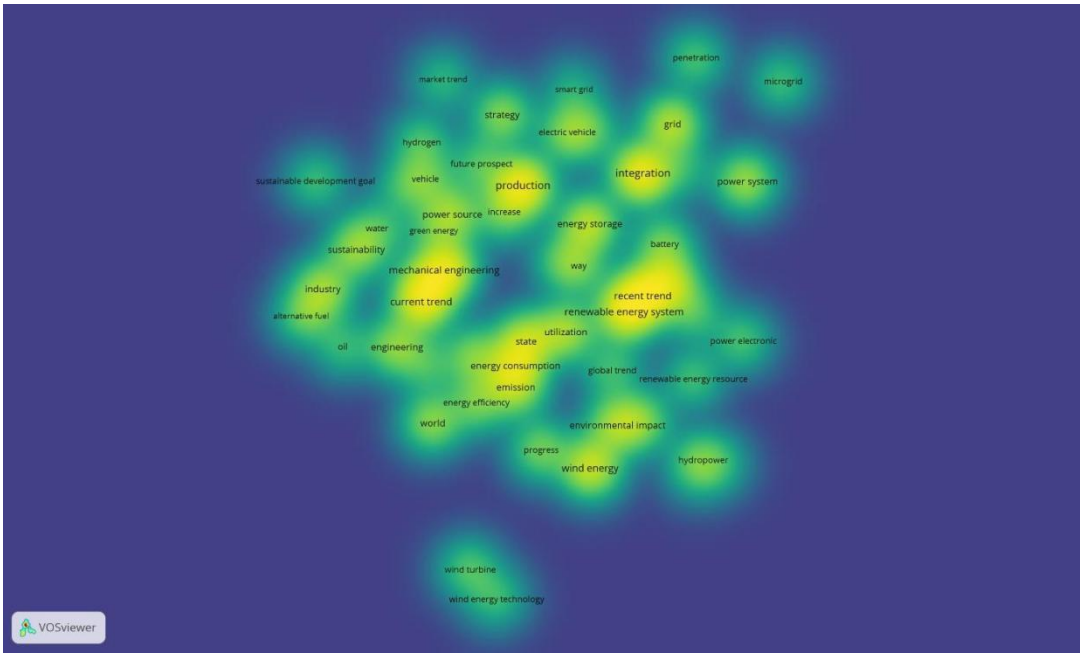


Figure 3. Cluster Identity by Vosviewers (2023)

These clusters provide a structured view of the several areas of research in the subject of sustainable energy technology in mechanical engineering. Each cluster works on a variety of themes, including alternative fuels, renewable energy sources, grid modernization, emissions reduction, hydrogen utilization, and general sustainable energy technologies. The terms within each cluster show the diverse character of research on this issue, as well as the current trends and directions that scholars are exploring to meet the global problem of sustainable energy and environmental conservation.

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

Since they are crucial to the creation of sustainable energy and transportation systems, electric vehicles and alternative fuels are the primary topics of Cluster 1. The phrase "biogas," a renewable alternative to conventional fuels, is often used to emphasize the importance of sustainable fuel sources. Electric vehicles are a substitute for more ecologically friendly modes of transportation. Important keywords that highlight this cluster's environmental features are water and sustainability. Cluster 2 focuses on clean energy technologies and renewable energy sources. Power electronics are crucial to the efficient control and conversion of renewable energy. The emphasis on clean energy technology emphasizes the need for innovative ways to make the transition to more environmentally friendly energy sources. The range of renewable resources included in this cluster is indicated by terms like hydropower and wind energy. Cluster 3 focuses on microgrids and smart grids, which are advancements in electricity distribution and management. Microgrids are especially relevant when thinking about sustainability and energy reliability since they provide robust and localized energy solutions. Smart grids facilitate the efficient distribution of power and the integration of renewable energy sources. This cluster looks at trends in grid modernization.
Cluster 4 addresses the important subject of emissions and wind energy's role in mitigating environmental impacts. Emissions are a major problem in terms of sustainability and climate change mitigation. Wind turbines, an essential component of renewable energy systems, represent the importance of reducing reliance on non-renewable energy sources. Cluster 5 looks at hydrogen's potential as a sustainable energy source, namely in fuel cells and transportation. Utilizing sustainable energy sources is necessary to reduce greenhouse gas emissions, and hydrogen has the potential to be a clean energy source. The cluster focuses on market trends and future uses of hydrogen-based technologies. Cluster 6 includes a comprehensive analysis of sustainable energy technologies. It works even if it has fewer components.

as a fundamental cluster including a variety of sustainable energy-related subjects, including mechanical engineering, energy storage, energy efficiency, and the multidisciplinary character 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

Together, these highly referenced publications cover a wide variety of subjects related to mechanical engineering's use of sustainable energy technology. They perform as fundamental resources, providing information on important topics such grid integration, energy storage, environmental impact, and the future of sustainable energy. These books are still used by scholars and decision-makers to guide their pursuit of 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:
"Production" is the most often occurring word in the dataset, demonstrating its importance in research on sustainable energy. This phrase probably refers to a number of different elements of energy generation, such as efficiency, technology, and methodologies. Another common phrase is "integration," which implies an emphasis on the smooth integration of sustainable energy technology into current systems. This might include multidisciplinary approaches to sustainability, grid integration, and technological integration. "Recent Trend" often appears, which highlights how dynamic sustainable energy technologies are. In order to keep current, researchers are eager to find and examine the most recent advancements and changes in the area.A crucial phrase that highlights the fundamental field from which many sustainable energy innovations come is "mechanical engineering." Innovative energy solutions are designed and developed in large part by mechanical engineers. Like "Recent Trend," "Current Trend" emphasizes the need of monitoring current advancements and new topics in sustainable energy research. The word "wind energy" is widely used, indicating the ongoing expansion of wind power production as a renewable energy source. Innovation and technology in wind energy continue to be important fields of research. "Power Generation" emphasizes how crucial effective energy generating techniques are.
It's probable that researchers are investigating several methods for producing sustainable and clean energy. For the management of sporadic renewable energy sources, "Energy Storage" is essential. The requirement for dependable energy storage systems is reflected in the term's focus. "State" may be used to describe the state or condition of technologies or energy systems. Researchers may be evaluating the performance and acceptance of renewable energy at this time. "Grid" implies an emphasis on grid-related elements, such as smart grid technology, microgrids, and grid integration. Incorporating renewable energy sources requires efficient grid management.
Fewer Occurrences:
Although "Wind Energy" is a common phrase, "Wind Energy Technology" is less common. This difference suggests that the dataset could include conversations on wind energy in a more comprehensive setting, including a range of topics outside of technical details. "Oil" is used less often, emphasizing the shift from traditional fossil fuels like oil to renewable energy sources. "Non-Renewable Energy Source" refers to the dataset's emphasis on comparing renewable and non-renewable energy sources. "Water" alludes to possible conversations on hydropower, the use of water in energy production, or environmental issues pertaining to water.The significance of technological solutions that support environmental sustainability is emphasized in "Clean Energy Technology." "Hydropower" is a subcategory of renewable energy sources that focuses on harnessing flowing water to generate electricity. "Market

Trend" might indicate an interest in the market dynamics and economic elements of sustainable energy technology. "Biofuel" refers to studies on renewable fuels made from biological sources. "New Trend" implies an emphasis on cutting-edge subjects and developments in the field of sustainable energy research. As a subset of renewable energy technology, "Geothermal Energy" focuses on the study of energy obtained from Earth's heat.

Discussion

The significance and implications of the bibliometric analysis findings are examined in the study paper's discussion section. According to the inquiry, mechanical engineering research output in sustainable energy technology has significantly increased over the last 20 years. This trend highlights how crucial it is for people everywhere to transition to more sustainable and environmentally friendly energy sources. Joint efforts have led to substantial advancements in the discipline, as shown by the participation of renowned authors and research institutes. The network of writers demonstrates that the creation of sustainable energy solutions is a multidisciplinary project including academics from several fields.

Prominent research issues and the transdisciplinary nature of sustainable energy technology were emphasized by the network of co-occurring terms. The interconnectivity of topics like renewable energy systems, energy storage, power production, and environmental impact emphasizes the necessity for integrated measures to address energy and environmental challenges. Subsequent research has been significantly influenced by the important articles included in the citation network. These articles serve as essential resources for academics and decision-makers, influencing the course of sustainable energy research. The dissemination of research findings has depended heavily on the publication of journals specialized to sustainable energy technologies. Highly cited journals are essential for building a community of scholars, encouraging information exchange, increasing the field's visibility, and obtaining recognition.

CONCLUSION

In conclusion, this bibliometric study offers a comprehensive review of sustainable energy technologies in mechanical engineering and provides valuable information on research trends and consequences. With a growing emphasis on innovation, multidisciplinary collaboration, and sustainability, the field has grown and evolved dramatically. The study's findings are a helpful resource for academics, legislators, and practitioners alike. They emphasize how important it is to keep funding sustainable energy solutions, provide guidance for next studies, and guide strategic partnerships. As the world grapples with environmental degradation and climate change, mechanical engineering advances in sustainable energy emerge as a glimmer of hope. This study provides the groundwork for advancing the transition to more environmentally sensitive, efficient, and greener energy systems. By using the insights from this research, stakeholders may collaborate to create a sustainable and prosperous energy future.

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